Handbook of Research on

Industrial Advancement in Scientific Knowledge



Vicente González-Prida Diaz and Jesus Pedro Zamora Bonilla

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Handbook of Research on Industrial Advancement in Scientific Knowledge

Vicente González-Prida Diaz
Universidad de Sevilla, Spain & Universidad Nacional de Educación a Distancia (UNED), Spain

Jesus Pedro Zamora Bonilla
Universidad Nacional de Educación a Distancia (UNED), Spain

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Becattini, Niccolò / *Politecnico di Milano, Italy* 182
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Díaz, Vicente González-Prida / *Universidad de Sevilla, Spain & Universidad Nacional de Educación a Distancia (UNED), Spain* 20, 38, 247
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Shendryk, Vira / *Sumy State University, Ukraine* 264
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Stegmaier, Raul / *Universidad Técnica Federico Santa María, Chile* 182
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The great transformation that will face European industry is driven by the need of digitizing the entire value chain around manufacturing for creating competitive advantages to maintain a dominant position in the global economy. This new paradigm is commonly known as Industry 4.0, and it has a significant policy support from the European Commission as well as different member states. However, this transition is full of uncertainties as the digitization of industry creates different concerns about employment, privacy, labor rights, and other issues related with this technological revolution. In this chapter, the authors trace back the origins of Industry 4.0 to the Web 2.0 phenomenon as well as they reflect upon the role of technodata and technofactories in a postindustrial society. Finally, they stress the need to reflect about developing a responsible digitization of industry that will consider societal concerns.

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The main application area of the digital transformation has been so far on the industrial and manufacturing process. Nevertheless, the concept Industry 4.0 has enormous potential in other areas such as its combination with the scientific method and the empirical logic. The term technoscience, coined in the second half of the 20th century, links both fields, the technological and the scientific field, establishing a joint growth where scientific knowledge takes advantage (and requires) of a technological infrastructure in order to advance. This chapter proposes to analyze some of the most relevant concepts in these matters in order to provide a more philosophical approach to technology, its effect on the proper engineering and scientific knowledge, and what some of the social features are that are inferred from these emerging technologies.

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This chapter aims to consider the effects of the new concept Industry 4.0 on decision making, particularly on the reduction of uncertainty and the risk associated with any choice between alternatives. For this purpose, this chapter begins by dealing with the concepts of risk and uncertainty and their epistemological evolution. After observing certain trends and recent studies in this regard, the authors address a more philosophical perception of risk, mainly on aspects related to engineering and social perception. The concept of human reliability will also be reviewed and how it can be improved with the application of emerging technologies, considering some methodological proposals to improve the decision making. After that, some of the possible future research directions will be briefly discussed. Finally, the chapter concludes by highlighting key aspects of the chapter as a context for other chapters in the book.

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The aim of this chapter is to show some of the assumptions that lie behind transhumanism. The concept of enhancement is analyzed. While, from transhumanism, human welfare depends on the enhancement of human capabilities, here it shall be argued that to begin with, a social debate over what is considered welfare is needed before we can establish what we wish to improve (enhance). This reflection must emphasize the necessity to reflect, ex ante, on what kind of technological development we want, viewing technology as a means to attain the agreed-upon type of welfare, rather than a goal in itself. On the basis of a socially open debate with an anticipatory perspective, society as a whole can establish which risks it is willing to take.

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Human perfection has been one of the main objectives of the human species since the appearance of Homo sapiens, but contemporary biomedical technologies represent a promise to achieve it in the near future. In view of the new possibilities offered by new technologies, a scientific-philosophical theoretical debate has emerged between those who are in favor of its use on humanity for non-therapeutic purposes (posthumanists) and those who reject it (bioconservatives). In this chapter, the so-called "enhancement technologies," the problems derived from their use with the aim of radically altering human abilities, and some of the most recent practical cases that have transcended the theoretical debate about their legitimacy are analyzed.

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This chapter seeks to show how the society of the digital swarm we live in has changed the way individuals behave to the point that we have become Homo digitalis. These changes occur with information privatization, meaning that not only are we passive consumers, but we are also producers and issuers of digital communication. The overarching argument of this reflection is the disappearance of the "reality principle" in the political, economic, and social spheres. This text highlights that the loss of the reality principle is the effect of microblogging as a digital practice, the uses of which can either impoverish the space of people's experience to undermine the public space or achieve the mobilization of citizens against of the censorship of the traditional means of communication by authoritarian political regimes, such as the case of the Arab Spring in 2011.

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Massive societal change will result from the rate of continuous technology advancement and the pace will increase. The enterprise will face operational and technical challenges and society will increasingly expect the highest ethical conduct. What strategy will allow the organization to remain innovative and thrive in these circumstances? To develop new insight, anticipatory skills, and better decision making, a case is made for the adoption of model building and simulation. In addition to the benefits of shared conceptual artefacts for communicating in the enterprise, modelling requires a deep understanding of the ethics and reflexivity needed to deal with complex issues and using a transdisciplinary framework for inquiry may increase understanding. For innovation to emerge, participatory and co-creative approaches for sense-making are proposed to shift the responsibility for ethical decisions to more actors in the enterprise. This approach allows leaders to engage with the informal coalitions in the enterprise and shape the required strategic direction.

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Leo A. M. van Dongen, University of Twente, The Netherlands

Maintenance is one of the key application areas of Industry 4.0. Every day, maintenance managers and technicians face the challenge of ensuring maximum machine reliability and availability, while minimizing the utilization of materials consumed by maintenance and repairs. As productivity is pressured to further improve, finding a successful balance between these aspects is becoming increasingly difficult. Therefore, integrating condition-monitoring systems with predictive and prescriptive maintenance principles, a new Industry 4.0-based maintenance can be obtained that enables maintenance engineers to better

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deal with this challenge. In this context, Maintenance 4.0 expands existing maintenance functions by the integration of Industry 4.0 technologies, like internet of things, cyber physical systems, augmented reality, and 3D printing. This chapter presents the main maintenance areas that are supported and enabled by Industry 4.0 technologies and introduces an Industry 4.0-based predictive maintenance approach for the manufacturing industry.

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Jan-jaap Moerman, University of Twente, The Netherlands
Jan Braaksma, University of Twente, The Netherlands
Leo A. M. van Dongen, University of Twente, The Netherlands

Asset-intensive organizations rely on physical assets that are expensive, complex, and have a significant impact on organizational performance. The management of such assets is essential when seeking for reliable performance in a world of increasing uncertainties. The observation that asset-intensive organizations deal with increasingly complex and tightly coupled systems and often operate in highly demanding environments may indicate that they should adopt practices from high reliability organizations (HRO) to ensure and maintain reliable performance in the fourth industrial revolution. This chapter operationalizes the HRO concept in the field of physical asset management, measures to what extent the underlying principles are recognized, and explores the relationship between the HRO principles and asset performance using a descriptive survey. Results indicated that the HRO principles are recognized and may, therefore, serve as an instrument for reliable performance when adopting new technologies. A positive relation between asset performance and the five HRO principles was identified.

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Pablo Viveros, Universidad Técnica Federico Santa María, Chile
Niccolò Becattini, Politecnico di Milano, Italy

In this chapter, an integrated proposal is described to guide analysts and developers in identifying and selecting optimal alternative solutions in innovative projects. The integration is inspired by the theory of inventive problem solving, and specifically the recent evolution of the OTSM-TRIZ with a body of knowledge of risk analysis assessment. The authors propose a solution assessment indicator based on TRIZ-resources to anticipate a lack of resources when solutions are proposed. The solution assessment considers both risk assessment logic for evaluation and TRIZ resources for parameter classification and categorization. Finally, the solution assessment indicator aims to anticipate potential uncertainty by considering both qualitative and quantitative teamwork approaches. Moreover, this chapter presents a case study that involves a group of young designers and engineers working on a gripper design project, where the designers must develop a new product for a university laboratory.

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Roderick Walden, University of Technology Sydney, Australia
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The adoption of new technology is key for any manufacturer wanting to stay relevant as the world transitions to Industry 4.0. The advance of additive manufacturing (AM) technologies—an important element of Industry 4.0—has become part of a globally accepted reality. However, conventional design practice and knowledge generation inside a manufacturing firm must evolve. Technology-driven innovation must embrace knowledge-directed design work that is aimed at forecasting and utilizing the potential of new technologies. The chapter includes two projects, both of which were manufactured using additive manufacturing laser sintering technology. Analysis of the projects positions them at either end of a wider spectrum of product design practice that more aptly captures the way design and industry must operate for technology-driven innovation and Industry 4.0. A place for conventional design for manufacture remains though the case studies indicate differences in the setting of values to inform practice, requiring new methods for creating and managing design knowledge in the future.

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To Mine or Not to Mine? Using Game Theory to Explain the Decision-Making Process in Asteroid Mining Investigations 224
Jesus Pedro Zamora Bonilla, Universidad Nacional de Educación a Distancia (UNED), Spain
Simone Centuori, Deimos Space S.L.U., Spain

Social studies of science have flourished within the last decades, making use of numerous intellectual tools from a high variety of academic fields in the social sciences and the humanities (sociology, anthropology, cultural studies, etc.). Game theory, however, has been one tool that has not been put to use too often, in spite of the obvious importance of strategic considerations in the negotiations between the relevant actors in research episodes. In this chapter, the authors illustrate the use of game-theoretical concepts and techniques with the analysis of a nascent research field: asteroid mining.

Chapter 13
Innovation in Scientific Knowledge Based on Forecasting Assessment: A Case Study on Automotive Spare Parts Demand 247
Ignacio Aranís Mahuzier, Universidad Técnica Federico Santa María, Chile
Pablo Viveros Gunckel, Universidad Técnica Federico Santa María, Chile
Rodrigo Mena Bustos, Universidad Técnica Federico Santa María, Chile
Christopher Nikulin Chandía, Universidad Técnica Federico Santa María, Chile
Vicente González-Prida Díaz, University of Sevilla, Spain & Universidad Nacional de Educación a Distancia (UNED), Spain

This chapter presents a study of forecasting methods applicable to the spare parts demand faced by an automotive company that maintains a share of nearly 25% of the automotive market and sells approximately 13,000 parts per year. These parts are characterized by having intermittent demand and, in some cases,

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low demand, which makes it difficult for such companies to perform well and to obtain accurate forecasts. Therefore, this chapter includes a study of methods such as the Croston, Syntetos and Boylan, and Teunter methods, which are known to resolve these issues. Furthermore, the rolling Grey method is included, which is usually used in environments with short historical series and great uncertainty. In this study, traditional methods of prognosis, such as moving averages, exponential smoothing, and exponential smoothing with tendency and seasonality, are not neglected.

Chapter 14
Decision Making for Energy Management in Smart Grid 264
Vira Shendryk, Sumy State University, Ukraine
Olha Boiko, Sumy State University, Ukraine
Yuliia Parfenenko, Sumy State University, Ukraine
Sergii Shendryk, Sumy State University, Ukraine
Sergii Tymchuk, Kharkiv Petro Vasylenko National Technical University of Agriculture, Ukraine

The chapter discusses the problem of energy management in Smart MicroGrid. The strategies of Smart MicroGrid energy management and objectives of Smart MicroGrid operation have been analyzed. The chapter emphasizes the potential of information technologies implementation to achieve energy management goals and provide a description of energy management information system which is used for MicroGrid planning and operation. The information flows which are used for making decision on Smart MicroGrid energy management have been analyzed.

Chapter 15
Application of MSTAM Methodology in Project Management: A Case Study of ITF Robotic Automation R&D Project 298
Siu Cheung Ho, City University of Hong Kong, Hong Kong
Kong Bieng Chuah, City University of Hong Kong, Hong Kong

Innovation technology development and commercialization are not new, but this is a hot topic in this decade in Hong Kong. The relevant researches are focused on two dimensions from research and development (R&D) technologist perspective (supply-side) and industry user perspective (demand-side). This is a part of the author's engineering doctorate thesis. The thesis title is "An Analysis of the Determinants of Innovation and Technology Fund (ITF) R&D Projects Commercialization in Hong Kong's Logistics and Supply Chain Industries." A pilot implementation case study has been conducted and tested, and the MSTAM methodology are workable for ITF R&D project deliverables commercialization to the industry.

Chapter 16
Data-Driven Decision Making to Select Condition-Based Maintenance Technology 324
María Carmen Carnero-Moya, University of Castilla-La Mancha, Spain & Universidade de Lisboa, Portugal

Condition-based maintenance (CBM) may be considered an essential part of the Industry 4.0 environment because it can improve production processes through the use of the latest digital technologies. The literature includes a large number of contributions on new techniques for diagnosis, signal treatment, analysis of technical parameters, and prognosis. However, to obtain the expected benefits of a vibration

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analysis program, it is necessary to choose the instruments and introduction process best suited to the organization, and so guarantee the best results using data-driven decision making in accordance with the needs of Industry 4.0. Despite the importance of these decisions, no relevant models are found in the literature. This contribution describes a fuzzy multicriteria model for choosing the most suitable technology in vibration analysis. The goal is to create a model that is easy for organizations to use, and which reflects the judgements of a number of experts in maintenance and vibration analysis. The model has been applied to a Spanish state-run healthcare organization.

Chapter 17
Decision Making in the Choice of Condition-Based Maintenance Techniques in a Subsidiary of a Petrochemical Company 344
María Carmen Carnero-Moya, University of Castilla-La Mancha, Spain & Universidade de Lisboa, Portugal
Francisco Javier Cárcel-Carrasco, Universitat Politècnica de València, Spain

Condition-based maintenance (CBM) may be considered an essential part of the Industry 4.0 environment because it can improve production processes through the use of the latest digital technologies, which allows improvements to products, processes, and business models. Nonetheless, despite this importance, there are no models or methodologies in the literature to assist in choosing predictive techniques and the level of complexity to be used in a given organization. This chapter describes a model for choosing the most suitable CBM technique to be introduced in a subsidiary of a petrochemical plant. The predictive techniques of vibration analysis, lubricant analysis, and a combination of the two were considered at three technological levels. The model was built using the measuring attractiveness by a categorical based evaluation technique (MACBETH) approach. The present model could avoid failures in these programmes when making decisions about the techniques and technologies most suited to the characteristics of the industrial plant.

Chapter 18
The Implementation of Nearly Zero Energy Buildings (nZEB) in Spain: Legislative Requirements and Policies 364
Elisa Peñalvo-López, Universitat Politècnica de València, Spain
Javier Cárcel-Carrasco, Universitat Politècnica de València, Spain
Manuel Valcuende-Paya, Universitat Politècnica de València, Spain
María Carmen Carnero-Moya, University of Castilla-La Mancha, Spain & Universidade de Lisboa, Portugal

The construction segment is an important economic sector in Europe, representing 9% of European gross domestic product (GDP) and providing approximately 18 million direct jobs. Construction activities that include renovation work and energy retrofits add almost twice as much value as the construction of new buildings, and small and medium-sized enterprises (SMEs) contribute more than 70% of the value added in the EU building sector. Furthermore, European legislation obliges member states to establish minimum energy efficiency requirements for buildings to achieve optimum levels of costs versus energy demand reduction. These requirements are reviewed every five years and represent categories of buildings based on their energy levels (demand and generation). This chapter analyzes the legislation associated to nearly zero energy buildings (nZEB) in Spain in order to identify the factors that will leverage their massive implementation.

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Preface

OVERVIEW

Today's society, where everyone praises and promotes technological development, it seems to be more critical than ever to review the effect of this quick process of technology growth, not only in industry and sciences but also across our social behavior and, in general terms, over the progression of humankind. Therefore, engineers, business leaders, politicians, entrepreneurs – everyone – should value the opportunity to pause sometimes to consider the consequences of their decision-making, not only with a short-term focus, but also with a long view of the unfolding future. That is where philosophers of science, historians, sociologists and humanities academics may play an important and relevant role for general enlightenment and awakening. In this sense, this book showcases diverse understandings about the new high-tech advances, what they mean to science, society and industry, their challenges, benefits, pros and cons, including the applications of such disruptive technologies.

Together with other prominent thinkers, the Spanish philosopher José Ortega y Gasset is considered one of the founders of the philosophy of technology. Ortega y Gasset, in his work *Meditation of the Technique*, affirmed that the first methods of human perfection were the tools created to supply solutions to the intrinsic deficiencies of the human species, such as the use of skins to maintain body temperature, or the use of sharp blades to cut meat or hunt animals. According to his thought, technology should allow three goals: ensuring the satisfaction of human needs, achieving such satisfaction with the minimum of effort and, finally, producing objects and services that provide new possibilities to the human being.

Handbook of Research on Industrial Advancement in Scientific Knowledge has been conceived of broadly to explore these goals, affording a global vision over the nowadays digital transformation. Consequently, the reader will identify throughout these pages methodologies and applications related to decision making, risk and uncertainty, as well as design and development, not only on scientific and industrial topics, but also on social and ethical matters. In other words, we present here a compilation of chapters that address different edges related to technology and science, where engineering considerations, mathematical approaches as well as management tools provide a better understanding and awareness of the so-called Industry 4.0, taking into account at the same time the impact of such novelties on our current society and its perception.

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SUMMARY OF TOPICS

Industry 4.0 refers to a fourth generation in the production and manufacturing activity of the commonly named Fourth Industrial Revolution, characterized by the application of intelligent systems and solutions based on the Internet of things, big data, augmented reality, etc. Due to the relevance of technology in our fashionable world, this publication aims to be an useful reference source that provides a wide range of deliberations, showing diverse understandings of the new high-tech advances and paradigms, what they mean to science and industry, their challenges, benefits, pros and cons, including adapted and updated applications of disruptive technologies.

In addition to this, uncertainty and risk are important matters from the point of view of organizations and individuals. Nowadays, the application of advanced technology to traditional and accepted scientific method may allow a better characterization of uncertainty, and reduce risk in decision-making. In general terms, the treatment, for example, of large amounts of data is a novel contribution to empirical logic and to the characteristics of the techno-science concept. Consequently, it is pertinent to research the effects of the new term Industry 4.0 on decision-making, particularly how this digital transformation may reduce the uncertainty and risk associated with choosing between alternatives. Invariably (and sometimes in a subconscious way), we make decisions based on a background of risk analysis in which the decision maker, according to their particular way of pondering alternatives, tends favorably in one way or another. Of course, there is no generally accepted way to assess uncertainty and, in practice, there is no consensus on what uncertainty and risk mean. That is why this book is also intended to study the concepts of uncertainty and risk under the new paradigm of Industry 4.0, aiming to suggest proposals for a techno-scientific method.

Finally, the reader will find a more humanistic and reflexive view of technology, particularly in the fields of logic, philosophy and history of science. In a few words, this book discusses Industry 4.0, and how it affects scientific research, manufacturing activities, business and social development, together with a humanistic perspective of this emerging technology disruption. Undoubtedly, this is a vast and challenging scope of research, so it has been observed along chapters written from many different angles.

The main topics here are related to a theoretical and practical view on advanced technologies and their inference to scientific knowledge, industrial development, as well as social advancement:

- Industry 4.0
- Techno-science
- Risk and uncertainty
- Decision making
- Logic and Philosophy of Science;
- Digitalization
- Advanced and disrupted technologies
- Industrial assets management
- Globalization of science
- Scientific method
- Social Implications of techno-science
- Barriers to high technology and transhumanism

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The above categories have also attracted pragmatic contributions that provide areas of application with great and feasible importance. These areas include:

- Mining investigation
- Automotive sector
- Smart grids
- Project management
- Hospital maintenance
- Petrochemical industry
- Buildings legislative policies

TARGET AUDIENCE

Handbook of Research on Industrial Advancement in Scientific Knowledge is aimed at worldwide readers, from business leaders to academicians. In fact, this book analyzes an interesting variety of subjects, providing an in-depth look at current global concerns on technology, science and social matters.

Therefore, scientists, engineers, academics, economists, researchers, science philosophers, technology developers, managers and others who take decisions on scientific and industrial fields will find this text useful in furthering their research or work in those areas pertinent to innovative emerging technologies.

IMPORTANCE OF EACH CHAPTER

Due to the fact that today's technology affects all aspect of human life, *Handbook of Research on Industrial Advancement in Scientific Knowledge* is a mix of relevant and diverse studies with many different and enriching points of view. Therefore, it can be structured in three parts or sections, although the boundary lines between such parts are not strictly and completely impermeable, and there are chapters that present characteristics from other sections:

- The first selection consists of six chapters (Chapters 1 to 6), which include theoretical aspects of technology, some of them from a humanistic, social and philosophical point of view.
- The second section consists of five chapters (Chapters 7 to 11) with contributions that deal with technology from a more engineering focussed and scientific perspective.
- Finally, the third section consists of seven chapters (Chapters from 12 to 18), which considers practical aspects, industrial cases and, in general terms, applications of current technology to very diverse areas.

A brief description of the eighteen chapters, with regard to their research material and the conclusions reached, are collected and summarized as follows:

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Section 1

Chapter 1, "Technodata and the Need of a Responsible Industry 4.0," presents the historical roots of the interest to adapt business models that rely on data, due to emergence of the Web 2.0 after the dot. com crash and, afterwards, the consolidation of the platform economy on the Internet, and how the development and introduction of these digital innovations must be aligned to societal expectations for not provoking exclusions and displacements of stakeholders in industry, economy and society.

Chapter 2, "Exploring the Effect of Emerging Technologies on Scientific Knowledge Production and the Industrial Advancement of Society," focuses on a kind of state-of-the-art, where new technologies and tools are depicted, in order to provide a view of the effect of technology over science, engineering, and the society in general terms. This chapter presents how, in the Fourth Industrial Revolution, the cybernetic infrastructure will play the same dynamic role played by the railroad in the first revolution and promote the inclusion of innovation and new technologies as the foundation of the new knowledge-intensive industry.

Chapter 3, "Decision Making Under Uncertainty and Risks in the Face of Rapidly Advancing Technologies," describes a general research framework combining technology-oriented risks and social aspects, linked with their perception in terms of impact or ethical standpoints. Along this chapter, the general context of risk-based decision making is depicted, supporting the chosen arguments with a historical and somewhat scientific state of the art in a very relevant manner.

Chapter 4, "Technological Revolution, Transhumanism, and Social Deliberation: Enhancement or Welfare?" analyses how technological development can lead to substantial changes in our own nature without control, implying to take risks that must be anticipated and obliging us to make decisions in the most open and consensual way possible.

Chapter 5, "Human Perfection and Contemporary Enhancement Technologies," shows how the main positions regarding the use of biotechnology on the human being—represented by the bioconservative and posthumanist currents—are very far apart, opening a large gap between those who are in favor of biotechnological improvement of a perfectionist nature and those who reject it. A fundamental part of this research is to analyze the possible risks and consequences of non-therapeutic biotechnological interventions.

Chapter 6, "The Society of the Digital Swarm: Microblogging and Construction of Subjectivity in Homo Digitalis," performs an analysis on the changes brought by the digital revolution of the Web, the proliferation of social networks and virtual communities, as well as the intensification of microblogging that have greatly transformed our habits, lifestyles and ways of communicating with others, and how a global digital citizen should contribute to an authentic information and knowledge society as a responsible person with rights and duties.

Section 2

Chapter 7, "Racing Ahead With Innovation and Ethical Decision Making: The Case for Hybrid Modelling and Simulation," explores how developing anticipatory models may be used to understand the structure of complexities that are part of the societal and technological change, although the fact that it is acknowledged that these models can never be complete or absolutely accurate. The position taken in this chapter is that it is crucial for innovation to emerge to teach critical reflection to ground perspec-

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tives (models, narratives), to remain open to different views, to acknowledge limits to knowledge, to be playful and humble and to ingrain value directives that capture these elements.

Chapter 8, "Towards an Industry 4.0-Based Maintenance Approach in the Manufacturing Processes," introduces how Industry 4.0 accepts the challenge of addressing new concepts of maintenance with numerous efforts on its implementation in various systems. Intelligent Maintenance Systems have brought new paradigm shift to an in-machine renovation and repair. The aim here is to have fully automatized system in order to make a machine capable of reconfiguration, compensation, and, in the last stage, self-maintenance.

Chapter 9, "Assessing HRO Principles for Reliable Performance in Asset-Intensive Organizations: Expecting the Unexpected," sets out the HRO concept (High Reliability Organizations), as a result of an increase in the complexity of physical assets due to the Fourth Industrial Revolution, and how they can benefit from a mindful infrastructure for high reliability to manage higher levels of uncertainty.

Chapter 10, "Anticipation of Problems in Innovative Projects Based on OTSM-TRIZ," provides insights into an operative algorithm that has been elaborated in order to guide the selection of the optimal project development route, when it is necessary to integrate new technical solutions. The findings and lessons gained present two types: the algorithm effectiveness and the usability level, in order to follow a systematic approach that aims to guide the data analytics, together with the identification, and problem resolution.

Chapter 11, "Design Knowledge Development and Additive Manufacturing Systems: How Does Design Knowledge Change With Design for AM?" broadly predicts two key new areas for product designers to apply their knowledge and practical skills in an Industry 4.0 environment, and depicts the adoption of new technology as a key step for any manufacturer wanting to stay relevant as the world transitions to Industry 4.0. The digitalization of manufacture and the advance of Additive Manufacturing (AM) technologies, which are important elements of Industry 4.0, have become part of a globally accepted reality.

Section 3

Chapter 12, "To Mine or Not to Mine? Using Game Theory to Explain the Decision-Making Process in Asteroid Mining Investigations," presents a complex model defined to describe the multifaceted science-industry interaction, typical of techno-science, and how a more important role of technology shall be expected in the future, leading to more complex interactions between science, industry, and governments.

Chapter 13, "Innovation in Scientific Knowledge Based on the Forecasting Assessment: A Case Study on Automotive Spare Parts Demand," focuses on the study of forecasting methods on scenarios characterized by having an intermittent demand, together with usually great amounts of data. Particularly, this study analyzes methodologies like the Moving Averages method, Holt Winters' Exponential Smoothing method, and Rolling Grey's method, in order to provide performance indicators though statistics and big data analytics.

Chapter 14, "Decision Making for Energy Management in Smart Grid," captures the state of information support according to the analysis of the current situation and the actual problems of determining the place of an energy smart grid in the Industry 4.0. This research refers also to those risk and uncertainty during making decision on energy management and information systems in renewable energy based smart grid.

Chapter 15, "Application of MSTAM Methodology in Project Management: A Case Study of ITF Robotic Automation R&D Project," analyses how factors like time, quality, control and other motivating

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factors are the main critical aspects affecting the projects commercialization in Logistics and Supply Chain Industry. Particularly, this study is using MSTAM (Market, Science, Technology, Application, and Market) methodology to apply in the Innovation and Technology Fund projects, in order to develop a solution for helping the industry to adopt the R&D deliverables in the Logistics and Supply Chain Industry in efficiency and effective way.

Chapter 16, "Data-Driven Decision Making to Select Condition-Based Maintenance Technology," shows how the choice of technology should take into account economic, technical, environmental, human resource and political matters. These questions may be addressed simultaneously by applying Multi-Criteria Decision Analysis (MCDA) techniques. In fact, this Chapter describes an objective model built with the fuzzy Analytic Hierarchy Process (FAHP) for choosing through data analytics the most suitable technology in a specific area, being the model applied to a Health Care Organization.

Chapter 17, "Decision Making in the Choice of Condition-Based Maintenance Techniques in a Subsidiary of a Petrochemical Company," performs a multicriteria decision model using an approach that selects the most appropriate predictive technique and technological level, providing a model application to a petrochemical plant. According to the authors, despite the importance of the various aspects involved in introducing a Computer Based Maintenance programme to achieving good results, the number of contributions analyzing these matters is still very small.

Chapter 18, "The Implementation of Nearly Zero Energy Buildings (nZEB) in Spain: Legislative Requirements and Policies," explores the implementation of new technologies in order to achieve high level of energy efficiency in buildings. This chapter analyses the legislation associated to Nearly Zero Energy Buildings (nZEB) in Spain in order to identify the factors that will leverage their massive implementation, especially in social housing. As occurred when implementing new technologies in organizations, this matter requires defining a national nZEB roadmap in order to identify the intermediate steps and the final goal.

CONCLUSION

The chapters listed above have been written by around 40 authors from the five continents (Australia, Chile, China, India, Italy, Netherlands, New Zealand, Russia, South Africa, Spain, Sweden, Ukraine). This diversity provides a more complete view of the state-of-the-art in technoscience around the world. Among the members of the editorial board and authors who have participated in *Handbook of Research on Industrial Advancement in Scientific Knowledge*, there are professionals involved in academic activities, engineering, manufacturing, asset management, commercial business, etc., bringing a reasonable and technical vision to the topics gathered in the book. Hence, the present compilation has provided space for diverse and assorted collaborations, together with case studies related to the phenomenon of the Fourth Industrial Revolution, its new technologies, their application to different sectors, as well as scientific advances and research works in real contexts.

As expected, there are also many participants from philosophy, ethical and social branches of knowledge. They motivate improvements, advances and new references from a humanistic perspective, fulfilling the orientation of the research towards society, which is a relevant value added by *Handbook of Research on Industrial Advancement in Scientific Knowledge*. Thus, there is a significant flow of ideas and experiences through this diversity of collaborators who have contributed to the book.

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As a general view of the book, the main points developed throughout the chapters can be summarized for example in the following ones:

1. The development and prominence of ethical decision making and what are the moral guiding for that.
2. Uncertainty increases, but the techniques for dealing with risk increases as well, providing this book some good principles.
3. Project management and manufacturing will change and, similarly, there are some guiding lines to adopt mentioned along the chapters.
4. Collaborative decision making and problem solving will be the norm, being clear that management paradigms will change in all sectors.

To summarize, general ideas are emerging from this book, thus individuals and teams will require reflexive practices in order to keep organizations focused on outcomes that consider the long view of the future.

The editors wish to thank all those who have contributed to the development and success of this book, since their research work as well as suggestions, comments and ideas provided are really enriching for all of us, seeding meaningful developments in knowledge, technology, and philosophy of science.

Vicente González-Prida Díaz
Universidad de Sevilla, Spain & Universidad Nacional de Educación a Distancia (UNED), Spain

Jesus Pedro Zamora Bonilla
Universidad Nacional de Educación a Distancia (UNED), Spain

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To all of them, thanks.

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Section 1

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Chapter 1
Technodata and the Need of a Responsible Industry 4.0

Raúl Tabarés Gutiérrez
Fundación Tecnalia Research and Innovation, Spain

Javier Echeverría Ezponda
Ikerbasque, Spain

ABSTRACT

The great transformation that will face European industry is driven by the need of digitizing the entire value chain around manufacturing for creating competitive advantages to maintain a dominant position in the global economy. This new paradigm is commonly known as Industry 4.0, and it has a significant policy support from the European Commission as well as different member states. However, this transition is full of uncertainties as the digitization of industry creates different concerns about employment, privacy, labor rights, and other issues related with this technological revolution. In this chapter, the authors trace back the origins of Industry 4.0 to the Web 2.0 phenomenon as well as they reflect upon the role of technodata and technofactories in a postindustrial society. Finally, they stress the need to reflect about developing a responsible digitization of industry that will consider societal concerns.

INTRODUCTION

Technological revolutions have been historical sources of great wealth as well as producers of deep societal transformations. New radical technologies like Robotics, Cyber-Physical Systems, Internet of Things (IoT), Artificial Intelligence and many others are favoring a transition to a new industrial revolution that will redefine the role of factories in the economy all over the next coming years. The introduction of digital technologies for automating and monitoring production process will create new routes for innovation, new services and new competitive advantages in manufacturing companies. The European Commission (EC) is promoting this new paradigm throughout what it has been originally coined as "Industry 4.0" in Germany some years ago, for embracing digitization and favoring the transition in factories to business models based in high-added value services. This push for digitization in the whole value chain of the manufacturing sector lies in the inability of Europe to compete with U.S. Internet companies and as a way to strength the current sector for assuring the international importance of it in the global economy.

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But this transition to a digitized industry is full of challenges as the main role of industry in the economy will be completely redefined, and this will create deep transformations in society. Loss of medium and low skilled jobs, the need of huge investments to acquire technology and maintain it, conflicts between workforce and managers, as well as issues related with privacy, security and new forms of alienation due to the introduction of autonomous technologies in factories are envisioned as non-side effects of this technological revolution. New tensions will emerge in the policy arena as well as in society as the factory is still the place where class struggle happens and already existing power relations will be affected by new forms of control. These societal and ethical consequences of the digitization of manufacturing processes will demand a more collaborative approach to technology design and development, for assuring that the outcomes of this new revolution can be beneficial to a larger part of society and preventing possible non-desired impacts.

In this contribution the authors pay attention at the historical roots of the Industry 4.0, that can be traced back to the origins of Web 2.0 and the platform economy, to understand the value of data in this digitized form of economy to create new innovations based on this new fuel. The text explores how this new type of industry is being promoted by policy makers and the role of technodata as the basis of this new kind of technofactories in the Third Environment is stressed. In addition, the authors underline the need of developing a Responsible Industry 4.0 that will consider and reflect on the views of the different stakeholders that will be affected by these great transformations that are envisioned in the manufacturing business.

Moreover, it is argued that the introduction of these new digital technologies in the factory must be aligned with societal expectations, for assuring the diffusion of the innovations as well as promoting their competitiveness, avoiding further modifications. If this kind of co-responsibility approaches are not considered, the authors predicts that the embracement of digitization in factories can face significant barriers that will deter its implementation. New problems can be raised in the factory in relation with the introduction of these new technologies as well as the experimentation of difficulties in this transition can lead to a lack of competitiveness in the manufacturing sector.

Finally, the authors conclude with a set of a policy recommendations for accommodating the introduction of technological innovations to the social concerns that can be risen up as main stoppers of the Industry 4.0 paradigm. Attention is also posed in the need of developing a much more diverse industry that can prevent biases, inequalities and negative externalities from the adoption of disruptive innovations by different companies. The authors stress the need of a developing a Responsible Industry 4.0 that can be beneficial to society and can pave the way for the digitization of manufacturing, avoiding at the same time, dramatic transformations in economy, employment & welfare.

WEB 2.0 AS THE ONSET OF PLATFORM ECONOMY

In 2004 Tim O´Reilly wrote a famous article describing the new features that were sharing a certain group of Internet companies that rose at this time in Silicon Valley after the dot com crash. These companies, according to O´Reilly, were creating the "Web as platform" paradigm (O´Reilly, 2005b) because they were developing new business models and new technologies that created a "perpetual beta" in software and making the Web more important than ever. O´Reilly also identified in his proposal a set of 7 principles to speak about a Web 2.0 version of the Web (O´Reilly, 2005b);

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1. *The Web as Platform*
2. *Harnessing Collective intelligence*
3. *Data is the next "Intel Inside"*
4. *End of the software release cycle*
5. *Lightweight programming models*
6. *Software above the level of single device*
7. *Rich user experiences*

Despite the fact that the term Web 2.0 was a buzzword for identifying several aspects and implications of a new approach to develop websites that was not focused only on technological assets (Anderson, 2007), several technologies like Ajax, XML, Flash and API´s can be recognized in this momentum that implied a breakout with the previous Web (Tabarés-Gutiérrez, 2015, 2016), and introduced more fragmentation in the platform (DiNucci, 1999). According to O´Reilly *Web 2.0 is the network as platform, spanning all connected devices; Web 2.0 applications are those that make the most of the intrinsic advantages of that platform: delivering software as a continually-updated service that gets better the more people use it, consuming and remixing data from multiple sources, including individual users, while providing their own data and services in a form that allows remixing by others, creating network effects through an "architecture of participation," and going beyond the page metaphor of Web 1.0 to deliver rich user experiences* (O´Reilly, 2005a)

One of the fathers of the Web, Tim Berners-Lee, has also expressed in several occasions his disconformity with this interpretation of Web 2.0 as a contrary idea to the previous Web as he claims that it was designed from the very beginning to connect people (Berners-Lee, 2000; Laningham, 2006). Despite this statement, it can be observed how after the appearance of Web 2.0 new platforms like Wikis (Anderson, 2007), Blogs (Doctorow, 2002; Nardi, Schiano, Gumbrecht, & Swartz, 2004) and Social Network Sites (Boyd & Ellison, 2007) clearly contributed to a growing user adoption of the Web due to the easy generation content tools that these new websites introduced on the Internet. Non-technical users without skills of HTML coding were attracted to the Web as well as other kinds of users that were already present. This was possible due to the emphasis of the Web 2.0 period for generating new multimedia contents that attracted much more attention than other previously present text-based contents (Tabarés-Gutiérrez, 2015, 2016).

It is in this moment when social media (Helmond, 2015; Kietzmann, Hermkens, McCarthy, & Silvestre, 2011; Mangold & Faulds, 2009) platforms like Facebook, Twitter or YouTube emerge and become the digital references where different users start to create, edit, remix, comment and upload different kind of contents. Pictures and videos will become the new drivers to attract attention (Goldhaber, 1997) and User Generated Content (UGC) (J Van Dijck, 2009; Ritzer & Jurgenson, 2010) sites will start to gain prominence and reconfigure the nature of the Internet. As time has gone by and digital business models based on user data have demonstrated their profitability, new platforms have risen in the Web. This is the case of Netflix, AirBnB, Uber or Spotify or other companies that have positioned themselves as intermediaries in our daily routines for watching movies in streaming, renting a flat, hiring transportation services or listening to music throughout streaming services. These companies and others that have popped up after the Web 2.0 paradigm and the appearance of mobile devices (Vogelstein, 2013) belong to what it has been called recently as "platform economy" (Kenney & Zysman, 2016), "platform capitalism" (Srnicek, 2017), "sharing economy" (Sundararajan, 2016) or "surveillance capitalism" (Zuboff, 2015). The disparity of terms used for referring to a new reality give us an idea about the important change

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that have happened in the business models that host the Web and their importance in global economy. This new platform economy is characterized by an accumulation of power, audiences and resources in digital platforms populated by users, producers and prosumers. Platform economy is defined as *a term that encompasses a growing number of digitally enabled activities in business, politics, and social interaction* (Kenney & Zysman, 2016).

Due to the growing digitalization of sociality (José Van Dijck, 2013) and the decentralization effect that Internet culture provokes on society (Castells, 1997, 2001) a transition to digital services that are promoted by nascent start up´s has been possible and new business have succeed in an increasing technology-mediated environment. These new companies are totally dependent on the contribution of human beings and the digitization of value-creating human activities (Kenney & Zysman, 2016) for creating new services and remaining competitive. The availability of large datasets that have been generated since the consolidation of UGC websites (J Van Dijck, 2009) and the pervasive use of mobile devices has made possible that the establishment of data driven business models in several areas of society has become the new norm. This exploitation of data introduced by users in a voluntary basis (pictures, videos, texts, etc.) or in an involuntary basis (data coming from web or mobile tracking) by platform owners on the Internet has led to the establishment of concepts like "digital labor" (Scholz, 2012) or "free labor" (Terranova, 2000) that reflect upon the new forms of labor exploitation that have introduced by digital capitalism.

Nowadays it can be noticed how this business paradigm is currently being extended to other fields like industry as the costs for manufacturing are decreasing and new forms of value must be build up for maintaining profits and developing new services that can generate more benefits in a post-industrial scenario. As Martin Zenney and John Zysman argue *If the industrial revolution was organized around the factory, today´s changes are organized around these digital platforms, loosely defined. Indeed, we are in the midst of a reorganization of our economy in which the platform owners are seemingly developing power that may be even more formidable than was that of the factory owners in the early industrial revolution* (Kenney & Zysman, 2016).

The evolution of these digital platforms that have emerged on the Internet have been focused in the development of Big Data tools (Boellstorff & Maurer, 2015) that allow them to analyze the increasing volumes of data that are generated but also for decreasing the costs of collection and storage of it. At the same time, these technologies have permitted to generate more sophisticated techniques that are a continuous source of innovation for these companies (Boyd & Crawford, 2011; Gray, 2014). In this sense, the irruption of Artificial Intelligence (AI) has been made possible due to the great advances of computing in data treatment but also for the large quantities of available data to train computers in specific tasks. The next frontier in this expanding paradigm about the role of data in business is the factory as it remains as an unexplored territory where there is not sufficient knowledge about production processes and there are no digital layers of information that can be used for providing a deeper understanding of what is happening at the sweatshop. In this sense, is of outmost importance for industry leaders to create new innovations that can aid to the inner working of the plant or developing new services that can be aligned to the sector where they work. This is one of the next steps in the digital transformation of society towards the post-industrial scenario where the classical manufacturing of goods is not likely to be as lucrative as it was in previous industrial revolutions with a continuous decreasing of manufacturing costs and profitability.

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INDUSTRY 4.0: TOWARDS A NEW PARADIGM FOR MANUFACTURING IN EUROPE

From 2010 onwards, it has been observed the emergence of a new paradigm in the current situation of European industry. Despite the fact that Europe has also boasted of a strong manufacturing sector that employs around 30 million people, represents around of the 16% of the GDP and contributes to more than 80% of total exports, the financial crisis that took place in 2008 has led to the loss of jobs, mainly among the unskilled or low-skilled workers (European Commission, 2013). Globalization and the rising of emerging economies in the south east of Asia has also favored the delocalization of factories and industrial plants due to the low labor costs that these countries can offer to multinational companies. In addition to, there is a shared consensus about the rising of a new industrial revolution that is on the way and it will redefine manufacturing and the classical conception of what a factory is due to emergence of several disruptive technologies coming from the digital transformation (Brynjolfsson & McAfee, 2014; Schwab, 2016).

Despite all of these factors, manufacturing is envisioned to be a major provider of employment in Europe in 2025 (EU Skills Panorama, 2014) and in this sense the rising of "Industry 4.0" paradigm is critical for achieving this objective. The digitization of European industry is one of the highlighted milestones that the European Commission is pushing forward throughout different policies aimed to modernize European factories and improving their capabilities for facing a more complex and challenging production ecosystem. Industry 4.0 is the term that is being used for describing a much more automatized, digitized and flexible production ecosystem. Despite the fact that the term was first used in 2011 at the Hannover Messe by a working group, the German government has used this concept for supporting their national industries in the digitization of their production process (Verniere, Van der Straeten, Torfs, Venderlinden, & Van den Kerkhof, 2017) and as a way to confront the growing competition overseas. The name has been widely accepted by other countries at the European level and it also counts with the backing of the EC. One of the most well knowns policy briefings delivered by the European Parliament defines Industry 4.0 as *a term applied to a group of rapid transformations in the design, manufacture, operation and service of manufacturing systems and products* (Davies, 2015).

Other terms have been also used to referring to this new paradigm such as "Smart factories", "Industrial Internet of Things", "Smart industry" or "Advanced manufacturing" but these terms have lost popularity in favor of Industry 4.0. Although the term has been recognized worldwide, in countries like USA and UK is known as "Connected Enterprise" or "Fourth Industrial Revolution" (Morrar, Arman, & Mousa, 2017). Basically, the potentialities of Industry 4.0 are related with the possibilities that digitization of physical world can bring to industrial plants as well as how decentralized decision making can be introduced throughout the connectivity between machines and humans in real time. This new paradigm is also considered as an evolution of the current factories towards the acquisition of automation capabilities and the merger of machinery and digital systems (see Figure 2).

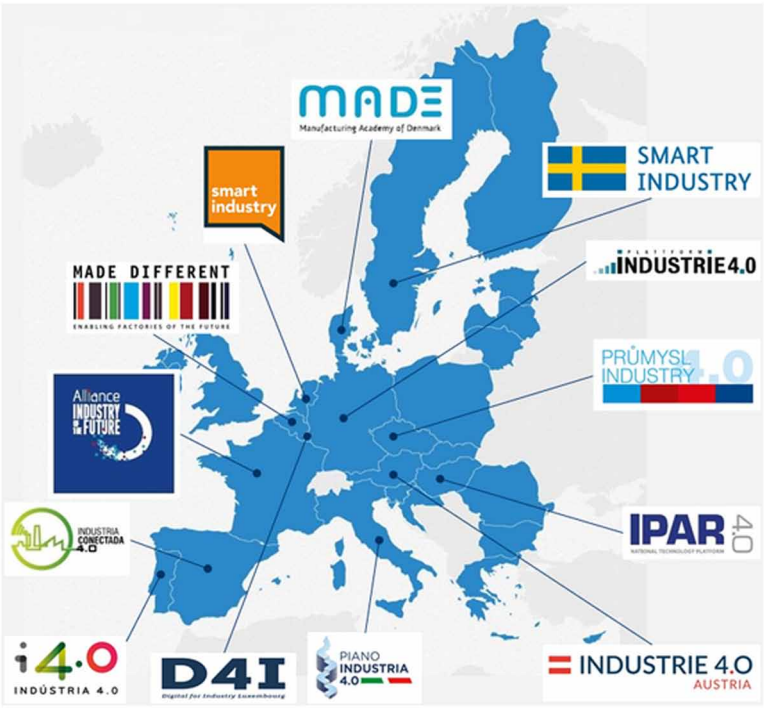
This new industrial revolution aim to digitally connect everything in and around a manufacturing operation (suppliers, the plant, distributors, even the product itself) for providing a highly integrated value chain (Davies, 2015). This major reconfiguration of production processes in factories needs of a significant policy support and that is one of the reasons behind the support of the EC to different research and innovation actions like "Factories of the Future" Public-Private Partnership program[1], where different stakeholders from academia, industry and government are collaborating. Heavy investment[2] is being fueled throughout this program and more than 2.000 organizations have benefited from this initiative

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thanks to the 240 projects that have been funded during the last years (Pazin, 2017). This effort by the EC is also aligned with other national strategies that different Member States have implemented in their countries to support their local industries. As it is shown in Figure 1, almost every member state has a specific Industry 4.0 program to support this technological transition of businesses and it is expected that in the near future new programs and policies will be planned and delivered at national and European levels to enable this transition.

The digitalization of traditional industry is a great challenge as it requires the collaboration of different actors that have not been present in the manufacturing sector till recent years. That is why a major policy support is expected to favor the engagement of new agents. Fabrication is of paramount importance in relation to employment in Europe with around 30 million direct jobs and 60 million indirect jobs (Pazin, 2017) and what´s more important; 59% of these jobs are distributed in SME´s (European Commission, 2013). This is one of the reasons that helps to understand the political strategy of manufacturing in the Eurozone and why it is highly interconnected with different institutions, companies, universities, research centers and other stakeholders that it makes this sector of outmost importance in every policy agenda for their political and social implications[3]. The EC is also committed with this significance and some parliamentarians like Andrus Ansip, Vice-President of the EC for the Digital Single Market has remarked this need for policy alignment in Europe around the idea of supporting the digitization of industry; *I congratulate the Member States which have already started their national political initiatives, committing significant financial and organizational resources to digitizing European industry. I warmly welcome*

Figure 1. Map of different European initiatives around Industry 4.0
(European Commission, 2017a)



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the newcomers and encourage other countries to join. The European platform of national initiatives is an example of a collaborative and cohesive European Union. This is a strong effort at European level, but it will produce results only if Member States do their part and support industry and innovation communities in their regions which drive digital transformation (European Commission, 2017a).

The framing of this call to join forces between Member States for supporting this new technological paradigm lies in the need of upgrading the European industry and creating a more competitive one that can guarantee well-paid jobs, exports and wealth. This modernization of the industry is also narrowed in the increasing competitiveness of emerging economies in the south-east of Asia and the predominance of the Chinese industry in the global market. Another big reason is that Germany has a more manufacturing-based economy that the USA and the UK and at the same time, the power achieved by US Internet companies in the last years makes so difficult for Europe to compete in these novel markets. This explains why Germany and Europe have adopted this strategy towards the digitization of industry for becoming world leaders and innovators in manufacturing (Fuchs, 2018).

Nevertheless, it must be stressed that the digitization of industry is also a never-ending process as the introduction of software to monitor industrial processes requires of people and technologies that can update and maintain software services upon request. The values of the Web 2.0 paradigm are also embedded in this industrial revolution offering a "perpetual beta" (O´Reilly, 2005b) in order to upgrade technologies for monitoring manufacturing. In this sense, the rising of disruptive technologies like Big Data, Robotics, Cybersecurity, Internet of Things (IoT), artificial intelligence (AI), Cyber-physical systems or Additive Manufacturing will redefine the operational processes of factories creating new opportunities for maximizing efficiency, agility and flexibility in manufacturing (Keller, Rosenberg, Brettel, & Friederichsen, 2014). However, this transition must face several challenges that have been identified to embrace a new technological paradigm. The integration of ICT in manufacturing processes does not only implies the acquisition of particular innovative technologies. It really means a more complex process that demands to rethink about the role of infrastructures, resources, processes and organizations themselves. Another of the representatives of the EC, Željko Pazin, which is the President of European Factories of the Future Research Association (EFFRA), stress how important is to reflect about what it means to get on board on this industrial revolution; *digitization means more than the installation of new ICT or high-speed connectivity. It is a complete transformation of where, how and why we manufacture. It is shaping the factory floor, products, the skills of workers and integrating services and supply chains.* (Pazin, 2017)

Challenges for Industry Digitization

Several challenges lie ahead in the implementation of the Industry 4.0 paradigm in the manufacturing European landscape, as the integration of digital technologies in factories does not merely depend on technology acquisition and technology transfer processes. Of course, it demands a major reconsideration of facilities, structures, resources and processes but it also stress several points of action that can hardly being tackled by organizations that do not have plenty of resources. In this sense, one of the major challenges that imposes Industry 4.0 is related with the need of large investments to upgrade and maintaining technological equipment. This barrier could deter the onboarding of SME´s as they do not usually have the kind of access to funding that is needed to accomplish these kinds of large investments.

In this sense it´s very likely that minor companies will have to cooperate in order to share resources and create open value chains (IEC, 2015). Big companies will be also forced to contribute to these collaborative environments as the nature of manufacturing production processes requires a high grade of

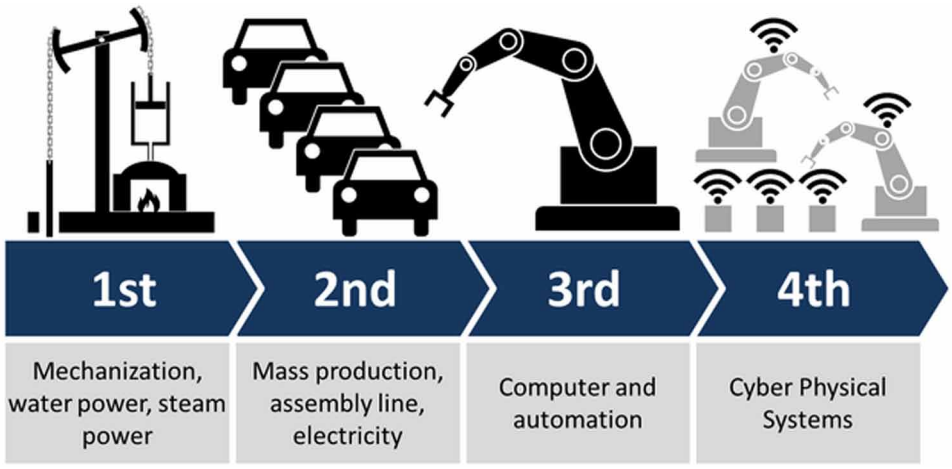
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interconnection between different organizations. Current trends in customization and personalization are imposing flexibility, agility and resilience as core components of production systems as well as shorter product lifecycles have become the new norm. These trends will demand new collaborative approaches to be developed in production ecosystems that can meet the increasing high-end specifications.

Another important challenge that may arise soon are possible asymmetries in digitization processes between regions. This is a problem that will draw a lot of attention from policy makers as inequalities between Member States can hinder the potential of an European data economy (European Commission, 2017b). Digital technologies have demonstrated their potential to create different kinds of divides (DiMaggio & Hargittai, 2001) in the past and legislators will have to take a closer look to the evolution of the different countries for assuring an inclusive industry for all Member States. Assuring high speed bandwidth connections, cybersecurity infrastructures and resources, as well as other kinds of digital equipment's and resources will be of outmost importance for paving the way to a smooth transition to a digitized economy.

Deskilling and reskilling phenomena are also envisioned as future problems in the current workforce as this modernization of industry is driven by automatization as well as other industrial revolutions have suffered too. Despite the fact there is a growing literature about the future impact of the digitization of factories in employment, there is no consensus at all about what it will be the indicative amount of jobs that can be lost due to this transition (Winick, 2018). It seems that many medium-income jobs will be affected by this revolution as it has already happened in the XIX century (Frey & Osborne, 2013) and it can be inferred that low-skill and medium-skill jobs could be at risk due to the impact of automatization in factories. However, there is at the same time a major challenge in the need of promoting a high-skilled workforce that can lead this technological revolution as Robotics, AI and Cyber-Physical Systems will improve the autonomy of employees but will demand advanced capabilities. This is one of the biggest problems that have been identified as some reports have stressed that around 900.000 jobs with specific digital skills could be demanded in 2020 in Europe (Gareis, K., Hüsing, T., Birov, S., Bludova, I., Schulz, C., & Korte, 2014). In fact, it is expected that in coming years 9 of 10 jobs will require digital skills and in this sense Europe is not satisfactorily prepared as 44% of Europeans do not have these basic abilities[4].

Figure 2. Industrial Revolutions and Future View
Source: Wikipedia



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All of these challenges remain unsolved and can act as stoppers of digitization processes in European industry if they are not properly tackled. The importance of manufacturing for Europe is essential and in this sense, there are several dark clouds that are appearing on the horizon, questioning the viability of this transition to a digitized industry.

TECHNODATA AS THE FUEL FOR INDUSTRY 4.0

As it has been exposed previously, the main driver of this new technological revolution lies in the need of digitizing the manufacturing network and infrastructures for creating virtual realities that can thrive new innovations. The role of data and the generation of digital layers of information that can store the functioning of real processes at the factory is one of the backbones where it lies the next industrial revolution. Innovations like Digital Twins are of paramount importance in this new industry as they comprise particular artifacts and their computer models that reflects its performance in a carefully way (Bruynseels, Santoni de Sio, & van den Hoven, 2018). These novel assets allow to develop new techniques such as predictive maintenance for maximizing efficiency as well as optimizing resources in production processes. Then; the unexpected can be envisioned with a percentage of error and providing some insights about what can it be done about it. This rediscovering of the real world throughout virtual realities and digital artifacts makes room for the emergence of technodata; data that is treated throughout different emergent technologies like Big Data, Machine Learning or AI and it is of outmost importance for the new industry as it constitutes the new fuel for a growing digitized industry. This emergence of technodata must be understood as a byproduct of the Third Environment and the technosciences (Echeverría, 1999). This is also a direct consequence of the development of Information and Communication Technologies (ICT), and its embedding in societal processes of every kind (business, social life, administrative, legal, etc.).

Technosciences emerge in society in the U.S.A. after the World War II thanks to the recommendations of several policy makers that started to lure attention to the important role of Science & Technology and its contribution to economic and societal development (Bush, 1945). Macro research projects commonly known as "Big Science" are funded by the federal government and other agencies like the NASA or the NSF combining huge investments, top-notch facilities and high-skilled researchers. Afterwards, other technoscientific initiatives are deployed in other countries, especially in Europe, like the CERN or the ESA (Echeverría, 2018). Nowadays, it can be observed how these initiatives are still on the edge with popular collaborative research and innovation programs in the old continent such as "Horizon 2020"[5] that are supported by the EC.

As well as with technoscience, it is needed to explain the hypothesis of the Third Environment as the authors consider this concept of great importance to frame the technological revolution that is being conducted. To do so, it is required to previously clarify the notion of technological systems as systems of human actions and not only as a set of artifacts, mediums or instruments (Quintanilla, 2005). A concept that is also influenced by the Orteguian idea of "supernature" that reflects on the transformative role of certain kind of technologies. The famous Spanish philosopher of technology also argued that thanks to techniques, human beings have generated "supernatures"; *man, thanks to his technical gift, manages for everything that he requires to be found in his surroundings – he creates, thus, a new, more favorable circumstance, segregating, we could say, a supernature by adapting nature to his needs* (p 65, Ortega y Gasset, 1965)

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Technologies and innovations have transformed nature and societies in a great extent creating new possibilities for human development. Inhabitants of urban areas are also a good example of this because they do not live in nature but in an artificial ecosystem developed by human technologies. Not only in a physical way but also in an intellectual way due to a different set of norms, values and laws that have been superimposed by human technologies of different kind. These two environments have been transformed by a third one, the Third Environment, which has been originated thanks to the development of the diverse ICT technological systems that have permitted *the emergence of a new social space–time, the third environment, that superimposes itself on the two great space–times that human beings have experienced and that we continue to experience: the physis and the polis* (J Echeverría, 1999).

It is in this Third Environment where technosocieties (Echeverría & Tabarés-Gutiérrez, 2016) have emerged due to ICT´s. Digital technologies now allow to create, maintain or blocking social relationships and interactions between citizens (and also with other techno-objects and technopersons) throughout technological mediation. ICT´s have created new digital infrastructures where information and data are the new valuable resources that can generate profits and economic activity. Of course, data treatment is nothing new as it has been one of the core activities in many industries, businesses and governments since long time ago (Boellstorff & Maurer, 2015) but the great advances in computing technologies (particularly in cloud computing) in the last years have allowed to generate new techno-objects that can sustain new innovations in this Third Environment. As it has been argued previously, the main goal of technosciences is not only conceptualizing the world but also to transform it (Echeverría, 2018) and this has been the case in the progressively digitization that has occurred in society. ICT´s not only create new objects but also mediates ways of life as well as they create new forms of living. Other authors have also spoken about the transformational nature of the ICT and they have coined other terms to this phenomenon like the infosphere (Floridi, 2002) or the informationalism (Castells, 1997). The emergence of Youtubers and other "digital personalities" in the Web that are able to attract attention to the content they produce as well as to monetize these audiences are examples of it (Tabarés-Gutiérrez, 2017). These new actors are also living in the Third Environment as technopersons but they have also a profound impact in the other two environments as they are superimposed into them.

In this sense, the emergence of technodata is the vital raw material that technofactories will have to gather, store, use, share and reuse for developing new services that will add a major value to their products and services. Nevertheless, the digitization of factories will provoke major transformations as ICT´s have provoked previous disruptions in business like media, tourism or music. This is of particular importance as the factory is one of the major providers of employment in Europe and the modernization that is on the way is creating several shadows of mass unemployment all over the continent. At the same time, the investment of capital that is needed to acquire digital technologies (and maintaining them) can create inequalities between regions, businesses and companies. The accumulation of capital and power in particular companies is expected to follow similar patterns to the Internet industry, where the rising of the platform economy has showed how a bunch of organizations have a dominant position in sectors like digital advertising, e-commerce or cloud computing (Gillespie, 2010; Kenney & Zysman, 2016; Srnicek, 2017; Sundararajan, 2016). But at the same time, it is still unclear that these transformations will happen in a smooth way as it has (almost) happened in the Internet industry. The factory is still the place where power relations and class struggles happens and due to the weight of European manufacturing in the total amount of jobs in the continent, it is very optimistic to think that these transformations will be materialized without social and political convulsions. Manufacturing still relies in a great significant

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portion of human labor and Germany specially has significant labor costs coming from the workforce. This emphasis in the digitization of industry can be seen as a capitalist need for reducing labor costs and maximizing profits but it is still not clear how human labor complexity will be reduced by automation in a substantial way (Fuchs, 2018). Machines have proven to be excellent with simple tasks in different production lines but there is still a long way ahead to create a robot that can deal with the physical barriers of an industrial plant and help humans at the same time in their daily routines.

Other challenges that will create the growing digitization of the industry are related with privacy, cybersecurity and surveillance. All of them will create new needs in terms of regulations and security as goods will be most of them transformed in services but also because of technodata will become the major asset of technofactories. This technodata is not a single raw material but a set of different aggregated data that will be built up throughout the combination of different sources and treated with different techniques and technologies like Big Data, AI or Machine Learning for obtaining valuable outputs that can generate new services or innovations. Data such as machine durability or employee performance in certain tasks can be stored, analyzed or aggregated to create new technodata that will constitute a valuable output. The emergence of data brokers in the industrial realm will be also another issue that will provoke privacy and security concerns as this technodata constitutes a commodity itself that can be sold for further treatments. Just like data brokers are also operating with current data provided by Social Media platforms and Internet activities that are monitored (Zuboff, 2015).

All in all, there is a clear transformation of the business models and value proposals on the way regarding the manufacturing sector as digital technologies imply a new conception of production processes. A major reconfiguration that needs to rethink traditional roles of workforce but also needs to rethink the entire role of industry in the European economy and society. The growing role of technology in manufacturing will create tensions in different areas of society and it will also create new (but at the same time old) conflicts as the displacement of workforce in production processes will be favored by industry digitization.

THE NEED FOR A RESPONSIBLE INDUSTRY 4.0

In previous sections there have been exposed the difficulties that will appear in coming years due to the transformation of the European industry and how this reconfiguration will impose several challenges in the foreseen path of digitization. The shadows of mass unemployment that can introduce the automatization of factories (Frey & Osborne, 2013) as well as the growing need for massive investments for incorporating technology in industrial plants (Davies, 2015) will create several tensions in the policy arena. Other emerging challenges that will appear due to the introduction of surveillance and monitoring techniques into the factory will affect regulatory frameworks and social consensus as it can be expected new conflicts between workers, trade unions and corporate managers in a classical class struggle basis.

In this sense, the authors would like to draw attention to and to reflect upon the idea of developing a “Responsible Industry 4.0”as the role of it in the European economy and society is of outmost importance. The need of developing and introducing technological innovations in the factory that will go hand in hand with societal expectations can produce better outputs and alleviate the strains that the new industrial revolution can bring into society. The EC has also adopted Responsible Research & Innovation (RRI) as a pillar in his strategy of Research & Development in the Horizon 2020 program (European

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Commission, 2012) but it must advance in his strategy to include RRI as a core value of Industry 4.0. This emerging paradigm will create a profound disruption of the classical understanding of industry as a major provider of manufactured goods, long-term jobs and supplier economic activities if it is finally fully embraced and RRI could help to mitigate the negative externalities that technological innovation can introduce in manufacturing. The EC provides the following definition for RRI; *Responsible research and innovation is an approach that anticipates and assesses potential implications and societal expectations with regard to research and innovation, with the aim to foster the design of inclusive and sustainable research and innovation* (European Commission, 2017c).

RRI can be a useful element in order to foresee the challenges and threats that digital tech could bring to factories as reframes responsibility in innovation contexts (Owen, Macnaghten, & Stilgoe, 2012) as well as confers new responsibilities (Douglas, 2003) not only for scientists but for other different stakeholders likewise universities, business, policy-makers and research funders, in order to prevent from technological "lock-in" (Collingridge, 1982) and "historical accidents" (David, 1985). In this sense, the Collingridge dilemma imposes several challenges for the digitization of industry as ethical issues can be early addressed during the technology design phase but at the same time, it is tough to envision which social and ethical consequences will appear after the design is implemented (Collingridge, 1982). Dual uses of technology as well as not envisioned problems that can appear with the introduction of particular technologies in the factory might appear at a stage where the change of their trajectories have not enough room.

In addition, the non-envisioned ethical and social consequences of different technologies are usually pointed out by stakeholders that are not usually part of the communities that take part in their design and development, as engineers and designers have usually positive attitudes to their creations and are not aware about its future recoils. Innovation is also a collective process that requires a collective approach to responsibility (Mitcham, 2003) and that many times is supported by public debate (Von Schomberg, 2013) with different stakeholders that contribute through their visions to the process of research, technological development and innovation. Therefore, involving actors and users into these processes to introduce new ideas and values is also encouraged for envisioning not socially acceptable or potentially dangerous products of technological innovation (Stilgoe et al., 2013) and at the same creating the "right impacts" (Owen et al., 2012).

This emphasis on promoting a collective responsibility between different stakeholders can help to reduce uncertainty and creating trust in different collectivities that are not usually included in Research & Innovation processes. Different non-side effects and trade-offs that can create technological innovations are important matters that must be discussed not only by technology makers. That is why incorporating different stakeholders to the loop can be mutually beneficial for aligning societal expectations and reducing uncertainty in complex systems that certainly will have a deep impact in economy and society. Involving different stakeholders and diverse collectivities can help to visualize future scenarios to avoid or to embrace, that the introduction of these technological innovations in factories can provoke.

RRI also can provide of economic benefits as the involvement of different stakeholders in research and innovation processes can lead to a greater diverse ecosystem that can imply a better quality of the technologies introduced in the factory. This is of special interest in relation with digitization processes as the growing importance of algorithms and other autonomous technologies in our lives are revealing how technology possess several biases that reflects the values of its developers (Quirós et al., 2018).

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Digital sector is a predominant white male industry and creating a diverse workforce will help to meet the needs of increasing and complex fragmented markets as well as saving costs in potential business loses that will not take care of this (Quirós et al., 2018).

Pursuing a more collaborative and diverse approach for this Industry 4.0 will also prevent future modifications of technologies that will be demanded by regulators to compliance with laws. Moreover, the inclusion of different agents in these R&D processes is a cost-effective strategy to obtain new ideas, procedures and outcomes that can help to create innovations and services aligned with the societal expectations and needs. These new agents can bridge research centers and companies with other domains that have been previously unexplored or remain inaccessible. Sustainability strategies can be introduced into technology roadmaps with low cost due to the collaboration with other outsiders of industry that are affected by technological innovations. Some examples that can lead to this kind of interdisciplinarity collaborations with industry are initiatives such as the recommendations that a group of experts has proposed to the EC on Civil Law Rules on Robotics (https://bit.ly/2Pmqj1z) or the "Ethics in Action" initiative driven by the IEEE (https://ethicsinaction.ieee.org/). These kinds of initiatives are umbrella actions that aim to inspire concrete actions by markets, sectors and companies which are surrounded by different stakeholders in their value chains. These specific actions can help to mitigate the ethical and social non- side effects of the introduction of Industry 4.0 paradigm in industrial landscapes.

To conclude with this section, the authors would like to encourage industry leaders to adopt a comprehensive approach to this new technological revolution as previous episodes in industrial history have shown how dramatic these transformations can be. Particularly, the authors argue that there are several major lines of action that policy makers will have to safeguard for promoting a Responsible Industry 4.0;

- Protecting employee labor rights in front up of technological innovation. The introduction of disruptive innovations like Robotics and AI will create new threats to employee labor rights as these autonomous technologies will diminish the influence zone of employees.
- Guaranteeing privacy, security and confidentiality of data, specially from employees. Technodata will become the major competitive asset in technofactories and these technodata will comprise different datasets that will aggregate not only data produced by machines but also from employee performance, habits, behaviors, etc. These data will be of specially complexity.
- Promoting digital skills and reskilling of workforce. New disruptive technologies will require new competences and knowledge as they will be embedded in traditional production processes. These episodes of technology transfer will create specific demands of skills as well as they will create skills obsolescence in different areas of production.
- Assuring meaningful participation of different stakeholders of value chains in digitization processes. Digital transformation of industry has a critical importance in the future and prosperity of Europe and therefore it shouldn´t be only at the hands of a bunch of European manufacturers. It is needed that a dialogue between different stakeholders that can be affected by these conversions must be enabled for envisioning non-side effects and anticipating them.
- Including marginal collectivities that can be excluded from advanced manufacturing. Industry 4.0 will need of a highly educated workforce and specialized profiles that can navigate in these new technofactories, and that is why the danger of exclusion of different collectivities, is greater than anytime at history. Women, migrants, elderly people and other marginal collectivities that face discrimination in the Internet industry could be also excluded in this new industrial paradigm.

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CONCLUSION

During this text the authors have explained the historical roots of the interest to adapt business models that rely on data due to emergence of the Web 2.0 after the dot.com crash and afterwards, the consolidation of the platform economy on the Internet. Digitization of physical and human activities present a clear need for adopting data-driven business models that are considered to be more profitable and innovative in post-industrial scenarios. It is in this growing digitization and monetization of human activities where the interest for an Industry 4.0 in Europe has been rised.

The digitalization of European industry and its value chain is focused in maintaining its important role in the global economy but also for creating new competitive advantages that can flourish by the generation of new services associated to the introduction of digital technologies to the manufacturing sector. This strategy has been pushed forward by Germany and the EC after the failing of the Lisbon Strategy and the inability of Europe to compete with US Internet giants. To strengthen a secondary strategic sector of the European economy, a highly interconnected one between the different Member States and at the same time, favoring the transition to a data economy, has becoming a new imperative in the policy arena for maintaining its leverage in the global economy.

Nevertheless, this strategy of Industry 4.0 raises different questions about its financial sustainability, positive impacts on employment, new conflicts in factories and shadows of accumulation of power due to the digitization asymmetries that can occur in this transition. To prevent these negative externalities that technological revolutions can bring to European societies the authors argue that is of outmost importance to implement a Responsible Industry 4.0 approach in the current strategy of digitization. The adoption of a collective and diverse approach that can include other visions and expectations that are not currently being held by technology leaders can result in a more suitable introduction of autonomous technologies in factories and therefore, alleviating tensions and strains that can be risen with these transformations.

The fourth industrial revolution should be also a major reconfiguration of what is the role of technology in society. The development and introduction of these digital innovations must be aligned to societal expectations for not provoking exclusions and displacements of stakeholders in industry, economy & society. A true industrial revolution will take all these factors into account for delivering a much more responsible way of developing and introducing technology that can provide prosperity and wellness for most of society and not for a minority, as well as avoiding dramatic transformations in economy, employment & welfare.

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KEY TERMS AND DEFINITIONS

Digitization or Digitalization: Application of different ICT technologies to design, control, monitor, evaluate, assess, and improve processes, products, services, or strategies.

Industry 4.0: Term used to describe a much more automatized, digitized, lean, and flexible approach to production processes in factories.

Platform Economy: A business paradigm that has been pushed by the accumulation of power and capital on the internet throughout the development of digital platforms that gathered a significant number of users.

Responsible Research and Innovation: RRI is an approach that tries to provide anticipation and assessment to potential implications of research and innovation.

Technodata: Data treated by advanced technologies in order to find patterns and insights that can boost business innovation.

Technofactories: Factories that rely on digitization and data for acquiring competitive advantages and high-value added services associated to manufacturing.

Web 2.0: Period of the web characterized by the irruption of several participatory platforms like wikis, blogs, and social networks as well as the introduction of new dynamic technologies like Ajax, APIs, and Flash.

ENDNOTES

1 More info about this initiative at this link https://ec.europa.eu/research/industrial_technologies/factories-of-the-future_en.html.

2 Total amount is around 1,15 billion euros for the period 2104-2020. More info at http://ec.europa.eu/research/press/2013/pdf/ppp/fof_factsheet.pdf.

3 Major European manufacturers like Volkswagen have a large list of suppliers (more than 40.000) that are already coordinated in digital platforms. See for instance https://www.volkswagen-media-services.com/en/detailpage/-/detail/Volkswagen-Group-expands-digital-supply-chain/view/4940553/4277f85fa0fe74e68f860d037e02125e?p_p_auth=fqbWuvt1.

4 Digital Single Market has published a factsheet stressing this issue. See https://ec.europa.eu/digital-single-market/en/news/digital-skills-gap-europe.

5 More information about this collaborative program of the European Commission can be founded at this link https://ec.europa.eu/programmes/horizon2020/.

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Chapter 2
Exploring the Effect of Emerging Technologies on Scientific Knowledge Production and the Industrial Advancement of Society

Vicente González-Prida Díaz
Universidad de Sevilla, Spain & Universidad Nacional de Educación a Distancia (UNED), Spain

Jesus Pedro Zamora Bonilla
Universidad Nacional de Educación a Distancia (UNED), Spain

ABSTRACT

The main application area of the digital transformation has been so far on the industrial and manufacturing process. Nevertheless, the concept Industry 4.0 has enormous potential in other areas such as its combination with the scientific method and the empirical logic. The term technoscience, coined in the second half of the 20th century, links both fields, the technological and the scientific field, establishing a joint growth where scientific knowledge takes advantage (and requires) of a technological infrastructure in order to advance. This chapter proposes to analyze some of the most relevant concepts in these matters in order to provide a more philosophical approach to technology, its effect on the proper engineering and scientific knowledge, and what some of the social features are that are inferred from these emerging technologies.

INTRODUCTION

The use of advanced technologies allows predictive analysis, emphasising the collection of large data, its analysis, visualisation and, ultimately, decision making with less uncertainty and mistakes. Two of the characteristic features of Industry 4.0 are, on the one hand, computerisation with the help of cyberphysical systems and, on the other hand, the development of smart factories based on the concept

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of the "Internet of things" (Ashton, 2009). This chapter analyses some of the most relevant concepts in these matters, observing a more philosophical approach to technology, its effect on the engineering and science knowledge and commenting on some of the social features that are inferred from these emerging technologies. In other words, this chapter emphasizes the effect of such new tools considered under the concept of Industry 4.0, trying to respond the research question about how these technologies make influence on the current scientific knowledge, the industry development and, in general terms, the society. As it is well known, cyber-physical systems are composed of computer-based components or digital monitoring and control devices, also called embedded systems (Lee, 2008). These systems communicate dynamically through a network, usually the Internet, and hence are called "Internet of Things" (as opposed to social media that could be described as "Internet of people").

The Industry 4.0.

The origin of the term Industry 4.0 refers to the Fourth Industrial Revolution, understanding that the First was when the steam engine emerged at the end of the 18th century, the Second when the use of electricity and mass production was implemented in the last third of 19th century, and the Third Industrial Revolution took place when factories began to be automated already in the 20th century. Nowadays, the Fourth Industrial Revolution is linked to the digital transformation applied to the Industry in the search for connectivity and operational excellence. It was named for the first time in a study conducted in Germany in 2011: "Smart Manufacturing for the Future" by the Germany Trade and Invest entity, which was published in GTAI (2014). Linked to the concept Industry 4.0 there are nine technologies usually defined as shown in the following chart (Table 1):

Table 1. Technologies linked to the Industry 4.0 concept (GTAI, 2014)

#	Technology	Description
1	Robotics and artificial vision	Cooperative and autonomous industrial robots. Numerous integrated sensors and standardised interfaces.
2	Additive manufacturing and 3D scanner	3D printing, especially for prototypes and spare parts. Decentralised 3D installations to reduce transport distances and inventory. Flexibility of forms, rapidity when not using tools, cost savings.
3	Augmented and virtual reality	Augmented reality for maintenance, logistics and all types of operating procedures. Display of support information, for example, through glasses.
4	Simulation and modeling	Simulation of networks (flows) of value. Optimisation based on real-time data from intelligent systems.
5	Horizontal and vertical integration	Integration of data between companies based on data transfer standards. Precondition for a fully automated value chain (from supplier to customer, from management to plant).
6	Industrial Internet (IoT, Internet of things)	Network of machines and products. Multidirectional communication between objects in the network. Cyberphysical systems.
7	Cloud computing	Management of huge volumes of data in open systems. Real-time communication for production systems.
8	Cybersecurity	Operation in networks and open systems. High level of network connection between machines, products and intelligent systems.
9	Big data and data analysis	Complete evaluation of the available data (for example, ERP, SCM, CRM and machine data). Support and optimisation in real time for decision making.

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Apart from these nine technologies, some others are usually added although they have a place in the nine mentioned. For example: autonomous or unmanned vehicles or aircraft (drones), new materials (graphene), artificial intelligence, digital platforms. This chapter is not intended to provide a systematic analysis in order to understand or compare such trends in technology. The relevance aspect in this research is how all these technologies have applications in the industrial field, in product and services and, of course, in academic and scientific research. Below are commented some of these tools encompassed in the concept of Industry 4.0.

Artificial Intelligence

Technologies known as Machine Learning or Artificial Intelligence are capable of processing in real time large volumes of information that are extracted from Big Data technologies. In practice, they basically consist of algorithms capable of learning autonomously from the information they receive, regardless of the sources, and the reaction of users and operators.

E-Science

E-Science is a term that gives support to science in terms of organisation of resources, services and all of the necessary management that allows the proactive execution of decision processes in the scientific field. The e-science includes electronic technologies (for example, information and communication technologies), as well as activities (for example, electronic monitoring, e-diagnosis), in order to support scientific research and social progress in general. From Candell et al. (2009), those terms with the prefix e- (electronic) are considered, they include the acts of monitoring, collecting, recording and distributing the data in real time about the state of the system under analysis. That is, from mail exchange activities (e-mailing), operations and maintenance of a manufacturing process (e-manufacturing), teaching activities or related to teaching (e-learning), etc.

Virtual or Augmented Reality

Virtual or augmented reality is a term that describes applications in real time that mix information from the physical world (real) with cybernetic (virtual) information. The augmented reality can be applied in simulation, training, or for the guidance of a person through complicated instructions by experts at a distance (Manca et al., 2013), for example, surgical operations, handling and control of robots (Benbelkacem et al., 2009). These visualisation systems can help the user to quickly identify problem areas and to evaluate the state of a system, since they transform large datasets into easy and understandable visualisations (Khosrowshahi et al., 2014).

Collaborative Robotics

A new generation of automata is currently emerging that cooperates closely with people. They are characterised by their flexibility and relative ease of programming. Until now, they have been used in industrial environments or atypical situations to avoid human presence in environments that can be dangerous, unsafe or with other types of restrictions. However, it has currently been given a new focus, developing robotics in areas such as the treatment of autism in psychology.

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Other Systems of Knowledge Exchange

Regarding the knowledge exchange, the creation of networks (networking) allows all the people who participate in an activity to share experiences and knowledge. The knowledge exchange through, for example, blogs and Internet portals, is one of the development areas to improve the knowledge of any field (Kans, 2013). Other systems of knowledge exchange (not necessarily between people) are for example the identification by Radio Frequency or RFID. This is a highly extended technology that allows obtaining data from an object at a distance. RFID technology is useful for the automatic tracking of objects (a fleet of vehicles, migratory movements, or even inventory items or spare parts etc.), as well as their identification, operation etc. (Kour et al., 2014). It allows for example the planning of activities that concern those elements to be more efficient.

Trends in Technology

The industrial and scientific advance conducted to the generation of complex products and services, as well as R&D results with high added value, will have to depend on those technology advances that are currently transforming the market. Nanotechnology, advanced materials, biotechnology etc. together with virtual and hybrid simulation, synthetic intelligence, etc. will be essential to keep competitive advantages in a wide spectrum of industrial activities (productive, service or research sectors). Possibly, the combined effect of artificial intelligence, robotics, nanotechnology, new materials and 3D printing (among others) is what affects more directly to all the industrial manufacturing. Some of these technologies are mentioned below:

Nanotechnology

The current development of microprocessor technology may maintain the exponential growth of the available process capacity in terms of price, size and energy consumption. This development is the actual basis on which the expansion of the digital revolution is based. Few technologies as those related to the manufacture of microprocessors are so critical, in general terms, for the advancement of the digital revolution and its effect on the industry. Today's integrated circuits are still based on silicon technology. This technology has been able to duplicate the number of transistors per chip every 2 years (Moore's Law), although the exponential growth of the processing capacity, connectivity and the next generation's Internet makes it necessary to establish a "beyond Moore" strategy.

Advanced Materials

Competitiveness in the new economy will essentially depend on the ability to develop and market new materials, shortening the necessary technological maturity cycles, in order to incorporate them into new products. The Cold War and the Space Race were stages in History that contributed greatly to the development of a whole generation of new materials that have been gradually incorporated into the market. In the same way, the exponential development of numerous key technologies will bring the emergence of a new generation of materials that will boost sectors such as automotive, aeronautics, medical, energy, etc. Till now, the technological maturity cycle of new materials has been extremely long. An example is the case of lithium batteries whose scientific basis was born in the 70s, but its massive commercialisation

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did not occur until the 90s. Responding to the demands of the new markets, it will be required to shorten significantly the time needed for the development of new materials and their manufacturing processes.

Biotechnology

The field of synthetic biology applied to manufacturing is in an initial state. However, it is expected that the advances that will happen in this sector will have unpredictable consequences on the production manufacturing. The systems engineering methodologies applied to the world of biology, can allow the establishment of manufacturing processes of biological products on an industrial scale.

Systems Engineering

The advances in new techniques of Systems Engineering are closely linked to the development of new materials and their application to the market. The extraordinary development of computer tools is allowing the simulation of manufacturing processes, connecting in a continuum way those material characteristics, the design and validation of the product, its manufacture etc.

3D Printing

3D printing represents the paradigm of production without intermediaries. Theoretically, it can make available to almost any user the complete productive process, from the design and development in the virtual world to the materialisation of an object in the physical world. While these technologies are maturing, the predictable market trend will be similar to that followed by other technologies: an evolution to general consumption that will reduce prices. The future direction of this technology is to enable the reproduction of more complex pieces, with greater size and precision.

Positive Effects of Technology on the Scientific Method

Former section has dealt with a kind of state-of-the-art. Now, this chapter contributes with a view of positive effects of technologies on the standardized scientific method, in order to provide later a philosophical view of technoscience. It is a fact that all of the above advanced tools have mainly an industrial approach. Nevertheless, due to the complexity of the current science (with sophisticated systems under analysis, the amount of data involved, etc.), the application of elements from Industry 4.0 can have positive effects in the control and monitoring of experimentation and, specifically, on the organisational, operational and technical complexities of scientific research.

Effects on Operational Complexities and Techniques

The Industry 4.0 technology allows automating advanced systems that are interconnected as well as to update and handle scalable systems that may use standardised elements and interfaces etc. Therefore, Industry 4.0 not only provides benefits in terms of forecasting the criticality status of systems under analysis, giving a more accurate assessment of the state of system health, or planning the different actions. It also provides benefits making it possible to extend the scope of the research, its level of depth as well as the simulation and reproduction of scenarios. One of the main advantages of the Industry

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4.0 application is consequently the efficiency improvement in the applicability of the scientific method and, collaterally:

- A standardised approach to management and research.
- An information and communication technology environment that supports all systems with standardised interfaces.
- An advanced body of information on the systems under analysis, with the ability to forecast their states and reduce the related uncertainties from heterogeneous data sources.

It is important to highlight the Big Data approach from various information sources and the creation of new services. Through the use of visualisation tools, the interpretation of data is easier, allowing a better use of the available information for its applicability in the scientific analysis. In addition to this, the introduction of network tools and the knowledge exchange facilitates better cooperation and openness between research centers and the possibility of accelerating the problem solving process. The applications of virtual reality (used for the orientation of tasks by experts) will reduce the formation costs and execution time at the same time that a greater precision in the scientific analysis is applied.

Effects on Organisational Complexities

Among other positive effects at an organisational level, Industry 4.0 can contribute to achieving and fulfilling those priorities that are defined for each scientific field. The expected benefits of a techno-scientific analysis would be:

- Long-term needs and socio-economic growth: The concepts of Industry 4.0 can facilitate the development of a methodology for the improvement of scientific and research capacity, as well as the impact of advances.
- Intelligent systems and processes: Intelligent technology applied to scientific research is closely related to methodologies aimed at self-correction systems, in order to maximise the capacity and utilisation of the resources invested.
- System integration, security and interoperability: The new policies from Industry 4.0 will provide greater interoperability in the means of analysis, calculations, and decrease in uncertainty as a result of greater reliability.
- The potential benefits of Industry 4.0 in terms of energy and sustainability should not be ignored. It is proven that its application reduces energy consumption and, therefore, improves the carbon footprint of any activity. Therefore, optimising techno-scientific methodologies in a global approach, contributes to the sustainability of progress and developments in a meaningful way.

PHILOSOPHICAL PERSPECTIVE OF TECHNOSCIENCE

Concepts

The term science is usually defined as the set of knowledge obtained through observation and reasoning, which is systematically structured. General principles and laws are deduced from science, with predic-

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tive capacity and with the possibility of being experimentally verifiable. On the other hand, technology is the set of theories and techniques that allow the practical use of scientific knowledge. That means, technology allows the design and creation of goods and services that facilitate adaptation to the environment and also allows satisfying both the essential needs and the desires of mankind. From both concepts arises the term "technoscience", widely used in the interdisciplinary community of science, technology and society, in order to designate the social and technological context of science. Technoscience is a way of applying science and technology where research is organised and knowledge is managed in a more industrial or business way, as a productive chain oriented to efficiency and profitability, with mostly private financing and public policies support. In the techno-scientific field, large multidisciplinary teams and extensive research networks participate with scientists, engineers, technicians, politicians, military, businessmen, managers, etc.

Technoscience is therefore a strategic asset of countries, civil societies and entrepreneurs since it focuses scientific and technological efforts towards a specific objective. That objective can be determined from a scope of economic and business development, political or military improvement, etc. The strength here is therefore related to the combination of different perspectives about technology. These viewpoints can be really useful, since they are applied from engineers till sociologist. It is a fact that techno-scientific results change human societies and people's lives, turning us in a certain way into users or consumers of technology. ICTs are the basic tools in the development of technoscience where innovation (through simulation processes, calculation, etc.), is based on the research of new products and services that capture markets and generate benefits (Harari, 2015).

In short, technoscience is a field open to innovation. It is obvious that technological advances have a great impact on mankind and this impact can be positive or negative depending on how people use such advances. Although it should be mentioned that risks are likely to arise as a result of intentional side effects or not (Taleb, 2007). In any of the cases, the technoscience has transformed the structure not only of the industrial practice, but also the structure of the scientific practice in all its dimensions, incorporating new values to the research activity. This techno-scientific research activity deals more and more with processes that are caused and controlled in laboratories by the same researcher.

Technoscience Viewed by Philosophy

It is interesting to consider the vision that philosophers have to technoscience and our consumer societies (Conde & Cerdá, 2008). According to the Spanish philosopher Ortega y Gasset (Ortega y Gasset, 1957), the human being surpasses nature, living more and more outside of it, building himself through language and culture, his own world. In this context, the technique is an exclusively human invention through which human beings construct their material world. The technique in this sense is not based on science but on the contrary, the technique precedes science (Heidegger, 1994). According to this, science is consequently a technical invention of Western civilization, born of the conjunction between the Greeks art of thinking, and the late medieval university. It is in itself an invention of the European Christian Church based on the models of the Platonic and Aristotelian Academy. The great success of science does not derive only from its method, but from the free dissemination of the scientific knowledge that takes place in the university. The science core remains technical where, more than knowing the "why" of things (a matter closer to philosophy), it is more focused on knowing "how" things work. From Galileo, scientific work uses a mathematical language, but retains when possible the experimentalism of the alchemists, as well as a certain "guild spirit" in the scientific community (Conde & Cerdá, 2008).

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The success of science in the West comes from a series of technical revolutions. Each of these revolutions has been based on a new way of conceiving and using industrial elements such as energy (for example the steam engine in the 1st industrial revolution), the manufacturing process (for example the mass production in the 2nd industrial revolution, and automation in the 3rd industrial revolution), as well as information (in the 4th industrial revolution). That means that if science arose from the technique, now technique cannot be conceived except as a derivative of science in what could be called technoscience. All advanced technology is today technoscience, where the knowledge comes from pure science and is implemented in the entire economic and social environment. The techno-scientific knowledge is immediately available to all its possible users, almost always at a low cost (Conde & Cerdá, 2008).

In general terms, technology innovates and invents new areas as part of the culture. By this way, it creates new possibilities that release mankind from constrictions imposed by nature that soon become new needs. Therefore, technology is radically transforming our life and exposes us to new environments of risk and uncertainty, but also of opportunities. As a consequence, the contemporary life is more artificial and more dependent on the techno-scientific results, being at the same time more comfortable and fascinating. The scenario in which this context develops is the market where, the more developed, the more accessible the products and services, the more open to the novelties are the consumers and, therefore, the more experimentalists we become (Lipovetsky, 2007). This circumstance leads us to a current hyper-consumer society that advances towards egalitarianism through consumption. That is, in other words, what globalisation brings us. In addition to this, according to Lipovetsky (2007), the overconsumption society has more positive than negative aspects, considering that, once most of the material needs have been met, mankind may gain time to cultivate other values such as the construction of a sustainable world.

In short, throughout history mankind has been modifying natural systems, segregating them from the mechanisms on which the civilization has been built. As a consequence, mankind has changed the world, our tasks and responsibilities have been globalised and what happens in any corner of the world, affects the whole. A final philosophical question could be related to the possibilities of transformation that the biotechnological revolution is achieving: Has mankind reached a limit where the danger that technical innovation brings may become unsustainable? The answer given by some authors as Sloterdijk, (1999) is that it is most likely that mankind will try everything or almost everything that the new biology may allow, regardless of the moral discussion that this entails.

Popper's Theory Regarding Scientific Method and the Industrial Application

Karl Raimund Popper (1902-1994) lived in a century characterised by the two world wars and by a significant advance of scientific development. In the early years of the twentieth century the philosophical theories of Emmanuel Kant (1724-1804), David Hume (1711-1779) and Auguste Comte (1788-1857) were of great importance. In particular, along the years 1922-1936 a scientific and philosophical movement called the Vienna Circle arose, bringing some of the most renowned philosophers of Europe, who were mainly concerned with the logic of science and the development of a common language to all sciences (Rojas et Al., 2013). Popper had good relations with this circle although with certain discrepancies. For example, Popper stated that epistemology deals with the increase of scientific knowledge, which results from testing hypotheses or theories (Popper 2002). Therefore, the central problem is from a methodological nature. The two fundamental questions of Popper's theory are:

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- The problem of induction, which is the inference made from particular statements to universal statements. That means, the truth of particular statements does not assure the truth of universal statements.
- The problem of demarcation, which consists in finding a criterion that distinguishes empirical from metaphysical statements. The scientist proposes statements, or systems of statements, and contrasts them step by step. Popper proposes falsifiability based on observation and experience as a demarcation criterion; these allow refuting or corroborating hypotheses or theories, checking the hypothesis looking for facts that can falsify it, if they are not considered provisionally true until a case is discovered that falsifies the hypothesis and can thus be discarded.

Science and engineering have different methods and seek different objectives. According to Popper, science seeks a universal truth, while engineering is not fixed in truth or universality. The engineer's purpose is utilitarian. In other words, engineers contribute to society through their ability to apply basic scientific principles to real problems in an efficient and effective way, using the scientific method to develop models that explain real phenomena (Verdugo, 1989). All observation is made from a specific point of view. That is why all observation has nuances derived from our way of thinking. In other words, observation is "theoretically influenced" and, in fact, only one observation would be needed to falsify a theory. A typical example is the case of the statement "All swans are white". That generalisation would be impossible to corroborate, unless all existing swans could be observed. If just one swan is found with a different colour, it is enough to prove false or refute the generalisation.

Popper states that theories are constructed as conjectures or speculative and provisional assumptions that the intellect creates in an attempt to solve problems, providing explanations on the behavior related to aspects of the world or the universe.

Science goes in progress when theory is demonstrated to be wrong and a new theory is introduced to better explain a phenomenon. In other words, scientific knowledge does not advance confirming new laws, but discarding laws that are contradicted by the experience. When hypotheses have been contrasted, they become scientific laws that have the character of provisionality. According to Popper those statements that do not have the possibility of being falsifiable do not belong to science and therefore are not objective. In this sense, the demarcation criterion is the ability of a proposition to be refuted or falsified. Only those propositions that an experiment or an observation may contradict, are accepted as scientific propositions. In other words, according to Popper, scientific theories are those ones that are potentially open to be false. Therefore, all science is constituted by conjectures, since they are fallible and there is no certainty in human knowledge. No theory can ever be considered as definitive or verified conclusively. The method of conjectures and refutations is the main instrument of scientific growth and can be conceived in more general terms as a critical or rational attitude.

Interestingly, the project management and its current application in industry programs, follows a prepopperian methodology. That means, it does not use the falsifiability method but, on the contrary, it is enough for project management the validation and verification of positive cases to accept, in this case, a design, procedure or a part of a project. Obviously, we are talking here about the application of an engineering method and not a scientific method. As commented, the objective that the engineer or manager seeks is the validity of the practical application and not the reason why specific events happen. This difference of one method from the other can be observed in greater detail in the following section.

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THE SCIENTIFIC-TECHNICAL METHODOLOGY AS A SOCIAL CONTRACT

Differences Between the Scientific and the Engineering Method

The problem of the constitution of norms and scientific criteria in the area of technology can be analysed from the point of view of the scientific method as a social contract. This viewpoint has been developed in references like Zamora (2003, 2011). The criteria regarding a scientific result (if it is good enough to be acceptable) depend on benefits of all kinds (academic, intellectual, and also social or economic). That means, the notion of acceptance may be different with context and what each scientist expects to receive or reach. Obviously, one of the first actions to be carried out is to differentiate between the scientific method and the engineering method. According to Rojas et Al. (2013), the differences between science and engineering are basically that science studies nature, its objects and phenomena and its processes and changes, and engineering studies the artificial object and its processes as technology. Science is motivated by curiosity, the need to understand, looking for the "why" of things. However, engineering is focused on the solution to problems of interest to mankind, considering for that purpose all the needed resources, the economy, etc. for the projection and building of useful objects. Therefore, engineers consider costs and returns efficiency, safety for human life, the acceptance of the society and the manufacturability of their projects. On the other hand, the difference between technology and innovation lies in: Technology is the application of scientific knowledge and technical procedures to the realisation of practical tasks through organised systems, including people and organisations, living beings and machines; and innovation focuses on renewing and making changes to improve something already existing. While technology is an application of science that seeks the "how", innovation is a consequence of change and improvement, not necessarily with a new product but it can be innovated a process, a service, an organisation, etc.

Of course, there are other definitions more exhaustive to the previous concepts. In the specific case of engineering there is also a set of rules that govern their actions, such as the design rules for testing, technical standards, inclusion of safety factors, etc. In general terms, engineering seeks the best solution to a problem, considering a set of limiting conditions. For engineers there is always a solution to a problem, even if it is just an approach. That is to say that, problems generally admit multiple solutions, and they can be complex systems with interconnected parts that contain not visible information. For that reason, models or simulations are applied in order to simplify reality by using the existing technology. Therefore, the knowledge of the state-of-the-art and the know-how of things are fundamental as a best practice in engineering. The following chart (table 2) presents a comparison between the scientific method and the engineering method (Rojas et Al., 2013).

Engineering, Science, and Society

It is clear that engineering knowledge comes mainly from technoscience. Without a strong scientific basis, engineering would be reduced to pure craftsmanship (Conde & Cerdá, 2008). In addition to this, if technoscience designs and proposes technical applications of science, engineering feeds on these results to build mechanisms or processes capable of reporting some usefulness. The engineer, therefore, is not limited to be a scientist, since engineering integrates into its activities other disciplines in order to support its solutions, such as economics, sociology, law, psychology and other subjects with a humanistic component. As commented, the main interest of the engineer is not the interest of the scientist.

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Table 2. Comparison between the scientific and the engineering method

Scientific method	Engineering method
Phenomenon observation	Problem identification
Existing knowledge	Information gathering
Hypotheses formulation	Search of possible solutions
Deduction: logic, mathematics, etc.	Preliminary design: modeling, simulation, calculations, etc.
Theory and fact confrontation	Solutions assessments and choice
Sharing with scientific community	Project development: drawings, measures, descriptive report, etc.
Acceptance by the scientific community	Production, building.
New upgraded knowledge	Improvement for market, society.

According to Aracil (2017), the engineer has to be able to integrate many partial answers to practical problems, conducting to a better total solution. It has to satisfy requirements from many different natures. Additionally, the solution has to be scientifically correct, technologically possible, economically viable, socially acceptable, etc. That is why the engineer is mainly focused on synthesis and optimisation. For engineering there are no answers, in the sense of true or false, but in the sense better or worse. The adoption of this view implies of course a kind of relativism (Aracil, 2017).

According to the above, what is the social commitment of the engineers? And, due to the fact there is a link between scientific knowledge and engineering, what is the social commitment of science? Although some answers have already been given, all of them are practically around that engineers also do science but have their own knowledge that is precisely the technologies. This knowledge is oriented to assist the engineers in their performance to produce an artificial world with the development of disciplines such as electrotechnics, aerodynamics, kinematics, materials science among many others. All these disciplines share with scientists the gathering of knowledge that they are testable and repeatable, since experimentation is feasible in their field. In addition, the engineering disciplines often use mathematics and reach a precision and a coherence that allows them to be considered as scientific.

However, as already commented, its objective is not to reveal laws of the natural world, but to establish procedures to conceive and calculate devices useful for society. The knowledge of engineers can, in most cases, be structured by laws and theories similar to those used by conventional science, although it extends and modifies them according to their objectives, for which reason they are also committed to the research of new knowledge. At the same time, the adoption by scientists of objectives that until now have been considered as belonging to engineers is taking place. With all this, a new behaviour is spreading among academic engineers who involve themselves in research works that produce better engineering solutions for certain projects. However, the different origins of engineers and scientists continue making influence in the disparity between the methods of each other, despite the great analogies in both domains: critical spirit, maximum rigor, use of mathematical methods, experimental testing, etc. Therefore, although the method of engineers could present features equivalent to those used by scientists, the different purposes that have traditionally pursued each other have modulated their different ways of proceeding, presenting at the same time many similarities.

In any case, the need to promote scientific analysis and the interaction between science and engineering in the training of engineers is obvious (Layton, 1984). However, engineers must face the complexity of the society in which he has to apply their professional work. The meaning of applied science adopted

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here is characterised by the fact that traditional scientists looks for applications to what is already known, which is not the same as what engineers do, since they are always motivated primarily by specific problems of society. Trying to find a solution to a given problem, when the engineer does not have a general knowledge adequate to his needs, will search in the experimentation related to that specific issue, without worrying about the universal validity of the results, although special rigor is applied as demanding by the scientist.

Academic Activity of Engineers and Its Effect on Society

In general terms, it has been observed previously that the requirements for an engineer are completely different from those of a scientist. The engineer is not free to choose the problems to solve, these problems are given, and it is necessary to find a solution for them. If a rigorous analysis cannot be applied successfully, then an approximate solution must be approached or the problem must be solved by experiments (Kline, 2000).

Engineers who work in university and research centers are faced with a dilemma: as engineering lecturers, they have to train professionals for society in a particular technical field; but as academics they also have to achieve legitimacy in the university world. As lecturers (and besides didactic skills), they must know the execution of the profession in order to be able to transmit it to their students and, therefore, to have direct experience in relevant problems for the corresponding activity; while as academics, they have to provide intellectual contributions of certain relevance. The balance between science and engineering has determined that, in some cases, engineers are inclined excessively towards science, taking place especially in those whose activity is in the academic environment. In other words, the quality of those engineers that belong to the academic world is being measured with the criteria of scientific production and not to engineering work. This fact, unfortunately, causes a distortion in the evaluation of academic engineers based exclusively (or mainly) to the quality and quantity of their publications.

When the academic engineer stops dealing with specific problems and his performance is focused in a general knowledge for its immediate publication, he ceases behaving as a real engineer, adopting the ways of a traditional scientist. Nevertheless, it is especially complex to evaluate those engineers who work in the academic environment, because they have to work between two different areas, trying to maintain a difficult balance between direct participation in engineering projects (whose assessment is quite difficult), and the publication of relevant contributions (which finally are more easily quantified). Both actions have in any case a direct focus on society, with a research scope in accordance with the interest of the funding source. Consequently, most of today's scientists and academics engineers are indeed not really free to research what they consider relevant, but their research works are directed or conducted to the interests of the funding source.

Social Responsibility of Industry 4.0

Industry 4.0 is a series of technologies (automation, Internet of things, the cloud, Big Data, sensors, artificial intelligence, etc.) that are used in production processes (smart factories) in order to collect data in real time and making them immediately available to those who must take decisions. These decisions are therefore, taken faster and better since, for example, artificial intelligence provides simulations that allow solutions to be ready for specific problems. Of course, it is interesting to have data in real time, but also to develop sophisticated models of prognosis. This context makes possible to produce more

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and to optimise resources and time, which are aspects that society is now demanding. In particular, the social environment requires more and sooner customised products and services (Garetti & Taisch, 2012).

It is foreseen that the labour force will have a minor impact on production cost, if it can be replaced in part by technology. Possibly, from the local viewpoint of a company or an industry, this can be one of the first consequences of technological advancement. Nevertheless, if the company produces more and cheaper, it will gain more, will have more opportunities to grow and, supposedly, to create jobs. In any case, even the most automated companies will not be able to ignore human staff, although it is possible its dedication will be more focused on data reading, information understanding and planning work. That means, the future focus of human work will be directed towards new skills, with obviously a gradual transit. In other words, the expectation regarding the labour effect by the implementation of technological advances from industry 4.0 is that human employment will be mainly dedicated to intellectual professions. Any industrial revolution has had an initial effect more or less disruptive, but has always produced an added value in terms of employment. Nevertheless, unlike the previous revolutions, in the case of the fourth revolution, society has been using the internet for 15 to 20 years. Therefore, this technology is already in the daily lives and it is now when it enters in industrial processes, and not vice versa. In any case, the implementation of this technology (especially in small and medium enterprises) is a great challenge in terms of training. The current trend is towards an economy based on data and information so it is essential to train professionals in competence centers with new technical skills that will be used in the new industry and replace jobs that will gradually disappear or will be replaced by machines (Pinzone et Al., 2017). That means, technology should be at the service of traditional companies and not in the other sense.

Innovation and Technology in the Current Social Context

Nowadays, the social context is immersed in an increasingly competitive market where companies continually launch innovative products and services which are constantly demanded by society. In fact, even without modifying the products, the production processes have to constantly adapt to the changing conditions that society requires with new supply chains, new customer needs, new business models, changes in the production infrastructure, new structures of cost, etc. In the knowledge-based economy, a fundamental element to sustain the creation of value is the confluence of science and technology that generates innovations. For this purpose, it is necessary to gather the necessary mechanisms that facilitate the constant flow of ideas and technical innovations to the consumer market. Apart from assuring the knowledge flow to society, it is necessary to be able to respond quickly to changes in the market, which requires high flexibility and, of course, willingness to change. The integration of knowledge and innovation with the industrial base will be the key to increasing productivity and providing competitive advantage in a global market in permanent change that constantly demands innovation.

In Europe, a large part of universities and research programs are financed with public funds and, consequently, this knowledge must be conducted to the service of the society that supports it with its taxes. Besides its academic objectives, the academic world has to reorient itself to be the reservoir of knowledge that serves as the basis for innovations which feed the productive manufacturing in order to meet market demands. The manufacturing sector is responsible for materialising knowledge, since the actual incentive for innovation is finally the generation of profit. For this goal, public and private innovation systems have to be agile enough, in order to respond quickly to markets, and to be proactive and anticipate social changes.

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Advanced production does not mean to abandon the manufacturing of less complex products, although complex products manufacturing does require advanced value chains. In other words, not to compete in the production of complex assets implies to renounce an advanced industrial manufacturing, losing high-tech areas and, consequently, capacity for innovation. Emerging economies, without leaving apart their competitive advantage of labour costs, they are rapidly escalating to levels of increasing complexity in many areas, in which, paradoxically, the innovative effort was made in the EU or the USA. For instance, manufacturing of laptops, solar panels, lithium batteries, monitors, etc. are essential for sectors such as defense, aerospace and energy. Having transferred manufacturing capacity to areas of the World with cheaper manpower (due to purely economic reasons), a base of technology and innovation has been created in those countries. In other words, the current situation is not only that the center of gravity of World economic activity is shifting towards the Pacific coast of Asia; it is also that the center of scientific and technological gravity is shifting too. These countries have intelligently entered into high-tech sectors, such as defense, aerospace and energy, areas that until now were exclusive to the US and the EU.

For years, it has been argued that R&D activity could be separated from production, reserving the research, innovation and design for developed societies, and transferring to third parties -for economic reasons- what was purely manufacturing. However, the reality has shown that this strategy leads, first, to lose the production capacity (with its corresponding jobs), and in a medium term to transfer also the capacity for design, development and integration.

CONCLUSION

This chapter has been structured starting with a kind of state-of-the-art, where some new technologies and tools have been depicted, in order to provide afterwards with a view of the effect of technology over science, engineering, and the society in general terms.

From a historical perspective, the role of engineering has been to build a better world for mankind, safer and more comfortable, making possible an increasingly higher margin of individual freedom, and changing our way of life. Engineering has achieved it based on scientific findings, rationalising, simplifying and optimising the operation of large complex systems that surround us (Conde & Cerdá, 2008). In today's World, teaching process confers skills rather than knowledge, as well as sufficient experience in other related areas. Perhaps, the current moment is the beginning of conceiving university education as a truly permanent formation, being one of the most necessary skills the ability to adapt proactively to new work environments. Consequently, the challenge to society will be huge. In many organisational aspects, the university and business models remain anchored in paradigms that are already obsolete. The intensity of communication and the available knowledge resources at very low prices allow to foresee a new kind of society more open and dynamic, built on a network, covering large areas of connectivity, with permeability between all its parts and totally intercommunicable. The industrial revolution based on the digital transformation may enable a higher excellence in many areas, but also more dissemination for intermediate knowledge and training. The appropriate fulfilment of this target will require every aspect well organised, in a structured and precise way, and with the commitment and responsibility that is required.

Mankind is heading towards a more multipolar world, in which the center of economic and even technological gravity tends to move towards different points of the globe. New commercial, industrial

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and technological powers are emerging and the number of competitors is increasing, a World that is ultimately closer and much more interconnected with a different distribution of the productive sector. Technology in general terms, and specifically digitalisation, will boost international trade towards higher levels of globalisation and independence. Supply chains will inevitably continue to globalise and will be increasingly interrelated, and as a consequence, the productive ecosystem will become global with steady increase. Therefore, competing in a global world requires global and holistic solutions. The simultaneous development of global connectivity, automation including the unprecedented development of synthetic intelligence, advances in robotics, the emergence of new materials and 3D printing technologies will revolutionise the industrial manufacturing. The competition for the markets domain will be fought in these integrated spaces of value creation.

It would be risky and to some extent pointless to try to predict which new products and which new processes will emerge in a mid and long term. However, there is a broad consensus that this new scenario will need to maintain a competitive industrial base, technologically advanced, sustainable and viable, creating stable quality employment which is the engine of innovation. The current technological revolution suggests reviewing the definition of "manufacturing", extending the limits of its traditional meaning to a broader one that encompasses biotechnology and the concurrence of the mechanical, electronic, software and biological worlds.

Particularly, exponential advances in digital technologies will allow adopting a holistic vision to the concept of manufacturing that integrates horizontally and vertically the different links of the value chain. Those supranational entities will need to update and strengthen the cybernetic infrastructure that supports the wide digitalisation, connectivity, robotisation and automation of the industrial base. That industrial base favours the establishment of global integrated spaces for the creation of value. Regardless of other economic and social benefits, that a modern cybernetic infrastructure would bring, the new productive factory must be based on a network. That means, in the Fourth Industrial Revolution, the cybernetic infrastructure will play the same dynamic role played by the railroad in the first revolution. Encouraging innovation and the inclusion of new technologies in the entire value chain, especially production-oriented, will be the foundation of the new knowledge-intensive industry.

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KEY TERMS AND DEFINITIONS

Engineering: Practical application of science and mathematics, as in the design and construction of machines, vehicles, structures, roads, and systems. It refers to the work or profession of an engineer.

Industry: Group of manufacturing businesses in a particular field. It refers also to any general business activity or manufacture in general.

Innovation: Something new or different introduced. It refers to the act of innovating which is basically the introduction of new things or methods.

Knowledge: Acquaintance with facts, truths, or principles in the mind. It refers also to the familiarity with an area of study, as by study or experience. In general terms, it is the sum of what is known.

Methodology: A set or system of methods or principles used in a discipline, as in the sciences.

Philosophy: Study of the truths and principles of existence, knowledge, and conduct. It refers also to the critical study of the basic principles of a branch of knowledge, as for example the philosophy of science.

Science: System of knowledge about the physical world, explaining or describing what it is and how it works in general laws, gained by observing, experimenting, and testing theories. It refers also to any skill that shows ability to use facts or principles.

Technology: Branch of knowledge that deals with the creation and use of technical means and their interrelation with life, society, and the environment, drawing upon such subjects as industrial arts, engineering, applied science, and pure science. It refers also to the sum of the ways in which social groups provide themselves with the material objects of their civilization.

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Chapter 3
Decision Making Under Uncertainty and Risks in the Face of Rapidly Advancing Technologies

Vicente González-Prida Díaz
Universidad de Sevilla, Spain & Universidad Nacional de Educación a Distancia (UNED), Spain

Jesus Pedro Zamora Bonilla
Universidad Nacional de Educación a Distancia (UNED), Spain

Pablo Viveros Gunckel
Universidad Técnica Federico Santa María, Valparaíso, Chile

ABSTRACT

This chapter aims to consider the effects of the new concept Industry 4.0 on decision making, particularly on the reduction of uncertainty and the risk associated with any choice between alternatives. For this purpose, this chapter begins by dealing with the concepts of risk and uncertainty and their epistemological evolution. After observing certain trends and recent studies in this regard, the authors address a more philosophical perception of risk, mainly on aspects related to engineering and social perception. The concept of human reliability will also be reviewed and how it can be improved with the application of emerging technologies, considering some methodological proposals to improve the decision making. After that, some of the possible future research directions will be briefly discussed. Finally, the chapter concludes by highlighting key aspects of the chapter as a context for other chapters in the book.

INTRODUCTION

Today decision making in science, technology and business is based on measurements and metrics that facilitate or justify the selection of one alternative over others. The current state of the technology allows for monitoring of almost any parameter that may be relevant in a decision. This is achieved by a multitude of connected sensor devices. This chapter is intended to suggest how the understanding of

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risk requires some new approaches since measurement tools have changed and have been refined with the new and advanced technology.

The concept of "uncertainty" obviously implies a lack of certainty, understanding it as a clear knowledge of something, or the firm adherence of the mind to something knowable, without fear of any error. On the other hand, the term "risk" is often associated with similar characteristics, although it adds negative effects depending on the decision taken, which can be quantified in terms of probability.

"Quantification" precisely implies the fact of numerically expressing a magnitude, so quantifying uncertainty or risk implies the numerical expression of something that is not knowable or not clear. Mathematically, this is equivalent to the complementary value of what is certain and therefore, adding both values results in the whole unit. Other meanings for the concept of "quantification" consist of introducing the principles of quantum mechanics in the study of a physical phenomenon, which would bring here the Heisenberg Uncertainty Principle.

In either case, uncertainty is a fascinating topic that encompasses a wide range of scientific and practical fields. The economy, physics, decision theory, risk assessment are areas of knowledge where this term has traditionally been treated. More recently, the analysis of uncertainty has become common in mathematical modeling, numerical analysis, advanced statistics, information technology, information technology and communication.

For example, in the specific case of an industrial design, this can be considered as an iterative process of reducing uncertainties, conceiving an idea with the intention of materializing it into a product, which must fulfill the required functions during a foreseen period of time. A good design should prevent the occurrence of failures during the life cycle of the product, satisfying the requirements of safety, environmental protection, and compliance with laws and regulations (Sanjurjo, 2013). A risk analysis therefore at this early stage, would identify and correct possible future scenarios of failures.

Just as a risk analysis is applied here for an industrial design, it is equally useful for other areas. In fact, the study of uncertainty and risk has been in contact with issues such as epistemology, administration science, psychology, public debate and the theories of democracy.

On the other hand, Industry 4.0 refers to a fourth generation in the manufacturing and productive activity, consisting of the so-called Fourth Industrial Revolution. This fourth revolution is characterized (Lasi et al. 2014) by intelligent systems based on the Internet of Things (IoT) solutions.

One of the application areas of Industry 4.0 is precisely to reduce the uncertainty in decision-making where, in an autonomous way, the intelligent system predicts errors, performs diagnoses and triggers actions in order to reduce risks at the same time that the process gains operative efficiency. Obviously, these systems demand a lot of data with high quality, coming from relevant information from multiple sources (Lee et al., 2014).

The digital revolution begins at the end of World War II when the transistor was developed, the passage to the integrated circuit was immediate and from that moment onwards, the process capacity has been growing exponentially following the well-known Law of Moore that predicted that every twenty-four months the processing capacity of microprocessors would double. This growth of the processing capacity and the storage of digital data, together with the connectivity provided by the Internet, has brought an unprecedented tractor effect in all fields of science and technology (Sanjurjo, 2016). The great advance, much less visible to the normal citizen, is recently taking place in the field of synthetic or artificial intelligence (AI), although the new techniques of neural networks have meant the definitive takeoff of this technology which is already present in many facets of our lives and, specifically, the reduction of uncertainties when making decisions or selecting alternatives.

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The selection of alternatives and their correct integration is not an easy task to perform; in fact, poorly conceived or barely introduced decisions can cause considerable losses in economic terms, in time, opportunities, etc. However, in any of the cases, the risk linked to the decisions will always be latent (Thonemann & Bradley, 2002).

In this chapter, the main idea intends to underline the quantification of uncertainty in the presence of data, models and more or less knowledge of any specific problem. The aim will be to make a contribution that can illustrate throughout the text the advantages and disadvantages of high advanced technologies particularly in the control and management of risk, as well as some of the many contributions found in the literature dealing with this topic and providing different treatments. These treatments are often and inevitably simplified in practice due to the amount of information, the reduced timing, budget constraints, or simply by the regulatory framework and cultural habits of those who make decisions.

In this sense and as an simple example (without the intention to lose the general character of the whole document), from the point of view of the complexity in decision-making, a possibility is the integration of methodologies, as is the case of OTSM-TRIZ (Nikulin et al., 2016) being an analytical tool that allows visualizing the consequences of a choice between several alternatives, with other tools used in decision making such as the AHP (Analytic Hierarchy Process) (Nikulin et at., 2017). Simplifying the assessment of cost/benefit impact and also leveraging the benefits of that technology currently available, these methodologies have a beneficial effect on knowledge management and, consequently, on the management of risk and uncertainty. OTSM corresponds to the Russian acronym "General theory of great reach thought", and TRIZ to "Inventive theory for problem solving". In any case, and as commented previously, there is not a particular focus on specific methods such as TRIZ or AHP. In fact (and despite some other academic concepts may be overlooked), this chapter is intended to provide a general overview on some trends, being not targeted in other further in-depth study.

In general terms, this chapter follows a natural process starting from the overall notions of risk and uncertainty, then deployed in the technological area and finally in the social field with a particular consideration on the human factor. With this, the document proposes the application of those features of advanced technology to the scientific method together with knowledge management tools in order to make a better characterization of uncertainty, the reduction of risk in decision-making and, basically, the treatment of big data, all of them as a relevant and novel contribution to the empirical logic and the characteristics of technoscience.

BACKGROUND AND LITERATURE REVIEW

Some authors define the risk simply as "the uncertainty of the future" (Rojas et al, 2013). In fact, the concept of risk seems to be unique to humans. It is our ability to exercise rational thinking that allows us to apply information from the past, react to the present and plan for the future.

The human being is above all a constructor of artifacts, of machines, of physical and abstract structures. The survival in new scenarios initiated a feedback process of tools development that required the generation of new skills. Thus, technology has played a fundamental role from the beginning of mankind, shaping our evolution as a species. Technology has made human beings in a short period of cosmic time, into the dominant species on the planet and, paradoxically, in the greatest danger for its future.

Since the beginning of time, it seems that the first humans already had a certain understanding of chance in their lives, forming an integral part of its own social development. Society became more

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sophisticated and science was gradually developing, emerging mathematics for representing those results, a priori, random or uncertain. That was the case for instance in ancient Greece of Euclid, father of geometry, or Pythagoras from Samos (570 to 495 BC) father of trigonometry, which, still today are important bases in measurements and technological equipment (Sanjurjo, 2016).

Likewise, the treaty of Sun Tzu (650 BC) "The art of war" (Griffith, 1963), describes risk and reward strategies associated with war, which even today is still a manual of use in many professional fields. Eventually, the understanding of probability concept promoted the development of risk. The probability laws initially derived from the quantification of possible outcomes in game situations. In that sense, an important contribution in that probability field development was performed by Thomas Bayes (Bayes & Price, 1763). His contribution, known today as "Bayes Theorem," is a powerful way of applying probability to situations where there is no sufficient information. This is possible by combining "prior information" with "current data" (if any) to produce a "later update" result with some probability estimation.

Thereafter, in order to predict the frequency and severity of undesirable incidents, a field of general interest became, both in the scientific and engineering field, and also in sectors as diverse as industrial, defense, economics or politics.

In that sense, technology plays a fundamental role in the history of mankind and constitutes an essential aspect of the human condition. But it is also equally evident that history cannot be explained solely in terms of technological changes. As a biological simile, the process of technological development can be considered as a continuous evolution, although not linear, which would have a certain parallelism with the Darwinian biological evolution. However, technological development should be considered as an evolutionary process of the practical and cumulative application of scientific and technical knowledge, modulated by the complex dynamic interrelationships that take place within the "human society" system (Sanjurjo, 2016).

The public perception of risk has been growing in recent times, due to the fact that events like earthquakes or other disasters (natural or not) have been retransmitted in almost real time worldwide. Therefore, risk has become familiar and it can be observed from different angles. The following references correspond to a review of the literature according to different epistemological approaches (De Rocquigny et al., 2008):

- For a review of risk analysis, quantification of uncertainty and sensitivity analysis: Bedford & Cooke (2001); Aven (2003); Saltelli et al. (2004).
- For an understanding of the uncertainty and risk theory and their interpretations: Helton & Burmaster (1996); Helton & Oberkampf (2004).
- For the subjective treatment of uncertainty and the distinction of epistemic and random components: Apostolakis (1999); Yager et al. (1994).
- For the particular case of a humanistic / philosophical approach to uncertainty and risk: Smithson & Bammer (2012); Russell (2013); Jaeger et al. (2013).
- For the particular case of an economic / business approach to uncertainty and risk: Runde & Mizuhara (2003); Barberá et al. (1998).
- For the particular case of a scientific / technical approach to uncertainty and risk: Nilsen & Aven (2003); Oberkampf et al. (2002); Kumar et al. (2013).

As mentioned, it is observed that risk management has always existed since the origin of mankind, although what has changed has been the data and methods applied in this management process. In the

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specific case of engineering, the different standardized norms are developed based on events, experience and the development of knowledge. Codes and standards are a reflection of an agreement between parties, producers, users and technicians, constituting a minimum that must be met. However, the 'state of the art' is above the regulated knowledge (Rojas et al. 2013).

Although the risk is present in the engineer's work, the duties and moral obligations have to be fulfilled. The conditions in which individuals and organizations make decisions reflect, the forces of the environment (facts and events), and generally have limited information that cannot be controlled, but that may influence in the future the results of their decisions. These decisions are associated with a certain degree of risk and are based on the perception and tolerance of each person and organization. Therefore, before deciding, an analysis should be made in order to allow the interested party to assess as many associated factors as possible.

The general categories of risks usually evaluated are: financial, operational, business interruption, property, natural disasters, safety, occupational health, public, environment, technology, obsolescence, human resources, intellectual property, reputation, public image, fraud, moral hazard, etc. (Rojas et al., 2013). The different decision criteria in a risk environment are based on statistical variables associated with the probability distribution of results, so that organizations develop statistical models, in order to forecast economic, environmental, political and social variables. In order to perform another analysis and compilation of references focused on the study of risk and uncertainty, it is possible to consider the criteria developed by Gonzalez-Prida & Teira, (2014), where analysis areas are distributed in the following aspects:

- In relation to general issues in risk theory: Doorn & Hansson (2011); Hansson (2010); Roeser (2010).
- In relation to specific risks: Dror & Cole (2010); Rid & Wendler (2010); Douglas (2009).
- In relation to decision theory and risk: Lumer (2010); Gregoriou et al. (2010).
- In relation to the perception of risk: Evans (2012); Wegwarth et al. (2011); Kahan (2010).
- In relation to ethical risk considerations: Van de Poel & Royakkers (2011); Munthe (2011).
- In relation to risk in society: Carro et al. (2010); Everson & Vos (2009).

From the above mentioned background, a problem can have many possible solutions, and calculating the expected results of all of them can be extremely slow and costly. The decision - making situations are considered within a continuous line from the certainty, a highly predictable scenario, till the turbulence of a scenario highly unpredictable. In order to minimize or avoid the catastrophic consequences associated with accidents, engineering has technical and social methods that allow decisions to reduce losses. The use of risk-based initiatives has been incorporated into engineering as a tool to measure and evaluate uncertainty, making a criticality ranking of the facilities or components, deciding mitigation actions, accepting and communicating eventualities, as well as managing the risks. The idea is to decide and implement preventive action before an accident where catastrophic consequences occur.

A risk management system is an approach based on the identification and control of those dangerous events, which have the potential to cause unwanted changes, in some cases with catastrophic consequences. Its implementation in the industrial environment allows operating industrial plants with safety, reliability, availability and profitability. Adequate risk management requires considering aspects such as: identifying hazards / threats, integrating relevant information in a database, analyzing and evaluating risks, mitigating risks, accepting the remaining risks, and communicating risks.

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PHILOSOPHY OF TECHNOLOGY RISK

On the Popperian Theory of Propensity vs. the Bayesian Theory of Subjective Probabilities

According to Popper's thought, induction and demarcation have both relation to engineering and, in that regard, the risk states implicitly in technological developments and industrial projects since it accompanies any change that implies choice and uncertainty (Rojas et al., 2013). Risk, such as the possibility of any damage or losses, occurring or not, is related to danger and vulnerability. According to Popper (Popper, 2002), science must assume risks, while engineering measures risk as the product between the probability (or frequency of occurrence) and the consequences (or severity) of a hazard, limiting its scope to a specific environment and during a certain period of time.

In conditions of certainty, the engineer can at least foresee and, if possible, control, the facts and their results. This condition implies the knowledge and the clear definition of both, the problem and the alternative solutions. Strategies against risk can be reactive or proactive, where the quantity, quality, as well as the type and reliability of the information available influence the level of risk and the fact that the person responsible for making the decision can make use of it. Making decisions may cause uncertainty and risk, appearing phenomena not directly attributable to the decision-maker, such as:

- Inexistence of historical data directly related to the alternatives being under studied.
- Biases in the calculation of data or possible events.
- Wrong analysis and interpretation of available information, bias in calculations, low reliability of statistical data, etc.
- Obsolescence due to rapid technological change.
- Introduction of new inputs and / or outputs (products).
- Economic and political changes, climate behavior, natural disasters...

In order to give an effective response to the challenges of society, technology as an emerging culture must be configured considering the fears, uncertainties and trends of the culture that employs it.

One of the first steps for risk analysis is to define the various scenarios where risk may materialize. Some of the techniques used are based on teams of experts, so that they can think in a planned way, and according to the available technical background. These simple techniques try to be a systematized common sense. A problem, only partially solved, lays in the consideration of unthinkable or improbable scenarios, that is, those aspects that, due to ignorance or because they were never observed, remain outside the analysis (Taleb, 2007).

When an installation or a device has a unique character, without any history before, computational simulation assumes great importance. Nevertheless, it introduces uncertainties, in some cases, due to lack of generic data or failure history. In fact, the state of the art of engineering is based on the method of trial and error, illuminated by the scientific method. Whenever there is a new technological development, there are risks. The zero risk does not exist. The more historical experience becomes available, the greater the capacity of engineering to minimize risks. When a new project materializes, for which there is no background, the risks will initially be high. As knowledge increases, the risk decreases due to greater experience, test results in operation, etc. (Rojas et al., 2013).

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For each defined risk scenario, two questions must be answered: What is its frequency or probability of occurrence? And what are the consequences if the accident materializes? With the answers, the risk of each scenario can be calculated, as the product between probability and consequences. The consequences can be measured in economic terms, losses, damages, etc. Engineering has well-defined methods and sufficient mathematical tools to calculate these losses with a good approach degree. The computational models to calculate the consequences have evolved remarkably in recent years. However, normal or accelerated deterioration can occur over time. In that sense, ASME employs two kinds of probabilities: objective and subjective. Probabilities derived from historical data failures, correspond to objective frequencies. However, even if the data is accurate, it is difficult to contemplate, in practice, that some failed components have been repaired and returned to service or replaced. Subjective probabilities arise from interviewing an expert in a patterned manner, when a failure may occur. The knowledge of the experts, achieved after long years of study and experience, must be "extracted" using techniques capable of avoiding their "contamination" with personal opinions.

The Bayes Theorem (Bayes & Price, 1763), or the so-called Bayesian transformation, is the tool generally used to combine the various probabilities. The Bayesian approach starts from an a priori distribution of probabilities in which the analyst has a certain degree of confidence before obtaining objective data, and then objective measurements of reality (tests) modify the degree of initial conviction.

Popper criticized the use of the Bayesian approach for considering subjective probabilities and proposed replacing classical probability theory with an objective theory of "past" probabilities, which he called as propensity theory. This theory considers those possibilities with greater tendency, where the propensities or tendencies are not mere possibilities, but physical realities. For example, if a dice has a certain weight distribution, there is a physical circumstance (field of propensities), which exerts its influence on each particular roll.

The current methods of inspection based on risk follow some of the guidelines of propensity theory, combining them with frequencies of historical occurrences. In general, it is not found in engineering texts questions, in the sense of Popper, to the use of subjective probabilities. On the contrary, they are also used in a growing trend in the industrial context, such as the API (American Petroleum Institute) or ASME.

The "technical" risk, as objective as it may be possible to be calculated, is not the "real" risk, since this is rather a measure of the perception of risk. The more information obtained (test results, observations, etc.), the perceived risk can be modified closer to the real risk that is unknown.

After analyzing risks, they should be compared to a value of acceptable risk in order to enable the decision making. A very used concept is the risk "As Low As Reasonably Practical" (ALARP), which considers that risk can only be minimized to a certain level under current technology and at a reasonable cost. The risks are "acceptable"' only if all reasonable practical steps have been taken to reduce them.

The admissible risk is no longer just a technical or expert concept; it is a concept that also involves the opinion of society. The socially acceptable level must be determined both by technology and by the level of social alarm. For example, the same risk is perceived in different ways depending on the perspective of different countries and cultures (as is the case for example of different ecological awareness depending on the culture).

Risks Inherent to Technological Progress and Its Effect on Society

Reasoning is a fundamental element of human capacity. No matter how decisions are made, risk always implies uncertainty. Today, when mankind is immersed in the greatest technological transformation

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since the Neolithic, it seems appropriate to make some reflections on the role of technology in history, the risks inherent in this, and how it will affect our future.

The effect of technology on the human evolution is not something recent; it has been present in the western culture at least since the Illustration and was taking shape during the Industrial Revolution. Nevertheless, as a matter of specific and systematic research, it has really gained momentum and interest since the Second World War and it is only since a few decades ago that a systematic analysis has been carried out and an extensive bibliography on the subject has been produced.

Until just a few decades ago, the theory of technological determinism prevailed in the academic media - especially in the United States - a theory that sought to explain the relationship between technology and society, advocating that technology was the determining and independent agent in the configuration of human societies (Sanjurjo, 2016).

This formulation implied, on the one hand, that technological changes were generated autonomously and independently of society and, on the other hand, that they generated, directly and automatically, changes on it (for example, the effect of the printing press appearance, the artillery, the steam engine, the railroad, the automobile, the aviation, the nuclear armament, the microprocessor, the mobile telephone, etc.).

However, this simplistic model, which could explain to some extent the effect produced by technological changes in society, did not respond if the reverse process also happened. That is, if social changes have influenced to the generated technological advances.

The dynamics of human societies is very complex and requires analyzing of the interdependence of all the factors that shape them as a holistic approach that encompasses not only the different economic, cultural, environmental, religious etc., but also all their complex interrelations. A simplification by a unidirectional and linear model such as that provided by orthodox determinism, (where technology is produced outside any influence of the environment), simply does not hold. A more complex model is required that includes the feedback of social changes in the generation of technological innovations (Smith & Marx, 1994) (MacKenzie & Wajcman 1999). The current society's dependence on technology is now much greater and much more complex than it was in the nineties, during the time of the above cited references. Practically, every aspect of the current human's life depends now on technology; health, education, leisure, defense, transport, professional practice, the way in which we communicate. Almost all aspects of what is considered Western society would be unthinkable in the absence of "the machines" that surround us, as already augured in a certain way Ricardo, (1821) and Roe, (1921), foreseeing the pernicious effect that the mechanization of industry would have on society.

However, the new feature of technology is not only a much greater dependence, but that this dependence has an exponential character. If it is accepted as valid the hypothesis that technological evolution unfolds exponentially in extension and depth, one would expect that its impact on society will be much greater in the future than it is today; In short, Western civilization would be heading towards a society largely "dominated by machines".

Today, the technological effect transcends the pure social effect of employment and new types of jobs that will be created or disappear. On the contrary, the debate should focus on the effect of the technification of society, and what would be the consequences of a society dominated by computer networks and intelligent machines with the ability to exchange information in real time, with its own capacity for learning, self-improvement of its algorithms and with increasing decision capacity (Sanjurjo, 2016).

It is evident that the First Industrial Revolution had profound effects on European society, which in many aspects still remain and that a huge cost was needed to pay in order to assimilate socially the

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effects of technological development. Nevertheless, the result has been finally a better, freer and more prosperous society.

If it is considered the introduction of automatic looms in England during the eighteenth century, coinciding with a change of energy model (steam engine), along with the subsequent advances of the 19th century, all this led to the transformation of the entire European industrial fabric (with enormous political and social implications). Similarly, the current industrial revolution will generate a different productive fabric, a strongly digitized industrial base forming part of an integrated digital space of value creation, which in turn will generate a more efficient base in the management of resources and decision making (Sanjurjo, 2013).

Today, there are unknown variables to face, similar to those discussed in the 19th century. However, a critical issue will be to determine what decisions mankind will put in the hands of "machines" and which will be reserved for humans. Will machines be allowed to decide on the life or death of human beings in certain circumstances? In that sense, one of the challenges in the future will be to face precisely how to control our own technology. In other words, the only alternative to ensure mankind's survival is to be willing to accept and manage the risks inherent in technological development, which is an essential element of improving human beings and the only viable option to solve the challenges to face. This will depend on the extent to which mankind is willing and able to control the technology generated by itself and how to face the enormous ethical challenges that will involve accepting technological advances that will affect the own essence as human beings (Sanjurjo, 2013).

Particularization of the Technology Effect on the Industry

Turning to a more engineering and concrete level, it is very risky to predict the future industrial structure within 20 or 25 years and even more, what topology will have and what variety of products and services may be present in the market. However, it is possible to extrapolate some of the evolutionary trends that are already observed today.

In general terms, the first thing that can be inferred is that, similarly to what happens in other sectors, the future productive fabric will be determined by the unstoppable development of digitalization, by the application in all its facets of knowledge to products and processes, and by having to compete in a scenario of continuous innovation. This innovative scenario will be partly generated by market demand and partly by the dynamic established as a result of massively applying knowledge to the industrial fabric.

As discussed above, the current society lives increasingly immersed in a digital civilization, and the industry will not be just an exception. The driving force behind the transformation of the manufacturing sector is the digital revolution, whose spectacular advances will make possible levels of connectivity, automation, robotization and virtual simulation with the potential to transform the entire productive fabric. The digital revolution is transforming the planet, and particularly the productive sector, into a smaller and fully interconnected space.

Precisely, digital connectivity in real time, to a new scale machine-machine and human-machine, with global coverage will allow the interconnection between all the elements of the value chain regardless of its geographical location. The development of the next generation of Internet, and the growing importance of the process based on databases and virtual applications (cloud computing) are going to suppose a real revulsion in the productive fabric and in the business models as we know them today (Garetti & Taisch, 2012). Another consequence of connectivity is that it will shorten the gestation cycle of products and shorten the time to reach the client being therefore more flexible to adapt to a rapidly evolving market.

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The concept of productive integrated space and value creation transcends what was understood up till now as the pure manufacturing activity, isolated from other activities of the value chain. The new paradigm requires - and digital technology allows - the integration of innovation, design, production, directly associated services and customer management (Sanjurjo, 2013). On the other hand, this breakthrough concept with the traditional way of establishing responsibilities will boost global supply chains, reducing risks and increasing efficiency.

Another factor reducing risk in the industry which brings this new industrial revolution is the automation and robotization of production centers. Although they were already introduced throughout the 20th century, the current advances in artificial intelligence and automation open a new field of application that will allow the use of new generations of mobile robots with learning ability, capable of interacting with operators and sharing with them the same tools, hardware and software and work space. It is not like in the past, simply to perform standardized perfectly defined and scheduled tasks, this is really a direct contribution to areas fully integrated with the humans in processes (Sanjurjo, 2016), sharing its knowledge in real time with humans, other robots, computers, databases, etc.

The paradox here is that the new highly automated and robotized industrial fabric will need less and less direct labor in the plant, but it will increase labor needs towards other higher links in the value chain, which logically implies a profound professional evolution of the manpower. This transformation of the social base in productive fabric is not going to be automatic and without traumas. The new economy of the Fourth Industrial Revolution will require an active population more and better trained to operate in a highly technified productive environment, which requires new professional capabilities (Bonvillian, 2013). In line with the above mentioned, risks and uncertainties are arising and must be taken into account. Some would include the following:

- The offshoring can produce vital dependencies from abroad.
- The relationship between production capacity and innovation capacity (when production is relocated abroad, innovation may be lost in the long term).
- The vertical integration, especially in complex products (added value will lie in the integration processes).
- The availability, in a time of accelerated changes and often unforeseen markets conditions, is essential to possible sudden changes in demand.
- The sustainability of an industrial base that requires the correct management of material and energy resources in a feasible change of paradigm.

The way of interpreting the previous aspects and prioritizing them over time can lead to different decisions with totally different consequences on the conformation of the industrial fabric [Sanjurjo, 2013].

THE HUMAN FACTOR AS A SOURCE OF UNCERTAINTY

Companies, organizations, industries etc. must have teams of people and managers skilled enough to take decisions under conditions of certainty, of uncertainty and risk (Sanjurjo, 2016). Without being exhaustive, these conditions in which decisions can be made can be defined as:

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- **Certainty:** The consequence of the results is known, exact, measurable and reliable information and its probabilities of occurrence of each of the decision alternatives, so that computer simulation models can be applied.
- **Risk:** There are several possible consequences for each course of action and the decision maker does not fully know the potential results, so the probability of occurrence is assigned to obtain the desired results within a desirable range.
- **Uncertainty:** There are several possible consequences for each course of action, the decision maker does not know the probability of occurrence of the variables, and the interactions of the different variables cannot be evaluated. As uncertainty increases, the possibility of failure also increases.

Regardless of religious meanings, human infallibility, understood as the inability of a person to make mistakes or fail, does not exist. In that sense comes into play the concept of human reliability which will have the aim of identifying the effects of possible deviations in activities or human actions, from the point of view of quality, performance, safety and efficiency of different organizations processes (Parra, 2010). That is to say, there is an uncertainty associated with the capacity for human decision making and its behavior, which entails a great difficulty of anticipation due to the complexity of the human being.

There arises the need for tools or methodologies to assess how changes in the behavior of a team, from all possible points of view: physical, psychological, mental, intellectual, practical, ethical, environment and all circumstances that can give in the context in which decisions are made. It must start from the view that humans are vulnerable and, even under the most favorable conditions, it may fail. Therefore, the management and decision making that includes human factor must implement a set of mitigating strategies and measures that allow assuring acceptable levels of reliability and risk reduction in case of erroneous decisions.

Traditionally, the use of experts' knowledge and methodologies such as brainstorms has been fundamental in deciding on a better or, at least, more consensual solution, when there are several options or alternatives. The multi-criteria and / or multi-objective decision techniques (González-Prida et al. 2014) are good options in this sense.

However, given the large amount of data that can be collected today, it is convenient to take advantage of computer resources and technology as a support for the processing and analysis of multiple variables needed to finally make a good decision. A methodological approach that seeks the identification, formalization and structuring of the valuable knowledge for empirical logic, based both on the knowledge of experts, as well as the information technology and technologies can be found in reference Grubessich et al., (2016).

In such reference, it is promoting an approach that search is increasing the degree of understanding of the system under analysis (usually complex) and thereby achieving particular goals within the scientific context. That proposal (Grubessich et al., 2016) brings suggestions for implementing and generating a Conceptual model which brings a simple and structured technoscientífic method.

As it has been commented, nowadays such an extremely high number of information is usually handled, having also a fundamental role in the selection and implementation of the adopted strategies and decisions, which makes the use of new technologies indispensable for its treatment and filtering.

In this sense, the OTSM-TRIZ methodology is a tool that allows evaluating the causal relationship between problems and solutions, which facilitates the person who must make decisions, anticipate potential problems that may affect the different decisions in practice. That is to say, OTSM-TRIZ is

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characterized as a tool that makes decisions, making it possible from a pragmatic point of view. As a consequence, decisions are made more efficient and objective (Cavallucci & Khomenko, 2007) reducing the possibility of human error.

In scientific practice, models can be conceptualized from a semantic, functionalist, epistemic or inferential perspective (Tuay Sigua, 2011). In particular, problem solving methods can be grouped, for example, depending on whether they are deterministic, stochastic, economic, or based on simulation (Beamon, 1998), to which the human factor must be added as a source of uncertainty. One of the biggest limitations of these models is obviously the lack of flexibility in the analysis and synthesis of possible consequences due to modifications in some stage of the analysis that is being carried out.

In this context, a strategy based on creative and flexible tools to evaluate solutions and demonstrate potential consequences can allow to simplify and analyze structurally conceptual solutions that can appear within the application of the scientific method, specifically in the process of solving problems, and how they would be improved with the integration of advanced technologies and the knowledge of different disciplines such as the OTSM-TRIZ and the AHP (Nikulin et al., 2016, 2017).

One way to promote human reliability is also through the correct management of intellectual capital. Intellectual capital is an asset, an intangible resource that has no monetary character. It is nevertheless one of the factors that adds more value to organizations and entities, allowing sustainable growth over time in innovation, economy, industry, science, etc.

The management and the increase of knowledge provide, in general terms, the economic development of the industries and the prosperity of the regions. Intellectual capital has been defined by Intelect, (1998) as "the set of intangible assets in an organization that, although it has not been considered in traditional accounting, this certainly has the effect of producing value or potential to produce it in the future". The intellectual capital is usually presented in three ways:

- Human Capital, such as the knowledge, experience and creativity of the employees employed by the company.
- Structural or Organizational Capital, which considers the capacity of the organization to carry out its function. That is, sources of information, technological systems, industrial properties, franchises, corporate culture, as well as the efficiency of the processes, the quality of the assistance, the capacity for innovation, etc.
- Relational capital of the entity with the agents of its environment (customers, suppliers, public bodies, etc.), as well as the valuation of the brand, the client portfolio, the relationships with these, etc.

The success of organizations in competitive contexts (such as economic, industrial, political sphere, science and technology), ultimately requires emphasis on the development and enhancement of their intangible assets as the intellectual capital. Productivity and motivation of people constituting the entities promote innovation, collaborative work, creativity and finally, an accumulation of wise decisions that generate value for the team, the group or the entity.

Anticipating failures in a human-machine system requires a fundamental model that should consider not only information processing, but also how human functioning is determined by the context or circumstances (Parra, 2010). This type of model corresponds to the concept of cognitively distributed (Hutchins, 1995). In that sense, Hollnagel (1998) describes the human and technological functions as bound systems, rather than simply the interaction of humans with machines.

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The classic principle of time-reliability correlation is an expression that conveys the idea of degradation of physical assets over time. That is, the occurrence of a failure event is a function of the time elapsed. A more sophisticated version of the same principle is found considering forced conditions of error, which is in many occasions the human being. For example, a determining factor here could be the time available (or remaining time to make a decision) in place of the elapsed (Parra, 2010).

Human error is usually treated as something inevitable, which always escapes control and measure. When determined misalignments cause serious incidents or accidents, in situations of dialogue between human and machine, it must be said that the system human-machine has failed. That is, the error is the overall combination of the system, which depends in turn on the ability of the machine to interpret humans in their variable capacities: psychological, mental, social, etc. (Parra, 2010). If it is intended to measure human error, that means to measure the limits and capacities of human beings and, for that purpose, it would be necessary to integrate technologies compatible with the human brain, considering consequently an infinity of variables.

FUTURE RESEARCH DIRECTIONS

This chapter may be used as a preliminary research that shows the evolution of risk, its perception throughout the decision makers or systems users as well as the new paradigm associated with the industry 4.0 technologies. In line with the technological advances that bring the a.m. paradigm of Industry 4.0, it is presumable that there will be continuous changes in strategies and decision making in areas of both organizational and individual nature (Cagliano et al., 2005). The role of decision making and its integration in the process of scientific analysis assumes relevant connotations when offering maximum value to the search of a final objective.

The general nature of the argumentation throughout this document is intended to stimulate the thought and initiate the discussion on these matters. Consequently, future research directions may highlight the scientific bottlenecks to be removed in the near future, providing new technological or methodological solutions to achieve this. The scientific study is also influenced by this tendency where, despite the multiple tools and methodologies that are created for the analysis, many fail to tackle the diversity of problems that may arise in practice (Stewart, 1997). There are several models available in the literature to help decision making capable of representing and predicting risks and for developing the recognition of obstacles, in order to avoid or mitigate their impact as much as possible.

However, usually their perspectives are always based on the experience and trial and error of the solutions created. Consequently, its application in the industrial and scientific context associated with decision-making is not always as plausible and effective as desired, since the solution will always depend on what the decision-maker can visualize during the process of change, as well as the distinctive characteristics of the systems on which such decisions are made (Braunscheidel & Suresh, 2009).

In this sense, Julio Caro Baroja (Caro Baroja, 1983) considers, for example, that technology is the study of the methods, systems, tools, machines and substances used in the works, which constitute one of the foundations of the life of human societies from the past and from the present. (Caro Baroja, 1983). In line with this definition, and in view of the effect of the digital revolution on all facets of society, future lines of research could be for example:

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- Evaluating the state of the art regarding the quantification of uncertainty and risk analysis, as well as the exposure of this field in terms of its modes and forms within scientific knowledge.
- Analyzing the historical evolution and treatment of uncertainty from various areas of knowledge (e.g. medicine and biology, engineering and physics, and/or economics and law).
- Reviewing methodologies currently in application and possible trends and synergies, analyzing real or simulated examples of application of a possible common methodology that simplifies the treatment of uncertainty and risk.

Since this document has been developed as a monolithic whole, with a discourse absence more in tune with specific technologies, future lines may refer to a distinction between the different fields. According to these possible lines of research, it appears appropriate to review the nature of uncertainty as its classic conception and its theoretical distinctions, as well as the treatment of uncertainty in different contexts and from endogenous and exogenous points of view regarding the systems under analysis, and considering the human factor as a subjective and relevant parameter in decision making. In that sense, it can be understood that would be relevant to obtain a standard methodology where possible subjective interpretations during the decision making can be considered as mathematical functions of a model, following the subjective preferences of the decision maker as a set of rational axioms.

CONCLUSION

Throughout this chapter, a general research framework has been described, combining technology-oriented risks and social aspects, linked with their perception in terms of impact or ethical standpoints. These aspects, together with the extension of risk assessment confer to the research its real added value. In other words, although the scientific contribution is not the key point here, the document relevance underlays over the foundations settlement of an original discussion on these issues.

In fact, throughout this document it is evident that there are diverse ways to approach the problem of uncertainty and its assessment. In this sense, it seems convenient to adapt to a probabilistic criterion that makes it easier to manipulate the problem. Nevertheless, subjectivity underlies the perception of risk dependent on cultural habits, operational imitations, and acceptability criteria, among many others, as factors that are inevitably involved in the decision-making process. Along this chapter, the general context of risk-based decision making has been depicted, supporting the chosen arguments with a historical and somewhat scientific state of the art in a very relevant manner. From the consulted bibliography, it is deduced that the theoretical approaches on the uncertainty imply a literature of long route with not a few controversies. These controversies even affect the basement and conditions in the use of the deterministic, probabilistic or extra-probabilistic settings. Similarly, epistemological considerations appear that underlie necessarily in the own description of uncertainty around the system under study.

Popper's critical rationalism is linked to the attempt to construct a purely deductive approach to science, to his vision of the theories evaluation and to increase knowledge and the falsifiability and demarcation criterion. However, the problems of engineering have a technical and social dimension, acquiring social aspects such connotation that must be part of the solutions given by engineers. Engineering must control its creations and minimize vulnerability to failures or disasters, having for the method of mathematical methodologies, but also philosophical, capable of analyzing and evaluating technical and non-technical

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risks. Its use is well established in industrial standards, understanding that, the greater the scientific and technological progress, the risk of failures will tend to decrease.

Engineers must therefore expand their vision to the field of sociology, psychology and philosophy in order to improve the use of human reliability tools, and also to improve the dialogue with society with which they must share decisions about risk, so that the following question can be better answered: what is an acceptable level of risk? In short, the engineering development path must advance applying science, creativity, technology, as well as perception of social and ethical reality, so that the risks of a project may be reduced from all points of view.

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KEY TERMS AND DEFINITIONS

Decision: The act or process of deciding. It refers also a determination, as of a question or doubt, by making a judgment.

Epistemology: A branch of philosophy that investigates the origin, nature, methods, and limits of human knowledge.

Logic: The science that studies the principles governing correct or reliable ways of reasoning. It refers also a particular method or way of reasoning or presenting arguments.

Philosophy: Study of the truths and principles of existence, knowledge, and conduct. It refers also to the critical study of the basic principles of a branch of knowledge, as for example the philosophy of science.

Risk: Exposure to the chance of injury or loss; a hazard or dangerous chance. It refers also to the degree of probability of a loss. The type of loss can be as life, fire, marine disaster, earthquake, etc.

Science: System of knowledge about the physical world, explaining or describing what it is and how it works in general laws, gained by observing, experimenting, and testing theories. It refers also to any skill that shows ability to use facts or principles.

Technology: Branch of knowledge that deals with the creation and use of technical means and their interrelation with life, society, and the environment, drawing upon such subjects as industrial arts, engineering, applied science, and pure science. It refers also to the sum of the ways in which social groups provide themselves with the material objects of their civilization.

Uncertainty: The state of being uncertain, doubt or hesitancy. It refers also to unpredictability, indeterminacy, indefiniteness, etc.

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Chapter 4
Technological Revolution, Transhumanism, and Social Deliberation:
Enhancement or Welfare?

Ana Cuevas-Badallo
University of Salamanca, Spain

Daniel Labrador-Montero
University of Salamanca, Spain

ABSTRACT

The aim of this chapter is to show some of the assumptions that lie behind transhumanism. The concept of enhancement is analyzed. While, from transhumanism, human welfare depends on the enhancement of human capabilities, here it shall be argued that to begin with, a social debate over what is considered welfare is needed before we can establish what we wish to improve (enhance). This reflection must emphasize the necessity to reflect, ex ante, on what kind of technological development we want, viewing technology as a means to attain the agreed-upon type of welfare, rather than a goal in itself. On the basis of a socially open debate with an anticipatory perspective, society as a whole can establish which risks it is willing to take.

INTRODUCTION

"I have always considered that the writer's mission is to foresee with comfortable anticipation what the problem will be […]" (Ortega y Gasset, 1939/1964: 319). Right at the beginning of the *Meditación de la técnica*, Ortega y Gasset poses such declaration. If transhumanism as a philosophical approach has some value it is because of its anticipatory character, not so common in philosophy. Transhumanism walks blindly in an unexplored territory, but at the same time offers some speculations (with more or less empirical basis) advancing future possible scenarios. Such scenarios, in case of taking place without previous analyses, could overcome any attempt of individual or collective control. In a technologically

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more developed future, there is a chance that most people do not keep hold of human biological nature. As Raymond Kurzweil (2007) inquires, what will happen if robots and artificial intelligence threaten future human beings? In such situation, could we reject transhumanism offerings, such as cognitive enhancement?

Transhumanism is often referred as "the greatest of dangers" (Fukuyama, 2002), and many critics to transhumanism recommend a regulation, if not a prohibition, of biotechnological developments whose goals are the irresponsible and postmodernists ramblings of an unnatural and exterminator evolutionism. However, this could be see as a simplistic view about scientific and technological development, taking into account that technoscience is complex system. To restrain an innovative pathway on the basis of the inappropriateness of the transhumanism goals could lead us to giving up on some positive outcomes of that innovative pathway as biomedical, computer, industrial and scientific-technological advances in general. Therefore, transhumanists *ex ante* deliberation and analysis could be necessary, but one that considers simultaneously the possibilities and purposes of the techno-scientific progress that society aims.

According to Anders Sandberg, "transhumanism is one of the few current movements that articulates a positive vision of the future" (Sandberg, 2015: 376). However, this positive standpoint of the future entails an idea about what human beings consider good or valuable, something that should be achievable by technological means.

In this paper the authors aim to expose the assumptions behind the transhumanism argument, and suggest a mechanism for reaching a more general agreement about the kind of criteria that should regulate the evolution and the application of technology. The mechanism is *public participation* and *anticipatory governance*, and the criterion is the search of a *consensus about welfare*. Welfare is an ideal used among transhumanists thinkers. However, we will argue that the concept of welfare used by some transhumanists is interrelated, generally, with the notion of enhancement.

With those goals, we will show the huge range of challenges posed by technological progress, where the so-called fourth industrial revolution plays an essential role transforming the values of society with respect to technology. It will be claim that, in some way, the industrial achievements and transhumanists' desires legitimize each other. In order to find a common and more democratic orientation of what the citizens search for *anticipatory governance* will be defended, a perspective that allows to make decisions on the basis of the envision of possible futures.

INDUSTRY 4.0 AND TRANSHUMANISM

The so-called fourth industrial revolution is considered to be a disruptive technological evolution, where the drive and goal will be the achievement of "smart factories" and flexible, cooperative, and personalized production. Nevertheless, this revolution "is not only about smart and connected machines and systems. […] It is the fusion of these technologies and their interaction across the physical, digital and biological domains that make the fourth industrial revolution fundamentally different from previous revolutions" (Schwab, 2016: 12). The fourth industrial revolution, as the previous ones, would be driven by technological development. In this particular case on the so called "converging technologies" (Internet of Things, Artificial Intelligence, Nanotechnology, Robotics and Biotechnology), that will make possible changes in the productive and industrial model, but also key changes in other social areas. This is not exclusive of the fourth revolution: every industrial revolution encompasses transformations on those societies that are affected by. The hallmark of this new revolution would be the broad and fast diffusion to every

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corner of the world (see Schwab, 2016: 12-13). Artificial Intelligence (AI thereinafter) and the digital age have changed the way of living of complex societies in every aspect. Nevertheless, the adaptation to an increasingly technological and virtual world is not the most important obstacle that the institutions and societies must face. In a possible future, it will no longer be interesting to elucidate the goals that a society should pursue or the direction of the transformation, but rather the very conception of what it means to be a human being. That is the reason why an *ex ante* reflection in the fields of biological and biomedical applications of new technologies is more necessary and challenging than ever.

It is in the biological domain where I see the greatest challenges for the development of both social norms and appropriate regulation. We are confronted with new questions around what it means to be human, what data and information about our bodies and health can or should be shared with others, and what rights and responsibilities we have when it comes to changing the very genetic code of future generations (Schwab, 2016: 26).

The possibilities that new technological advances offer cannot be left to the desires of the market. The human condition itself is at stake. Some biotechnological, biomedical or robotic developments of the fourth industrial revolution could affect, albeit indirectly, on the physical, cognitive and biological aspects of human beings. Transhumanism needs this technological revolution and, therefore legitimizes it in favour of its claims. For example, it is difficult to understand Kurzweil (2005) project without the advancements of technologies of computation and AI, or the ambitions of Aubrey de Grey and Michael Rae (2007) without the progress in techniques, methods, and knowledge of the biomedical fields. However, transhumanism goals not only need technological advance, but also require that these intentions equate of the society as a whole. That is precisely why it is necessary that transhumanism goals fit into the society value system.

Indeed, a revolution of this kind entails severe changes in other social sectors. As Leon Kass (2003) states, "biotechnology is bigger than its processes and products; it is a form of human empowerment", something that Kass himself considers with objections. An industrial revolution implies a change of attitude, of public understanding about the driving technologies, and also of the purposes that a society aims. Therefore, transhumanism standards legitimize technological-industrial progress as something inherently good or profitable, and arrange the ground for future applications of new technological developments, the fourth revolution. Being a disruptive event in all social areas, a new technological revolution can generate a change in the system of values, as well as new ethical and political perspectives that can welcome some of the transhumanists purposes.

TRANSHUMANISM, HUMAN NATURE, AND EVOLUTIONARY ESSENTIALISM

It is well known that Julian Huxley coined the term 'transhumanism' in his book *Religion without revelation* of 1927. However, it was three decades later in *New bottles for new wine* where Huxley explained the meaning of the concept:

The human species can, if it wishes, transcend itself —not just sporadically, an individual here in one way, an individual there in another way, but in its entirety, as humanity. We need a name for this new

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belief. Perhaps transhumanism will serve: man remaining man, but transcending himself, by realizing new possibilities of and for his human nature.

"I believe in transhumanism": once there are enough people who can truly say that, the human species will be on the threshold of a new kind of existence, as different from ours as ours is from that of Peking man. It will at last be consciously fulfilling its real Destiny (Huxley, 1957: 17).

The passage has been interpreted in many different ways, nevertheless the idea of "man remaining man, but transcending himself" and the comparison with the Peking man seem quite different to many of the transhumanists stances. One of the difficulties of analysing and discussing transhumanism is mainly based on the broad number of ideas, ideologies, criteria, and means that this concept encompasses. It is not the same to discuss about eugenics, cyborgization, or IA. However, there must be some link that allows transhumanism, as a trend of thought, to base its argumentation from such diverse areas. The link is rooted in the deepest transhumanism ideology, and is the notion of enhancement. However, this concept does not clarify anything by itself, and it is necessary to analyse what it presumes.

Some authors maintain a broad concept of enhancement that includes almost any kind of progress or novelty related to human beings, from the invention of writing, the establishment of democracy, or the possible benignant applications of technology. Nevertheless, transhumanists usually make sense of enhancement in a specific context and in connexion with a set of specific wishes and values. This is ignored by many transhumanists who, in their postmodernist vein, try to avoid what history shows, and uphold that looking for enhancement and transgression are inherent traits of human beings (for instance, Nick Bostrom, 2005).

However, are really comparable the claims of domination over nature of Francis Bacon or the Renaissance humanism and posthumanists proposals or eugenics? Bostrom makes an interpretation of history as a justification for the present, although not of any present, but the transhumanist present. It could be desirable, and even inevitable at times, to decontextualize examples and transform them into the interpreter's values and objectives. So, while the concept of enhancement is usually employed by transhumanists, it is impossible to find an agreement among the different definitions of what enhancement means. In this context the concept of enhancement can rarely be separated from *human nature* and *therapy*, which are already troublesome concepts. Transhumanism tries to go beyond them: through rejection or denial, in the case of *human nature*, and through the opposition, in the case of *therapy*.

A large number of criticisms of transhumanism rely on arguments grounded on the notion of human nature (see Kass, 2002 or Fukuyama, 2002, for instance). The immediate reply from transhumanism is to stigmatise such criticism because of its essentialism. Transhumanism does not deny that there are biological traits shared by all human beings, but they uphold that there is nothing like an immutable and universal common essence. Delegitimizing the essentialist vision of human nature, transhumanists demolish the ethical structure built on it.

The limitation of the arguments based on the human nature -in a strong sense- is obvious if we take into account the current biological theories. Ethics should not be based on a specific and essentialist concept of a human nature, as David Hull (1986) maintains, since human beings, like any other biological species, are variable both genetically and phenotypically, therefore, there is no a specific set of common features that define or describe the essence of human beings. As Tim Lewens (2012) points out, it is necessary to set aside references to human nature in the debate about enhancement. However, if normative ethics coming from a conception about the human nature cannot be the basis for the values

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and criteria that allow us to discern in which sense it is morally right to enhance, then it is necessary to offer an alternative way for making the evaluation.

The notion that replaces "human nature" is "the necessary evolution" as something precious and desirable. "Transcending himself," in words of Huxley, or "rising to higher or divine orders", in words of Pico della Mirandola (1486/1956), seems to good in themselves, the very essence of humanity. Thus, for transhumanism the meaning of humanity is to overcome, to exceed the current state of affairs. Evolution, for transhumanism, would lose its arbitrariness, circumstantial, or local relativity of its benefits (it is impossible to affirm that one species is superior to its predecessors), to become something directed and linked to enhancement. Evolution is understood in terms of progress, which goes from a point of departure and moves to a next and better stage. An essentialist claim is substituted by another, but now with a *teleological evolutionary* sense.

With the irruption of Darwinism, Bostrom (2005) maintains, humanity realized that they are not the ultimate being or the goal of evolution. However, it is at least doubtful that this justifies the possibility of a teleological evolution guided by human beings. Actually, the horrors fulfilled by eugenics in the early twentieth century were based on cultural evolutionism, social Darwinism, or by totalitarianism that sought a political benefit rather than a new age for humanity.

There are many transhumanists that consider "exponential" or rapid technological progress as a justification of transhumanism as a tool for adaptation. Marvin Minsky (2007) rhetorically asks why not to remain the same, unalterable, and his answer is quite clarifying: "we do not have an alternative. If we remain unalterable in our current state, we will not last long" (p. 252). Kurzweil poses that in a close future there will be non-biological systems with intelligence equivalent to humans'. His certainty about the unstoppable technological and scientific progress in ethical debates (Kurzweil, 2007: 285-286) implies that technology is not anymore only an instrument but also a source of concern and limitation. As Allen Buchanan (2011) explains, the development of technologies that aspire to enhancement will not depend on whether the citizens approve them or not. The real question is how to frame such possibilities in the liberal and democratic democracies and what resources are allocated to establish "effective and morally sensitive policies and institutions for coping with the challenges of enhancement" (p. 16). Human evolution, for Kurzweil, must inevitably be linked to technological evolution: there is no way to avoid a radical progress that depends on millions of small steps that aim a no imaginable final stage. The conclusion is that human evolution has reached a stage of techno-evolution, and it has merged with technological development: "technology itself is an exponential evolutionary process, a continuation of the biological evolution created before by humanity, an evolution that had an exponential development in turn" (Kurzweil, 2007: 289). The concept of enhancement is detached from the essentialism of human nature, and becomes, in many cases, into a different conception of evolutionism, understood now as the essential need and aspiration of the human being. The progress for human beings is the specific *telos* of a being that can and should build herself. Within transhumanism that *telos* acquires a component of overcoming, of increase of capacities, of going beyond. The enhancement becomes an end in itself.

THE WELFARIST APPROACH TO HUMAN ENHANCEMENT AND WELFARE AS FULFILMENT OF THE VITAL PROJECT

Although the notion of enhancement in transhumanism cannot be understood without denying the essence of human nature, there is an even deeper conceptual confrontation about the concept of therapy

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or treatment. The therapy/enhancement distinction has conventionally been used to demarcate the scope of action and limits of human enhancement. Thus, enhancement has been understood, in general, as going beyond therapy. However, it is problematic that demarcation depends on an accurate definition of 'therapy', taking into account that our understanding of health and disease is variable and often, reliant on the idea of human nature.

In "Well-being and enhancement", Julian Savulescu, Anders Sandberg and Guy Kahane (2011) establish a distinction between different approaches to the notion of improvement, coming to the agreement that the correct is "well-being". Curiously, some of these perspectives highlight the impossibility of defining enhancement or indicating its irrelevance. On one hand, *the sociological pragmatic approach* emphasizes the confusion about the concept of enhancement, riddled with errors or culturally related assumptions. However, as Erik Parens (1998) explains, this would happen with any other concept that replace enhancement, and the same can be said abut the notion of well-being. On the other hand, *the ideological approach* suggests avoiding the use of terms like enhancement or well-being and recommends instead a list of permissible practices based on a set of values. From *the not-medicine approach*, on the contrary, the concept of enhancement is not avoided, but tries to define what would be the natural state of things. That is, enhancement implies going beyond restoring health to its normal state. The difficulty then arises defining what a normal state is and to what extent diversity must be respected (an issue analysed in depth by Singer, 2003). Finally, *the functional approach* bases the notion of enhancement on the increase of a function or a physical or psychological capacity without the need of using a criterion of demarcation such as human nature or normality to distinguish it from therapy: any increase of a skill is an enhancement.

The difficulties of those approach strength even more the position of Savulescu et al.. Moving away from the sanitary-therapeutic scope, Savulescu et al. suggest that the enhancement must be referred to an enhancement of human life, of the welfare. Thus, in welfarism enhancement is defined as: "Any change in the biology or psychology of a person which increases the chances of leading a good life in the relevant set of circumstances" (Savulescu, Sandberg & Kahane, 2011: 7). The strength of the argument lies on the fact that not every increase of a capacity means necessarily enhancement; that is, it is possible that an intelligence rise, for example, would not be beneficial in the specific circumstances in which the life of an individual develops and, therefore, it would not be considered an enhancement. In this way, they claim, a general normative theory can be build around the welfare value. Of course, the matter of what it is considered good or a good life can hardly be agreed and eases the way to introduce social values within of what can be understood as enhancement.

However, sometimes, it is difficult to fit the concept of enhancement into welfarism due to the individual-social conflict. While the concept of enhancement gives preference to the individual subject, the concept of welfare is always in relation to the social context. In welfarism, the concept of enhancement is overmuch related to the value of welfare (something quite clear in Savulescu, 2007): the enhancement suggested refer always to the increase of capacities that ultimately depend on biology (although taking into account the particular and social circumstance). Thus, Savulescu et al. (2011) consider that enhancement can be of three kinds: medical treatments, enhancements in human potential, or superhuman enhancements (p. 8). But, what about the technological development that implies an increase in welfare or a significant advance for society, but it is far from assuming a direct intervention in the bodies or minds of individuals? Cannot the human, as Huxley said, transcend himself through technological

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progress, but without directly biological consequences? And, most important, transhumanists seem to forget that in order to transgress once and for all the current state of affairs, a social change is necessary and not just some individual changes.

At this point, it is convenient to get back the Ortega y Gasset thought about technology, as Antonio Diéguez (2014, 2017) has already done. Humans are different from animals, from Ortega's point of view (1939/1964), because of their ability to move away from vital or biological needs (which in the case of animals represent their entire life). Human beings do not have the biological compulsion to improve themselves. Their true life, or the meaning of it, consists of actions and conditions that have nothing to do with biological needs.

Technology must be a medium and never an end in itself, and it has not the function of correcting biological needs, but the elimination of them, so human beings can give meaning to their lives beyond those needs. Technology struggles against the imposed circumstance. Now, the human being's strongest need is not in biological: "Man does not have the resolution to be in the world. What he has to do is to be well. Only this seems necessary and everything else is necessary only to the extent that it makes welfare possible" (Ortega 1939/1964: 328).[1]

However, in contrast to the rest of species, living well or welfare is somewhat variable. "Man, biological centaur" in Ortega's terms, inevitably holds on to his nature, but at the same time transcends his biological nature thanks to technology. There is no need for technology to modify human nature, because human beings transgress it thanks to their "extra-natural" nature. That "extra-natural" part is shifting, circumstantial, historical and, at the same time, the most typical of human beings. It is his or her life project, what directs the life of every person. Ortega proposes to modify the world through the human "extra-world" and, therefor, humanity saves the effort for settling biological needs and dedicates that effort to their life projects.

Nevertheless, transhumanism suggests the opposite: instead of changing the world human beings should change themselves to adapt and specialize. Human being has no essence, technology does: human welfare. Technology tries to turn the world into a place for human beings, and not all the way around, but transforming the human beings for the world (and not the world for human beings as traditionally technology has done). For example, authors like Sandberg considers the possibility of developing actions that increase those technological possibilities to adapt humans beings to the expected environmental alterations that the planet will suffer as a consequence of climate change. Paradoxically, technologies developed to adapt the world to the necessities of human beings would now be the instrument through which individuals are modified to adapt to the new environment created by uncontrolled technological development. As Diéguez (2014) accurately points out, transhumanis leads to the absurdity of promulgating the extinction of the human being in favour of its adaptation.

Human beings continuously mutate, maybe not in a biological level, but on a cultural and social level. According to Ortega (1939/1964), technology is only an instrument, "the vital program is pre-technical" (p. 343), and it is the society as a whole who has to guide the goal of technology: technological development does not have value by itself. A new product does not turn into a technology, but the immersion of that product in a goal, in a vital project does. A computer is useless for a medieval man, or a future intelligence object is incomprehensible for us. And the same can be said to those Palaeolithic rudiments that nowadays have lost all meaning. Each society in every vital moment has to develop its technology according to its pretensions. These goals cannot be drowned in a sea of technological possibilities,

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technological development cannot impose the goals to society. In conclusion, technical progress cannot determine what life should be for human beings, but on the contrary. It is necessary to consider with precaution the overwhelming technological capacity, and avoid the imposition of technological reason on the rest of human aspects.

ENHANCEMENT AND RISKS, THE PUBLIC DELIBERATION IN ANTICIPATORY GOVERNANCE

As seen above, transhumanism and the ideal of human enhancement are based on the development of some technologies, as well as on the consideration of the neutrality of those technologies. Nevertheless, one of the main features of contemporary technological development, as recent history has thought us, is the uncertainty about the outcomes of the implementations of techno-scientific systems (Rowe, 1994; Stirling, 2008; Wynne, 1992). The new converging technologies (Roco and Bainbridge, 2003), essential for the fourth industrial revolution and for transhumanism, such as nanotechnology, biotechnology, informational technology and cognitive technology are met with great expectation from the industry, but with reservations from the public. On the other side, new converging technologies create in turn new kind of risks, multi-faceted risk, making more difficult than ever to point to the origin of the non-desired consequences. The ongoing risk regulatory mechanisms were designed for conventional technologies, and they are not ready to deal with those new technologies. New risks, called "manufactured risks" (Giddens, 1999), overtake our forecasting capabilities and are different from merely accidents or human mistakes, but a new feature of the technological complexity and the interaction between technological and natural systems. As Ian Hacking (1986) points out, new technologies may interact with other portions of the world and generate unpredictable and harmful outcomes by "interference effects." Something that could have been well understood in the lab may disrupt in unexpected ways when is liberated "into the wild." We have to face the Collingridge's dilemma of control:

The social consequences of a technology cannot be predicted early in the life of the technology. By the time undesirable consequences are discovered, however, the technology is often so much part of the whole economics and social fabric that its control is extremely difficult. This is the dilemma of control. When change is easy, the need for it cannot be foreseen; when the need for change is apparent, change has become expensive, difficult and time consuming. (Collingridge 1980:11)

Neverthelss, being aware of this new situation can have a positive outcome: the reflexive modernization, which means our self confrontation with the effects of risk society (Giddens, 1998), i. e. the possibility of taking brave initiatives in the face of a problematic future (Beck, 1996), and the necessity that people take more control over aspects of their lives. In that sense, manufactured risk requires we envisage non-existent or possible events as a basis for making decisions, even if risk management is inherently speculative, and it demands that we imagine non-existent or possible future occurrences as a basis for making decisions.

In that context several theoretical and practical analysis have emerged, known as technology evaluation. One of them -and quite recent- anticipatory governance, has been defined as "a broad-based capacity extended through society that can act on a variety of inputs to manage emerging knowledge-based technologies while such management is still possible" (Guston, 2008: vi). Anticipatory governance

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"motivates activities designed to build subsidiary capacities in foresight, engagement, and integration, as well as through their production ensemble" (Barben et al., 2008). In Owen et al. words (Owen, Bessant and Heintz, 2013), this new perspective tries to foresee the economic, social, environmental or otherwise future outcomes and implications of current decisions associated with research and its development. Those outcomes can be plausible, intended, or potentially unintended. Methodologies applied in scenarios of anticipatory governance include: foresight, technology assessment, and scenario development with the aim of exploring other pathways. The main goal is to encourage scientists and technologists to ask 'what if . . . ' and 'what else might it do', and to explore possible impacts and implications that may otherwise remain uncovered and little discussed. Those who defend anticipatory governance uphold that the thesis that "to do" or "not to do" are the only relevant questions, is false, because assuming that thesis is the same as presuming that there is only *one way* that things can get done. Responsible innovation and responsible governance means that instead of accepting the deterministic motto that "science finds, industry applies, man adapts (Guston, 2013), we need to open the debate and take control of the orientation that the society wants to impose to technological development.

Anticipatory governance can be applied to transhumanists future scenarios. If an analysis about what can happen in the future is conducted it is not difficult to reach the conclusion that "those who already have economic resources will readily gain access to new technologies. And those new technologies will make them stronger competitors for more resources" (Parens, 1998, p. S1). This is not specifically new of human enhancement: every technological development, at least at the first stages of being released to the market, is mainly available for those who have economic resources. But what it is specific to enhancement is that it would make the privileged ones even more privileged. If the desires of transhumanists come true and a new species overcome to human beings, they will coexist with the former, but superior to previous ordinary humans. And if human beings already have treated other species as objects, the possibility that transhumans will do the same is not preposterous. At least, that possibility should be considered.

On the other side, as Parens has pointed out:

In the past the rich had access to new technological tools that enabled them to increase their productivity and thus their resources. (…) But how much one could benefit from those new foods and products was to some extent limited by one's draw in the genetic lottery. (…) One of the new things about the new biotechnologies is that one's draw in the genetic lottery does no pose the same sort of limitation. Now, in addition to buying access to the new technologies, we have the prospect of people purchasing, as it were, a better genetic daw. Thus having resources makes one a doubly strong competitor for new resources (Parens, 1998, p. S8).

In the case of resources such as food of good quality, access to education or health care, still nowadays are not equally distributed. However, those who are not lucky in the birth context lottery (family, country, political situation), at least can have some chances in the genetic lottery. But with the possibilities open in a transhuman future genetic lottery will disappear for those who have economic resources. Actually, the public debate about enhancement is not based on futuristic possibilities, but currently and socially sanctioned. Enhancement is a more or less common practice among athletes, when they take performance-enhancing drugs. The practice is known by another less fancy name: "doping", and when those athletes are caught doping the public as well the referees and different committees sanction them and take away the awards they have won. The idea of competing with an extra help seems unfair: "the

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intensely competitive nature of sport means that one person's liberty to use a drug that significantly enhances performance affects the other competitors. Their liberty to compete fairly and equally without using drugs is severely constrained by the drug-using athlete's actions" (Murray, 2007, p. 500). Could the conclusion about the unfairness of competing using different standards be applied to other kind of enhancement? Should citizens set aside to the decisions related to enhancement?

There are several options to face the course of action. One in leaving the decisions about what it is more convenient for future generations to experts, scientist, technologists and entrepreneurs. Nevertheless, the risks to leave the decisions only in the hands of the experts are too high: their reasons for making some choices are not necessarily the best reasons for the society as a whole. First of all, science is not neutral, nor enhancement is always positive, and equates with welfare. As recent philosophy and history of science have shown us (Kitcher 2001; Longino 1990, 2002), in scientific research, as well as in technological development, there are particular interests that guide how science and technology are being produced. We cannot ignore that even in areas distant from human or social interests, scientist and technologists, with their own goals, values, and preferences (context-dependent), affect the outcomes of scientific knowledge. And even more in the case of scientific and technological processes that rise the potentials of human enhancement. As Sykes and Macnaghten (2013) point "Science is no longer indisputably a force for good. It produces unforeseen effects, increasingly global in scale and long-term in nature." (p. 86).

Another possibility is to open the debate as much as possible. In this vein, from the point of view of moral and political philosophy, there have been some interesting proposals like, for instance, the deliberative democracy of Jürgen Habermas (1981, 1985). If the aim is to create a political and participative attitude in the democratic state, citizens have to be in possession of knowledge about the issues that are concerned by. Deliberation has to do with an attitude towards social cooperation: the attitude that consists on being open to the reasons and rights of others. Deliberation, in Habermas terms, suppose an exchange of points of view, but on the basis of an agreement about some morals truths. Precisely, the existence of something like moral truths is one of the most controversial aspects of Habermas's theory. Actually, the ethics of complexity shows otherwise, as "our sense of right and wrong, good and bad, and what deserves respect and what does not, cannot be justified on a priori grounds" (Woermann, & Cilliers, 2012: 448).

Actually, the idea of welfarism as something that has to be socially and culturally built, as has been defended in this chapter, can be understood from the ethics of complexity of Woermann and Cilliers. The provisional and non-universal character of the ethical principles is a more appropriate framework to understand how the deliberation has to be carried out. The complexity of those different systems, with also different normative and ethical points of view, need to be taken into account. The method of deliberation that we defend is closer to John Dewey's pragmatic approach. Deliberation, as Dewey defends, has to be based on action and not on passive disposition, with an open public communication and debate. Science would be the model for Dewey, a knowledge built on the basis of the public deliberation and where the agreement is never definitive. Democracy has to imitate the way that science is produce.

Every public deliberation about scientific or technological issues should be done on the scientific framework. To defend that the expert knowledge is not enough to reach some agreements about the decisions that societies have to be made is not the same as saying that scientific knowledge has not to be considered in the debate. And, in the other way around, that science provides the best knowledge about reality does not mean that other kind of comprehensions and wisdoms has to be put aside.

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Despite the criticality of the topic of the simple or complex grounds of the ethical or moral points of view, here the issue will be analysed from a different angle: a third option is to recognise the epistemological differences between the general public and the experts, difference related with the complexity of the phenomena (Morin, 2008), and encourage the dialogue between all the stakeholders (Sykes, and Macnaghten, 2013). Nowadays, the interchange of opinions and information among different participants is one of the favourite options. People of diverse qualifications and experiences, with no special expertise in scientific topics, are able to embrace in successful dialogues with scientists and technologists and to reach meaningful and useful results. Participants should explore the impacts of technology in different future societal contexts in order to look for some agreement about the risks that are willing to take (Kahn and Wiener 1967, Bradfield et al. 2005). Initiatives for public participation in science have taken a variety of forms, depending on: the nature and number of participants, how they are selected, the time frame, and the geographic scale; the method by which the public input is gathered; the extent to which this input may be binding for policy decisions; the type of issue at stake (Bucchi and Neressini, 2008, p. 458)

Of course, this last option has pros and cons: on the one hand, it is convenient (and even necessary) to engage different members of society in the decisions related to new convergent technologies, so the final conclusions would be reached taking into account a great panoply of perspectives, values, and expected goals. Nevertheless, it is unclear how such dialogue can be established in a meaningful way or whether a great variety of citizens will be interested in joining it. There are not many people (experts or citizens), which are just waiting there to be called to participate. Instead, of "the general public", certain groups of people with high education and social level are the participants, and those groups do not necessarily represent the characteristics of the general public (Maranta et al, 2003: 152). On the other side, there is a suspicion that the public that participate in those processes could be "manufactured", biasing the process of understanding what the general public considers regarding science (Saris, 2004). And the same can be said on the side of experts, which also are chosen for dialogue processes, assuming that they represent the possible multiple perspectives of all the interest groups related to the specific scientific realm (Burgess, 2014). In addition, deliberation is usually designed so that attitudinal changes occur mainly on the side of the public, trying to reach consensus solutions with the community of scientists (Zorn et al., 2010). But the pros are also noteworthy. However in order to participate in public processes related to new scientific and technological research, citizens need to know that the engagement is considered as relevant. Otherwise it is seen as another strategy to gain the approval or, even worst, to circumvent the probable public complains. For example, the Public Consultation done by the European Commission on synthetic biology, indicate that some citizens are willing to participate in those debates, and they show a great interest in research in synthetic biology, are supportive of research in this field, taking into account the great possible benefits. However, they are also for an external regulation that, without slowing down scientific research, can look after to avoid some of the serious dangers that also can be the outcome of synthetic biology, like, for instance the malicious use by bioterrorists or the harmful effects that could have the release to the environment of synthetic organisms.

Transhumanists possibilities are usually focused on future possibilities afforded by convergent technologies. The vast majority of transhumanists share a vision about enhancement between elated and unavoidable (see Stock, 1994; Silver, 1998). A vision of the future where the new technologies will open the door to possibilities that human beings will not reject. And for that reason, the anticipatory public and open discussion about transhumanism is more necessary than ever. As Adams, Murphy and Clarke (2009) emphasize:

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The present is governed, at almost every scale, as if the future is what matters most. Anticipatory modes enable the production of possible futures that are lived and felt as inevitable in the present, rendering hope and fear as important political vectors. Parsing anticipation means exploring the politics of affect as much as speculative epistemologies. The breathless futurology of biotechnology and nanotechnology stun us, generating a sense that we not only can but must hold anticipation" (p. 248).

Anticipation is not the same as speculation, because in the first case we are thinking ahead but proceeding now, i.e. orienting the current policies, scientific research, or technological action toward the future that we want. The future, of course, is unknown and uncertain, but that does not mean that the actions that we perform now are not relevant for the outcomes that we will face in the future. "Anticipation is not just betting on the future; it is a moral economy in which the future sets the conditions of possibility for action in the present, in which the future is inhabited in the present" (Adams, Murphy and Clarke, 2009, p. 249).

Nevertheless, those kind of anticipatory strategies have also been criticized. Fuller (2009) for instance, describes anticipatory governance as a: "strategy to facilitate the acceptance of new techno-sciences by inviting people to voice their hopes and concerns in focus groups, science cafes, and computer-based interactive spaces before the innovations are actually implemented" (p. 209). Instead of going through the possible situation of public misunderstanding or the rejection to new practices or artefacts (as happened in the past with the GMO's), the tactic is design participatory scenarios where the new technologies are "sold" following strategies of marketing, because "opportunities for participation will prevent heated public controversies on sensitive issues related to science and technology and restore otherwise declining public trust in science" (Bucchi and Neressini, 2008, p. 457).

In a similar sense Nordmann (2007) considers anticipatory governance as an "unwarranted exercise in 'speculative ethics' or a new-fangled subdivision of bioethics". Foreseeing the extent of a new techno-scientific possibility is a waste of ethical and intellectual resources "by overlooking current ethical challenges for hypothetical ones in the future."

All those criticisms to the participatory model and anticipatory governance have relevant basis, and they are of great importance and force those who try to put them into practice to be cautious when drawing conclusions. However, the option of not taking into account the judgment of citizens that on one way or another may be overwhelmed by those new scenarios open up by transhumanism is not adequate either. The notion of enhancement is sufficiently controversial and risky to merit a deep debate with the participation of as many stakeholders as possible. Even the opinion of those who consider the inviolability of the human essence from controversial moral, religious or metaphysical points of view must be taken into account. By the participative dialogue we could, if not avoid the risks, at least assume that they are due to decisions that all of us have made, and not only a small group of experts who are also guided by their own set of values that does not necessarily be neither better nor superior to the rest of society. In fact, there are already in our societies debates regarding how the enhancement is valued -as in the case of sports and doping- debates that anticipate the sensitivity that different members of the society have regarding what it is considered fair and what it is considered socially more appropriate. Contemporary citizens have a strong responsibility with respect to future generations:

Because of their potential seriousness, we are called upon to anticipate global and long-term future consequences of our actions. People and non-humans distant in time and space become our moral

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neighbours. But how can we act responsibly toward them if we concentrate on the consequences of our actions? If these extend beyond our foresight, then are we pushed toward paralysis rather than toward action? (Grinbaum and Groves, 2013, p. 126)

CONCLUSION

The transhumanists aspirations regarding what the future of humanity should be are based on a collection of assumptions that deserve a serene analysis. On the one hand, transhumanism is based on a notion of enhancement that is taken for granted, despite the fact that within transhumanists there is no consensus regarding its meaning. On the other hand, technological developments are considered to have a character if not positive, at least neutral, ignoring the considerations concerning that science and technology are not value free. Instead, it seems more interesting to substitute the notion of enhancement for welfare and to open the discussion about the future we want through anticipatory and participatory mechanisms. Obviously, those mechanism are not lacking of problems, however, the weaknesses of these models can not make us throwing the baby out with the bathwater, because the alternative, leaving technological development that can lead to substantial changes in our own nature without control can imply to take risks that must be anticipated and oblige us to make decisions in the most open and consensual way possible.

The participatory mechanisms defended in the chapter are based on action, i.e., on the active dimension of being a citizen. Deliberation, public communication, and debate in the framework of the present-day scientific knowledge are the basis for building socially and culturally the notion of welfare. And the same can be said for technological development. To reach some kind of normative and definitive principles is neither possible nor suitable, because the practice of unceasing deliberation is the best way to educate the deliberation habit.

To guide the technological progress towards welfare can help us to have technologies with an instrumental value. The criteria and values of stakeholders and citizens have to guide the technological destiny, because if the technology is the one who point the way of human desires, then technology will lose its real meaning.

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Chapter 5
Human Perfection and Contemporary Enhancement Technologies

Jesús Parra-Sáez
University of Murcia, Spain

ABSTRACT

Human perfection has been one of the main objectives of the human species since the appearance of Homo sapiens, but contemporary biomedical technologies represent a promise to achieve it in the near future. In view of the new possibilities offered by new technologies, a scientific-philosophical theoretical debate has emerged between those who are in favor of its use on humanity for non-therapeutic purposes (posthumanists) and those who reject it (bioconservatives). In this chapter, the so-called "enhancement technologies," the problems derived from their use with the aim of radically altering human abilities, and some of the most recent practical cases that have transcended the theoretical debate about their legitimacy are analyzed.

INTRODUCTION

The 20th century and the beginning of the 21st century have seen the theoretical and practical maximization of the interest of the human being to perfect itself. With the proposal of "eugenics" as a science in the late nineteenth century, the first half of the twentieth century was characterized—through the work of governments as diverse as the British, American, and German—by the state struggle against racial degeneration and the search for a qualitative improvement of human abilities. Although the eugenics movement ceased its activity after the Holocaust and the discovery of the Nazi experiments, "the human enhancement dream" remained active in the international scientific sphere (Kevles, 1985; Parra-Sáez, 2018a). Thus, the second half of the 20th century witnessed—due to historical events such as the discovery of DNA by Watson and Crick in 1953 and the development of advanced biomedical techniques such as genetic engineering in the '70s—the emergence of new possibilities and problems associated with them in the field of human enhancement and technology. These new biomedical techniques were developed in

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the beginning with the aim of detecting pathologies and diseases—most of them with genetic-hereditary nature—for their later containment or, in the best of cases, elimination.

To a greater or lesser extent, the scientific-medical and ethical-political spheres have accepted the therapeutic purpose of the use of biotechnology on the human being. However, in recent decades, the possibility of expanding its use to non-therapeutic objectives has been proposed from various scientific-philosophical schools of thought, especially from posthumanism and transhumanism. In some cases, this possibility has even been proposed as a need or obligation (Savulescu, 2001). In this way, the purpose of this idea is to focus on the use of new biomedical technologies towards the improvement of "positive abilities" (non-pathological) of the human being, that is, its physical structure (resistance or muscular recovery), its cognitive structure (intelligence and data assimilation), its moral and behavioral capacity (decrease of violence and increase of empathy) and, of course, the extension of its life. This proposal has generated a broad debate that encompasses a great diversity of research fields such as bioethics, politics, medicine, biology, technology, and neuroscience—among others—in which two great scientific and philosophical perspectives are confronted: those who are in favor of the use of biotechnology in order to perfect humanity (posthumanism) and those who are openly against it (bioconservatism).

The main purpose of this chapter—beyond showing the theoretical-philosophical debate between posthumanists and bioconservatives thinkers that is usually collected in articles and publications—is to clarify what are the new technologies of human enhancement, how they work, and what are the possible benefits and risks of its application. In recent years, the concern for genetic engineering is giving way to the emergence of new techniques that have overcome this theoretical debate to enter fully into our daily lives. A good example is the latest generation of cochlear implants and the cyborg technology. This is one of the most interesting technologies, since there are practical cases in which cybernetic implants have been installed on human beings with the aim of recovering natural senses such as vision or hearing abilities (therapeutic intervention), which have represented for some thinkers—of conservative persuasion—a step towards the generally rejected "perfectionist biotechnological enhancement." In this way, the vertiginous development of this type of technology has completely surpassed the theoretical stage about the legitimacy of its use, ushering in a practical stage wrapped in uncertainty.

BACKGROUND

The last third of the 19th century was characterized by the extension of eugenics thinking in the scientific, political, and social fields of the Victorian United Kingdom. It was the British anthropologist and geographer Sir Francis Galton, cousin of Charles Darwin, who in his book *Inquiries into Human Faculty and Its Development* (Galton, 1907) proposed "eugenics" as the only science capable of achieving the desired enhancement of human abilities.[1] Following this ideology, several countries around the world—especially Great Britain, the United States, and Germany—began in the first half of the 20th century a chain of negative eugenic policies based on segregation, racism, and the sterilization of immigrants or disabled people with the fundamental objective of preventing the racial degeneration of their people.

Following the success of numerous eugenic laws such as the "Deficiency Act" of 1913 in Great Britain, the "Immigration Act" of 1924 in the United States, and the laws "For the Prevention of Genetically Diseased Offspring" (*Gesetz zur Verhütung erbkranken Nachwuchses*) and "For the Protection of German Blood and German Honor" (*Gesetz zum Schutze des deutschen Blutes und der deutschen Ehre*) of 1933 and 1935, respectively, in Germany, eugenics ideology suffered a severe setback with its

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international rejection due to the Holocaust and Nazi experimentation (Kevles, 1985; Klautke, 2016). It is not surprising, therefore, that immediately after the war the international community decided to establish—through the *Universal Declaration of Human Rights* of 1948 and the *International Covenant on Civil and Political Rights* of 1966 by the UN, and *The Race Question* of 1950 and the *Declaration on Race and Racial Prejudice* of 1978 by UNESCO—that such events should never happen again, much less with eugenic-racial motivations.

However, due to important historical-scientific events such as the discovery of DNA in 1953, the development of new biomedical technologies in the '70s (genetic diagnoses and genetic engineering), and the current promising research with stem cells and nanotechnology, a line of thought has emerged that intends to carry out an enhancement of natural human abilities through biotechnological tools. This movement is generally known as "new eugenics" or "liberal eugenics," although in the scientific-philosophical environment it is common to use the term "biotechnological human enhancement" or BHE (Soutullo, 1997; Agar, 1998). Finally, around human enhancement and the application of new biomedical techniques for its achievement, a broad ethical-scientific debate—which constitutes one of the main issues of contemporary bioethics—is taking place in which professionals from a wide variety of research areas such as biology, technology, philosophy, and law are involved. Its objective is to clarify whether biotechnological human improvement will be a step forward in the history of humanity (better people and better societies) or, on the contrary, a step towards segregation, discrimination, and racism characteristic of the 20th century eugenics movement (Parra-Sáez, 2018a).

BIOTECHNOLOGICAL HUMAN ENHANCEMENT AND ITS ETHICAL-SOCIAL PROBLEMS

Enhancement Technologies: Benefits and Risks

The debate about a new dimension in the abilities and skills of our species does not make sense without mentioning the overwhelming development of biotechnology, which has taken place since the last third of the 20th century until today and which promises to continue its progression in the future. Habitually, experts in fields as diverse as bioethics, philosophy, medicine, and technology focus their studies on the consequences of modifying human biological-genetic characteristics, but they ignore—in many cases—the tools that can make it possible. As a solution to this almost always involuntary "omission", this section will show what the main technologies for human enhancement are, what they consist of, how they are regulated at the international, continental and national levels (focusing on Spain for the latter),[2] and what are their possible benefits and risks for the future of human beings.

Chronologically, the first technological means of enhancement were the so-called "genetic diagnoses" (PGD and PD). "Pre-implantation Genetic Diagnosis" (PGD) consists of a study of the DNA from a human embryo through which a series of results related to its negative characteristics (therapeutic/pathological) can be obtained—it can be used to detect anomalies in any chromosome or gene—and positive characteristics (non-pathological), such as the sex of the baby. Once the genetic results have been obtained, the embryo could be accepted or rejected in order to be implanted in the maternal uterus (*in vitro* fertilization). This is what is generally known as "gene sounding" (Suzuki & Knudtson, 1991). This marks a differential fact, because although in its beginnings *in vitro* fertilization was developed with the main objectives of alleviating the serious difficulties of certain couples to reproduce and prevent-

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ing genetic-hereditary diseases, the knowledge offered by pre-implantation genetic diagnosis opens the possibility of a hypothetical emergence of the phenomenon known as "virtual children" or "babies on demand", that is, the implantation of an embryo according to the interests or eugenic guidelines of their future parents (Postigo & Díaz de Terán, 2004). On the other hand, "Prenatal Diagnosis" (PD) tries to glimpse any type of genetic-hereditary anomaly of the future child who is already in a fetal state. The techniques used can be non-invasive, such as ultrasound, x-ray, or control of biochemical markers of chromosomopathies, or invasive, such as biopsies, fetoscopies, or cordocentesis.[3] The only possible options in response to a genetic problem would be aborting or continuing with the pregnancy, as opposed to choosing not to implant an anomalous embryo, as happens with the PGD (Villela & Linares, 2012). This is the main reason why PD is directly related to eugenic abortion, which has been legal in Spain since 1985 if the unborn baby will suffer from a serious illness: "the detection of genetic defects or chromosomal aberrations can lead to the carrying out of a therapeutic abortion that constitutes one of the legal suppositions of voluntary interruption of pregnancy according to Spanish legislation" (Soutullo, 1997, p. 170). Both diagnoses are regulated in Spain by laws 35/1988, 42/1988, 45/2003, and 14/2006 for strictly therapeutic use. Similarly, through Article 12 of the *Convention for the Protection of Human Rights and Dignity of the Human Being with regard to the Application of Biology and Medicine*, the Council of Europe (1997) established that genetic diagnoses "may be performed only for health purposes or for scientific research linked to health purposes, and subject to appropriate genetic counseling". At the same time, the *International Declaration on Human Genetic Data* delimits the legitimacy of scientific research in the field of human genetics and provides several guidelines about the use of human genetic data.

Simultaneously with these technologies, "genetic engineering" was developed. This has served since its invention to make diagnoses about hereditary genetic diseases and to apply new medical treatments that try to palliate them, for instance completing or substituting defective genes for functional genes. In this way, this biomedical technology offers the possibility of manipulating certain genes of the human biological structure in order to eliminate hereditary pathologies (in its therapeutic facet) or to enhance, for example, our immune system or our muscular development (in its perfectionist facet). However, genetic manipulation has been one of the main concerns of the most conservative thinkers because of the possible variation of our genuine human genome, which constitutes our species as we know it. For this reason it has been widely regulated by Spanish and international legislation through articles 159 and 160 of Law 10/1995 corresponding to the Spanish Penal Code, the *Universal Declaration on the Human Genome and Human Rights* of 1997, and the *International Declaration on Human Genetic Data* of 2003 issued by UNESCO. Nevertheless, in recent years genetic engineering has begun to be considered—by thinkers such as Nicholas Agar or Julian Savulescu—as a tool for enhancement analogous to traditional and natural methods (culture, literacy, diet, and exercise) that is only distinguished from them by their immediacy and not by their moral essence. For these thinkers, the supposed moral differences between using genetic engineering and using natural tools will ultimately disappear when the technologies for enhancement are presented as satisfactory, that is, without risks for human subjects: "when these enhancement technologies become available [risk-free biomedical technologies], environmental enhancements, considered collectively, could be more dangerous than genetic enhancements" (Agar, 2014, pp. 153-154).

In the last two decades, the attention to biomedical research with stem cells has increased due to the interesting therapeutic possibilities it offers, especially the development of human biological tissues for implantation into humans. This technique consists of obtaining cells from the cell mass of human embryos[4]—for which reason they are generally known as "Embryonic Stem Cells"—that can be used to treat pathologies and degenerative diseases such as diabetes or Parkinson's Disease. These cells are

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pluripotent, that is, they have the capacity to develop in specialized cells (blood, cardiac, neuronal, liver, and even skeletal) that will become fundamental human tissues such as organs: "they could be directed to form new bones, neural cells, cardiac tissue, and [in general] to cure diseases" (Pence, 2015, p. 175). In this way, proponents of BHE see in the stem cells the opportunity—through the conversion of cells in fundamental tissues—to develop an infinity of human biological replacement parts, thus eliminating transplant waiting lists (Savulescu, 2002; González, 2005). In regards to its legal control, in international law, there are very diverse positions, and the cultural, religious and political differences between the different States complicate the possibility of reaching an agreement on their international regulation. The European Union does not stipulate what the regulation of stem cell research should be, so in some Member States, there is no regulation. However, in most of them, research with embryonic stem cells is allowed for exclusive therapeutic purposes. For instance, in Spain, research with stem cells is regulated by laws 1/2007 and 14/2007. Both laws allow the use of this kind of technology for strictly therapeutic aims (Jiménez, 2017).

For its part, and according to several experts in technology, the additive manufacturing or three-dimensional printing (3D), that is, the layered manufacture of objects based on a digital model "has the potential to revolutionize manufacturing at least as much as the assembly line concept did in the early 20th century" (Häggström, 2016, p. 134). Its use in the field of medicine and human improvement focuses on the printing of artificial substitutes of human anatomy (prostheses, artificial organs). Medical applications of 3D printing include the creation of skin, bones (especially articulations), customized prosthetics, vascular tissue, and heart valves. The main goal is to develop this technology—through "bio-printing", that is, 3D printing using differentiated cells, pluripotent stem cells or multipotent stem cells—so that it has the capacity to replace any type of human organ or tissue without rejection by patients (Zhang & Zhang, 2015; Murphy & Atala, 2014). This is, therefore, another option to eliminate transplant waiting lists. However, having the ability to print almost any object raises issues about intellectual property (theft of digital models in order to print it illegally), arms control (diverse functional guns have been printed through a 3D printer in a satisfactory way), and the use of stem cells as a printing material to manufacture human organs (Häggström, 2016).

On the other hand, one of the most recent and hopeful enhancement technologies is biotechnology in miniature—involving materials of a billionth of a meter—generally known as "nanotechnology." Beyond its therapeutic applications, such as the elimination of coronary or cardiovascular diseases through the introduction of mini-robots into the bloodstream, or the use of carbon nanotubes to transport nanoparticles to red blood cells to facilitate and improve drug administration (Hassoun, 2008), one of the main refining proposals is to use miniature robots in human anatomy—making a diagnosis of the cellular damage caused or associated with aging and facilitating its repair (Zealley & de Grey, 2013), as has been proposed by the Immortality Institute (LongeCity today) and gerontologists such as Aubrey de Grey—with the aim of stopping aging and, thus, natural death:

Billions of nanobots will travel through the bloodstream in our bodies and brains. In our bodies, they will destroy pathogens, correct DNA errors, eliminate toxins, and perform many other tasks to enhance our physical well-being. As a result, we will be able to live indefinitely without aging (Kurzweil, 2005, p. 227).

In recent years the scope of applications of nanotechnology has widened to include many other areas, especially involving the study of the human brain and environmental pollution. Thus, one of its main lines of research analyzes the functionality of the introduction of nanobots into the human brain in order

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to scan it at the atomic level while, unlike other habitual destructive tools such as scanners, protecting its neuronal structure (Silva, 2006). At the same time and independently of its direct application on the human being, nanotechnology could also serve to repair—eliminating the high pollution rates of the planet or perfecting nuclear waste management—environmental problems (Belloni et al., 2009; Parra-Sáez, 2018b), something essential for the satisfactory development of human life. Nevertheless, the legislation that controls and limits nanotechnology has yet to be defined at the international and national levels. So far there have been only communications on strategies to control nanotechnology through risk prevention, such as the advice expressed by the European Community in 2004 or the guidelines offered by the Center for Responsible Nanotechnology and the Foresight Institute for the responsible development and the correct application of nanotechnology on society and the environment.

Finally, the technological enhancement tool most accepted in the social field corresponds to cybernetic implants, generally known as "cyborg technology." The use of this type of technology on the human being, as happens with the others, is allowed for exclusively therapeutic purposes. Cybernetic implants or cyborg technology generally refers to the introduction into a living organism (human or non-human) of artificial technology as a substitution for or a complement to the biological structure of that organism, that is, "to integrate the transforming possibilities of the NBIC [nanotechnology, biotechnology, information technologies and cognitive sciences] with the ontic reality of the body" (Peres Díaz, 2016, p. 130). This is the main reason why it is common to find terms such as "man-machine" (human organism with artificial implants) and "fyborg" (functional cybernetics in human organisms or fusion between biology and technology), coined by the Russian transhumanist thinker Alexander Chislenko (Stock, 2002). Its main use is to replace lost or defective biological organs by artificial copies that supply—and even improve—their natural function. The aim of scientists is to gradually introduce biotechnological enhancements on human subjects, so that they will move away from their status as "natural beings" while approaching themselves as "self-designed beings" (Martorell Campos, 2012). This idea has been introduced by transhumanist and posthumanist thinkers as the intermediate step between humanity, as we know it, and the future post-human being resulting from perfectionist interventions called "the post-human" or "homo excelsior" by experts in human enhancement such as Anders Sandberg (Sandberg & Diéguez, 2015). Although cyborg reality seems a futuristic situation that cannot be achieved in the short term, the truth is that this biomedical technology is increasingly common in contemporary societies. One of the main applications of this sort of biotechnology is the so-called "cognitive neural implantation," that is, the installation of prostheses in the central nervous system to enhance cognitive functions and, ultimately, our intelligence (Echarte & García Valdecasas, 2014; Bostrom, 2014), although the best-known applications are the "implantation of artificial prostheses" and the "cochlear implantation" (Clark, 2003; Moya, 2018). Precisely this, together with the subcutaneous implantation of microchips, represents the most recent and interesting practical example of biotechnological human enhancement.

Practical Cases of BHE: Subcutaneous Microchips and Cochlear Implants

Nowadays, some of the most well-known, developed, and applied cyborg technologies are subcutaneous microchips and cochlear implants. As a paradigmatic example of the former, it is interesting to take the case of the Swedish company Epicenter, which at the beginning of 2015—with the support of the *Swedish Biohacking Group* and the company Biohax—implanted subcutaneous radio frequency chips (CHIP RFID / Radio Frequency Identification) into 160 of its workers on a voluntary basis as a method of personal identification to access the company's facilities and use its tools (photocopier, vending machines,

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computers). This case also alludes to the field of nanotechnology because, although the chip in question has a very small size and is installed between the fingers of the hand, the idea is to radically reduce its size. For its part, the Belgian company NewFusion followed the example of the Swedish company and did the same with just over half of its employees (7 of 12) at the end of 2016, while the US company *The Square Market* proposed to its employees in mid-2017 the use of this type of implant as a method to technologically innovate the way they work, live, and compete with other companies. Ultimately, the objective is for these implants to replace other identification tools such as health cards, passports, and bank cards. At the same time these would also serve as medical indicators, measuring in real time our sugar, cholesterol, and blood pressure levels. However, this type of intervention poses a problem for the most conservative thinkers. For the detractors of the transhumanist thought, a subcutaneous implantation of microchips like those carried out by the aforementioned companies supposes a violation of freedom and personal privacy of the intervened subjects that will lead to state and business control.

With regard to the second category of BHE, there are several interesting cases. Strictly speaking, the first cochlear implants were made in the '50s and '60s of the 20th century, first in Paris by Djourno and Eyriès, and later by Dr. House, neurosurgeon James Doyle, and engineer Jack Urban (Wilson & Dorman, 2008). However, the most representative examples of biotechnological intromission in society did not arrive until the 21st century. One of these cases was that of the American writer Michael Chorost, who underwent a biomedical intervention in 2004 in which an electronic device was installed in his head in order to recover his hearing ability.[5] Specifically, Chorost has a cochlear implant in his skull that picks up a radio signal that is processed by a receiver located in his ear in order to transmit the information to his brain. Of course, this intervention was carried out for a manifestly therapeutic purpose, to recover a lost natural ability. Nevertheless, the initial therapeutic pretensions for this type of practice are giving way to a discourse of a distinctly perfectionist nature (Ochsner, 2015; Lee, 2016). A clear example is that of the British artist Neil Harbisson—the first human subject legally recognized as a cyborg[6]—who, thanks to a cochlear implant called an "eyeborg"[7] (an antenna with an internet connection installed in his skull and exiting through the occipital bone), is capable of "hearing" the different frequencies of the colors as a solution to his inability to differentiate them visually due to the monochromatism he suffers (Carter & Palermo, 2016). As can be seen later, what is truly characteristic of this case is that a manifestly therapeutic biotechnological enhancement, represented by Harbisson's eyeborg, seems to have crossed the thin line, sometimes practically imperceptible, line that separates a therapeutic intervention from an enhancing intervention. This was one of the fears expressed by the bioconservative sector at the beginning of the ethical-scientific debate around BHE, and it was the German philosopher Jürgen Habermas (2003) who made it clear that it was absolutely necessary to delimit unequivocally what represents a therapeutic enhancement and what represents a perfectionist enhancement. In this case, an intervention whose only objective was to recover a natural human ability (hearing) has finally ultimately a new type of perception or sense.

The Ethical-Scientific Debate Around BHE

Surrounding the contemporary technologies of human enhancement and its perfecting possibilities, a broad scientific-philosophical debate has emerged in recent years between those who are reluctant to accept them and those who reaffirm their legitimacy. The school of thought against perfectionist enhancement is generally known as bioconservatism, and among its ranks are important thinkers such as Jürgen Habermas, Francis Fukuyama, Leon Kass and Michael Sandel. Their contributions to the debate

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are characterized by the acceptance of the use of new technologies for exclusively therapeutic purposes and the rejection, for ethical and social reasons, of their application with refining objectives. On the other side, the pro-enhancement school of thought is usually known as posthumanism—although some thinkers prefer to call it transhumanism—whose main representatives include Julian Savulescu, Nick Bostrom, and Anders Sandberg. Its position is to legitimize the use of biotechnology for therapeutic and perfectionist purposes and to aim at maximizing human characteristics beyond what is strictly natural. In this way, the ethical-scientific debate about the application of contemporary enhancement technologies is based on the ethical problems related to BHE and can be divided into two subtypes: 1) particular problems of each enhancement technology, and 2) general ethical problems of biotechnological human enhancement.

1) Regarding genetic diagnoses (PGD and PD), the ethical problems attributed to them are based on genetic-sexual and genetic-social discrimination. Although the information offered by this type of diagnoses is usually used to support the performance of an abortion—for therapeutic reasons—it can also be extrapolated to do the same for social, racial, or discriminatory reasons. This case would be, for instance, an abortion motivated by sex—especially female—based on the understanding that a boy will grow up to enjoy a greater range of opportunities,[8] or a eugenic abortion based on a genetic-hereditary disease that the future born will suffer. The first example corresponds to what is usually called "sexual discrimination," while the second refers to "biological-social discrimination." As for the first, it is common that in countries such as China and India prospective parents prefer to have a son instead of a daughter because of the social stigmatization of women (Sandel, 2015; Jiménez, 2017), while, in relation to the second, associations of relatives and patients with illnesses like Down Syndrome have shown that eugenic abortions discriminate socially against those afflicted by this type of genetic-hereditary disease (Singer, 2002; Villela & Linares, 2012; Pence, 2015). In fact, in countries like Japan, this kind of diagnoses is considered a social problem due to the exclusion and discrimination of people with disabilities as a result of their application. They believe that these techniques could support eugenic selection (Shimazono, 2017). However, embryonic sexual and racial selection is prohibited both by international law and by national law, that is, the use of genetic diagnoses and assisted reproduction techniques for non-therapeutic purposes is not allowed.

On the other hand, one of the main ethical problems refers to genetic engineering and the possibility of irreversibly altering the human genome. On October 1, 1990, the National Institute of Health and the Department of Energy made official the creation of the "Human Genome Project," that is, a research project made up of scientists from numerous universities and research centers around the world that had a double objective: 1) to map in detail the situation of all the genes in the chromosomes, and 2) to describe the complete sequencing of the human genome. The project was put into operation one year later, and it concluded its work in 2003 with the publication of the complete cartography of human genetics, which meant a before-and-after in biomedical research (Reguero, 2014). The ethical problems appear when a government or an institution has to establish what should be done with the genetic data obtained from the research, although it is true that international law has been clear about it through Article 1 of the *International Declaration on Human Genetic Data*: "the aim of this Declaration is to ensure the respect of human dignity and protection of human rights and fundamental freedoms in the collection, processing, use and storage of human genetic data." Besides, there are also those who point to problems derived from genetic manipulation, especially related to personal identity, human dignity and the objectification or reification of the human being in his passage from subject to object of experimentation (Vidal, 2001; Habermas, 2003; Sandel, 2015). Pence (2015) talks about five potential problems about genetic enhancement: 1) devaluation of the conventional human being, 2) modification of human nature, 3) return to the

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eugenic movement ideology, 4) growth of social injustice, and 5) design of children. Precisely, the birth rate conversion into a business based on commercial, genetic and personal interests, that is, to consider the future born as a product (designer babies), is one of the most studied problems.

Meanwhile, research with embryonic stem cells has been opposed by conservative sectors of thought due to the debate about the moral, biological, and ontological status of the embryo—especially with regard to the destruction of the blastocyst of embryos that are between the sixth and the eighth day of development—understanding that it would be ending a human life in favor of experimentation (Sandel, 2015). Precisely because of this problem, several governments refused to grant public funding for the development of stem cell research if embryos were destroyed in the process. For example, during the presidency of George W. Bush, the US Congress established "as a federal crime to create or use human embryos for medical research" (Pence, 2015, p. 176), declaring on July 19, 2006, that the US government should not support in any way the destruction of innocent human lives resulting from this practice. In this way, from this line of thinking it is understood that, if an embryo is a person or a *potential* person, experimenting with it in order to obtain stem cells interferes with intrinsic rights to the human species such as the right to dignity and the freedom to live (Singer, 2003). In this way, the controversy about the procurement of embryonic stem cells is directly related to the concept of "person" that is attributed to an embryo by the most religious or traditional segments of society. According to this idea, this type of technology obviates respect for "people who are yet to be born" while promoting the reification of the individual. Nevertheless, there are differences between these same segments. For instance, Catholicism gives the embryo the status of "person" since its conception, while Judaism and Islamism do it when 40 days have passed, so in these latter cases there would be no problem with the tests performed on the embryo before that moment. At the same time, certain segments of Hinduism and Buddhism accept this type of techniques (Jiménez, 2016). Perhaps, extracting stem cells from adult individuals instead of embryos could be a better option. Besides, the therapeutic success of stem cells obtained in adults—for the regeneration of cardiac and neuronal tissues—has been scientifically proven, and this kind of cellular extraction would avoid the ethical problems related to the ontological-moral status of embryos (Bellver-Capella, 2012).

With respect to 3D printing, the main problem of the three-dimension technology alludes to the imperfection of the process, that is, mechanical problems, inaccuracy in the control of cell proliferation, nozzle clogging or density of cells (Murphy & Atala, 2014). The technique of scanning and printing must be perfected, especially in view of its medical uses. In addition, the current difficulty of using cells in certain forms of printing (especially regarding cell survival during the process) makes indispensable the improvement of the resistance and integrity of the printing materials (Zhang & Zhang, 2015). Finally, the possibility of creating functional weapons in a simple and cheap way, thanks to a 3D printer (from revolvers to automatic rifles) seriously complicates the arms development control, both economic-commercial (unregistered weapons, sale on the black market) as a legal level (Häggström, 2016). This threat is so close that in August 2018 the US government legalized the publication and download of weapons designs for 3D printing. As the only security measure, the government has restricted automatic weapons, although it allows the printing of weapons with a caliber less than 50 mm. In response, several American states (Washington, Massachusetts, Connecticut, New Jersey, Pennsylvania, Oregon, Maryland, and New York) have filed a lawsuit in Seattle Federal Court to prevent it.

For its part, around the use of nanotechnology, views have emerged that are openly against the development of miniature technology applicable to the human organism, insofar as it can be used as a weapon against the human being, for human subjects who have been inoculated with nanobots and

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for the rest of living beings that inhabit our planet. Regarding the first case, several studies show that there are nanomaterials that can cause damage to the human biological structure, and therefore, it can be used for that purpose (Resnik, 2007). Regarding the second case, it is possible to alter the brain areas that intervene in the behavioral process of the subject who has been inoculated with nanobots in order to inhibit moral behaviors or provoke violent behaviors (nanotechnological terrorism). However, the possibility that nanotechnology could create technology (new nanobots) by itself without human intervention and control—known as "Grey goo"—may be even more interesting. As the mathematician Olle Häggstöm asks: "What happens if the growth of the nano-robot population is still beyond our control?" (Häggström, 2016, p. 142). The American engineer Eric Drexler coined the term "Grey goo" in 1986 to anticipate a likely apocalyptic scenario in which self-replicating nanobots consume all biomass on Earth due to its uncontrolled developing. In this respect, the Foresight Institute offers various instructions or ethical-moral guidelines related to the development and responsible application of nanotechnology in the face of the possibility, among other things, of self-replicating nanotechnological entities, that is, entities capable of creating nanotechnology by themselves (autonomous) from materials that can be found in our environment, and without the need for action or human legitimation. Some of its most characteristic instructions are: A) the replication must require materials that are not in the natural environment, that is, materials that only the human being can provide; B) the replication must require codes that are encrypted (by human beings); and C) manufacturing devices may create final products (which will not have the capacity to self-replicate), but may not replicate themselves (Kurzweil, 2005).

Finally, the problems discerned around cybernetic implants are directly related to the loss of humanity inherent in the technological devices installed in the human organism and in the capacities—superior to those which are merely natural—that these types of devices already offer and will offer in the future. Following the practical case of the cochlear implants discussed in the previous section, Harbisson claims to be able to receive a spectrum of infrared and ultraviolet colors that the human being is unable to achieve through the natural senses (Iribas, 2007). In fact, Harbisson has coined the term "cyborgism" to refer to the artistic movement that applies new qualities granted by cybernetics—which the rest of "conventional" human beings lack—to create works of art (Moya, 2018). This has provoked the concern of the most conservative since, strictly speaking, this implant supposes a biotechnological perfectionist human enhancement that allows intervened subjects to do things that they would not naturally be able to do (Lee, 2016). Another of the intervened subjects, Chorost, affirms quite the opposite: that his cochlear implant, far from giving him capacities superior to the human ones, offers him the opportunity to be equal to other people and thus integrate more easily in the society (Chorost, 2005).

2) The general ethical problems around BHE are intimately related to the fatal consequences for humanity—loss of identity, compromising of human dignity, and reification of the individual—derived from biotechnological interventions that represent a radical change for the human subject in fundamental aspects of his life (Parra-Sáez, 2017). Thus, these problems do not allude to enhancement technologies, but rather to the claims of the post-humanist sector to achieve a radical enhancement of human natural characteristics, as Habermas made clear when he stated that "the problem, of course, is not genetic engineering [or any other type of technology], but the mode and scope of its use" (Habermas, 2003, p. 43).

In this regard, the first problem usually pointed out by the most conservative theorists is about the technological intervention on the germline, that is, the alteration of characteristics in which agents involved in reproduction intervene. Unlike interventions in the somatic line—which only alter the individual who undergoes them—the biotechnological enhancements that alter germ cells modify the subjects that have been treated and their descendants, who will have their natural abilities altered even

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before their birth (Vidal, 2001; Loftis, 2005). The problem is, therefore, that if any mistake is made in the intervention–for example a genetic error—it will continue its path from generation to generation. Therefore, several pieces of legislation have been passed to prevent this from happening, as when the European Parliament in 1989 condemned the manipulation of human genetic material—especially if it is intended to alter the germ line—through the *Resolution on Ethical and Legal Issues of Genetic Engineering*, or when UNESCO defined any technological intervention on the germline as "against nature" through the *Universal Declaration on the Human Genome and Human Rights* (1997). In addition, his first article established that "the human genome underlies the fundamental unity of all members of the human family, as well as the recognition of their inherent dignity and diversity. In a symbolic sense, it is the heritage of humanity."

Another one of the ethical-moral problems frequently raised by the bioconservative end of the spectrum is that related to personal identity, or rather, its loss due to the application of biotechnology on the human being with perfecting purposes. Experts belonging to fields as diverse as psychology, metaphysics, and ethics understand that a biotechnological enhancement with a radical nature—especially one that aims to extend human life to unsuspected limits—will result in the appearance of a human subject with characteristics considerably different from those before the technological intervention, ultimately causing a crisis of identity or personality in the subject (Glannon, 2002; Habermas, 2003). According to the New Zealand philosopher Nicholas Agar (2014), this type of intervention interferes with what he calls "autobiographical memory," that is, the union of all the experiences that the subject has had throughout its existence and that have been key in the formation of his personal identity, to the extent that the post-intervention subject has a series of characteristics of which he has no experience and that push him to forge a new "posthuman identity." For its part, Sandel (2015) talks about the possibility of losing our ability to be responsible for what we do and how we are, and therefore, our identity. The idea is that our capacity to consider ourselves responsible for our way of being and acting disappears with the radical enhancement of our abilities. If we had not been biotechnologically altered, would we behave in the same way? Would we have the same personality? Who is responsible for what we are and what we do? As Sagols declare: "the assumption of what we are will imply having to assume what others have done; the teenager will no longer say: 'that's me' [by nature], but because another person wanted that I was like that" (Sagols, 2010, p. 32).

Similarly, there is a great concern about the effects on human dignity anticipated from BHE. If by human dignity we understand—as much of the philosophical field proposes—the recognition of the value of the human being as such belonging to the human species, which establishes equality between human beings regardless of their biological, personal, and social circumstances, any biotechnological intervention that interrupts this recognition supposes an unacceptable ethical problem. The underlying idea is that a technologically enhanced subject will not carry out this recognition of the human value of the "other" due to its post-enhancement superiority—greater intelligence or physical strength—and the natural human tendency to dominate other subjects (Fukuyama, 2002; Habermas, 2003; Kass, 2004). In response to this situation, Sandel (2015) makes an ethical-philosophical proposal called "ethics of gift or talent". The American political philosopher affirms that "much what is valuable in our lives is not the result of our own action and hence isn't something we can take credit for" (Buchanan, 2017, p. 135). What Sandel holds is that we should appreciate our life and our natural human abilities as gifts, that is, accepting what chance delivers (genetic lottery); while Habermas (2003) proposes the commonly known "species ethics", that is, everything that human beings share among themselves: self-recognition and respect towards others human subjects as members of the same species. As Varga says about the

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Habermas' idea, "the ultimate answer is that one should be moral and build societies that treat others with respect, because of what one is and what one acknowledges to be" (Varga, 2010, p. 81). However, international law widely protects human dignity through the Convention for the Protection of Human Rights and Dignity of the Human Being with regard to the Application of Biology and Medicine (Council of Europe), The American Convention on Human Rights (Organization of American States), the Charter of Fundamental Rights (European Union), and the Universal Declaration on Bioethics and Human Rights (UNESCO).

At the same time, several thinkers understand that in a "2.0" society—in which different human subjects have been perfected biotechnologically—inequalities of a biological and socioeconomic nature related to the access and "fair distribution" of the enhancement technologies would appear (Campos, 2010). As Sparrow writes, "decisions about enhancement of future people may harm others. The presence of social and economic inequality often has significant implications for the quality of life of all citizens" (Sparrow, 2011, p. 38). Thus, access to enhancement technologies would be restricted to individuals who have a higher socioeconomic level, while other human beings could not bear the costs of biotechnological interventions (Lema, 2015). After the improvement, the enhanced subjects would have enormous physical and intellectual advantages over the unenhanced subjects, something that could mean the inequality of equal opportunities between both, and ultimately, the segregation of the "natural" and "obsolete" humans. In this case, there would be a human domination by the "improved" or "posthuman" subjects. This is the so-called division "gen-rich/gen-poor" anticipated by Silver in his famous work *Remarking Eden* and widely collected in science fiction films such as *Gattaca* (1997).

Finally, and as far as the objectification of the human subject is concerned, human freedom has been defined in countless areas and in different ways, although in general terms it is accepted that an important part of human freedom is based on the conglomeration of ideals, interests, and voluntary actions of a human being. Ultimately, being free means—among other things—being able to choose what we do, think, and say. The problem appears when the intention is to use biotechnology to alter the positive characteristics of the human being when he/she is still in an embryonic state. The Australian philosopher Julian Savulescu (2001), who affirms—through the "Principle of Procreative Beneficence"—that we have a moral obligation to use biotechnology on embryo to obtain the best possible child, is a good example. However, in this way of thinking a fundamental problem is glimpsed: the desire for domination (or power) of the parents and the objectification of the children. This concern is based on the idea that future parents will choose—guided by their personal interests—the characteristics of their future children, turning them into mere objects that will follow a vital biological-genetic plan drawn up by their parents, ignoring their natural right to have an open future (Sparrow, 2012; Sandel, 2015). However, both international and national laws manifest the protection of individual freedom as a fundamental point, so any type of human enhancement that limits the freedom of the individual is strictly prohibited. Modifying the non-pathological characteristics of a human being that is yet to be born is not legal today.

THE FUTURE OF RESEARCH AND THE ETHICAL-SCIENTIFIC DEBATE AROUND BHE

The development of new biomedical technologies and their possible application for refining purposes will lead the scientific-philosophical debate about human enhancement in the future—in fact it is already doing so, as shown by the research of centers such as the Oxford Uehiro Center for Practical Ethics, the

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Center for Research Ethics & Bioethics of the University of Uppsala, and the Immortality Institute—to research in neuroscience and neuroethics, the control of behavior through biotechnological cognitive enhancement, and cellular repair focused on life extension. The idea of these investigations—especially the first two—is to elucidate whether modifying or altering the human cognitive structure through technological means can result in a moral or behavioral enhancement of the subject (elimination of scourges such as racism or violence). In a positive case, this biotechnological enhancement could allow solving fundamental problems of contemporary bioethics related to clinical ethics (the care of human health), animal ethics (the care of fauna and our relationship with it), and environmental ethics (the care of natural environments and the survival of planet Earth).

In addition, the problems surrounding human enhancement and contemporary biomedical technologies will gradually enter into public opinion, given that in the end citizens must accept or reject their legitimacy and application. It seems obvious that, in order not to return to the old eugenic goals of the first half of the 20th century, BHE must always be voluntary, and be available to all subjects (something practically impossible) to avoid inequalities between them for social or economic reasons. That is why the interdisciplinary public debates among experts about this type of intervention, as well as its possible benefits and risks, will be increased—as the researchers of BHE have been asking for years— while reports and research projects carried out, on the part of the bioconservative and posthumanist sectors, they will no longer be restricted[9] to the ethical, scientific, and medical fields (Cortina, 1993; Habermas, 2003; McGee, 2003).

For our part, it seems interesting to include in the ethical-scientific debate around BHE the possibility of carrying out a type of non-therapeutic improvement that avoids the ethical problems discussed previously. We call this proposal "relative enhancement". From our perspective, the problems of biotechnological human enhancement discussed before (loss of identity, freedom, and autonomy; reification of the individual; violation of human dignity, etc.), are not directly related to their status ("perfectionist enhancement" or "therapeutic enhancement"), but with the nature and radical consequences of its application. In this way, the improvement of the non-pathological qualities (intelligence, strength, physical resistance, moral capacity) that does not imply a radical change between the biotechnological pre-intervention subject and the biotechnological post-intervention subject (a relative enhancement of their abilities) would largely avoid the ethical problems pointed out by the most conservative thinkers, especially those related to the loss of identity and the lack of reciprocal recognition between human subjects (violation of human dignity). Now, what is the difference between moderate and radical enhancement? The New Zealander thinker Nicholas Agar writes the following: "I endorse moderate enhancement–the improvement of significant attributes and abilities to levels *within or close to* what is currently possible for human beings. I reject radical enhancement–the improvement of significant attributes and abilities to levels that *greatly exceed* what is currently possible for human beings" (Agar, 2014 p. xi). Based on this idea, we think that a moderate improvement should not exceed the maximum limit that a human being has reached for a particular skill or non-pathological ability. For instance, Jeanne Calment is the longest documented person in history, reaching the age of 122 years and 164 days, while the latest studies on lifespan suggest that the maximum age that a human being can reach naturally (with very few exceptions) is close to 115 years (Dong, Milholland & Vijg, 2016). In this way, any type of biotechnological improvement that exceeds these limits could be considered as "radical enhancement," that is, an improvement that implies an insurmountable breach (personal and social) between the pre-enhancement subject and the post-enhancement subject. We definitely believe that this is a research line to be developed in the future (Parra-Sáez, 2017).

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Finally, the matter of biotechnological human enhancement is linked to the sectors of the economy, trade, and advertising, and will be even more so in the future when the improvement technologies are developed and perfected. As Bellver-Capella tell: "all the biotechnological development has been the fruit of the hybridization between science, business, State and society" (Bellver-Capella, 2012, p. 93), and the possible legitimization of perfectionist human enhancement goes through a scientific (if the expected biotechnological improvement can be achieved), ethical (if the processes of human perfection do not imply important ethical problems), economic (public and private financing, profitability of developing enhancement technologies and its introduction in the contemporary liberal market), social (problems related to distribution, possible social and economic inequalities between individuals, and the acceptance or support of public opinion), and of course, commercial positive analysis (marketing strategies, sales and advertising). In this way, human enhancement technologies are shown as a true innovation in economic, corporate and medical sectors. Some thinkers like Drexler—known as the molecular nanotechnology's father—understand that the capacity of nanotechnology for the elimination of nuclear waste can be a huge step in the world economy (exponential cost reduction), while new technologies—as a whole—can end up with scourges such as extreme poverty, and radically improve the living conditions and well-being of human beings (Agar, 2015). Others like Kass (2004) anticipated the complex business of organ trade that will be increased thanks to the development of stem cells and 3D technology. Precisely this type of technology promises in the future to distribute robotic spare parts of any part of the human anatomy (from limbs to organs) with a minimum economic cost. For this reason, experts in the digital technology sector begin to talk about 3D printing as the next "technological revolution" and as the main pillar "of the third industrial revolution." (Fressoli & Smith, 2015; Dodziuk, 2016). For his part, Buchanan (2017) talks about "the age of biomedical enhancement" that must both reflect and encourage the growth of human knowledge (technological, scientific, genetic, biomedical, economic, legal and ethical knowledge), while Diéguez (2017) reflects on the advent of "synthetic biology", that is, an interdisciplinary discipline that combines research in biotechnology, genetic engineering and evolutionary biology among others. It tries to build artificial biological systems for research, engineering and biomedical applications. In this regard, synthetic biology promises to radically change fundamental aspects of human biology and human evolution. In short, for many thinkers and experts, contemporary enhancement technologies imply a true innovation—even revolution—in all kinds of fields. In fact, posthumanist thinkers hope to achieve human perfection (super-intelligence, super-strength, super-morality, and immortality) through them.

CONCLUSION

With the recent memory of eugenic policies prevailing in the first half of the 20th century and its discriminatory-racial nature, enhancement technologies began to emerge as artificial tools that promised to end the suffering of individuals caused by genetic-hereditary diseases. Thus, since the 1970s, genetic diagnoses have allowed us to know the biological status of children who had not yet been born (even in their embryo stage), while genetic engineering has managed to replace defective or non-functional genes with healthy and functional genes. The same happens today with more recent biomedical technologies, such as nanotechnology, 3D printing or cochlear implants, which allow, respectively, improving medical treatments (personalized treatments optimized) and replacing organs or recovering natural abilities lost by artificial devices.

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Having established the approval of society in general and sciences in particular towards the use of biotechnology on the human being for strictly therapeutic purposes, the scientific-medical, ethical-philosophical, and socio-political fields are immersed in a broad debate around the possibility, necessity, and legitimacy of applying the new biomedical technologies to carry out an enhancement of non-pathological human characteristics (those related to health or absence of disease), such as the increase of cognition above the natural levels. At this point, the main positions—represented by the bioconservative and posthumanist currents—are very far apart, opening a large gap between those who are in favor of biotechnological improvement of a perfectionist nature and those who reject it. In this regard, the most conservative thinkers have pointed out a whole range of problems that, on the one hand, allude to contemporary enhancement technologies and, on the other, allude to the radical enhancements of our non-pathological characteristics. These problems allude fundamentally to human dignity (the non-recognition of the intrinsic value of human beings in themselves), to the loss of identity of intervened subjects, and to the reification of the subject enhanced by virtue of the interests of others.

However, practical cases such as that of Harbisson, which have overcome the theoretical stage of the scientific-philosophical debate, and the enormous benefits (therapeutic and perfectionist) that can be provided by the enhancement technologies, such as the decrease in rates of cancer patients, new ways of perceiving information external to the subject, and the creation of a more tolerant and less racist society, suggest that it is a not inconsiderable possibility to look for a formula that allows applying biotechnological tools on the human being to perfect its non-pathological natural aspects, which escape to the ethical problems anticipated by the most conservative thinkers. Of course, a fundamental part of this formula would be to analyze the possible risks and consequences of non-therapeutic biotechnological interventions. In this regard, and taking into account that these problems would appear, in theory, as a consequence of an intervention that could radically alter the life of an individual, an interesting possibility could be to allow perfectionist interventions of a moderate nature (relative biotechnological enhancement), that is, interventions whose aim is to perfect non-pathological characteristics but that are not likely to cause problems of identity, freedom or personal recognition among members of the human species.

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KEY TERMS AND DEFINITIONS

Bioconservatism: Current of scientific-philosophical thought that rejects the application of biotechnology on the human being with perfectionist purposes, legitimizing its use exclusively for therapeutic purposes.

Center for Research Ethics and Bioethics: Swedish research center of a multidisciplinary nature that tries to solve ethical-philosophical and legal aspects in the field of bioethics and medicine.

Enhancement Technologies: Biotechnological tools developed between the end of the 20th century and the beginning of the 21st century, which offer the possibility of enhancing human abilities beyond the strictly natural.

Eugenics: Emerging racial ideology in the second half of the nineteenth century, whose main objective was to carry out a qualitative improvement of the human species through the fight against racial degeneration.

Foresight Institute: It is an organization responsible for research around the correct application of biotechnology on the human being, and the prevention of risks associated with its misuse.

Immortality Institute: International foundation that investigates the possibility of ending aging as an inescapable cause of death, with the indefinite extension of human life through biomedical technologies. Currently the foundation works under the name of "LongeCity."

Oxford Uehiro Centre for Practical Ethics: Research center that promotes the public debate and ethical-critical reflection on issues related to practical ethics, such as biotechnological human enhancement.

Perfectionist Human Enhancement: Enhancement through technological tools focused on the strengthening of the positive (non-therapeutic/pathological) characteristics of the human being, such as those related to the level of their physical strength or intelligence.

Posthumanism: Current of scientific-philosophical thought that legitimizes the application of biotechnology on the human being, with therapeutic and perfectionist objectives.

Therapeutic Human Enhancement: Enhancement through technological means focused on the detection and subsequent elimination of diseases or genetic-hereditary pathologies in the human being.

ENDNOTES

1 Several thinkers, such as the Spanish philosopher Ortega y Gasset in his work *Meditation of the Technique*, have affirmed that the first methods of human perfection were the tools created to supply the intrinsic deficiencies to the human species, such as the use of skins to maintain body temperature or sharp blades to cut meat or hunt animals.

2 In general, biomedical research in Spain is regulated by law 14/2007.

3 "Fetoscopy" is a biomedical technique used to visualize the fetus through an endoscopy performed on the abdominal wall, while "cordocentesis" is based on obtaining fetal blood through a puncture in the umbilical cord.

4 Actually, stem cells can also be obtained from the umbilical cord and the bone marrow, although in the field of biotechnological human enhancement it is usually discussed only about the use of embryos for research with stem cells, probably due to the supernumerary embryos available from assisted reproduction techniques.

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[5] In 2005 Chorost published a report about his experience with the cochlear implant under the name of *Rebuilt: How Becoming Part Computer Made Me More Human*.

[6] In 2004, Harbisson got the UK Passport Agency to allow him to include his "eyeborg" in his passport photo as just another part of his natural body.

[7] Harbisson has a device installed in his occipital bone that converts visible colors into sound waves.

[8] Some thinkers who study the problem of new technologies understand that the possibility—thanks to genetic diagnosis—of choosing genetic characteristics (for example the sex of the baby) will have as a direct consequence a sexual discrimination with a certainly economic and social nature, in the extent to which parents will prefer to have a son for the range of possibilities they will have in the future (broader than that of women in most contemporary societies), while in other cases, they would prefer to have a daughter because they will have fewer possibilities of inheriting concrete genetic pathologies such as hemophilia.

[9] It is usual that the information corresponding to human perfection, the development of enhancement technologies, and their voluntary application for therapeutic and perfectionist purposes is restricted to areas of study in medicine, biology, technology, philosophy, and ethics. However, it is not usual for the general public—because of ignorance of the specific terminology of the topic or the ridiculous number of publications of studies outside the academic environment—to have easy access to this information and to forge a critical opinion about that.

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Chapter 6
The Society of the Digital Swarm:
Microblogging and Construction of Subjectivity in Homo Digitalis

Daniel Toscano López
Universidad del Desarrollo, Chile

ABSTRACT

This chapter seeks to show how the society of the digital swarm we live in has changed the way individuals behave to the point that we have become Homo digitalis. These changes occur with information privatization, meaning that not only are we passive consumers, but we are also producers and issuers of digital communication. The overarching argument of this reflection is the disappearance of the "reality principle" in the political, economic, and social spheres. This text highlights that the loss of the reality principle is the effect of microblogging as a digital practice, the uses of which can either impoverish the space of people's experience to undermine the public space or achieve the mobilization of citizens against of the censorship of the traditional means of communication by authoritarian political regimes, such as the case of the Arab Spring in 2011.

INTRODUCTION

At the dawn of the 21st century, the takeoff of digital technologies reveals the power that human beings have today to express themselves without limits of time and space. The information and data traveling through cyberspace break with the traditional notions of linear and chronological time, and physical space as they reach their recipients and a global audience immediately. Through platforms such as YouTube, Facebook, Instagram, and Snapchat ordinary people, heads of state, church leaders, and businessmen express emotions, opinions and thoughts. Internet and social networks are empowering users through services such as microblogging, as they can publish short messages, express a variety of moods, and experience the feeling of recognition and importance. The emergence of social networks has had a dramatic impact on emotions; for example, the Internet arouses emotions and shapes spaces for users to express

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themselves. Hence, digital practices such as microblogging not only serve as vehicles of emotion, they also transform such emotions. Therefore, microblogging is a technique of digital self-expression and self-construction of one's own subjectivity.

In the current times, the digital and global age have caused a growing personalization of the individuals; thus, the conditions that configure a zombie and narcissistic subjectivity are created. In other words, in the digital medium the citizens of Western democracies take the risk of sliding down a slippery slope: becoming politically spoiled children. Simply put, these citizens are becoming dictators of their opinions and personal whims, and dictators who hold an amputated citizenship, since they are placing a stronger emphasis on their rights than their duties. From a social standpoint, they become primitive savages, without social ties, impoverished in their space of experience and detached from the others. Finally, from an economic perspective, the individual becomes an autistic efficient machine, which competes in the labor market against others, behaving as if they lived in a global cavern, where they fight for fire, life and food.

BACKGROUND

According to Serrano-Puche (2015) there are numerous digital devices, especially mobile phones, that affect the daily life of the human being. This author explains the social impact of digital technologies on the identity of individuals. Through the study of tweets, Bollen et al. (2011) conducted a sentiment analysis, which is the analysis of opinions and expressed attitudes as indicators of people's well-being. These researchers correlated journalistic events of a political, social and cultural nature with important changes in moods expressed through tweets (p. 17). In line with this, Zhang et al. (2011) discuss in their research the relationship between the market and retweets. In this study, these authors correlated words such as "hope", "fear", "concern" with key words of the economy such as "dollar", "gold" or "oil". From a political viewpoint, Tumasjan et al. (2010), Sang and Bos (2012) and Jungherr et al. (2012) investigate sentiment expressed in the microblogging data in order to predict elections. It is important to underline that much of this scholarly work has recognized the contents of microblogging as quarries that contain levels of emotion and both positive and negative feelings. For these researchers microblogging is an indicator that helps mapping the fluctuation of feelings and what an audience expresses. In the context of the Arab Revolution, Jamali (2015) argues that the reactions to messages on the Internet to mobilize people against authoritarian regimes vary according to educational levels. For example, less information-literate citizens were not as critic of those messages and became mere followers of movement leaders; whereas more media-literate people were more moderate and preferred not to make immediate decisions, as opposed to giving "likes" or tagging others.

It is important to note that beyond the previous investigations, which in any case are more empirical and address Internet and microblogging as "given" phenomena, the development of digital technology at the beginning of this century has also sparked studies that debate whether the computer culture, developing Internet and World Wide Web empower citizens with greater freedom of expression or, on the contrary, impoverishes the quality of public discourse. Both critics and optimists raise arguments that either highlight the dangers or emphasize positive aspects of the use of digital technology and the connectivity culture.

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With regard to the critics, in the preface to the book "*In the Swarm: Digital Prospects*", the South Korean philosopher Byung-Chul Han makes a critique of the digital world in the following terms:

This new medium is reprogramming us, yet we fail to grasp the radical paradigm shift that is underway. We are hobbling along after the very medium that, below our threshold of conscious decision, is definitively changing the ways that we act, perceive, feel, think, and live together. We are enraptured by the digital medium yet unable to gauge the consequences of our frenzy fully. The crisis we are now experiencing follows from our blindness and stupefaction. (2017, p. ix).

Therefore, he describes a society, like a swarm, in which information has overrun people's privacy. The digital swarm is a fragmented society, and for that reason, according to him, one of its main concerns is the tendency towards individualism and isolation fostered by the digital medium. As a number of critics of Internet and practices such as microblogging have made plain, digital media affect social interaction, because they define social habits and are driven by economic interests (Bourdieu, 1993). Platforms such as Facebook spread norms and social values by different communities worldwide, because they are techno-cultural constructs and socioeconomic structures which application through communication technologies are the manifestation of a social habit and a sociological parameter (Van Dijck, 2013). Platforms are manifestations of the global power of new corporations, in such a way that international communication and social networks are mediated by a kind of cultural imperialism (Chalaby, 2007). In this context, according to some social theorists such as Patrice Flichy (2010) and Dominique Cardon (2010), social media platforms simplify discourses and reduce the robustness of public opinion. For these authors, the digital age affects the quality of public discourse because it gives the same legitimacy to both amateurs and traditional leaders, professionals and experts. The fact that people are subject to floods of data that cannot be processed leads to disconnection from the world, causing them to be citizens indifferent to responsibilities. In line with this assertion, in his book, "*Homo Deus": A Brief History of Tomorrow,* Harari (2016) claims that "the Internet is a free and lawless zone that erodes state sovereignty, ignores borders, abolishes privacy and poses perhaps the most formidable global security risk" (p. 377). It is important to note that one collateral social effect of the digital media is that lower classes have less information and less possibilities. Also, "the chasm between the U.S. government's rhetoric on Internet freedom and the reality of their own restrictions on the exports of technology has not been lost even on authoritarian states" (Morozov, 2011, p. 210). In short, from a critical perspective to the digital world, people can become cyber-dependent individuals who are prone to lose their privacy, autonomy and individuality when shipwrecked in the midst of the constant flow of data.

However, it is interesting to notice how microblogging offers opportunities for expression, collaboration and participation from an optimist viewpoint. For the optimist, microblogging can be seen as a practice of publishing messages without restrictions, and not as an abusive practice that poses a threat to privacy. While microblogging can contribute to the personal development of individuals, it can also exert a positive influence in the educational field, to name an example, to the extent that students can form learning communities in which they debate, exchange ideas and work collaboratively. In the same way, according to Sterne (2003) and Jenkins (2006), digital technology contributes with information to empower citizens and their cultural formation; it gives them more freedom of expression, and becomes a potential for users to be more autonomous in the construction of their own social reality.

Within the nascent field of stratified medicine, experiencing and knowing groups of patients with orphan, rare or infrequent diseases in advance becomes an essential part for medical and pharmaceutical

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research studies. Currently, thanks to digital platforms, patients become "collaborative agents" of health research (Lewin, 2015). If the common denominator of these groups of patients is both the fact of seeking better treatment options and the subjective experience of the disease, pain and suffering, then the patients will be able to contribute with their opinions in the formulation of hypotheses for clinical research. These contributions are formulated in websites and virtual communities mobilized by a certain type of disease. Through virtual forums, "patient groups", families, and support groups may become researchers that produce capital knowledge for decision-making in health care and in the design of new medical technologies (Mazanderani, Lockock & Powell, 2013, p.896). The capture of the patient's perception, their value judgments, the impact they have on the disease in daily life, the answers they give and the viewpoint presented about risks, uncertainties and benefits play a central role. The collection of this vital information is possible because there is a construction and conformation of large data banks, where the protagonists become Patient-reported outcomes (PROs). In short, the active role of patients and patient associations helps to validate research, and strengthens the idea of "public good", in order to guarantee that they have a voice to make decisions about an essential area that directly affects them. In this sense "the technosciences are already part of the social order and get their resources and legitimacy through serving society" (Styhre & Sundgren, 2011, p.70). Therefore, digital technologies can contribute to the empowerment and organization of these social groups and groups of patients, which is giving rise to an institutional dynamic that also traces the course and the access that new therapies must provide to people.

Although this debate among critics and optimists about the effects of digital platforms on the individual and society transcends the objective of this chapter, it suffices to note that this discussion cannot have as a backdrop the idea of a technological determinism that gives technology the absolute power of transformation of social reality. The modeling of society and the construction of the subjectivity of *homo digitalis* is mediated not only by techno-political aspects, but also by socio-economic and cultural-educational aspects. That is why this text adopts an intermediate position between technological optimism and radical criticism of digital technology.

Regarding new technologies of the twenty-first century, individuals should not have an attitude of defensive rejection, or unthoughtful assimilation. After all, the digital medium is a double-edged sword, because as Harari (2016) suggests:

In 2008 Google actually launched Google Flu Trends, that tracks flu outbreaks by monitoring Google searches. The service is still being developed, and due to privacy limitations it tracks only search words and allegedly avoids reading private emails. But it is already capable of ringing the flu alarm bells ten days before traditional health services. (p. 341)

However, Harari also states: "In the twenty-first century our personal data is probably the most valuable resource most humans still have to offer, and we are giving it to the tech giants in exchange for email services and funny cat videos" (p. 346). In this chapter it is argued that culture and society must incorporate meaningful, relevant digital technologies in the form of knowledge for an individual's existence; such technologies need to contribute to the construction of a public space that involves others. Therefore, there is a need for an education in the digital world that provides tools for citizens to discover the meaning involved in the relationship between *homo digitalis* and the digital network on their own. It is essential that *homo digitalis* understand the consequences of the digital in their everyday life by building tools to think about their existence and to contribute to the construction of public space.

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DIGITAL MEDIA AND ARTIFICIAL PRODUCTION OF RISK

The emergence of the digital world has had antecedents such as the telegraph in the nineteenth century, the telephone and radio at the beginning of the twentieth century, and television in the mid-twentieth century. Since much earlier still, technologies have been transforming the human being from a condition of *homo typographicus* (Gutenberg Galaxy), consisting on a deep awareness of himself and an exaltation of the visual, passing through *homo electronicus* (Faraday Galaxy), bringing the man of the masses to existence, to finally reach to a *homo digitalis* condition (Digital Galaxy) without direction or spirit (McLuhan, 1962).

Nowadays, digital media and the phenomenon of the internet, along with their new neo-techniques and devices, are giving a strong blow to the forms of social and public participation. In this way, the public as a space of respect among people who look at each other, no longer recognizes or values the opinion of the other because "the distant and the near are equal" in the digital galaxy. When there is no novelty in the opinion of the other, the lack of incorporation of alterity ends up diminishing the space of experience. On the other hand, the public is no longer discussing public affairs in the digital age, starting from respect for others or *pathos* of distance, because the individual is locked in narcissism and in the struggle for self-recognition.

Ulrich Beck (1992; 1999) identified pre-industrial hazards, industrial risks and global risks. The first were natural disasters, famines, pestilences or "blows of fate" on mankind from the outside, which were attributed to metaphysical entities, such as gods and demons or nature itself. Industrial risks, typical of an industrial society or the first modernity, are generated within the decision-making process and, therefore, are predictable events that can be subject to statistical calculation. In response to this type of risk for which institutions, politicians and businessmen are responsible, a "security pact" rises, consisting in the invention of private and public social insurance. Finally, Beck's point is that global risk develops within the second modernity and goes beyond all calculation, because society is threatened from within by nuclear, chemical, genetic, and ecological "mega dangers". In this context, the "pillars of risk" are undermined, that is, "monetary compensation", "anticipated control" and "calculability of consequences and damages. "These new risks go beyond time and space, because they are based on digitalization or virtuality that operates outside the logic of the reality principle, as well as health policies. Therefore, its consequences and damage to be incalculable create a "conscious unconsciousness of risk production." This type of global risk is the same as that of the digital world. The risk of digital technologies, which is the main subject to be described in deeper detail in this document, is one that goes beyond decision making, and therefore has its own lines of force, enunciation, subjectification, etc. Among the risks that arise from the use of digital technology, in general the development of Information Technologies and in particular the Internet and Web 2.0 (social networks, blogs, forums, wikis, etc.), include: cyberbullying from one minor to another using technologies such as the Internet or mobile; grooming, when adults try to gain the trust of a minor by faking their identity with the intention of blackmailing, obtaining videos or intimate photos of the victim; sexting, or sending insinuating, erotic or pornographic texts or images that can later be used by the victimizer for the purpose of blackmailing or sextortion; phishing, or scam mode that "harvests and fishes passwords" of the victim; identity theft and cyberaddiction or compulsive connection. Nobody really knows the overall result involved in the risks of using digital technology. Therefore, the freedom of decision is the freedom of someone who is forced to make decisions without being aware of its consequences (Beck, 1999).

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Individualization is a distinctive feature in the current global risk society as warned by Ulrich Beck (2002). According to this author, individualization is not market individualism or an atomization-related market, but it is rather the institutionalized market that, within the context of financial capitalism and advanced liberal societies, invites people to become individuals: "to conceive himself or herself as the center of action, as the planning office with respect to his/her own biography, abilities, orientations, relationships and so on" (Beck, 1992, p. 135). This means that if individuals have tried to plan and design their own existence without success, they will be solely responsible for their failure. Regarding the risks that come with the appearance of the digital world, there may be a risk of loss of the reality principle. This risk represents a substitution of the real world for the virtual world, in which individuals who are disaffiliated or socially excluded construct their subjectivity, and, at the same time, have the choice to humanely capitalize their own existence.

However, digital risk cannot be understood as if it were a solid reality or essence, because it is rather a "transitory or transactional reality" (Foucault, 2004, pp. 300-301) that has become the new human condition of our present. Digital and technology risks are becoming more prominent and more dangerous, but can be modified. O Malley, Rose & Valverde (2009) claim that:

Risk is not regarded as intrinsically real, but as a particular way in which problems are viewed or imagined and dealt with. What is specific to risk, in their view, is that it is a probabilistic technique, whereby large numbers of events are sorted into a distribution, and the distribution in turn is used as a means of making predictions to reduce harm. As such it is highly abstract, giving rise to a very wide array of specific forms and ensembles of government. In such work, the interest not only is in the diversity of forms taken by risk, but also with their political and moral implications (O Malley, Rose & Valverde, 2009, p. 18).

The telecommunications industry and digital technology provide more access to people to the Internet, but also expose them to the risk of undermining the reality principle, impoverishing their experience horizon and destroying forms of public participation. The digital world generates a kind of "ontological security" in the homo digitalis, but paradoxically, this digital world finds its misfortune there, because it ends up living in a "point-time" (Punkt-Zeit), fragmented and abstracted from reality. Freud (1933) defines the reality principle as a force and the ability to control impulses and delay gratification. However, nowadays the reality principle is increasingly suppressed in favor of seduction and addiction to the world. Like bees in a rapture of joy, individuals (*homo digitalis*) are immersed in the general buzz of a digital swarm that attracts them with their siren chants of messages, sounds and the like.

In his philosophical reflections on "the Scent of Time", Byung-Chul Han argues that the digital medium is producing a crisis in our sense of time. He refers to the atomized time as a dyschronic phenomenon, because there is no experience of duration. This loss of the scent of time is not the consequence of the real acceleration, but that of an atomized time in which the individual goes tumbling (2009, p. 7). In this sense, the *homo digitalis* lives submerged in a present without tension and without substance, in an "empty duration" in which the experience of continuity is destroyed. At the same time, he lives in a point-time and in a non-duration experience characterized by narrative discontinuity. The digitalization of society can generate a cacophony of voices, but not a narrative, not a discourse. In the point-time there is loss of the reality principle, as well as facticity and the Earth. If the principle of reality, of reality as it is, allows human beings to put their feet on the ground and in facticity, the referential sphere of the real and history in cyberspace will be abandoned. Therefore, in the digital swarm the loss of respect, or the loss of distance of the other and the others, disintegrates the public world without necessarily being

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aware of this. Within the digital world, new types of society personal lives are created. For that reason, it is necessary to ask the following questions: what unpublished and unexpected forms of subjectivity are arising in this society of the digital swarm? What types of digital practices are prevailing? How do these practices affect public space and shape individuals?

THE INDIVIDUAL IN THE SOCIETY OF THE DIGITAL SWARM

Starting with the latter question about the effects generated by the society of the digital swarm on the individuals and the public space, when the human relations are mediated exclusively by social networks and internet, information tsunamis and data storms flood society and create a wreck of uncertainties for the individual. Accordingly, the only plank to which they can cling seems to be self-recognition and self-propaganda. Such attitudes are described as follows:

If you go to India and see an elephant, you don't look at the elephant and ask yourself, 'What do I feel?' – you are too busy looking for your smartphone, taking a picture of the elephant, posting it on Facebook and then checking your account every two minutes to see how many likes you got (Harari, 2016, p.388).

At the moment when people connect compulsively to the network through practices such as microblogging, there is an elimination of distance, because everything remains as close and just as far away. Instead of propitiating a legitimate encounter with others, alterity is suppressed. The digital network becomes "the desert of the equal", because it eliminates the possibility that individuals acquire a transforming experience of themselves, and that gives meaning to their existence. It is well known that for Arendt (1961) the original terrain of freedom is the sphere of politics and, in general, the fragile sphere of human affairs. In his words, freedom is "actually the reason that men live together in political organization at all. Without it, political life as such would be meaningless. The *raison d'etre* of politics is freedom, and its field of experience is action" (Arendt, 1961, p. 146).

However, in this digital era, the *homo digitalis* becomes a slave of having to register each experience, no matter how trivial, because for them it only makes sense to do or experience something they can share later with everyone in their network. Following Arendt and the context of antiquity, one could say that although it is in the "inner space" that man protects himself from the world and that it is where he is most secure against external interference than any other place in the world, the construction of public space and the consciousness of freedom are not in that sphere or interior space: it can be found in the political field of the relationship with others (Arendt, 1961, p.146). According to Arendt, to be free it is necessary to free oneself from the necessities of life and participate in a common public space, so that freedom could govern behavior and action. However, in the digital world, the human being tries to protect himself, no longer in the inner space, but both in cyberspace and in selfishness, which is fed by the momentary, safe feeling each click and like provides. In short, in the digital world, individuals become buyers and sellers of fragmented and atomized experiences, motivated by the self-promotion and digital self-expression.

In the case of implementation of new digital practices, individuals register fragments of perception, emotion and thoughts through microblogging to the point of turning them into data. Instead of expanding the public space, microblogging dramatically impoverishes the horizon of experiences, because self-propaganda is encouraged and undermines their ability to think. Consequently, the *homo digitalis* is

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losing sensitivity, that is, the ability to realize how they are affected by those same experiences converted into data with each "like". With the digitalization of social relations, a loss of the reality (*ananké*) is created in terms of necessity and in terms of what is inevitable, due to its unbearable character. In line with this, for McLuhan (1962) electronic technologies and technological devices are not passive entities and external to people, but dynamic processes that reshape subjects. That is why, the ability to adapt to the physical and social environment is lost by means of digitalization.

The loss of the reality principle leads to changes for the individual in the political, social and economic spheres: "spoiled child" (political), "primitive savage" (social) and "autistic performance machine" (economic). These would be the three behaviors acquired in the society of the digital swarm. In relation to the first figure, spoiled child, which is a sign of the change that has taken place in politics by virtue of digitalization, it should be noted that the practices associated with microblogging and the Internet have contributed to forging this type of subjectivity. Spoiled child is a form of subjectivity adopted by the *homo digitalis*, which only demands obligations and has no responsibilities. "Spoiled child" is an individual who loves the freedom to express opinions in social networks without having to answer for what he says.

When the *homo digitalis* lives submerged in the Internet, he lives in the society of opinion (*Meinungsgessellschaft*), in which the primacy of caprice and the growing narcization of the ego progressively undermine the public space. If speech and communicative action (Handeln kommunikativen) are not possible in a society like that, then digital media means that a society becomes increasingly poor in discourse and loses the idea of building an empathy-based community (Han, 2013). Byung Chul Han claims: "windows on a computer are windows with doors; they communicate with other windows without intermediary spaces or authorities. Digital windows open not onto a public space but onto other windows" (2017, p. 16). In this case, the Internet today does not manifest itself as a public or common space because the production of information moves from the public to the private; then, the private is introduced into the most intimate part of the human being. This look at other windows of the spoiled child means that he is only able to recognize himself, and not others, through his computer. Consequently, he does not see other citizens, he does not touch them, he does not feel them, since he is in a permanent withdrawal within himself, living only for him. Simply put, self-absorption in the digital world turns the individual into a kind of whimsical citizen who shows little genuine interest in the feelings of other people.

On the other hand, the primitive savage, as the second figure *homo digitalis* becomes, is not interested in forming a community because he does not identify with any, and there is only a concern to satisfy his needs. Indifferent to the fate of others, he remains impulsively connected to cyberspace, submerged in a sea of fleeting, sudden and ephemeral experiences. *Homo digitalis*, transformed into a primitive savage, is a hunter of "quotas of experiences", without an experience of the duration. Instead, he lives in personal self-exploration. He wants to have new experiences, without this implying sensitivity. As a consequence, this individual falls into extreme social isolation, losing all sorts of social skills, which is what the Japanese call *hikikomori*. In countries such as South Korea, the compulsive use of the Internet is a public health problem, because one in ten children suffers from addiction. In other countries such as France and Germany there are hotels that offer a "digital detoxification" for 450 euros per night. Accordingly, the challenge that lies ahead is to provide educational and pedagogical tools so that digital citizens can make less compulsive and harmful use of digital media. For example, In Spain and Latin America, social networks are already transforming teaching and learning practices in universities, since they have become a space for the exchange of information that allows collaborative work between groups and the promotion of cooperation. A first case is the University of Valencia. They have created an application

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called Pesedia dedicated to educate children and adolescents in preventing the privacy risks that social networks entail. It is an experience carried out with children between 12 and 14 years old at the Escola d' Estiu 2016 (Summer School) of the Universitat Politècnica de València. They claim that:

through a set of proposed games, children and adolescents interact in Pesedia and learn to detect risky actions that, if carried out in a public social network could compromise their privacy. With such games, children and adolescents are aware of, among other things, the dangers of public exposure of data, the labeling and geo-positioning of photos, the decontextualization of conversations, as well as the future repercussions of our digital fingerprint (Argente, Vivancos, Alemany, & García-Formnes, 2017).

A second case is the University of Guadalajara. Research by Los Altos center of the University of Guadalajara analyzed the use of social networks as a strategy for the students' learning process. It is emphasized that teachers' mediating and innovative role is important, as they co-participate with students in the construction of knowledge. It is, then, a type of learning that finds the Network as a potential tool to organize tasks, collaborative activities and cooperative projects according to the information context and each student's particular learning style (visual, auditory, kinesthetic) (Torres & Carranza, 2011).

Finally, with the emergence of digital work, platform capitalism and different types of ventures, a new set of work skills is needed. People must adapt to new forms of employment in which they must be capitalists of their own human capital within the context of precarious work. For example, microblogging also "include innovation in rural areas where farmers can use a mobile phone to regulate their irrigation pumps" (Alijani, 2017, p. 9). In the digital age, people and organizations are continuously reinventing themselves. As a result, they are becoming autistic performance machines. While in some countries like the United States, social networks and digital technology have been used to connect with friends, escape routine and cultivate hobbies (make videos, music or photography), in the case of the Arab Spring they were an attractive vehicle through which the public could express their ideas in a context of repression and lack of freedom.

MICROBLOGGING PRACTICE AND ARAB SPRING

In 2009 Iran used microblogging to spread information about the protests against President Mahmoud Almadinejab. In a similar fashion, in a country like China 37% of its Internet users, that is 125 million individuals, use microblogs. This highlights a series of changes in which the digital revolution has not been alien to the political and social revolution, as it is the case of some Arab countries such as Egypt, Tunisia and Yemen. As a result, these dictatorships had to yield to protests that were provoked through the Internet. Since microblogs spread information fast, no political power could block them. While in the West, microblogging seems to destroy the public sphere, in the East it is a source of collective mobilization.

For decades, in several nations of the Middle East and North Africa, authoritarian regimes have dominated every aspect of public life. However, more recently, various social, economic, political and technological changes have created the conditions for mass discontent to be transformed into waves of protests that gave rise to a revolution known as the Arab Spring or the Arab awakening. Towards the end of 2010 and the beginning of 2011, there were popular uprisings in Egypt, Tunisia, Yemen, Libya, Bahrain, Syria, Jordan and Morocco in which citizens demanded rights and opportunities, similar to those offered in Western democracies. Although the analysis of this phenomenon must be viewed from the singularity

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of the events in each country, it is also true that information and communication technologies (ICTs) have played a distinctive role. The Internet or the microblogging phenomenon do not actually explain the causes of social protests, because there are aspects that could have a greater impact such as corruption, increased unemployment, economic inequality and repression. In addition to this, "the majority of the Arabic countries are considered to be mono-national. This factor facilities to the pace of social media among different nations and the formation of massive groups in the social media" (Jamali, 2015, p. 2). Beyond a technological determinism, the role played by the Internet, mobile phones and microblogging was to develop new experiences of political participation and new forms of social movements. That is why within the context of the Arab Spring, without a doubt, "communication technologies are tools appropriated by social actors to achieve specific goals" (Moussa, 2016, p. 4).

There have been occasional outbreaks of protests against authoritarian regimes since 1990. By the 2000s, digital platforms and the use of the Internet had already played an important role in allowing collective action to materialize in some Arab countries. These first attempts were easily stifled by the intervention of the police and by the lack of widespread public support. As an important antecedent to the uprisings in the Middle East, in 2009 Iranian people protested against the election of President Mahmound Almadinejab. Marcovitz claims: "since the Iranian media is tightly controlled by the mullahs, the protest leaders turned to Facebook, Twitter, and other social media to organize public demonstrations. The demonstrations became known as the Green Revolution" (Marcovitz, 2014, p. 24). As a symbol and an illustration of Iranian protests, we have the case of the death of the young Neda Agha-Soltan, who was the victim of the violence used by the authorities to dissolve the multitudinous demonstrations. These images were captured on video and uploaded to Youtube. Although the uprising in Iran was not successful, however, it showed the way and generated a ripple effect, so that in other countries a wave of protests and upheavals spread across the Arab world.

The Arab Revolution began in December 2010 with the occupation and appropriation of public places by thousands of people who mobilized to expose the abuses of authoritarian and personalist governments that had precisely occupied these places with symbols, images and monuments: "in modern times, the public square has also become a potent symbol of government authority and a site for displaying state power. Indeed, across various Arab Spring countries, authoritarian governments have tightly controlled these spaces. Libya and Syria were perhaps the most extreme examples, with images of "the leader and other monuments to the regime dominating these areas" (Jamshidi, 2014, p. 46). That is why the practice of microblogging played a crucial role in the Arab Revolution because for the first time, in a long time, cyberspace and public space were articulated with each other in order to claim rights and freedoms that had been undermined by authoritarian governments: "the region's public plazas transformed from state dominated products of urban development to physical symbols of popular political engagement. They became the embodiment of people power, giving concrete form to resistance and providing protesters with something durable to defend" (Jamshidi, 2014, p. 46). In Tunisia on, December 17, 2010, the Tunisian street vendor Mohamed Bouazizi self-immolates after the confiscation of his fruit stand by the police, causing protests: "the clips of the protests found their way immediately into tweets and Facebook pages—one with seven hundred thousand participants—reaching the international media. This event has been considered the official start of the Arab Spring.

Local activists and trade unionists quickly moved on by helping organize more rallies. Within the following three weeks much of central Tunisia was involved in what came to be an uprising, with the citizens demanding jobs, dignity, and freedom" (Bayat, 2017, p. 8). Finally, on January 14, 2011, the dictator Zine al-Abidine Ben Ali resigned as a president and flees to Saudi Arabia. In the case of Egypt,

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since 2005, the Kifaya network movement, which means "enough," had published messages in support of the people of Palestine, in opposition to the American invasion of Iraq and resistance to the Mubarak regime. Within the context of the 2011 Egyptian revolution, which occured due to social discontent over the corruption of the regime, the lack of freedom and police repression, Facebook and Twitter allowed the masses to cooperate with each other, gathering some 100,000 people in the square Tahrir in Cairo overthrowing Mubarak. In the words of Jamshidi: "to spread their message, campaign organizers have arranged conferences, contacted relevant individuals and organizations, and created a website where detainees and their relatives can share their stories with the public" (2014, p. 55).

In June 2010, the beating and murder of activist Khaled Said by an Egyptian police officer were captured in images that were later downloaded from the Internet, which caused protests. However, some time later:

When Mubarak stepped down the demonstrators could not fill the vacuum. Egypt had only two institutions sufficiently organized to rule the country: the army and the Muslim Brotherhood. Hence the revolution was hijacked first by the Brotherhood, and eventually by the army (Harari, 2016, p. 142).

Something similar happened in Yemen where, despite the fact that the dictator was overthrown, the new government yielded to terrorist groups such as Al Qaeda. A few days after the fall of Mubarak, in Bahrain thousands of people protested the inflation, repression and discrimination of the Shia working class carried out by Sunni elites. On January 13, 2011, the first protests in Libya erupted against Gaddafi. Terbil's arrest mobilized most of the demonstrators in the city of Benghazi, "who were alerted to the protest by Facebook post, marched on government offices and demanded the release of Terbil- who was ultimately set free by Libyan authorities" (Marcovitz, 2014, p. 11). In short, the leaders and activists of the protests against the system used Internet and social networks in order to spread news, because "Gaddafi controlled the Libyan press, but he had no power over Facebook, Twitter and other social media forums" (Marcovitz, 2014, p.9).

The fall of several despots like Ben Ali in Tunisia, Mubarak in Egypt, Ali Abdullah Saleh in Yemen, and Gaddafi in Libya occurred in response to popular revolts that spread like wildfire. Therefore, the role of the Internet and microblogging in those riots was key to its rapid and intense spread. Naturally, the use of Internet and social networks in the revolution does not explain the complexity of the phenomenon of the Arab revolution, but allowed that information was not monopolized by a bureaucratic regime, at least while it lasted. At the same time, they made it possible for people to experience being seen and having power, as well as experiencing a certain sense of freedom of expression:

when a post is 'liked' by others, the author may develop the idea that there are people outside his current network whom he or she can lead. From a psychological viewpoint, this imparts a sense that they can be more effective than before. On the other hand, the followers develop the sense that they are not alone in the ideas they hold (Jamali, 2015, p. 5).

SOLUTIONS AND RECOMMENDATIONS

A genealogical approach could help to establish the ways in which the digital world is transforming our daily life. A challenge would be to identify not only new digital practices that affect fields such as eco-

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nomics, health, education, but also practices that give rise to new subjectivities. It will be relevant, then, to analyze the new digital practices that are emerging with the new digital technologies that inevitably model people's subjectivity. Issues such as the impact of digital work on the quality of people's life and understanding the growing gaps among digital technology, individuals, businesses and policies will be fundamental in an era when work becomes precarious, individuals have a false sense of autonomy, relationships become ephemeral.

It is important not to demonize the use of social networks and digital practices that shape people's lives. In the same train of thought, information that threatens and affects people's privacy should not be irresponsibly disclosed. On the one hand, it is essential, then, that new digital citizens become aware of the digital practices that are shaping them. In addition, it is crucial for them to take charge of their privacy in social networks in a responsible and appropriate way. From the viewpoint of public educational policies, it is necessary that the use of social networks and their digital practices be integrated into the curriculum of training for children and adolescents. Education in information and knowledge society generates a creative, cultural and collaborative use of social networks.

In relation to digital technology and the communications industries, as UNICEF points out, governments, schools, entrepreneurs have two priorities: to give more children access to the internet; and then protecting them when they are online. Hence, in the future it will be important to continue innovating teaching methods and didactics in the use of digital technologies so that they are an instrument and not an end to which people become addicted.

FUTURE RESEARCH DIRECTIONS

For economists, politicians, and researchers from different areas of knowledge, microblogging constitutes an opportunity to collect data on the desires, feelings and opinions that people have in relation to issues such as their political preferences, consumption, and expectations. The study of digital technologies and the way they transform people's lives acquires the power to transform those data into decisions. It is essential that future research studies the scope and impact of different types of societies and individuals from a more empirical perspective.

CONCLUSION

In the digital world, many domains of social life are restructured around digital communication. The changes brought about by the digital revolution of the Web, the proliferation of social networks and virtual communities, as well as the intensification of microblogging have greatly transformed our habits, lifestyles and ways of communicating with others. It is fair to say that the emergence of social media brings a new set of challenges related to a user's privacy. Digital technology is fully integrated into daily life. It is no longer possible to separate the Internet and microblogging from daily activities.

The digital revolution has no reverse gear and it is difficult to put the emergency brake on this train, in which the information accelerates and accumulates rapidly. The non-responsible use of social networks brings with it a society in which individuals disintegrate and atomize without achieving a common and lasting project. Clinging to irrelevant information that promotes egoistic self-recognition turns citizens into narcissistic beings, who govern themselves from the tyranny of their own opinions. In addition to

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distancing themselves from the reality principle, citizens transform themselves into spoiled children, at the level of political relations; into primitive savages, regarding social relations; and into an autistic acting machine, in economic relations.

The concepts of 'spoiled children', 'primitive savages' and 'autistic efficient machines' are three behaviors acquired in the society of the digital swarm by the emergence of a new subjectivity called *homo digitalis*, which considers loss of the reality principle (*Realitätsprinzip*) as one of its most important consequences. Another of the most dramatic changes that involves the compulsive use of the Internet is that the human being reduces their space of experience and multiplies the horizon of expectation. However, educating the homo digitalis in the consumption, use and production of responsible and meaningful information can shed some light into the use of such practices for less selfish purposes and build learning communities, patient communities with illnesses, and cooperative communities. Accordingly, digital citizens must be responsible for analyzing the extent and ways they are affected by the avalanche of digital products that threaten to capture their time and attention. A global digital citizen should contribute to an authentic information and knowledge society as a responsible person with rights and duties.

As in the case of the waves of resistance and Arab outrage, some of them do not necessarily denote the configuration of a political discourse, as catapulted by the digital medium against authoritarian regimes. The case of the Arab revolution is an example that represents the use of social networks as a tool for emancipation. In this context, microblogging practice has been an instrument of collective action against despotic governments. Social networks served as instant, powerful, and effective communication tools in countries where censorship has been the predominant feature for decades. The overthrow of the political leaders of Egypt, Tunisia and Yemen after protests, fueled by the use of microblogging, reveals its social transformation power to shape the public space. In order to have a genuine democratic space that becomes a vaccine against all kinds of subjugation, even facing the dictatorship of the individualist opinion that entails the digital medium, there is the question of how to cultivate critical thinking and achieve public discourse. Digital technology is allowing individuals to inform themselves about news, find employment, have fun, buy and sell products, contact people, share hobbies, etc. It is true that fascination for these technologies and the very practice of microblogging, makes the current homo digitalis run the risk of falling into the cyber dependence that leads to constant hyperconnection.

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KEY TERMS AND DEFINITIONS

Arab Spring: Dissatisfied mass revolution against the oppression of authoritarian and personalist regimes that dominated for decades the public life of several countries in the Middle East and North Africa.

Digital Swarm: Particular way in which the current technological society is configured. In this, the individuals are not mass but a cacophony of opposing voices.

Dyschronic: Time without the experience of the duration of the digital world.

Hikikomori: Japanese term that describes the attitude of extreme isolation suffered by some people for different reasons, with the corresponding loss of social skills.

Homo Digitalis: Type of subjectivity that has been built through practices and technologies of the digital world.

Kifaya: Network movement that means "enough" and that had published messages in order to resistance to the Mubarak regime.

Microblogging: Digital practice, usually written, that allows people to send, receive, and post short messages. It also allows users digital self-expression and self-construction, maintaining networks of friends, search for jobs, among others.

Pesedia: Social network dedicated to the prevention and education of children and adolescents about the risks to privacy that social networks entail.

Principle of Reality: The need (*Ananke*) or what is inevitable because it is unbearable. It also consists in the ability of the human being to adapt to the physical and social environment. The loss of this principle leads to changes for the individual in the political, social, and economic spheres.

Risk: The possibility of the loss of the reality principle and the disappearance of the public man.

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Section 2

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Chapter 7
Racing Ahead With Innovation: The Case for Hybrid Models and Ethical Decisions

Jan Hendrik Roodt
Waikato Institute of Technology, New Zealand

ABSTRACT

Massive societal change will result from the rate of continuous technology advancement and the pace will increase. The enterprise will face operational and technical challenges and society will increasingly expect the highest ethical conduct. What strategy will allow the organization to remain innovative and thrive in these circumstances? To develop new insight, anticipatory skills, and better decision making, a case is made for the adoption of model building and simulation. In addition to the benefits of shared conceptual artefacts for communicating in the enterprise, modelling requires a deep understanding of the ethics and reflexivity needed to deal with complex issues and using a transdisciplinary framework for inquiry may increase understanding. For innovation to emerge, participatory and co-creative approaches for sense-making are proposed to shift the responsibility for ethical decisions to more actors in the enterprise. This approach allows leaders to engage with the informal coalitions in the enterprise and shape the required strategic direction.

INTRODUCTION

The pull of applications and simultaneous technology push are seen as major drivers for Industry 4.0 (Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014). Artificial Intelligence, Virtual Reality, Additive Manufacturing, Robotics and the Internet of Things are the technologies and applications that are visible manifestation of the disruptive nature of the Fourth Industrial Revolution. Lasi *et al.* concludes that this will have a massive effect on business and information systems engineering.

The position and focus of this chapter is that there is a need for interventions that will allow enterprise to maintain calm as the storm of change rages, to remain viable and to make ethical decisions. Several avenues exist to achieve these goals, and as the title suggests, modern modelling approaches in support of innovation and decision-making are proposed as crucial for success. Specifically, including a hybrid

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anticipatory modelling and simulation capability formally into the workflow of an enterprise may act as the catalyst to ensure that knowledge generation and innovation proceed at the pace required and that decisions are made ethically and transparently.

This chapter will explore several aspects of information and knowledge, model building for sense-making from a broad philosophical and ethical perspective, transdisciplinarity as an appropriate mode of inquiry, and innovation. Finally, the ideas around hybrid system models and simulation will be introduced. Practical aspects of enabling a capability and workflow in the enterprise will be explored and combined with organisational change initiatives, and in conclusion, the prospects for future work in this area will be touched on.

BACKGROUND AND STRUCTURE OF THIS CHAPTER

People, in general, experience a sense of unease around situations that imply change. Over the past 250 years, humanity has experienced unprecedented change. This was brought on by the first industrial revolution, in essence, an explosion of technology, and with it came an explosion of the population (Brynjolfsson & McAfee, 2016). Steam machines made mechanical production possible and allowed for the effective distribution of heavy loads of produce over long distances using steam trains. The supply chain was suddenly long, fast and potentially more complicated than before.

The second industrial revolution was made possible by the invention of electricity and the assembly line. Between the end of the Second World War and the turn of the century, the advent of the computer, digital technology and the internet ushered in the third industrial revolution (Schwab, 2017).

Around 2007 Apple released the iPhone. It was more than a phone, more than a personal digital assistant and more than a small computer. It integrated these concepts and offered an internet connected communications device, with small applications available to do a multitude of tasks. These applications, developed by a new breed of software developers, were available from an electronic repository, curated by Apple, and at prices that disrupted the concept of boxed software available only in a physical shop. Just as with electronic music and movie downloads, the concept of the supply chain for digital goods changed overnight. The world of advertising was impacted; Facebook and other social channels suddenly had a new portal for delivery, and advertisements could be served based on specific usage patterns.

Shapiro and Varian (1998) foresaw this type of disruption about ten years earlier and observed that software and hardware platforms must be collectively managed as an ecosystem to remain viable in the changing environment. Steve Jobs subscribed to the position of Alan Kay (2018), who famously said: "*People who are really serious about software should make their own hardware*" and took it one step further by also curating the type of content delivered by their ecosystem. The technology changed, but as Shapiro and Varian pointed out, the laws of economics did not change. In this case the innovation was around the control of the platform for delivery, the mechanisms of delivery and the deliverables that are tightly integrated and controlled to gain a competitive advantage. Being first to market with this complete package had the obvious advantage that it attracted more customers and subsequently more developers to the ecosystem.

The introduction of the iPhone followed the earlier presentation of a revolutionary music player, the iPod, that used solid-state storage and could store and play music downloaded from the iTunes web store owned by Apple. The proven technology of the iPod found its way into iPhone, which essentially incorporated all the functionality of an iPod and more. The pace of this disruption took many competitors,

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including Nokia and Blackberry by surprise and forcefully pushed them out of the market of high-end phones, and in a way opened the market for Samsung, who was quick to emulate the look and feel of the iPhone. The key insight is that the iPhone looked like a phone and had the required functionality, but added a host of other key service offerings to the same device.

How is it possible that the leaders in the field did not see this disruption coming, and why is it that other contenders, including Microsoft, who could arguably have been in a similar or even better position than Apple in 2000, did not successfully move first?

In the case of Blackberry there were distinct leadership problems as was revealed around 2011 (Molen), and perhaps many of the people in the organisation already had innovative ideas when Apple first emerged in the telephony market. It was also not for lack of an available theory about disruption (Griffin, 2015). Griffin, however, points out that market disruption is not identifiable early on. He uses Uber and Tesla as other examples of disruptive forces utilising the combination of new technologies effectively to disrupt segments, and in the pure services domain, one could cite AirBnB. His key observation is that, as with Apple, these companies are more than what they started to replace. Uber is not just a replacement for taxis (business based on the data available from bookings and drivers alike) and Tesla brings more to the table than just an electric vehicle (with an extensive development in electrical storage and supply infrastructure), while Airbnb changes the game by allowing every person with a spare room or couch to be part of the hospitality industry. It is easy in hindsight to discover a disruption pattern and to explain the dynamics. Perhaps, one could claim, Apple was lucky! One explanation, namely 'foresight in hindsight' will be explored later by introducing the use of simulation to discover patterns and system emergent dynamics.

It is essential to recognise that society, in general, had to be in a particular position of readiness to adopt the changes and innovation. This is a more difficult pattern to unfold and explain. What makes it hard is that there seems to be a regression of the human psyche, described in great detail by Fisher (2006). This regression is described as neo-primitivism, with cults of the body, fundamentalism, adventure tourism, violent combat sports and more. It is as if there is a longing for an imagined world where it is simpler to resolve significant problems using primitive approaches. Peter Allen introduces a recent issue of E:CO by stating that the modern world has difficulty accepting that problems are potentially open and evolving, with no guarantee that science will find the answers as we have come to expect (Allen, 2017). He states that researchers may need more imaginative complex systems concept models to bring insight to bear on the next wave of issues being faced – we need a new way of doing our research!

Simply put, using previous trends and mining data for rules may not be up to the task. And this sits at the heart of the issue addressed in this chapter: we have to look broader than a singularly focussed research question or simply trying to look into the future of technology and services. A clear understanding of information and real complexity and how we deal with it ethically should underpin decision-making. What skills are required to make sense of the new realities and what virtues will enable success at all levels of an enterprise? How does this support crucial innovation throughout the organisation?

The author will briefly introduce necessary theoretical aspects of cybernetics, information theory and general systems theory to show how these developments pushed the understanding of the general complex nature of the world forward. These concepts play an essential role in the context of gaining insight and knowledge about the world and affect all modern model development and simulation of systems (mental, qualitative and quantitative approaches alike). In turn, clarity and insight are pillars for practical, timeous and virtuous decisions, based on shared knowledge that may lead to innovation in the enterprise.

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THEORETICAL BACKGROUND: COMPLEXITY, CYBERNETICS, INFORMATION AND GENERAL SYSTEMS THEORY

After World War II many eminent scientists and engineers contributed to the field described by Wiener as Cybernetics (Wiener, 1948). The concept of information played a key role, and Shannon (2001) introduced a mathematical theory and model for communication systems that consisted primarily of five elements. The information from a source is turned into a form that can be transmitted by a transmitter to a receiver via a medium that can carry the transmission. This transmission is subject to interfering noise from a range of sources, which changes the transmitted information before it reaches the receiver. The receiver is a device that can prepare the information into a format that can be understood at the destination. This is a very elegant model and one that has stood the test of time. It handles information from the perspective of a communicated signal in an electronic and machine perspective.

The concept of information is core to systems theory and the first wave of cybernetics. Morin (2008, pp. 13-15) states that information is a concept that links physics (Second law of thermodynamics and entropy - the tendency for disorder to increase over time) with the idea of the organisation (in the biological sense and not in the mathematical sense that may imply reducibility (Boulding, 2007, pp. 205-207)). He notes that entropy is, from a mathematical perspective, inversely proportional to information. Conceptually this means that as information increases, disorder is expected to decrease. This surprising insight from communications theory does not take into account the multi-dimensional character of information, and as Morin points out, it does not aid the understanding of the birth or the growth of information. It does not clarify the concept of meaning and knowledge. And although it can be linked to the statistical aspects of information loss, it does not confer insight as to the meaning of the information. The reason the author touches on this here and ropes in the philosophical view is that information is now accepted as being inseparable from structural/organisational contexts. It is also inextricably link to innovation.

In the theory developed for telecommunications, Shannon considered the source of, and the destination for, the information as objects (mathematically based and engineered machines). As was made clear before, the biological organisation that is part of the general concept of information production and flow is, in fact, part of the system that generates, transmits and 'consumes' information. This gave rise to the next development in cybernetics: cognition was brought into the picture and with it came the concept of reflexive systems. The system contains the observers, and the observed and understanding enters the picture as a product of information and context. From a communications perspective, this means that communication cannot be attributed to a single actor (context, sender and receiver have roles).

The third wave of development in cybernetics concerned the concept of emergence and artificial life (Varela & Bourgine, 1992). The focus was now squarely on the ability of a system to evolve in unpredictable and complex ways. This development was reflected in the understanding and description of philosophical complexity, in contrast to the mathematical work on complex systems in chemistry and physics. Cilliers gave an extensive description of the features (or fingerprints) of complex systems (Cilliers, 1998), which included the following significant aspects as described by Woermann (2016):

1. Complex systems have highly interconnected and organised components,
2. Complex systems cannot be analysed and fully uncovered or known,
3. Complex systems self-organise and have structure,
4. Complex systems exhibits emergence, and
5. Complex systems are 'incompressible' as a result of circular and interrelational causality.

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Other features will be explored as required. For example, Cilliers extended the features and considered structure, hierarchies and boundaries of complex systems (Cilliers, 2001). Humans develop mental models of the world to make sense of it. All models, including our mental constructs, are in some way a simplification of the real world entity or group of entities that they reflect. Cilliers points out that with complex systems the modellers have no way of knowing how their simplifications and boundary setting introduce flaws and what these flaws are.

The above observation is essential for the discussion of sense-making, often using modelling in many forms as tools for innovation and decision-making. The consequence for cybernetics and artificial life is that the real complex aspects of the 'lived' world cannot be traced back in practice to simple rules of generation, because of the unknown number of local, non-linear (including circular and recursive non-linear) dynamic interactions that may exist. Decision-making based on classic linear methods becomes null and void.

Complexity as a concept, mentioned in the heading of this section, was used extensively in the preceding paragraphs. Kurt Richardson, introducing the classic paper by Boulding, states that complexity thinking arguably emerged from the work of the general systems movement. Initially, it was used to describe model building "somewhere between the highly generalised constructions of pure mathematics and the specific theories of the specialised disciplines". Boulding refers to the work of Bertalanffy and states that Bertalannfy was responsible for coining the term "General Systems Theory" – GST (Boulding, 2007). Boulding explains the need for GST saying that knowledge is a function of social organisation and humans. Knowledge increases when meaningful information is shared. As was pointed out, Shannon's theory cannot adequately handle the semantic level of communication. It does however build on the general ideas of the communication system that Shannon introduced to develop the ideas that are familiar today: a framework of context and structure for the system, the ability of the system to be open to information (energy) flowing in and out of the system from an environment and the ability to maintain a non-equilibrium position to regenerate and grow. Later, Ralph Stacey considered learning and knowledge generation and posited that the information shared by humans generates the knowledge that emerges between the minds of individuals, rather than in the minds of individuals (Stacey, 2001). It follows, if Stacey's position is accepted, that knowledge and the ability to act on it, add to it and to describe it, may be influenced by the perspectives of the people dealing with it: the cultural view becomes important. More importantly, one can conclude that information is not transferred in the sense of Shannon's communication theory, but the process of sharing contextually transforms it. One can start to see how this impacts how we think about innovation.

Similarly, information in the context of one discipline may have a different interpretation in another discipline and perhaps a similar explanation in yet another discipline. From a GST viewpoint, the whole is the composite of these views. The reader may agree that such a multi-disciplinary and holistic view should represent a reasonable perspective on an issue. What may be overlooked however is the relation between the views.

Another aspect that is hidden from view in the GST approach is the organisationally recursively-generative nature of these systems (Morin, 2008, pp. 60-62). In these systems, the components generate the system, and the system generates the components. The parts are more than just components as a result of the relationship with the system, and the system is more than the sum of the elements, as a result of the emerging behaviour that stems from the components and the system (as a context). The system can reflect on itself, as the parts can reflect on itself and the system. Simply put, people can think about the system, change it and be altered by modifications to the system they belong to.

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PRACTICAL DEVELOPMENT

Knowledge and a Method for Inquiry

In the previous section, the discussion shifted from concentrating on information to the concept of knowledge, where information is used to make sense (or to generate meaning) and to act on the inputs from the environment in a certain way. The question that is now obvious is this: If modelling is the way we make sense of the world, how can decisions be made if it is impossible to have an accurate model?

This impacts on how we deal with modern complex issues and development of strategy and operational plans. It has obvious implications for the process of innovation, because as Rogers explains, innovation is only innovation if the idea, object or practice is *perceived as new* and adopted by the target group (Rogers, 2003). Innovation is driven by a range of decisions about a view of advantages, disadvantages and consequences of the change that may come with implementing and use thereof.

In the context of this chapter, the interest is in making these decisions in an ethical manner to unlock innovation for the common good. The author, however, will not consider ethics as a yardstick, purely to decide how ethical (virtuous) a choice is. Instead, the notion of ethics as an integrated strategy (Woermann & Cilliers, 2012) must be considered. The strategy is based, in principle, on an agreement that sense-making is not the same as searching for (an) absolute truth, and that an acceptance of uncertainty and acknowledgement of responsibility for the choices made during the framing of information and situations, is paramount. This is a key position to take, as it allows for a pragmatic approach to the practicalities of modelling systems (mentally and in software) and using it as an anticipatory thinking tool.

The sense-making approach requires using the information and development of knowledge about the whole, parts and relationships making up systems, taking into account a diversity of contextual viewpoints. This knowledge is subject to constant revision. Woermann and Cilliers talk about the attitude of awareness of the fact that the process of modelling to make sense is a given and that it will yield incomplete insight and will by default exclude aspects without the modeller being aware of the exclusions.

This position has found favour in what is called transdisciplinary research as described by Thompson Klein, who refers to the shifts in how knowledge is viewed: from a "foundation or linear structure" to "a network or web" (Thompson Klein, 2004). In physics, the concept of the hologram comes to mind, where the information in the hologram can be reconstructed equally by the original holographic plate, or by a small part of the plate. Moran uses the same metaphor and links it to the recursive nature of complex systems (Morin, 2008, p. 50).

The framework of transdisciplinary research (TDR) allows for a mix of research and enquiry methodologies to be used to develop an understanding of a complex issue from the web of views (including culture, policy, religion, and discipline-specific understanding). It is a recursive approach combining structuring, analysis and synthesis. TDR has the following attributes (Hirsch Hadorn, 2008):

1. Grasp the complexity of the problem and focus on both components of the problem and the interactions between them,
2. Account for the diversity of scientific and societal views of the problem,
3. Link abstract and case-specific knowledge,
4. Synthesize understanding focused on the problem to be solved, and
5. Done for the common good.

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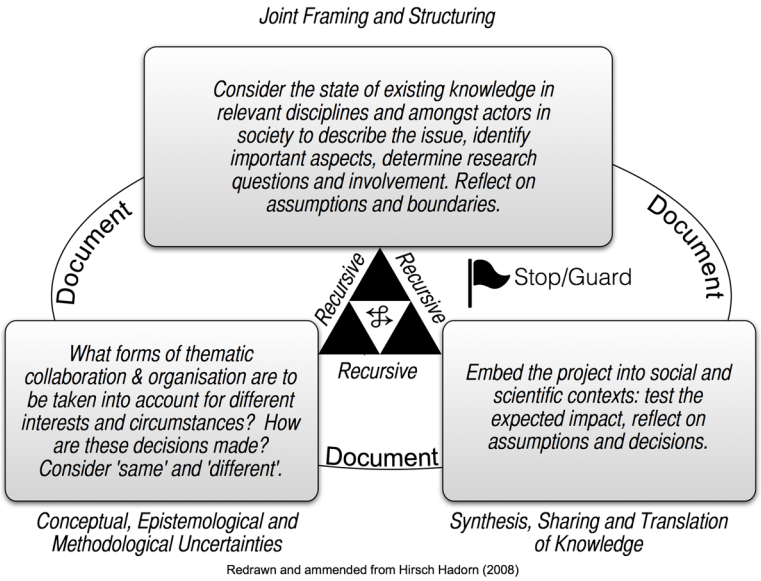
TDR is *inquiry-driven*, not discipline-driven, but recognises the utility of disciplinary knowledge bases in the development of knowledge "*pertinent to the inquiry for the purposes of action in the world"* (Montuori, 2005). It considers context and connection, and it includes knowledge creation by the researcher that is reflective and self-critical. As the requirements are evolved and the structuring continues, possible (re)solutions are synthesised. Rigorous, transparent documentation of all aspects of the recursive process is crucial to the co-development of a result that is accepted as for the good of all. The framework is depicted in Figure 1 as a recursive process.

The framework insists on documenting decisions and assumptions and hints at ways to call for acknowledging that a good-enough, but incomplete, position is reached at some point as a practical way to cap effort, and perhaps to call for a revisiting at a future date when the system (with new understanding embedded) may have evolved, and new features and issues may have emerged (H. Roodt & Koen, 2014).

Good Decisions Based on Anticipatory Capacity Using a Cascade of Models

Knowing why complex problems are hard to address, is an important step in developing a good strategy. Some go so far as to claim that a good problem statement is only possible in hindsight and that one should rely on a hunch to get started. Perez-Breva (2016) says that a problem must be solvable (must have at least one solution), recognisable (one must be able to explain it to people) and verifiable (one must be able to test that the innovation does what is intended). And for many simpler problems this is indeed achievable, but the question that is being asked in the context of Industry 4.0 is very different: How can an organisation stay relevant through innovation practiced at all levels while the speed of change increases, while classic linear decision making fails, and when the system-wide impact of interventions may have unexpected consequences? Is an intervention in the workflow, designed to increase co-creation and anticipatory responses to the changing environment, a possibility?

Figure 1. The transdisciplinary research framework depicted as a recursive process



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Rittel and Webber (1973) stated that one of the intractable problems we face is finding ways to narrow the gap between "what is" and "what ought to be" when we deal with problems that contain society as part of the system. Known as "wicked problems", they do not have optimal solutions (Pidd, 1996). They can only be resolved (an agreed-upon reasonable option is found) or dissolved (by declaring them incomprehensible, irrelevant or by putting the search for an outcome on hold).

Modelling and sense-making reduce complex problems by successive simplification to communicate the essence of the issues being faced. Unfortunately, mental pattern search mostly results in parts of the problem space being linked to previous experience and collapsed into 'known' units. The expectation is that a known dynamic pattern will unfold into the future! Schultz calls this lazy outcome the 'veneer of simplicity' (Schultz, 2010). These mental simplifications deliver simple answers that will seemingly do the job, often with disastrous results!

Klein *et al.* (2011) make a case for anticipatory thinking as an alternative to predictive thinking and calls it the ability to prepare for change and opportunity. Three modes of anticipatory thinking are considered by Klein and his co-authors: pattern matching, trajectory and trend tracking and combinatorial event evaluation. Rhodes and Ross (2009) make a case for model-based methods as part of the survival strategy of engineering organisations. They rightly point out that systems engineering aims to deliver system solutions in the context of a user requirement that evolves. Such systems involve the views and needs of a host of stakeholders and require, according to Buede "big picture people" – systems thinkers (Buede, 2009). A depth of understanding is achieved by iteration through the design process to get to a sufficiently detailed and appropriate solution.

Pieters considers several methods to responsibly capture the intricate patterns and relationships in a problem space to develop non-quantitative models to capture the diversity and possibility of the problem domain (Pieters, 2010). When these models are derived using TDR as a framework, and with appropriate consideration of the need to reflect on both what is inside the description and what was knowingly left out, it is possible to share and communicate an understanding of the problem and to identify aspects that are important to all involved.

General Morphological Analysis (GMA) can be used to gain an understanding of ill-structured domains (Ritchey, 2018) because it allows for the facilitated and collaborative structuring of the field of interest into variables and ranges of conditions along with agreed upon relationships between the entities in the field. It is clear that such a qualitative model cannot be complete or robust in a probabilistic way (J. Roodt, 2007). Like all models, it reflects the understanding of those that were part of the facilitated co-creation of the model, including how the ill-structured domain was described, how the questions about it were framed and what the cognitive biases of those involved (Kahneman, 2012).

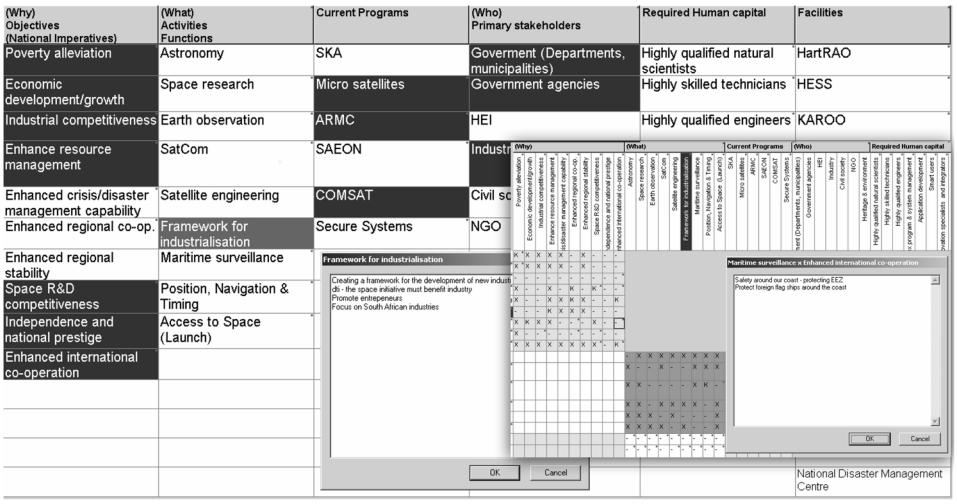
Being qualitative naturally opens it up to broad interpretation. Davenport says that these models developed for decision-making, are black boxes, "*with information going in* [and] *decisions coming out*". He points to the murky processes used to create the decisions and the logic applied as part of the hidden system (Davenport, 2013). This is in essence why the traceability of context, logic and data during the model building process becomes crucial, both in the concept phase and in the codification.

Instead, the quest becomes one of identifying 'possibility trajectory' structures, rather than looking at probabilities of outcomes (Brinsmead & Hooker, 2011), thus neatly overcoming the unreachable goal of finding the single optimal solution. Instead, the goal is to see possible patterns and structure that can be used to make informed decisions about the uncertain future. A typical GMA field is depicted in Figure 2.

The other issue being faced, as mentioned earlier in the chapter, is that complex societal problems (and opportunities) have roots in a multitude of disciplinary fields, including regulatory frameworks, culture

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Figure 2. A typical GMA pattern showing reasoning fields activated and cross-consistency matrix and documented comments



and equivalent knowledge bases, technology and spirituality. Each of these comes with a 'preferred' research and sense-making methodology. This was elaborated upon by Brown (2010) in their work on transdisciplinary research approaches.

Other pattern-based approaches include pattern languages for the architectural design of new solutions and how towns and cities and even houses are designed (Alexander, Ishikawa, & Silverstein, 1977). In the engineering domain, similar approaches are available (deVreede, Kolfschoten, & Briggs, 2006) and include the plethora of design thinking canvasses and approaches available since 2010 (Liedtka, King, & Bennett, 2013). These are all useful in developing a broad common understanding of the complex issue at hand and to search for ways to solve it.

While the qualitative models and simulations convey a certain richness of compelling narratives, quantitative models have the benefit of persuasion by numbers. Dynamic trends and trajectory tracking are valuable in building an understanding of the consequences of systemic change. Rather than working towards a final solution, the knowledge about the systems is built through successive iterations as the system changes over time (often in response to actions by the researchers).

Considering rhino poaching, Koen *et al.* (2017) mentions that although the initial approach was to develop a predictive model using Bayesian Networks, it was soon discovered that the model had more value as a laboratory tool to look for trends based on a range of inputs. This opened up a broader discussion that included a new cluster of stakeholders and a different set of strategies to address resource plundering.

Bayesian network models (BNM) can be used to combine historical data and expert opinion. From a TDR perspective, this is important, as it forces the modeller to consider the past and the boundaries set for the information captured, the current context and a broad stakeholder group, and the reasons why previous attempts at solving the problem may have failed.

Agent-based modelling (ABM) has come to prominence on the back of work in artificial intelligence and uses insights from the concepts of small world networks (Buchanan, 2002). Using software-based agents to represent different actors, and by allowing them to have memory and decision-making capabili-

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ties, often based on heuristic rules, it is possible to build a simulation laboratory to study the combined effects of actions and events. In an opinion piece in Nature, the hope is expressed that this type of approach will overtake the mostly historical modes of decision making (Farmer & Foley, 2009).

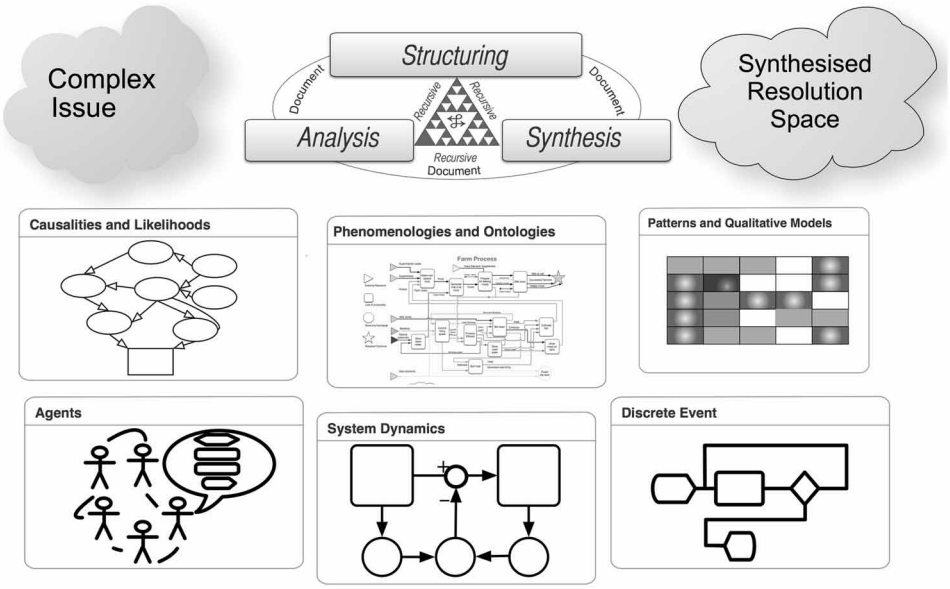
ABM can also be used for quantitative experimentation. ABM has found acceptance in social science and economics, and here the problem of empirical validation of the models and the simulation environments become essential. For example, access to the mental models of a human, or a collective in society tend to be unobservable, and accordingly cannot be accurately represented. Despite these issues ABM has been shown to be useful in understanding industry and market patterns, economic development, understanding patterns of innovation and dynamics of demand and consumption (Fagiolo, Moneta, & Windrum, 2007).

One aspect that had not been discussed is that of the level of abstraction required by different approaches to modelling. Qualitative models tend to contain little detail about micro aspects of the problem space and are often deployed to develop strategy, to understand policy issues and to consider change initiatives. These are highly abstracted models. Models using system dynamics approaches are also highly abstracted and rely on discovery of feedback loops (circular causality) between nodes (or stocks). The temporal dynamics are reflected in the fact that differential equations describe many of the circular feedback loops. It is obvious this type of abstraction is valuable if the system can be closed in a sense.

The following diagram (Figure 3) depicts the different modelling approaches described so far. It includes process-centric approaches like discrete event modelling and also shows the how different views (ontology and phenomenology) play a role in developing a multi-faceted view of a complex issue.

As the cycles and aspects of modelling proceed, different aspects or views of reality are made known. Earlier it was mentioned that some aspects of a domain are intentionally left unexplored. Other aspects remain hidden despite our best attempts at ensuring that we cover the "important parts". The best we can do is to ensure that our models of reality are credible and fit for purpose and that we make decisions based on our understanding in an ethical manner. How do we ensure these models are credible?

Figure 3. A cascade of modelling approaches used to develop an anticipatory capacity



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Credible Models

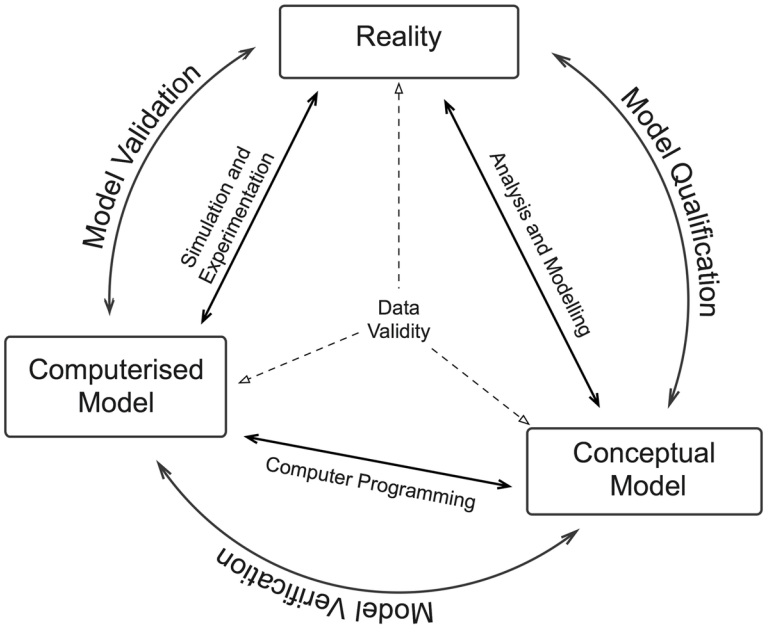
Knepell and Arangno referred to the original work in 1979 of the Society for Modelling and Simulation International (SCS) (Schlesinger et al., 1979) to develop a formal and accepted terminology and methodology for ensuring model credibility (Knepell & Arangno, 1993). Sargent starts the process of qualification, verification and validation (QVV) by considering the reality or problem entity, or the system under scrutiny (Sargent, 2013). This can be a system in the real world, an idea that is proposed as a possible artefact, a process or any phenomenon. In the case of applied systems thinking, the goal is to bring about the change or strategic direction required by actors (Mingers, 2006).

Through a process of analysis (investigation) and synthesis (bringing information and concepts together), a conceptual model is developed. Novak defines a concept as "*a perceived regularity or pattern in events or objects, or records of events or objects, designated by a label*" (Novak, 2010). It implies that the model can be an artefact of any form: verbal descriptions, mathematical equations, graphical relationships, or logical framework, to name a few.

Often the model is then implemented (codified) in some form on a computer (executable software, interactive graphics, etc.). Using this computerised model in a simulation environment, experiments may be conducted and inferences made about the system under investigation (see Figure 4).

After selecting the appropriate method of modelling, the modelling process considers questions such as: "*What should be included and excluded from the model?*" and "*What is the purpose and application of the model?*" (Falkenhainer & Forbus, 1991). Robert Shannon states that there is no formula for model development. It requires skill, experience and an understanding of a broad range of disciplines. He adds that modelling is an iterative process of refinement, selection and assumption testing until a useful and acceptable (for the intended use case) approximation is arrived at (R. E. Shannon, 1975). This is similar

Figure 4. QVV process as described by Sargent (2013)



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to the spiral software development model proposed by Boehm where the software grows in utility with every completed spiral, but there is also a diminishing return on the level of effort with each spiral that is concluded (Boehm, 1988).

'Conceptual Model Validation' describes the steps taken to ensure that the conceptual model is a proper translation of the system under scrutiny. Qualification of the conceptual model is the process of establishing the relevance and adequacy of the abstraction of the real system to the questions the model is expected to answer. The conceptual model must reflect the phenomenological and ontological aspects of the system. As Hoover and Perry state in their work on this subject: Validating the conceptual model can be thought of as a binding process in which the simulation analyst, the decision makers, and the manager of the system agree upon which aspects of the real system will be included in the model, and on what information the model will provide an output. They conclude that there is no standard method of qualification (Hoover & Perry, 1990).

As mentioned, the first step in the building of a model is to consider its (intended) functionality and use, in order to gain a grasp of the entities making up the system and then to consider the interactions among its various components (Ritchey, 1996). From a digital modelling perspective, this is similar to the Function-Behaviour-Structure framework of Gero (2014). The nature of interactions is not necessarily causal, but can also imply co-existence or any other hierarchical or directional relationship. The latter aspects of directionality (what acts on what) and the interpretation of context for focus in the real world, as well as hierarchy, are of particular importance.

Pidd (1996) argues that data should not solely drive a model, but that a model should also drive data requirements and collection. Data should be seen as supporting evidence. When dealing with complex systems, the information gathered about the system, generally speaking, cannot be used to extrapolate to the future behaviour of the system with any confidence. This arises from the adaptive behaviour of complex systems and the fact that they may respond to being investigated.

'Verification' is used to check whether the computerised or codified model was built correctly – that it properly represents all aspects of the conceptual model. When a model is used for experimentation and inference, it is assumed that it will behave like the phenomenon it was abstracted from, or that it will perform in a way that is consistent with what may be expected in the real world. This is called 'Validation'. Even if the model delivers surprising new insight, it must be possible to reason accurately as to why the result is reasonable or not. Petty distinguishes between informal and formal methods of assessment (Petty, 2009).

Independent reviews can be used to validate models in cases where they cannot be reviewed against real events. Independent reviews include:

1. **Scientific, Social or Technical Review:** By experts in the relevant domains who should ensure that the model provides an appropriate representation of the system under scrutiny, based (as far as possible) on current understanding derived from appropriate knowledge bases.
2. **Operational Review:** By those with real world experience within the operational domain to ensure that realistic and appropriate mappings have been modelled.
3. **Independent Review:** By entities not previously involved with the development and use of the model. Their involvement helps to ensure that the model, within a domain of use, produces 'sensible' output. Included within independent review could be comparison with other models, independent studies or interviews, to name a few options.

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The QVV process is inherently iterative for any complex system. This is a result of the process of discovery and boundary setting, changes in focus as new insight is generated and the inclusion of more knowledge frameworks as the process proceeds.

Does this mean that models of complex systems can be verified and validated in an absolute, mathematical manner, or that that should be the aim? This is a fair question and one that was considered by Oreskes (1998) by making a case for evaluation (rather than validation) of models: model validation is impossible if the model is of anything interesting in nature or society, but evaluation and refuting of models are possible. From a complexity perspective, one should return to the fundamental position ascribed to in the first section of this chapter, and that is that no model of complex phenomena is complete or accurate. However, this is no excuse for giving up on modelling as a way of making sense and building understanding, or even as a dynamic method for documenting a current state of affairs, as understood by those involved. In general, there is no reason to believe that any good will come of actions, regardless of how solidly they are based on values and excellent decision making. Rather than throwing out the proverbial baby with the bath water, a pragmatic approach would be to deal with models in the way that Cilliers (2001) proposes: *I would argue that models attempt to grasp the structure of complex systems* (p139*). … Although we cannot escape the use of models, we can also not escape the responsibility involved in using them – a responsibility that can never be shifted onto the models themselves* (p145).

The process of making sense of a complex issue by cascading it through successive layers of model building in a structured fashion is key to developing anticipatory mind-sets. The qualification, validation and verification of models and subsequent experiments (simulation) is an operational thread that runs through the whole process from inception to use and alongside the recursive and iterative process of knowledge discovery. The aim is to deliver a traceable and transparent narrative, co-created by knowledgeable people that address the complex issue in a considered fashion. The next question to address is how credible models support reflexive practice and innovation.

Reflexive Practice and Innovation

Botha *et al.* (Botha, Klerkx, Small, & Turner, 2014) answers our question partially when they consider the question of developing a culture of innovation in the agricultural sector and make the point that innovation is an emergent property of the interaction of researchers working together to understand a complex issue and to co-create a possible solution. It is not easy to achieve this though, and Roux points out that the initial TDR phase of framing and structuring is time-consuming and demanding, and requires leaders skilled in facilitating multi-party learning in groups with individuals from diverse backgrounds (Roux, Stirzaker, Breen, Lefroy, & Cresswell, 2010).

The introduction of reflexive monitors on the co-creation teams addressing the complex problem domain is seen as a pivotal intervention to ensure that team members reflect on process, decisions, actions and progress towards overarching goals. These monitors challenge and encourage and address adherence to frameworks, methodologies and required commitment to accountability.

From an organisational perspective, a broad framework for accountability needs to be in place for morally defendable innovation outcomes. This is required to define the purpose and reach of the knowledge quest and to foster the value systems (‘virtues’) necessary to work with the realities of complexity effectively.

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Finally, it was mentioned that innovation is only innovation if it is adopted for practice (as a solution to a problem). The process of developing a cascade of models at different levels of abstraction, with the ability to support many views of the same complex issue, ensures that a broad and transparent narrative (in fact, a story, as it is being told by those involved) develops around the complex domain of interest. The transdisciplinary research framework requires broad consultation and co-creation of insight, including the targeted recipients of the outcome.

Developing the Enterprise Environment for Innovation: Instruments for Change

Wheatley (2005) is concerned that many practices of organising and leading the enterprise is flawed, as it attempts to dominate life. Leaders control and dominate and react to uncertainty and chaos by tightening controls. Indeed, if one considers the classic eight steps process of Kotter (2011), the position of the leaders (in charge) versus workers are quite clear. Kotter states:

1. Increase Urgency,
2. Build the Guiding Team
3. Get the Vision Right
4. Communicate for Buy-In
5. Empower Action
6. Create Short-Term Wins
7. Don't Let Up
8. Make Change Stick

But disruption introduced by Industry 4.0, which Schwab (2017) says will require new and radical ways to diffuse innovation, and skills to contain the fundamental backlash against the changes, cannot be managed in a top-down manner anymore, as Research In Motion (RIM) found out in 2011 (Molen). That event escalated, and soon afterwards, Blackberry effectively departed the technology landscape. Rodgers summarises the standard change management approaches by grouping them into three broad categories (Rodgers, 2007). He notes that the three types are often used in some combination, and almost never in isolation (Figure 5).

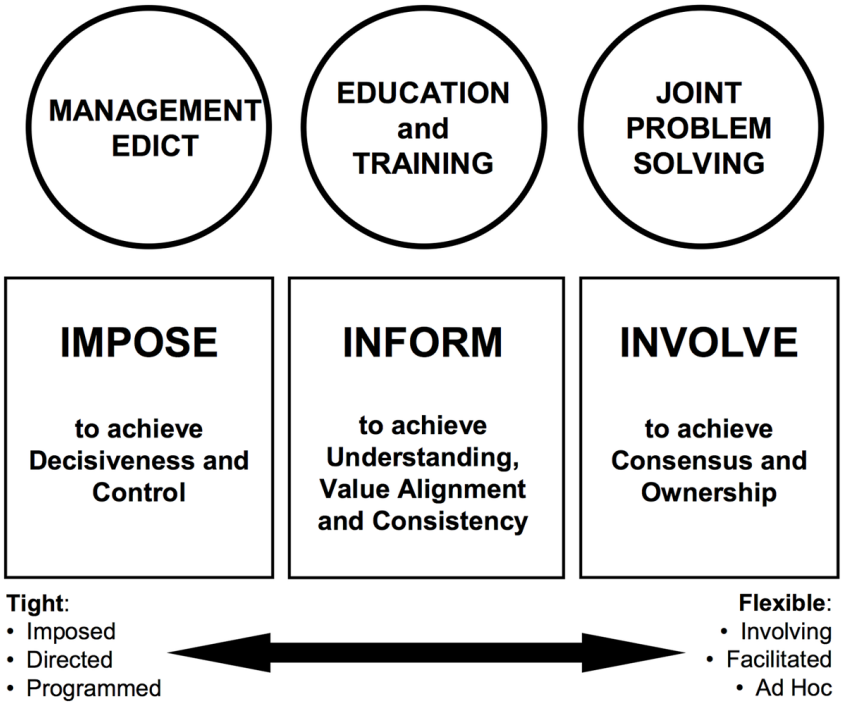
Wheatley (2005, pp. 36-41) draws on the work of others to make a case for self-organisation as a key driver towards an enterprise that is more aligned with complexity principles and lists three conditions:

1. Clarity of identity and intent as enablers for sense-making,
2. Wealth of shared information as the medium for ethical decisions and interaction,
3. Trusting relationships as the pathway to agility and responsiveness.

This is a different approach to life in the enterprise and sits comfortably with the concepts of emergent innovation and reflexive practice – it moves towards a complex adaptive system (CAS). The role of shared understanding and collective ownership of ideas and decisions, is clear. Mobilising parts of an organisation or a whole enterprise into this mode of operation is not without challenges, as was reported by Rowe and Hogarth working with health care (Rowe & Hogarth, 2005).

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Figure 5. Three approaches to change management as depicted by Rodgers (2007)



Ethics

Considering the approaches discussed so far, it is finally possible to return to the question of ethical decision making, by drawing attention to the emergent and reflexive nature of the enterprise environment, and to introduce a set of guiding principles ('virtues') as developed by Woermann (2013). Parallels to the approaches discussed above are obvious.

The first virtue, *transgressivity*, calls into question the strict adherence to rules and regulations in a modern enterprise, where tasks often unfold in unpredictable ways and where previous guiding principles cannot be used blindly. The case is made for an environment where individuals can be bold about decisions and remain humble about the limits of the knowledge available to make the decisions. Shorter and quicker decision cycles, guided by fuzzy or vague general rules, executed in co-creative ways are required. The key to success is in acknowledging and identifying the boundaries, taking risks and that individuals and teams remain self-critical.

Irony can be employed to develop a sense of community when ethics is seen as one of the ways we develop practice and ourselves. The key trait is that of creativity in the face of unfolding opposites, being able to take a playful view on the issue at hand and to facilitate meaning through the mix of organisational and societal narratives. This is congruent with the views of Rodgers (Rodgers, 2008) who values the development of informal coalitions and the engaging of the socio-political aspects of the enterprise.

Moral imagination implies the ability to consider the outcomes of decisions, taking into account that the world is an uncertain place, and that openness and tolerance of a diversity of views are required. As-

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sumptions can be exposed and questioned, context becomes important and visible, and contradictions are seen as views on the system under discussion. A host of possible outcomes may be explored to develop anticipatory skills and to actively judge appropriateness from different disciplinary and cultural positions.

A Case Study From Literature

The PHAAR programme (making a Public Health Approach a Reality) was a change initiative in the public health sector in the United Kingdom. The direction and process of change were uncertain, but considering the features of complex systems and specifically that of CAS, it was clear that the process had to be iterative. The goal was merely to improve alignment between health visiting practice and public health policy. The executive empowered all points of the affected part of the organisation to determine the pace and the direction of change.

As was argued before, complex systems cannot be approached by relying on history only as evidence for the outcomes in the future, and the PHAAR team had to get to grips with the uncertainty and unpredictability and the urge to engineer change, rather than to create conditions for change to emerge (Rowe & Hogarth, 2005, p. 399). A few important aspects of the paper are summarised here to act as signposts at most, and *not* as a 'template for change':

1. The conditions for change developed through a range of actions like reflection, debate, information sharing and knowledge building and development of new relationships.
2. Different views, even within disciplines caused tension and paradoxes that had to be managed.
3. Critical reflection, a necessary ingredient for sense-making and co-creation, was hard to develop.
4. Differences in value systems surfaced.
5. Multi-skilled teams came into being and the community being served was part of the co-creation effort.
6. Some solutions generated by the process were not attractive to some in the bigger health care system, leading to robust debate and eventually rather radical change with support of the Executive team.
7. A smaller set of guiding principles were introduced in place of volumes of standards and guidelines, which added risk and required personal responsibility to come into play.
8. Responsibility for the ramifications of change and unintended consequences was moved into the hands of those introducing the ideas, surfacing contradictions and personal risk.
9. Assumptions were exposed and questioned using sets of 'wicked' questions (p. 402).

The nine elements clearly expand on the three guiding principles that Wheatley mentioned and demonstrates the need for the virtuous guiding principles discussed by Woermann.

Snowden and Boone developed five guiding principles for managers leading in a complex environment that resonate with the approach followed in the PHAAR study (Snowden & Boone, 2007). They call for more interactive communication in an environment where some hard barriers are negotiated up front, so that people can police their own compliance and reaction to local stimuli and develop a coherent response to complex phenomena. Leaders are required to develop an environment from which good decisions and outcomes can emerge, without forcing predetermined outcomes: they have to take some risks in this regard, and finally they need to develop a culture of vigorous debate where diverse views are encouraged. How is this approach injected into the environment?

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Rodgers says that it is not strategies and plans enacted from the top that change organisations, but instead what is said about those plans and strategies: It is how people talk about them, make sense of them and what they do, or don't do, as a result (Rodgers, 2007). This was again highlighted by the dramatic problems that surfaced at a New Zealand technology institute and reported on in 2018 (Cooke).

The classic concept of change management is not valid any longer and is replaced by managers directly engaging with organisational dynamics, being part of informal discussions, and developing coalitions around ideas. By being part of the sense-making process, the manager can deal with the paradox of being in control, AND also not being in charge.

CURRENT RESEARCH AND FUTURE DIRECTIONS

Several solution design methods beyond traditional scientific, operations research and classic engineering are currently in practice. The current methods rely heavily on ideation, rapid iteration and prototype development (products and services). In the experience of the author the key areas that remain hard to master include the development of clear multidimensional and rich strategies for innovatively steering the enterprise through wicked problems, the setting of boundaries for intervention development and skill sets for anticipatory and ethically sound decision making. Our current research themes, with impact in societal regeneration, agriculture under pressure of climate change and living within the means of the planetary resource base (the circular economy), regularly surface the frustration of enterprise leaders that want to be seen to deliver quick decisions and simple solutions.

As a result, current research is focussed on transdisciplinary integrative systems methods and enterprise actionable strategies for thriving under the changes of Industry 4.0 and is reflected to some degree in this chapter. Successful innovation is seen as an emergent property of outcomes and interventions derived according to principles discussed in the chapter.

Specifically, model makers (to use a more accommodating label) are often the individuals with the broad, integrative knowledge base and extensive networks. The application of these resources needs to be investigated further as they could play an important role in energising the knowledge and innovation cycles.

The formal concept of cascading hybrid models for sense-making and decision taking in organisations is relatively new, and more work needs to be done to consider simulation frameworks and tools that will make this approach acceptable and easy to integrate into the enterprise.

CONCLUSION

This chapter steered clear of addressing the specifics of technology push and application pull of the emerging disruption called Industry 4.0. It rather focussed on organisational and individual coping strategies. It was proposed that better understanding of the complexity we face is required to prosper and to continue to innovate. The required innovation is treated as an emergent property of 'doing things right'.

We will need abilities in decision-making that may not exist in the enterprise today, and complex ethical issues will abound. Developing anticipatory skills, reflexive practice and adopting appropriate guiding principles, as part of ingrained ethical decision-making at many levels, will deliver the requisite agility and pro-active approaches required. These skills and understanding of the complex issues being

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faced must be derived from a broad set of knowledge bases that are treated with humbleness. Using a framework for inquiry that is open and builds understanding in a recursive manner is required, and the argument was made that a transdisciplinary approach is applicable.

Developing models and using them to understand the structure of the complexities that will be part of the societal and technological change, is imperative, despite that fact that it is acknowledged that these models can never be complete or absolutely accurate. The benefit and necessity for access to a cascade of model representations of the structure of the complex issues, with representations derived at different levels of abstraction, was explained.

Changing the way that the enterprise operates to include model making as part of anticipatory thinking, was discussed. Arguments were made for participatory and co-creative approaches, where teams have multiple skills and where responsibility resides at all levels of ethical and critical decisions. Although hard to implement, examples abound and using complex adaptive systems as a metaphor indicated how this could be achieved.

Finally, it was noted throughout the chapter that adopting a complexity viewpoint and using that to adapt to change, is not a license for anything goes relativism. The position taken in this chapter is that it is crucial to teach critical reflection to ground perspectives (models, narratives), to remain open to different views, to acknowledge limits to knowledge, to be playful and humble and to ingrain value directives that capture these elements.

We can only do our best to put in place the mechanisms that allow us to always question our "knowledge" and to continue exploring. We must try to imagine possible futures, and to carry on modifying our views about reality, and about what it is that we want. – Peter Allen (2000)

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KEY TERMS AND DEFINITIONS

Abstraction: A term used to describe the level of detail in a model. Highly abstracted models have minimum detail and are used at the strategic level of thinking. Low abstraction indicates lots of details down to the micro level of process and parts.

Causality: A term to describe cause and effect. Several types of causality are recognized: linear (x causes y and a doubling in x causes a doubling in y), circular (x causes a change in y which in turn causes a change in x), recursive (x is caused by the system that is x – society is made of people that bear children that make up society), nonlinear (as opposed to linear the change in x causes a change in y that follows a power law, for example).

Complexity: A feature of phenomena that is hard to describe using reductionist (looking at the parts of a system) approaches, with no agreed upon theory or science.

Decision: Action based on judgement of a situation.

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Enterprise: A broad concept of all human activity, from traditional business to not-for-profits and everything in between.

Ethics: Values and moral principles that govern behavior in society.

Holism: A concept to describe systems consisting of interconnected parts that combine in non-linear ways to make up the system so that the system is more than the sum of the parts.

Innovation: an offering experienced as new and valuable and subsequently adopted for use by an individual or collective.

Model: A representation of something in the world, used to reason about the world and to develop understanding. Models include artefacts, process descriptions, ideas, computer software (amongst others) that reflect aspects of past, current, or imagined future reality.

Reality: A view and experience of the world by an individual or collective.

Transdisciplinary: A theoretical (axiomatic) inquiry method and position that transcends disciplines and considers all knowledge bases on an even footing.

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Chapter 8
Towards an Industry 4.0–Based Maintenance Approach in the Manufacturing Processes

J. Roberto Reyes García
University of Twente, The Netherlands

Alberto Martinetti
University of Twente, The Netherlands

Juan M. Jauregui Becker
University of Twente, The Netherlands

Sarbjeet Singh
Luleå University of Technology, Sweden

Leo A. M. van Dongen
University of Twente, The Netherlands

ABSTRACT

Maintenance is one of the key application areas of Industry 4.0. Every day, maintenance managers and technicians face the challenge of ensuring maximum machine reliability and availability, while minimizing the utilization of materials consumed by maintenance and repairs. As productivity is pressured to further improve, finding a successful balance between these aspects is becoming increasingly difficult. Therefore, integrating condition-monitoring systems with predictive and prescriptive maintenance principles, a new Industry 4.0-based maintenance can be obtained that enables maintenance engineers to better deal with this challenge. In this context, Maintenance 4.0 expands existing maintenance functions by the integration of Industry 4.0 technologies, like internet of things, cyber physical systems, augmented reality, and 3D printing. This chapter presents the main maintenance areas that are supported and enabled by Industry 4.0 technologies and introduces an Industry 4.0-based predictive maintenance approach for the manufacturing industry.

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INDUSTRY 4.0 AND MAINTENANCE

The term Industry 4.0 (I4.0) refers to a new technological vision on how management of manufacturing and production processes can be redefined through the implementation of advanced information technologies, robotics and monitoring devices (Kagermann, Wahlster, & Helbig, 2013) (Deloitte AG, 2015) (Gottorp Jeppesen, 2015). The "4.0" designation suggests that the world is now facing the fourth industrial revolution.

Figure 1 illustrates the transformation of manufacturing industry through the four industrial revolutions moments.

The First Industrial Revolution ran from 1760 to 1840; it was driven by the introduction of mechanical production facilities with the help of water and steam power to replace manual labor. It includes the adoption of structured chemical manufacturing and iron production processes. In general terms, it can be summarized as the rise of factory systems.

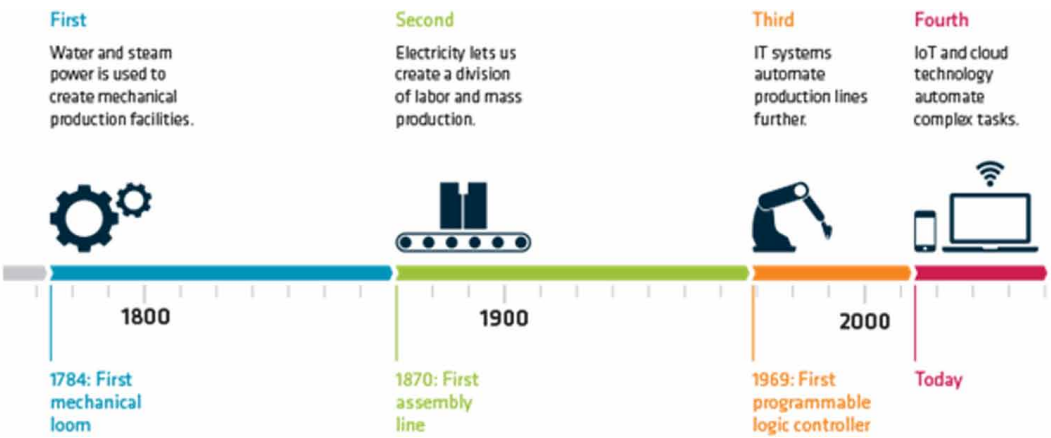
The Second Industrial Revolution, also known as the Technological Revolution, ran from 1870 to 1914 and was driven by the introduction of the division of labor and mass production with the help of electrical power. The factory systems were developed to allow mass production through assembly lines. This booming period was characterized by inventions that radically changed the life style: telegraph and telephone, typewriter, lightbulb, high voltage electric current, first car, first plane and compressed-air brake.

The Third Industrial Revolution, known as the Digital Revolution, started in the 1960's and marked the change from analogue and mechanical technology to digital technology that further automates production.

Programmable Logic Controller (PLC) is universally considered the main expression of this radical change in production manufacturing. It enabled to automate several processes reducing the human involvement.

Finally, the Fourth Industrial revolution started in 2010 and is based on Cyber-Physical Systems (CPS) and the use of the internet to create networks in the production environment and bring services to the customers and the organizations themselves (Kagermann, Wahlster, & Helbig, 2013) (Deloitte

Figure 1. Industrial revolutions' timeline
Source: *Gottorp Jeppesen, 2015*



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AG, 2015) (PwC, 2016) (Geissbauer, Vedso, & Schrauf, 2016) (Bruurmijn, 2016) (Sniderman, Mahto, & Cotteleer, 2016) (Khan & Turowski, 2016).

In general terms, I4.0 is a new production paradigm in which manufacturing industry and production processes will be redefined through the implementation of advanced information technologies, robotics, monitoring devices, and the internet (Kagermann, Wahlster, & Helbig, 2013) (Deloitte AG, 2015) (Sniderman, Mahto, & Cotteleer, 2016). Moreover, Industry 4.0 enables new business models focused on services. In the very short future, there will be millions of intelligent production facilities that are all across connected, and they will provide huge quantities of data (big data) about their own operating conditions and product statuses in the cloud (BDI, 2016). All that big data can be used to optimize products and the process themselves. Moreover, smart algorithms can link existing (historical) data to new (incoming) information and predict disturbances caused by the new operational conditions.

Besides, big data provides a foundation for offering both to the workers of the production facilities and to the customers, personalized data-based services in addition to the physical end-product. For instance, operators can collect and analyze data about the total amount of raw materials they get for all of the machines they are responsible for, and use it to generate new services, such as an automatic reconfiguration planning that can cope with the lack of materials. Customers on the other hand, can use the data to get services such as personalized reports in their own IT system, with the information of the possible delays and new forecasted delivery time of their products.

Maintenance 4.0

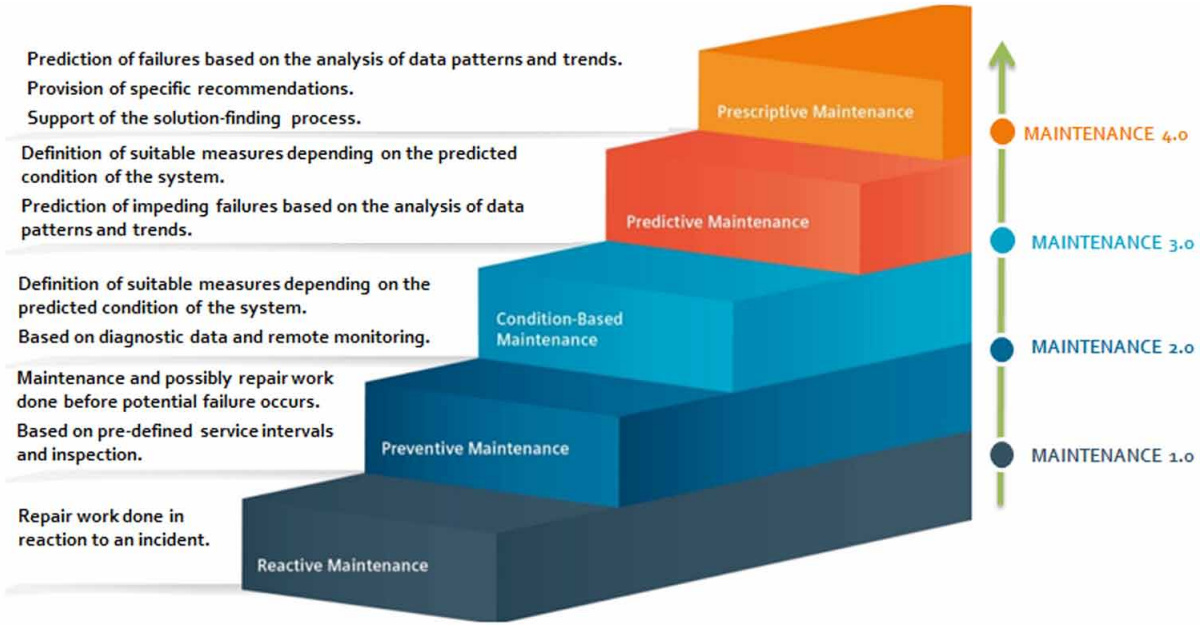
One of the key challenges for I4.0 relates to the goal of producing tailored and customer-specific solutions (Deloitte AG, 2015). For this to be possible, manufacturing systems must possess a high degree of flexibility, availability and reliability, which are considerations that can now be achieved by means of a good maintenance strategy and management. Therefore, the field of maintenance plays an important role to raise the potential of I4.0. Besides, maintenance is one of the application areas of I4.0 (Kans, Galar, & Thaduri, 2015).

Maintenance is a complex process that essentially involves the planning, organization, implementation and monitoring of all the technical and administrative processes associated with inspecting, servicing, repairing and enhancing machines and systems. In the context of I4.0, the maintenance function is often denoted as Maintenance 4.0, Smart Maintenance or e-Maintenance (Fumagalli, Macchi, Colace, Rondi, & Alfieri, 2016). Maintenance 4.0 refers to a form of self-learning and smart systems that predicts failures, makes diagnosis and triggers maintenance by making use of the Internet of Things (IoT) (MacDougall, 2014). Smart maintenance has enormous potential in terms of information and innovation, by making use of real time data regarding the overall status of the machine, its main components, the availability of spare parts, and the tracking of the maintenance staff performance (Kranz, 2017). Figure 2 shows the evolution of the maintenance function and the place of Maintenance 4.0.

For creating a Maintenance 4.0 policy, I4.0- and IoT- technologies are a crucial enabler (MacDougall, 2014) (Fraunhofer IPA, 2016) (Roubaud, 2017). With these technologies, faults and fluctuations that were invisible before, can be now detected and sometimes even predicted. Instead of solving a problem after it happens, with Maintenance 4.0 systems, production engineers will be alerted ahead of time in order to take the necessary actions to ensure no problem occurs at all (Roubaud, 2017).

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Figure 2. Maintenance evolution
Source: *Adapted from Kalt & Rosenberger, 2015*



MAINTENANCE AREAS SUPPORTED AND ENABLED BY INDUSTRY 4.0 TECHNOLOGIES

Information availability in the manufacturing sector can be significantly improved, which in turn can be used to develop optimized (predictive) maintenance strategies (Fraunhofer IPA, 2016). That is particularly possible by means of the technologies and best practices coming along with I4.0 (e.g. increasing standardization, overall lowering of the cost of the monitoring technologies, evolution in the market of solutions' providers, migration to cloud models) (i-scoop, 2017).

Furthermore, the value of large volumes of data generated in the production floor is not limited to helping maintenance personnel to predict and prevent breakdowns. Once the data has been processed and disseminated by the smart maintenance service, it can also be used to enable continuous improvements to machinery and systems (ACATECH, 2015). Particularly, four maintenance areas can benefit from the Industry 4.0 approach and its technologies: 1) Condition Monitoring (CM) & Condition Based Maintenance (CBM); 2) Predictive Maintenance (PdM); 3) Prescriptive Maintenance (RxM).

Condition Monitoring (CM) and Condition-Based Maintenance (CBM)

In order to maintain its functionality for critical mechanical systems, their condition should be periodically evaluated to decide upon the required maintenance activities to be performed. In this regard, Condition Monitoring (CM) and, consequently, Condition-Based Maintenance (CBM) are suitable for maintenance activities based on constant monitoring of an asset.

The trigger for the CBM activity is a measured parameter that is indicative of the machine condition. This may be a performance indicator, or a diagnostic measurement that gives early warning of deteriora-

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tion, and is termed condition monitoring CM (Starr, et al., 2010). Therefore, CM can be referred as the heart of CBM (Campos & Prakash, 2006).

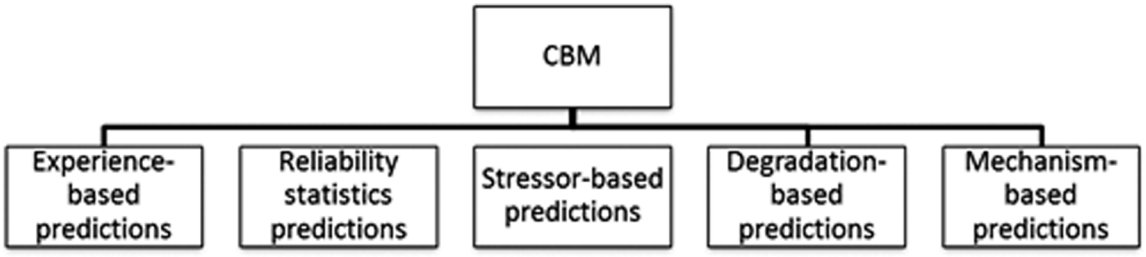
CM is the process of monitoring a parameter of condition in machinery (e.g. vibration or temperature), in order to identify a significant change which is indicative of a developing fault (ISO, 1993) (IAEA, 2007) (Tiddens, Braaksma, & Tinga, 2016). On the other hand, in CBM, once the timing of equipment failure is known, action can be taken to prevent or delay failure. CBM dictates that maintenance should only be performed when certain indicators show signs of decreasing performance or upcoming failure. In CBM, sensors are installed in the system to monitor its components and perform maintenance based on the monitored system's health (Jardine, Lin, & Banjevic, 2006) (Nain & Varde, 2013) (Lee, Wu, Zhao, Ghaffari, & Liao, 2014) (Farrar & Lieven, 2007). Similar to CM, CBM consist of three steps (Jardine, Lin, & Banjevic, 2006), where actually the first two make reference to the CM process (ISO, 1993) (IAEA, 2007):

1. **Data Acquisition:** Is the process of capturing relevant condition information which can indicate the health status of the system. This data can be very versatile ranging from temperature, oil analysis, vibration data, humidity data, etc.
2. **Data Processing:** Cleaning the data from errors/noise and analysing the data to improve its understanding and interpretation. The processing of data is very dependent on the type of data. For example, analysis of vibration data and oil data apply different techniques.
3. **Maintenance Decision Making:** Based on processed data a decision must be made whether maintenance is required. Decision support can be divided into diagnostics and prognostics. In the former is focussed on detection, isolation and identification of faults when they occur. The latter focuses on predicting faults before they occur.

Additionally, CBM allows preventive and corrective actions to be scheduled at the optimal time, thus reducing the total cost of ownership and of maintenance as well (Starr, et al., 2010) (IAEA, 2007). However, CBM also implies extra costs to the maintenance cycle which would not exist in other forms of maintenance. In particular, CBM is highly effective where safety and reliability is the paramount concern such as the aircraft industry, semiconductor manufacturing, nuclear, oil and gas industry (Fiix®, 2017).

In the context of providing decision-making support for maintenance actions, CBM can be referred as a prognostics maintenance technique (Jardine, Lin, & Banjevic, 2006). In this regard, Tiddens et al. (Tiddens, Braaksma, & Tinga, 2015) propose a framework consisting of five maturity levels of prognostics, which can also be representative as a CBM classification as shown in Figure 3.

Figure 3. Prognostics classification framework



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The proposed levels are:

1. Experience based predictions of failure times are based on knowledge and previous experience outside (e.g. Original Equipment Manufacturer) or within the company.
2. Reliability statistics prediction analyses are based on historical (failure) records of comparable equipment without considering component specific (usage) differences.
3. Stressor based predictions are based on historical records supplemented with stressor data (e.g. temperature, humidity) to include environmental and operational variances.
4. Degradation based predictions are based on the extrapolation of a general path of a prognostic parameter, a degradation measure, to a failure threshold. The prognostic parameter is inferred from sensor readings. The prediction includes the current state of degradation and results in an expected lifetime of a specific system in a specific environment.
5. Mechanism based predictions are based on direct sensing of the critical failure mechanisms of individual components. It results in an expected lifetime of a specific system in specified conditions.

In general, the various types of CBM usually found in practice are (Jardine, Lin, & Banjevic, 2006) (IAEA, 2007) (Tiddens, Braaksma, & Tinga, 2016) (Fiix®, 2017):

- **Vibration Analysis:** Rotating equipment such as compressors, pumps, motors all exhibit a certain degree of vibration. As they degrade, or fall out of alignment, the amount of vibration increases. Vibration sensors can be used to detect when this becomes excessive.
- **Infrared:** IR cameras can be used to detect high temperature conditions in energized equipment.
- **Ultrasonic:** Detection of deep subsurface defects such as boat hull corrosion.
- **Acoustic:** Used to detect gas, liquid or vacuum leaks.
- **Oil Analysis:** Measure the number and size of particles in a sample to determine asset wear.
- **Electrical:** Motor current readings using clamp on ammeters.
- **Operational Performance:** Sensors throughout a system to measure pressure, temperature, flow, etc.

Predictive Maintenance (PdM)

The common premise of Predictive Maintenance (PdM) is that regular monitoring of the actual mechanical condition, operating efficiency, and other indicators of the operating condition of machines and process systems, will provide the data required to ensure the maximum interval between repairs and minimize the number and cost of unscheduled outages created by machine failures (Mobley, 2002). PdM is a condition-driven preventive maintenance program, but unlike CBM, PdM goes a step further and once data is coming from equipment in real-time (or near real-time), advanced analytics are used to identify asset reliability risks that could impact business operations (Bellias, 2017).

Simply stated, PdM is a philosophy that, uses the actual operating condition of plant equipment and systems to optimize total plant operation (Mobley, 2002). Typically, predictive maintenance decreases the total machine downtime by 30% to 50% and increases machine life by 20% to 40% (ACATECH, 2015).

Similar to CBM, when predictive maintenance is working effectively, maintenance is only performed on machines when it is required. That is, just before failure is likely to occur. This brings several cost savings (Fiix®, 2017):

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- Minimizing the time that the equipment is being maintained;
- Minimizing the production hours lost to maintenance; and
- Minimizing the cost of spare parts and supplies.

In addition, a well-known best practice in industry is to CM in conjunction with some form of PdM to determine a machine's current maintenance status. Explicitly, one can say that any form of maintenance of machinery is based on an indication that a problem is about to occur. As a consequence, both the CM and PdM of machinery will (Smith, 2016):

- Avoid any unexpected catastrophic breakdowns that would otherwise have expensive or dangerous consequences;
- Reduce the number of overhauls on machines to a minimum, thereby reducing maintenance costs;
- Eliminate unnecessary interventions with the otherwise consequent risk of introducing faults on smoothly operating machines;
- Allow spare parts to be ordered in timely manner, thus eliminating costly inventories;
- Reduce the intervention time, thereby minimising production loss via unanticipated time delays, because the specific fault to be repaired is known in advance, enabling any overhauls to be scheduled when it is most convenient.

However, when implementing PdM, cost savings also come at a price. Some CM techniques can be expensive and could require experienced personnel in data analysis in order to be effective. Besides, despite the fact that of PdM has existed for many years, the massive investments in technology typically needed to handle the massive volumes of data required, had limited deployment to only the largest organizations.

Conversely, the decreasing cost of sensors, computing power, and bandwidth, coupled with increasing technological advancements, has made PdM a much more viable option, and one that could be feasible to scale on a broad level across facilities and organizations of all sizes (Coleman, Damodaran, Chandramouli, & Deuel, 2017). Besides, with the increasing effect of big data instrumentation and the IoT, more conditional, usage and wear data exists on assets today. This, enables PdM to utilize smart and connected technologies that unite digital and physical assets, which makes small-scale applications also possible (Watts, 2016).

It is of outmost importance to realize that simply gathering the information from sensors and systems is not enough to yield the benefits of PdM. The ability to aggregate and then analyze data can be crucial to predicting malfunctions, but this often requires new capabilities for creating, handling, and making use of data (Coleman, Damodaran, Chandramouli, & Deuel, 2017). Fortunately, with the boost of Industry 4.0 and its technologies, PdM analytics capabilities are increasingly growing in tandem with the growth of connectivity and data, enabling organizations to make sense of the data they collect.

Computerized Maintenance Management Systems (CMMS)

In response to the lack of an actual link between maintenance solutions and monitoring techniques (S.Takata, et al., 2004), advanced manufacturing systems have introduced the use of CM applications for maintenance purposes in order to gain awareness of equipment condition and to identify failures ahead of time (M.Mori, M.Fujishima, Komatsua, Zhao, & Liu, 2008). Real-time monitoring of machine

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tools and equipment together with visualization and data analysis, under the umbrella of collaboration between the two systems, can lead to condition-based maintenance techniques (Mourtzis, Vlachou, Milas, & Xanthopoulos, 2016).

Today, a new generation of cloud-based Computerized Maintenance Management Systems (CMMS) can digitally capture asset information in real-time to help predict maintenance issues, improve maintenance staff efficiency, assist with regulatory compliance, and manage inventory and budgets (Lachance, 2016). CMMS can be effective for any organization that is constantly working on reactive maintenance and unable to do preventive maintenance, frustrated with tracking and managing spare parts inventory, having difficulty with providing documentation for regulatory compliance, or wasting time on costly manual processes for tracking maintenance (eMaint, 2017). These new systems are scalable, meaning they easily capture today's data and are also designed to capture the demands of tomorrow's data before it is even known what that data is or how large their demands will be. CMMS are also easy to use and will help the organizations to save time, money and a lot of headache. Cloud-based systems are growing in popularity because individual operators can now access the system online. A cloud-based CMMS solution works by storing asset data, automating work order and request processes, monitoring equipment using predictive maintenance, scheduling maintenance work and resources, recording inventory levels, and providing management with reports in order to make data-driven decisions, all in a cloud-based environment (Lachance, 2016).

There are quite a lot of advantages when it comes to cloud-based maintenance management applications. Simply, anything that is cloud-based means that the application is hosted through the internet; these applications are often utilized in CMMS tools. Five of the main advantages are listed below (Chan, 2017):

- **Ease of Use:** First of all, the application and data are stored within a cloud service then can accessed just about anywhere. Wherever a mobile device is available, there's access. This is especially handy if the application is specifically designed for a mobile usage.
- **Backup:** When using a cloud-based system, and it has been done correctly, the server hosting the information is often hosted between multiple locations. Meaning that if locally hosted information is ever lost, then there's still a backup of all the data in a secure location.
- **Real-Time Collaboration:** When using a cloud-based application, it means that anything anyone does is immediately related to the group at large. This means that if someone is editing a document, then others who have access can also edit it in real-time while also seeing what the first edits are impacting. This level of transparency and immediacy really bolsters a team environment and allows for collaborations that simply traditional applications can't match.
- **Always Updated:** The greatness that comes with cloud-based computing is that the data and software is hosted off-site. This means that up-time is constant and that updates to bugs and errors can be rolled out instantly. Making sure that the applications are running smoothly and allowing users to focus on what matters: their work.
- **History:** When any changes are made within a cloud-based maintenance management application, they'll have a time stamp to when any updates have taken place. This gives users the full picture of what happened if something goes wrong or if there's the need to look back on all the maintenance that have been performed on a given asset, time frame, or by whom.

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Prescriptive Maintenance (RxM)

As industry adopts Software-as-a-Service (SaaS) and cloud-based systems such as CMMS, there is greater opportunity to take control of operations, quality and safety to move beyond preventive or predictive maintenance. In fact, the ability to connect assets and feed information into a central system gives organizations the power to turn data into powerful insights and automatically take corrective, preventive or predictive action (eMaint, 2017).

With the digitization of the industry and the advancement of computing and visualization technologies, a new era is emerging in the fields of maintenance, the so-called prescriptive maintenance (Matyas, Nemeth, Kovacs, & Glawar, 2017). The concept of prescriptive maintenance extends beyond the mere prediction of failures; based on the analyses of historical data and incoming real-time data, required maintenance measures are predicted by a system and a course of action is prescribed. This allows for a flexible maintenance strategy in which maintenance is only applied when and where it is needed. This virtually eliminates the traditional preventive maintenance schedule (Kovacevic, 2017). Don't just predict problems, prescribe a solution. That is the premise behind Prescriptive Maintenance (RxM) (Kennedy, 2017).

By evolving from time based, to condition based, to predictive and prescriptive maintenance, companies are evolving their maintenance systems from being simply efficient to becoming truly strategic. Beyond maintenance, cognitive systems can integrate maintenance and operations data with other data sources, such as quality, warranty and engineering data, to become critical to how entire companies operate. RxM means moving from planned preventive maintenance to proactive and smart maintenance planning (Khoshafian & Rostetter, 2015). Though RxM is still in its infancy, many thought leaders are considering its potential to become the next level of reliability and maintenance best practice (Kennedy, 2017).

Prescriptive maintenance requires that various asset management and maintenance systems are well integrated. For example, a predictive maintenance solution might recommend that a piece of equipment get overhauled based on analysis of vibration and temperature readings, but a prescriptive system would kick off a work order to field technicians based on this information and oversee the entire maintenance workflows (Bellias, 2017). Thus, when a change in the equipment occurs, prescriptive maintenance will not only show what and when a failure is going to happen, but why it is happening. Taking it one step further, prescriptive maintenance will take the analysis and determine different options and the potential outcomes to mitigate any risk to the operation (Kovacevic, 2017).

Several key business drivers are stimulating interest in Rx strategies and driving solution development. For example:

- **Automation:** As more automation is used in manufacturing, the speed of response required in dealing with maintenance issues is going to get faster (Miklovic, n.d.).
- **Economics:** Decisions as to what's the best option from an economic standpoint are getting more complex. "It just isn't enough to know what can fail or when it might fail … it requires having enough information to understand the options for maintenance as well as the financial implications of each option" (Miklovic, n.d.).
- **Workforce Changes:** Older workers are retiring, and newer, younger workers expect smart, assistive tools to help them do their job (Kennedy, 2017).
- **Operating Conditions:** Assets not only fail by their own means, but also by the manner in which they are operated (Kennedy, 2017). For example, a pump manufacturer will recommend specific

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operating design conditions such as discharge pressure and temperature, but there is a lot of variability in process operating conditions and also in the composition of the fluids. Prescriptive analytics can consider these conditions and make recommendations accordingly.

- **Asset Performance:** A higher level of sophistication is required in the way asset and process data are organized (Kennedy, 2017). With the Industrial Internet of Things and Services (IIoTS), analytics platforms are unique in their ability to ingest years of operational data and massive quantities of unconventional data scattered through different systems of record.

On the other hand, the volume of available data for maintenance decisions has increased significantly with the growing popularity of condition monitoring, multisensory technologies and cloud computing. Therefore, one major problem for developing data based prescriptive maintenance measures is the lack of formalized data structures (Matyas, Nemeth, Kovacs, & Glawar, 2017). Even when organizations are successful with PdM, they may still not be able to move to prescriptive maintenance. There are numerous barriers, but a few have been listed below for consideration (Kovacevic, 2017);

- **Cost:** While the cost of the sensors, data storage, and analytical engines come down, there is still a cost in the hardware and software. Also, there will be some learning costs that are incurred when organizations are still using traditional maintenance techniques while prescriptive maintenance is being tested and validated.
- **Regulations:** Certain regulations may not allow the traditional maintenance approach to fade into the past. Take, for example, the requirements to replace or rebuild pressure relief valves (PRVs). Even though there is evidence that the life of the asset may not impact the reliability of it, PRVs must still be replaced on a time-based frequency. As a result, prescriptive maintenance may not be allowed in place of traditional maintenance activities when dealing with regulatory bodies.
- **Culture:** Depending on the level of trust in technology in an organization or the long-held beliefs of what maintenance is and how it should be done, there may be significant hurdles to overcome with the company culture to implement prescriptive maintenance.

So, one should keep in mind that, as stated by James Kovacevic, founder of *High Performance Reliability*, and author of *A smarter way of preventive maintenance*: *Prescriptive Maintenance can be a powerful approach to maintenance if done properly. However, we are just at the beginning of the journey with it, and we will likely see it transform how maintenance is performed in the years to come.*

INTRODUCTION TO AN INDUSTRY 4.0-BASED PREDICTIVE MAINTENANCE APPROACH FOR THE MANUFACTURING INDUSTRY

The importance of the maintenance function is nowadays widely recognized in industrial organizations. Due to its influence on the production system and on other areas such as quality and safety, but especially as a consequence of its financial impact, companies are looking upon the maintenance function more cautiously. Industry experience shows that selecting an effective and efficient maintenance strategy can have a significant effect on the performance of production systems and on reducing overall expenses (Al-Najjar & Alsyouf, 2004) (Alsyouf, 2007) (Pintelon & Parodi-Herz, 2008) (Georgescu, 2010). Moreover,

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increasing profits in larger amounts by means of savings in unnecessary maintenance expenditures has been claimed as easier and more likely to happen than by increasing sales (Wireman, 2007).

Since failures can be reduced to a minimum level, improving the performance of the maintenance function will mainly reflect in increased availability and higher productivity. Differences between carefully maintained systems and systems that are badly or not maintained at all, are also reflected in the cost and quality of the final product. Therefore, it is essential not to neglect the performance of the maintenance actions and look for its continuous improvement.

Every day, maintenance managers and technicians face the challenge of ensuring maximum machine reliability and availability, at the same time as keeping the costs and amount of materials consumed by maintenance and repairs to a minimum. However, this is a demand that existing maintenance concepts are usually unable to satisfy. Based on CM systems and predictive to prescriptive maintenance principles, an Industry 4.0-based maintenance approach enables maintenance engineers to deal with such demand.

With this approach, firstly the root-causes of failures are identified. Secondly, data from sensors monitoring machine condition is automatically reviewed to pick up any patterns that indicate a possible fault. And thirdly, all retrieved data is processed and analysed by specialized software. This allows the onset of a stoppage to be recognized early and corrective measures to be planned and introduced in the most effective way. It also means unplanned downtimes can be avoided and both staff and resources can be employed more effectively.

Founded on predictive capabilities, the employment of an Industry 4.0-based predictive maintenance approach aims at reducing unscheduled downtime and saving cost by increasing the machines' reliability. At a glance, usually two pillars are needed for a successful implementation of a PdM programme: 1) a condition monitoring system (CMS); and 2) a suitable computerized maintenance management system (CMMS). Additionally, a third component is proposed here, the utilization of a simplified Mechanism Based Failure Analysis (sMBFA). Figure 4 shows the three components for an Industry 4.0-based predictive maintenance approach for the manufacturing industry.

Simplified - Mechanism Based Failure Analysis

The first step in this approach is to follow a method based on the physics of failure as suggested by Tinga (2012). The procedure is called the Mechanism Based Failure Analysis (MBFA). The premise of the method is that by understanding and modelling the component failure mechanisms that lead to a system failure, the time to failure for a given usage profile can be calculated accurately. Then, that information can be utilized to assess the optimal maintenance interval. To carry out the sMBFA, the 5 steps shown in Figure 5 need to be followed.

Step 1: *Define the problem*. The first step in the analysis is the problem definition, starting with the specification of a failure. In this step, normally a functional failure is described. Then, that failure is used as the top event in the fault tree analysis that will be developed in the next step.

Step 2: *Determine the failure modes*. The next step in the failure analysis procedure is the execution of a Fault Tree Analysis (FTA) to identify all failure modes that could possibly lead to the failure defined in the first step. The resulting fault tree should indicate all possible underlying events (root causes) that may be responsible for the occurrence of the top-level event.

Step 3: *Determine priorities in the failure modes*. Since the number of failure modes is considerable, a selection of the most critical modes must be made. This selection is usually made based either

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Figure 4. Industry 4.0-based Predictive Maintenance approach proposed for the manufacturing industry

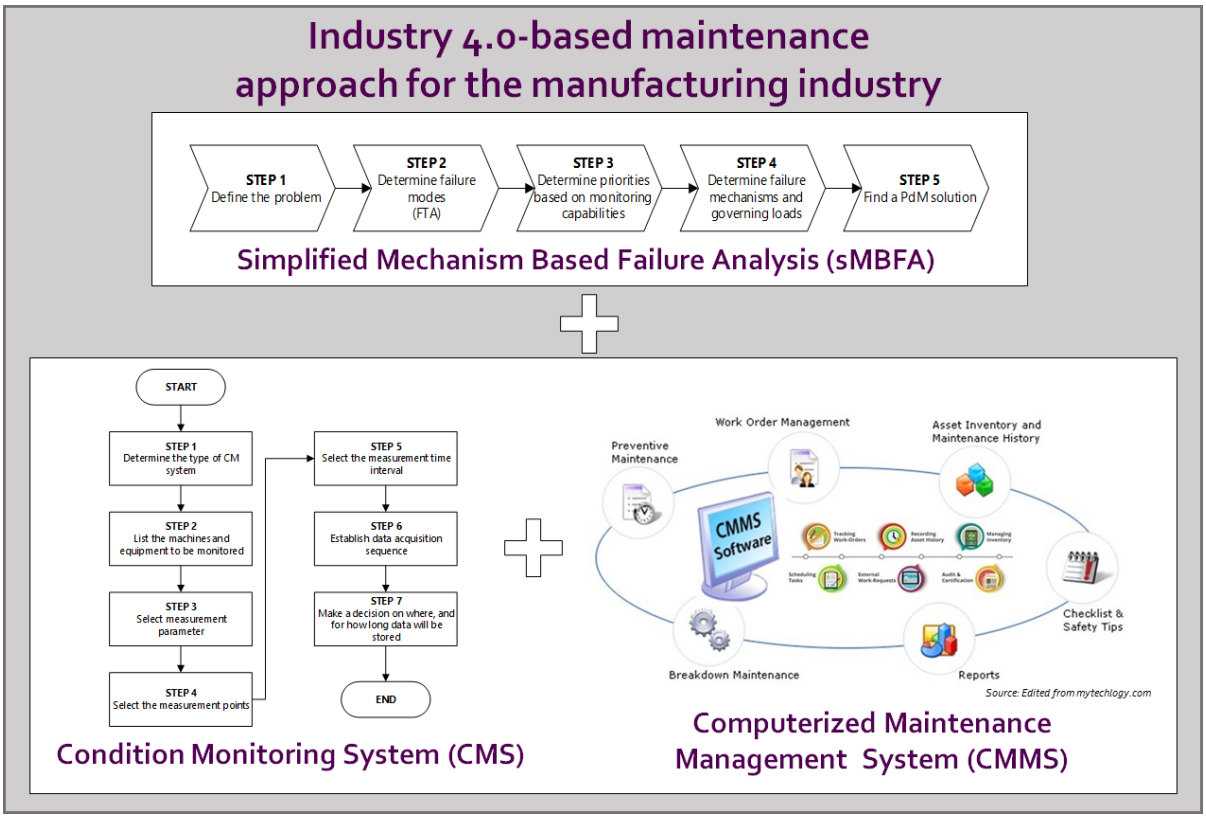
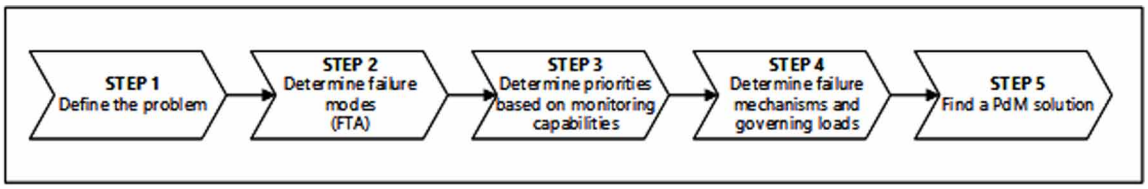


Figure 5. Basic steps of the sMBFA
Source: Based on Tinga, 2012



on costs or on failure frequency (which is related to availability and safety). However, in this case, the interest lays on establishing a PdM programme, therefore, the prioritization is based on the capabilities to monitor the failures.

Step 4: *Determine the failure mechanisms and governing loads.* The next step in the failure analysis is the assessment of the failure mechanisms causing the various failure modes. This final deepening step of a root cause analysis is essential, since it provides valuable insight in the possible solutions for the problem. In addition to the failure mechanisms, the governing loads that eventually because failures can also be determined. Reduction of this load will yield an increase of the system service life, whereas monitoring of this load enables the prediction of upcoming failures.

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Step 5: *Find a PdM solution*. As explained before, the final goal of this analysis is towards the implementation of a PdM-FTA. In this context, the solutions should be limited to those that involve the monitoring and prediction of failures. All other solutions are out of the scope of this study.

By following a sMBFA, and since the failure mechanism and governing loads have been determined, it is generally rather easy to decide whether the loads or the capacity of the system constitute the root cause. For capacity problems, a modification of the system should be considered, while for loading problems the usage and associated loading of the system should be reduced.

Although, in this case, the main focus of the sMBFA technique should be on setting up a monitoring program for the usage, loads or condition that may aid to make the failures predictable and carry out a maintenance activity in response. Therefore, once the sMBFA has helped to find the components to be monitored, the CMS should be focused on those components. Then, the CMMS should be used to analyze the data collected by the CMS, and to deliver information that helps to predict failures and make decisions on when to do maintenance.

Condition Monitoring (CM) Programme

A Condition Monitoring (CM) programme is usually established to ensure that the satisfactory operation of a stand-alone machine occurs. And, despite the fact that a simple CM programme does not mean to achieve an Industry 4.0 maintenance setting, CM is the consecutive step to go through the transformation process, and only after successfully implementing a CM environment, the goals of an Industry 4.0-based maintenance approach can be pursued.

In the following steps, a logical progression is considered in the establishment of a typical CM programme. Therefore, depending on the type of machine being monitored, and the impact of any form of plant failure regarding these machines within the production environment, the steps described below might be used in establishing a workable CMS. Figure 6 shows an overview of the implementation process of the CMS.

Step 1: Determine the type of CMS necessary, namely periodic or permanent, and that best meets the needs of the plant or asset in question.

Step 2: List all the machines, equipment, or components to be monitored. This could be based on the importance of those machines within the overall production line.

Step 3: Select the most appropriate measurement parameter. For example, temperature, vibration, humidity, pressure. This could be based, for example, on the costs, feasibility, existing monitoring devices, or the easiness for installation, processing, or analysis of the data or signals.

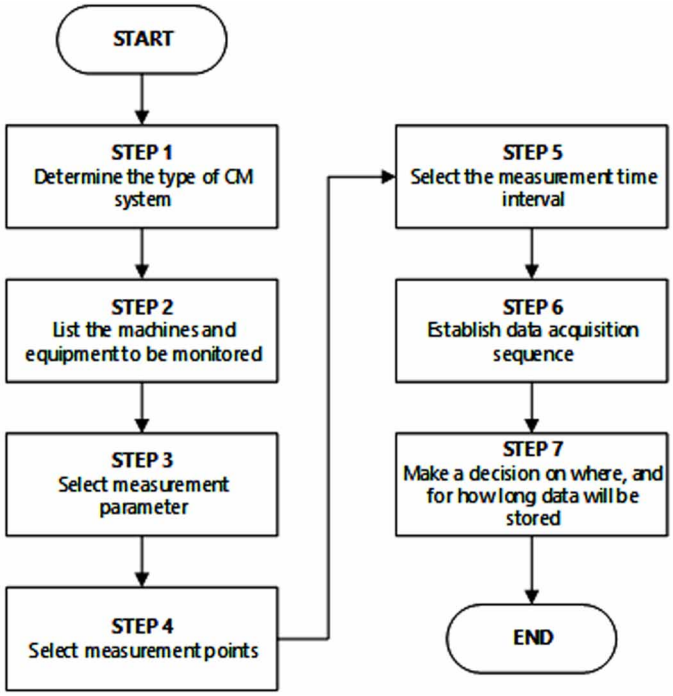
Step 4: Select the strategic measurement locations on the machine(s). Accordingly, when a periodic (i.e. offline) monitoring system is employed, the number of points at which measurements are made is limited only by the requirement of keeping measurement time to a minimum.

Step 5: Selecting the time interval between these measurements. The selection of the time interval between measurements requires knowledge of the specific machine. Some machines develop faults quite quickly, while others run trouble-free for years.

Step 6: Establish an optimum sequence of data acquisition. The sequence in which data is acquired must be planned so that data can be acquired efficiently. For example, the data collection may be planned

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Figure 6. Basic steps for the establishment of a typical CM programme in the manufacturing industry



on the basis of plant layout for the type of data required, or on the sequence of components in the machine, such as from its driver-to-driven components.

Step 7: Make a decision on where to store the collected data, how much data will be collected, and for how long it will be stored. Depending on the machine and on the production needs, the data could be stored in a local server or in the cloud. It should be kept in mind that the CM programme is planned to be the base of an Industry 4.0-based maintenance strategy. Therefore, all collected data should have a purpose.

Finally, an important aspect to take into consideration, is the fact that the early detection of faults can only be carried out successfully by comparison with a reference spectrum. CM techniques employed during transient operating environments of the machine (i.e. when the machine is running up to full speed, or the opposite when slowing down from full speed) differs significantly from the techniques employed during steady-state operating conditions (Smith, 2016). For that reason, it is essential that a careful investigation is undertaken to ensure that specific condition monitoring techniques are selected, which will be appropriate for the conditions of measurement.

Computerized Maintenance Management System (CMMS)

A CMMS is computer software designed to simplify maintenance management (MicroMain Co., 2017). CMMSs are vital for the coordination of all activities related to the availability, productivity and maintainability of complex systems (Labib, 2008). A CMMS is intended to help facilities managers track assets, schedule repairs, monitor work orders, mange costs, and adhere to compliance standards (Service

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Channel, 2017). Therefore, in parallel to a CM programme, a CMMS should be available in the organization in order to have a successful PdM programme (Hart, 2017).

A CMMS contains current and historical repair information for every piece of equipment maintained. This information is intended to help maintenance workers do their jobs more effectively (for example, determining which machines require maintenance and which storerooms contain the spare parts they need) and to help management make informed decisions (for example, calculating the cost of machine breakdown repair versus preventive maintenance for each machine, possibly leading to better allocation of resources) (Ayala, 2016).

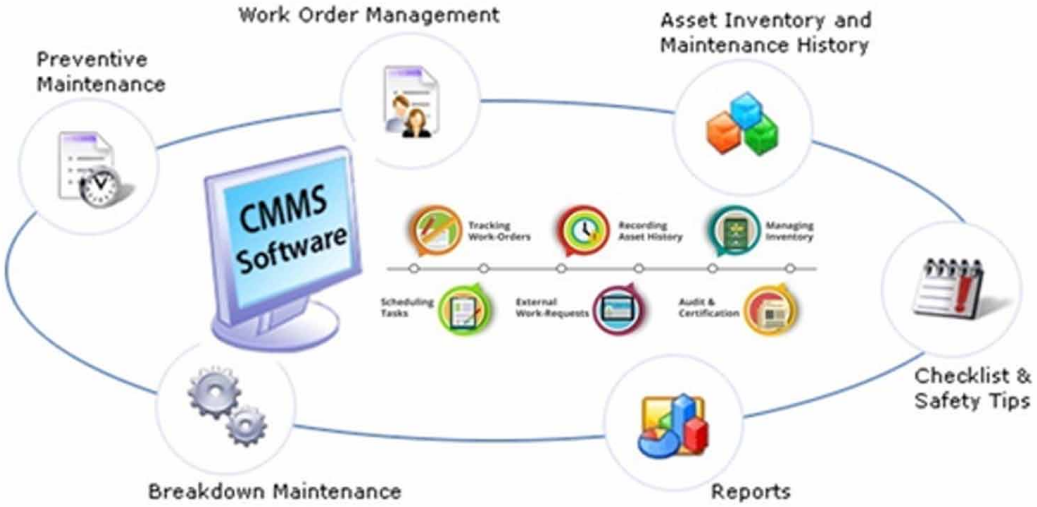
Furthermore, CMMSs can be effective for any organization that is constantly working on reactive maintenance and unable to do preventive maintenance, frustrated with tracking and managing spare parts inventory, having difficulty with providing documentation for regulatory compliance, or wasting time on costly manual processes for tracking maintenance (eMaint, 2017).

The capacity of CMMSs to handle vast quantities of data purposefully and rapidly has opened new opportunities for maintenance, facilitating a more deliberate and considered approach to managing assets. Some of the benefits that can result from the application of a CMMS are (Labib, 2008):

- **Resource Control:** Tighter control of resources.
- **Cost Management:** Better cost management and audibility.
- **Scheduling:** Ability to schedule complex, fast-moving workloads.
- **Integration:** Integration with other business systems.
- **Reduction of Breakdowns:** Improved reliability of physical assets through the application of an effective maintenance programme.

Moreover, the latest generation of CMMSs are designed to work seamlessly in fully connected organizations, collecting all sorts of useful information and distributing it to every member of the team who needs it. Figure 7 shows an overview of the capabilities of common CMMSs. At the smallest scale, that

Figure 7. An example of the usual components of a CMMS software
Source: *Edited from mytechlogy.com*



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means that maintenance techs and other workers can access schedules, records, and other info on the fly thanks to mobile device compatibility (Daniel, 2016).

Nowadays, many CMMSs are available in the market. Good CMMSs serve also as powerful management tools. By tracking and summarizing maintenance info automatically, they let decision makers take a real-time look at how your equipment is performing. CMMS can provide actionable information on improvements to be made in the maintenance procedures and warn about upcoming problems before they become critical. In addition, with the boost of Industry 4.0, CMMSs are focusing now on new areas as a direction for future development (Fiix®, 2017). For example:

- Mobile CMMS applications. Maintenance workers spend most of their time outside the office fixing machines and taking care of buildings. So making the CMMS available in the field on their mobile phone is essential. With a mobile app, technicians can record what they are doing as they are doing it, take pictures of the work, and request help onsite.
- Easy-to-use CMMS software. Many established CMMS companies make products that are very difficult to use. The interface hasn't changed since the late 1990's and many unnecessary, complicated features have been added to the product. Nowadays, more innovative CMMS companies are trying to simplify the maintenance process and to make the software easy to use.
- Fast CMMS data entry. The majority of CMMS projects that fail do so because it is too difficult and time consuming to enter data into the system. The next frontier in CMMS design centres around designing intuitive, efficient ways to enter data into the system.
- Cloud-based CMMS. New CMMS companies are mostly focused on providing a private CMMS for their clients, which runs online, through the cloud. The CMMS provider takes care of all the IT, security, and backups, making this a great option for modern maintenance teams.

THE FUTURE STEP OF THE INDUSTRY 4.0: SELF- MAINTENANCE TECHNIQUES

As discussed, Industry 4.0 has brought a new technological shift by implementing cutting-edge information technologies, machine learning and monitoring devices in the controlling of manufacturing and production systems. It is also often viewed that Industry 4.0 demands progress in new maintenance concepts with the use of smart devices, such as micro and Nano sensors, controllers, actuators and algorithms like Neural Networks, Fuzzy Logic, Match Matrix, Bayesian Network etc. This is due to the evolution in the number of physical resources that are required to operate well beyond their expected life, and the prerequisite to design equipment with added prominence on reliability and maintainability. In I4.0, the manufacturing and production systems often encounter a collection of applications that increase time-to-repair, and increase management overheads. In order to address these maintenance issues, it is necessary to develop systems that support advanced intelligent maintenance systems or smart maintenance technologies. Self-maintenance machines can be a good option with the capabilities of condition monitoring, diagnosing, repair planning and executing in order to extend the life and performance of equipment. The objective of this section of chapter is to discuss the idea and issues of self-maintenance and scenarios where self-maintenance can be successfully implemented. The concept of self-maintenance systems was initiated in 1990s with the objective of designing a system that applies embedded intelligence together with built-in sensors and actuators. More precisely, self-maintenance is

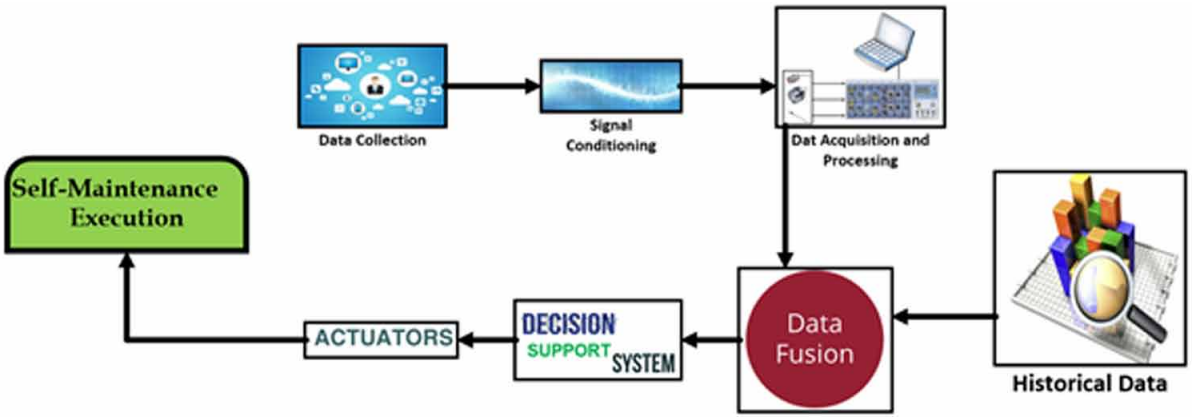
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the capability of a system to provide self-monitoring and diagnostic tools to manage equipment usage and to address maintenance, renovation or repair. The objective of Self-maintenance system is to offer real time, fast and accurate maintenance systems with required capabilities to deal with faults and failures in an innovative way (Figure 8).

The need of self-maintenance machines is becoming a prerequisite in certain cases such as offshore wind turbines, aerospace sector, toxic industrial environment and the nuclear industry where it becomes nearly impossible to deal during emergency issues where during the event of a fault, there is very less possibility to access the site thereby strengthening the need for self-maintenance strategies. In time critical situations self-maintenance system can compensate the failure of subsystems by reconfiguring the parameters in an autonomous manner, increasing reliability and safety of the products with substantial saving of time and money (Sarbjeet et. al., 2014). There is great potential of self-maintenance to support the progress of high reliable systems as unsuitable maintenance planning, too much or too little can produce either high costs or abridged reliability (Endrenyi and Asgarpoor 2001). With the passage to time even the finest systems degrade due to use and wear therefore well-organized maintenance scheduling is critical for unremitting reliability of a production system (Jardine et al. 2006). The emerging fields of autonomic computing and artificial immune systems are using the concept of robustness, sustainability, resilience, and autonomy to achieve higher reliability (Lee et al. 2011). The self-maintenance techniques take into account most of the systems and components listed as essential for CBM and CMMS, such as different smart sensors for efficient gathering and processing of information to analysis and decision making, wireless sensor networks, adaptive system, end-user systems and processes;

- **Self-Maintenance and Data Acquisition Systems:** Data acquisition systems in self-maintenance machines are used. It serves as an essential component for binding together a wide variety of products, such as sensors to provide the alarms when critical parameters are exceeded. It is the process of sampling signals from machines sensors and converting them into digital numeric values that can be operated by a computer. However, in order for this approach to be effective it is necessary to identify 'what needs to be monitored and why'. In fact, only the critical components triggering downtime should be monitored, thereby reducing the amount of irrelevant data collected and anal-

Figure 8. Architecture of Self-maintenance system
Source: *Modified from Sarbjeet et al., 2014*



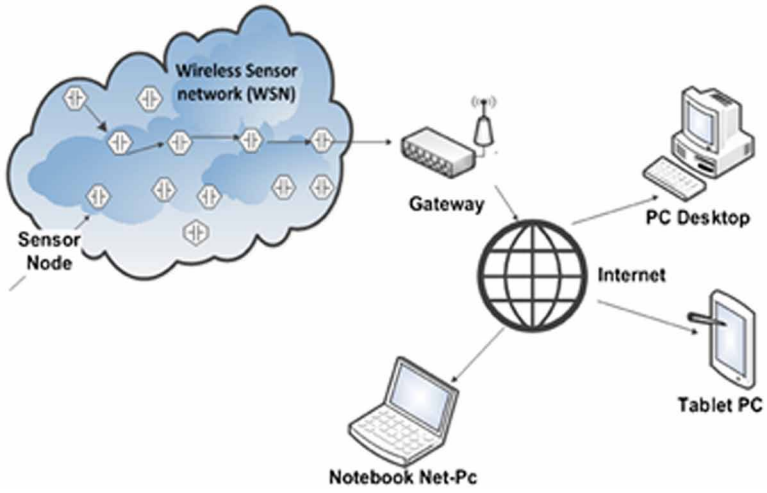
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ysis. Thus, a significant constituent of a self-maintaining system is the planning and ranking tools used by maintenance staff and planning processes to mitigate the costs of the implementation.

- **Smart Sensors:** The technology of Smart sensors in Industry 4.0 monitors the truthfulness of the system and predict network failures. Smart sensors in self-maintenance machines uses microprocessor to collects real-time data for analyzing variety of tasks including self-diagnostics and decision making. Sensors execute an input function and actuators an output function that is used to govern external device. The development of advanced network components allows the network to heal itself based on the measurements of sensors. Smart sensors intermittently monitor the condition of the machine by analyzing the data obtained from the sensing element. The data from sensors of these system can identify the cause of failure and trends can be predicted. Self-maintenance systems can make systems more reliable, reconfigurable and adaptable, particular for systems with critical component failure rate by fusing adaptive systems with modular designs.
- **Wireless Sensor Network (WSN):** Wireless sensor network (WSN) is network of nodes to sense and control the environment facilitating interaction between persons or computers and the surrounding environment (Verdone et al. 2008). Wireless Sensor Network (Figure 9) monitor conditions, such as temperature, sound, vibration, and pressure etc. and pass data to a main location. The sensor nodes are capable of performing processing, gathering information and communicating with other connected nodes in the network. It is used in many industrial applications for machine health monitoring and generated an increasing interest from industrial and research perspectives (Hac 2009; Raghavendra et al. 2004).
- **Adaptability to Frequent Changes in Operating Regime:** The self-maintenance systems should be knowledge-based and adaptive to frequent changes in operating characteristics of the machine and process with negligible additional cost of sensors or intrusive access. The adaptive agent of self-maintenance system can compensate the failure of subsystems by reconfiguring the parameters in an autonomous manner and minimize expensive human intervention. In future, the self-maintenance techniques should be aware of the varying operating regimes in order to strongly select prognostics models to assure prediction accuracy (Lee et al. 2011). Intelligent adaptive control approach for self-maintenance have already been applied for investigating control using fuzzy logic control of material processing in sheet metal forming (Hinduja et al. 2000) and electro-chemical machining (ECM) (Keasbury et al. 2004). The expensive heavy equipment, such as offshore wind turbines, aerospace components, aircraft propellers etc. are expensive to shut down or repair.
- **End-User Systems and Processes**: It seems that self-maintenance pivots around the point that maintenance operators are kept out of the loop but in actual the effectiveness and security of the self-maintaining system is highly dependent on an effective interaction with maintenance staff and collaborative structures. It can be a dicey statement that a self-maintenance system is a plug-in and forget system because it needs efforts while planning, implementing and evaluation. The implementation of self-maintenance systems needs the support of architecture of CMMS and CM systems—especially allowing the maintenance staff to interact with the self-maintenance systems. This will demand CMMS and CM systems to allow for effective integration of new tools, information types, media and processes (Bjorling and Uday 2009).

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Figure 9. Wireless sensor network (WSN)
Source: *Sarbjeet et al., 2014*



CONCLUSION AND FUTURE RESEARCH

Industry 4.0 accepts the challenge of addressing new concepts of maintenance with numerous efforts on its implementation in various systems. Intelligent Maintenance Systems have brought new paradigm shift to an in-machine renovation and repair. The concept of CBM may have a significant effect on labor cost and maintenance downtime with some condition monitoring modules fabricated into existing systems. As per our perception, techniques can propose real-time, fast and accurate maintenance system with required capabilities to deal with faults and failures in an innovative way even without human intervention (in case of self-maintenance) in order to increase the overall dependability. The discussed solutions can minimize unnecessary and costly preventive maintenance, optimize maintenance scheduling, reduce lead-time for spare parts and resources all of which can result in significant cost savings. It has been concluded that the aim is to have fully automatized system in order to make a machine capable of reconfiguration, compensation, and, in the last stage, self-maintenance.

Future research of Maintenance 4.0 needs to focus on system integration between machines, infrastructures and personnel. A cooperative environment, where operators can benefit from data gathered with sensors and from information elaborated with Artificial Intelligence, will lead to more efficient solutions. Until now, we monitor the machines and we take decisions; next step will encompass the ability of the machines to learn from situations in order to increase the overall antifragility of the system (Martinetti et al., 2018).

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KEY TERMS AND DEFINITIONS

Computerized Maintenance Management Systems (CMMS): A computerized database that stores and manages all the information necessary for maintenance operations.

Condition Monitoring (CM): The set of processes and activities meant to track parameters of a machine or an infrastructure.

Condition-Based Maintenance (CBM): Maintenance policy focused on the condition of the system based on conditions and remote monitoring.

Cyber-Physical Systems (CPS): Environment where physical and digital components are tightly interconnected.

Industrial Internet of Things and Services (IIoTS): The use of internet of things technologies (machine learning, big data, etc.) to enhance manufacturing and industrial processes.

Internet of Things (IoT): The infrastructure that connects physical devices.

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Predictive Maintenance (PdM): Maintenance policy focused on the predicted condition of the system based on impending failures as results of data, patterns, and trends analysis.

Prescriptive Maintenance (RxM): Maintenance policy focused on PdM actions, empowered with provision of specific recommendations towards a solution-finding process.

Software-as-a-Service (SaaS): Business model based on offering software licensed on subscription and, generally, centrally hosted.

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Chapter 9
Assessing HRO Principles for Reliable Performance in Asset-Intensive Organizations:
Expecting the Unexpected

Jan-jaap Moerman
University of Twente, The Netherlands

Jan Braaksma
University of Twente, The Netherlands

Leo A. M. van Dongen
University of Twente, The Netherlands

ABSTRACT

Asset-intensive organizations rely on physical assets that are expensive, complex, and have a significant impact on organizational performance. The management of such assets is essential when seeking for reliable performance in a world of increasing uncertainties. The observation that asset-intensive organizations deal with increasingly complex and tightly coupled systems and often operate in highly demanding environments may indicate that they should adopt practices from high reliability organizations (HRO) to ensure and maintain reliable performance in the fourth industrial revolution. This chapter operationalizes the HRO concept in the field of physical asset management, measures to what extent the underlying principles are recognized, and explores the relationship between the HRO principles and asset performance using a descriptive survey. Results indicated that the HRO principles are recognized and may, therefore, serve as an instrument for reliable performance when adopting new technologies. A positive relation between asset performance and the five HRO principles was identified.

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INTRODUCTION

Asset-intensive organizations such as utilities, heavy engineering, pharmaceuticals and transportation, rely on physical assets that are expensive, complex and have a significant impact on organisational performance. The management of such assets is essential when seeking reliable performance. The new paradigm of the fourth industrial revolution (Bloem et al., 2014), in which operational technology and information technology will increasingly merge, has a significant impact on asset-intensive organizations. Digital technologies will be more and more integrated into physical assets, not only enabling further communication between machines and people but also between machines themselves.

Despite the promises of advanced digital technologies in managing physical assets, adding more technologies also increases the technical complexity of physical assets (Martinetti, Braaksma, & van Dongen, 2017). This increased complexity may result in chains of reactions that decrease predictability and cause unexpected failures, which are often stated by asset-intensive organizations as the primary operational risk to business (LaRiviere, McAfee, Rao, Narayanan, & Sun, 2016).

The observation that many asset-intensive organizations deal with increasingly complex tightly-coupled systems, intensified by the pace of technology and digitization summarised by the industry 4.0 paradigm, and often operate in highly demanding environments, has led the authors to the idea that they should adopt practices from High Reliability Organizations (HRO) (La Porte, 1996; Roberts, 1990; Roberts & Rousseau, 1989). These practices may support them in ensuring and maintaining reliable performance of their assets in the fourth industrial revolution. In current published literature, there is limited empirical evidence of the usefulness of the HRO concept outside the more mature safety domain from which it originated. This chapter aims to extend current insights on the application of HRO by assessing the HRO concept in the context of asset-intensive organizations. It provides practical examples for practitioners in managing uncertainties to prevent mindlessness when adopting new digital technologies. This chapter operationalises the HRO concept to determine to what extend HRO practices are recognised in asset-intensive organizations, and it explores the relationship between the HRO practices and perceived asset performance.

This chapter is structured as follows. The first section introduces the main concepts from literature in asset management and organizational reliability relevant to this research. The research design in the next section includes a detailed description of the methodology that has been followed. The next two sections present the results and the implications for practitioners. The chapter concludes with the conclusion and recommendations for further research.

LITERATURE BACKGROUND

This section defines asset management and the need for reliable performance. It introduces the concept which has been used as the foundation for the survey among asset-intensive organizations which will be described in the results section.

Asset-Intensive Organizations as Reliability-Seeking Organizations

The management of physical assets, like buildings, infrastructures, utilities, plants, and transportation, is addressed by the discipline of asset management. Asset management is defined as a "coordinated

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activity of an organization to realize value from assets" (ISO, 2014, p. 14). Asset management involves the balancing of costs, opportunities and risks against the desired performance of assets to achieve organizational objectives. Many different methods and tools are available to manage physical assets effectively. Many of these methods and tools are discussed under the topic of maintenance management, which can be considered as a predecessor of asset management (Amadi-Echendu, 2004). Based on an extensive review of 37 maintenance concepts, Fraser et al. (2015) concluded that Reliability Centered Maintenance (RCM), Total Productive Maintenance (TPM) and Condition Based Maintenance (CBM) are the three most important and popular maintenance concepts as summarized by Ruitenburg (2017).

RCM was developed in the aviation industry, to assess the reliability of the designs of new aeroplanes (Smith & Hinchcliffe, 2003). RCM can be defined as "a process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context" (Moubray, 1997, p. 7). In response to the maintenance and support problems encountered in manufacturing environments, the Japanese developed and introduced the concept of TPM. TPM is a maintenance system defined by Nakajima (1988), which covers the entire life of equipment in every division including planning, manufacturing, and maintenance. Its purpose is to limit the disruptive consequences

of equipment failures in production systems to ensure reliable performance. Where RCM and TPM are clearly defined maintenance concepts, CBM is instead a large collection of different but similar approaches to maintenance (Veldman, Wortmann, & Klingenberg, 2011). In general, the primary goal of CBM is to perform a real-time assessment of equipment conditions to make proper maintenance decisions, consequently reducing unnecessary maintenance and related costs (Gupta & Lawsirirat, 2006). For example, the condition of physical assets can be measured by equipping them with (additional) sensors. Knowing which activities have been executed or knowing that some physical assets have been deployed for heavy work for a long time, enables the organization, for example, to adjust the maintenance schedules in response.

Based on the three important concepts in maintenance, all sharing a strong focus on technical reliability, asset-intensive organizations can be characterized as reliability-seeking organizations. The main emphasis in academics is on the application of tools and techniques to improve the quality, safety and reliability of the physical asset itself, regarding the physical asset as a technical system (Gits, 1992). However, many physical asset systems can also be characterised as socio-technical systems. Socio-technical systems are work systems that involve complex interactions between humans (e.g. operators, mechanics), machines (e.g. installations, infrastructure, rolling stock) and various environmental aspects (Trist, 1981). This concept is also acknowledged by Van Dongen (2011), who states that the management of physical assets, like rolling stock, can not only be guaranteed by technically perfect designs and maintenance concepts. The managers, operators, and mechanics determine, to a great extent, the final result. Therefore, it can be argued that besides the technical reliability, the reliability of the organization should also be taken into consideration when seeking reliable performance.

Reliable Performance in the Fourth Industrial Revolution

Industry 4.0, also referred to as the 'Fourth Industrial Revolution', is currently a much-discussed topic that has the potential to affect entire industries by transforming the way goods are designed, manufactured, delivered and paid. The rapid adoption and application of pervasive digital technologies in several industries, as advocated by the industry 4.0 paradigm, not only radically change products and services, but also fundamentally reshape organizations (Yoo, Richard J. Boland, Lyytinen, & Majchrzak, 2012),

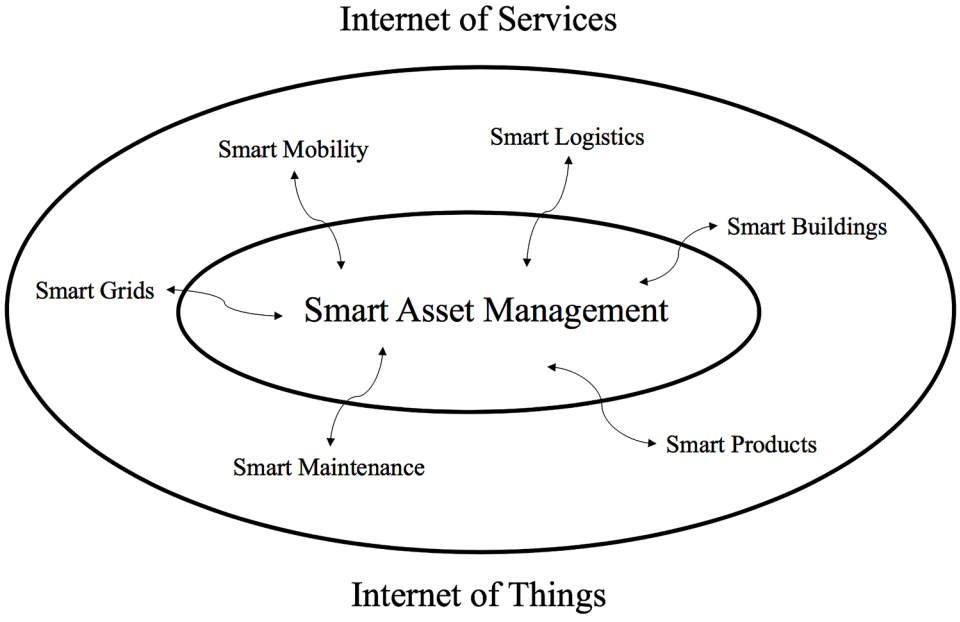
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with an increasing pace. As briefly summarised by Hofmann and Rüsch (2017), Hermann et al. (2016) identified four industry 4.0 components based on their review of academic and business publications:

1. **Cyber-Physical Systems:** Industry 4.0 is characterised by an unprecedented connection via the internet or other distributed ledgers and so-called cyber-physical systems, which can be considered systems that bring the physical and the virtual world together (Akanmu & Anumba, 2015).
2. **Internet of Things:** "Smart, connected products offer exponentially expanding opportunities for new functionality, far greater reliability, much higher product utilization, and capabilities that cut across and transcend traditional product boundaries" (Porter & Heppelmann, 2014, p. 4).
3. **Internet of Services:** There are strong indications that, similar to the internet of things, an internet of services is emerging, based on the idea that services are made readily available through web technologies, allowing companies and private users to combine, create and offer new kind of value-added services (Andersson & Mattsson, 2015)
4. **Smart Factory:** The concepts of cyber-physical systems, internet of things and internet of services are closely linked to each other and enable the so-called 'smart factory', which is built on the idea of a decentralized production system, in which "human beings, machines and resources communicate with each other as naturally as in a social network" (Kagermann, Helbig, & Wahlster, 2013, p. 19). Something similar can be stated for 'smart asset management' (Figure 1) which relies more and more on cyber-physical communications.

However, as more heterogeneous modules, originally produced by diverse actors, are combined to create innovations, which is indeed the case based on the key components of industry 4.0, organizations

Figure 1. Industry 4.0 and smart asset management based on the smart factory
(Kagermann et al., 2013, p. 19)



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increasingly run the risk of complex systemic failure or other forms of unintended consequences (Perrow, 1984). When complex systems fail, there is an initial tendency to attribute the failure to human error. Yet, as described by Madni and Jackson (2009), research has repeatedly shown that in many cases it is not human error but organizational factors that set up adverse conditions that increase the likelihood of system failures.

Reliability, as pursued by many asset-intensive organizations, is a complex and challenging organizational trait to achieve, in which managers face the challenge of coping with new (digital) uncertainties in the face of diminishing reservoirs of organizational slack (Schulman, 1993). Two main theories of reliability can be distinguished in relation to the performance of complex, hazardous operations (Wildavsky, 1989), which may serve as guidance for asset-intensive organizations in pursuit of reliable performance.

Reliable performance can be achieved by routine-based reliability and mindfulness-based reliability as described by Butler and Gray (2006). Routine-based reliability posits that reliable performance can be achieved efficiently by creating repeatable packages of decision rules and associated actions. Organizationally, routine-based reliability involves the design and execution of standard operating procedures and decision-making processes, which may be unique to the organization or widely accepted across an industry (Spender, 1989). Routines are based on interpretations of the past more than anticipations of the future. Organizations adapt to experience in response to feedback about outcomes (Levitt & March, 1988). While routines are essential tools for creating reliable performance, they are not without limitations (Weick, Sutcliffe, & Obstfeld, 2008) and predispose us to see situations in particular ways (Langer, 1989).

While routine-based approaches focus on reducing or eliminating situated human cognition as the cause of errors, mindfulness-based approaches concentrate on promoting highly situated human cognition as the solution to individual and organizational reliability problems (Weick & Sutcliffe, 2011). Reliability would be equated not with invariance but with resilience (Schulman, 1993). From a mindful perspective, "one's response to a particular situation is not an attempt to make the best choice from among available options but to create options" (Langer, 1997, pp. 113-114). Mindfulness-based approaches hold that the ability of individuals and organizations to achieve reliable performance in changing environments depends on how they think: how they gather information, how they perceive the world around them, and whether they can change their perspective to reflect the situation at hand (Langer, 1989). The problem, as also pointed out by Akkermans and Van Wassenhove (2013) in response to grey swans (Taleb, 2007, p. 37), is that people have to know where to look, and that people need to be willing to expect the unexpected, and act swiftly and decisively when the unexpected happens. As Schulman (1993, p. 371) concluded in his analysis of the Diablo Canyon case: "…a core capability of adaptation and resilience is the key to maintaining organizational reliability at the highest levels".

The introduction of new pervasive digital technologies in organizations creates unseen and unexpected fault lines, and organizations must now learn to carefully deal with those fault lines to take full advantage of new digital technologies. (Yoo et al., 2012). A different approach to ensure and maintain reliable performance of physical assets is therefore required. Companies should be accompanied and supported on their road to Industry 4.0 in a practical manner. This could be achieved through concepts and frameworks, which features different building blocks and dimensions of Industry 4.0 and therefore may serve as an orientation guideline (Hofmann & Rüsch, 2017). This is where the concept of High Reliable Organizations (HRO) might be helpful in guiding asset managers and asset owners for safeguarding reliable performance in an increasingly digitally connected world.

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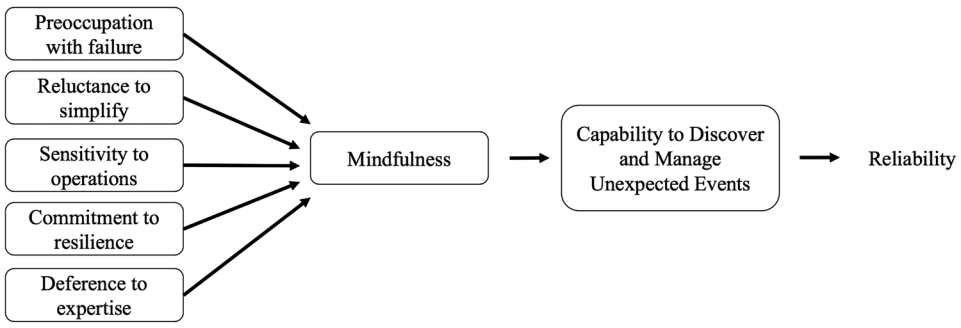
A Mindful Approach for Reliable Performance

Reliability-seeking organisations are not distinguished by their absolute errors or accident rate, but rather by their "effective management of innately risky technologies through organisational control of both hazard and probability" (Rochlin, 1993). HROs are a subset of high-risk organizations, designed and managed to avoid accidents in complex, tightly-coupled systems (Roberts & Rousseau, 1989). An HRO is, for instance, a nuclear power plant, an aircraft carrier, an air-traffic-control team, a firefighting unit, or a hospital's emergency department. HRO researchers argue that accidents in complex systems are not inevitable because there are processes in place that enable high-hazard organizations to effectively prevent and contain catastrophic errors helping them to achieve a consistent record of safety over long time periods (Roberts, 1990).

The key difference between HROs and other organizations is the sensitivity or mindfulness with which people in most HROs react to even very weak signs that some kind of change or danger is approaching (Weick & Sutcliffe, 2011). From the perspective of performance as a continuing process or set of activities, high reliability is a dynamic process of organising rather than one of being an HRO. Pursuing and achieving reliability is a continuous, ongoing accomplishment (Sutcliffe, 2011). Effective HROs tend to develop both anticipation and resilience to achieve reliable performance (Schulman, 2004). Anticipation refers to the prediction and prevention of potential dangers before damage is done, whereas resilience refers to the capacity to cope with unanticipated dangers after they have become manifest and learning to bounce back (containment). Unlike effective HROs, traditional non-HRO organizations tend to lean heavily toward one or the other of the two. Most organizations focus on anticipation of expected surprises, risk aversion, and planned defences against foreseeable risks (Weick et al., 2008). Weick and Sutcliffe identified five principles that they define as 'reliability-enhancing' (Figure 2):

- Preoccupation with failure refers to HROs' constant preoccupation with potential errors and failures;
- Reluctance to simplify focuses on HROs' ability to collect, analyse and prioritise all warning signs that something may be wrong and avoid making any assumptions regarding the causes of failure;
- Sensitivity to operations refers to the ability to obtain and maintain the bigger picture of operations that enables HROs to anticipate effectively potential future failures;

Figure 2. A mindful infrastructure for high reliability
(Weick et al., 2008)



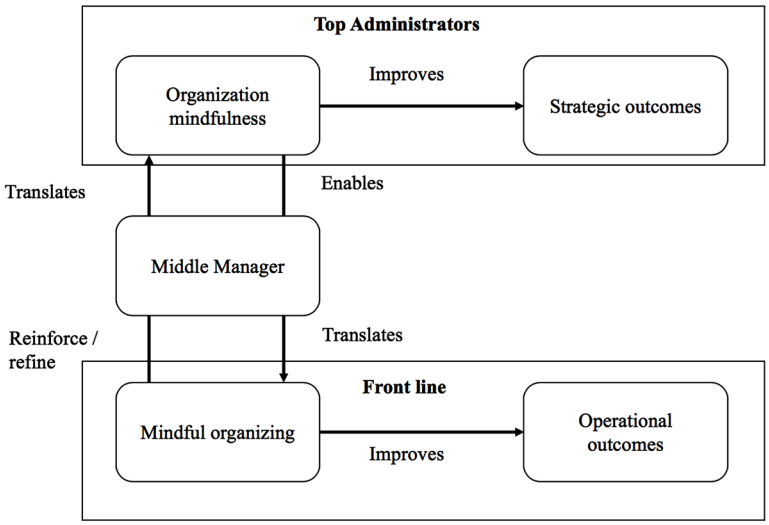
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- Commitment to resilience is concerned with the ability of HROs to not only effectively anticipate errors but also to cope with and bounce back from errors and unexpected events;
- Deference to expertise refers to deferring decision-making in case of emergencies to individuals with the expert knowledge to deal with a specific problem, irrespective of their status within the organizational hierarchy.

These five principles do not operate in isolation. They must be supported by a systems-thinking approach enabling network interactions to build mindful relationships in and between organizations. Vogus and Sutcliffe (2012) suggested that two actions are required; that of 'organisational mindfulness' and 'mindful organising'. Both are required for organisations to achieve improved levels of organizational mindfulness (Figure 3). Senior management (Top administrators in Figure 3) is concerned with 'organisational mindfulness' focused on strategic outcomes. Operations (Front line in Figure 3) is concerned with 'mindful organising' focusing on operational outcomes. Middle managers play an important role in translating and enabling both organisational levels.

HROs can be valuable to other organizations because they are harbingers of adaptive organizational forms for an increasingly complex environment (Weick et al., 2008) and may be considered as a good practice in achieving reliable performance. The HRO concept provides insight into adaptive organisational forms for complex environments. For example, the qualities of well-functioning HROs can be generalised and applied to medical care (Sutcliffe, 2011). Furthermore, other studies on HRO showed the case of applying the principles of HRO to improve the quality and safety in hospitals (Cady, 2008; Chassin & Loeb, 2013) and to identify barriers and opportunities for adoption in the construction industry (Harvey, Waterson, & Dainty, 2016). This chapter investigates the application of the HRO principles at asset-intensive organizations.

Figure 3. Reconciling Organizational Mindfulness and Mindful Organizing
Adopted from Vogus and Sutcliffe (2012, p. 728)



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RESEARCH DESIGN

The research approach consists of a descriptive survey of asset-intensive organizations in the Netherlands. Descriptive survey research is aimed at understanding the relevance of a phenomenon in a population, for instance, the level of adoption of best practices (Karlsson, 2016, p. 83).

The research consists of a replication study (Weick & Sutcliffe, 2011) using a descriptive survey method (Forza, 2002, p. 155). It is aimed to identify to what extent the HRO principles, as identified by Weick et al. (2008), are recognised at asset-intensive organizations and to identify possible relations between these HRO principles and asset performance. Furthermore, the survey provides insights to what extent current practices of asset-intensive organizations incorporate the five principles of mindfulness as seen by HROs.

The survey research process, as described by Forza in research methods for operations management (Karlsson, 2016), consists of different processes that need to be followed to ensure the quality of the research. These processes include a strong link to the theoretical level, designing the survey, pilot testing, collecting and analysing data and interpreting and reporting the results, which will be briefly summarised below.

The authors collaborated with the Dutch Cooperation of Effective Maintenance (NVDO) in designing and executing the survey via an online survey tool. The NVDO represents a large number of asset-intensive organizations in the Netherlands. The unit of analysis is similar to the original assessment of Weick and Sutcliffe (2011) and is aimed at individual respondents. The target audience of this survey in asset-intensive organizations includes asset owners, asset users, asset managers and service providers. By measuring the attitude of the respondents of the survey towards a mindful infrastructure for high reliability, the authors assessed the current capability of asset-intensive organizations in the Netherlands to discover and manage unexpected events.

The theoretical foundations, constructs and operational definitions of a mindful infrastructure for high reliability (refer to Appendix) have been adopted from Weick and Sutcliffe (2011). Although the survey has been designed to be applicable in multiple domains the following steps were executed to validate the applicability of the survey to fit the field of asset management.

- The first step was to translate the original questionnaire into Dutch to align with the needs of the target audience for a better understanding (and response) of the questions.
- The next step was the validation of the Dutch questions by an expert team consisting of both practitioners of the NVDO and academics from the University of Twente. This step was critical in the operationalisation of the survey to ensure that the survey was consistent with the respondents' level of understanding but still complied with academic standards. The major changes were made in the reformulation and contextualization of the Dutch questions to ensure the right interpretations of respondents. Due to the nature of this study (replication study), the content of the constructs was not changed.
- A pilot test has been performed to assess the quality of the online survey (e.g. questions, survey length, direct and reverse wording) and to gain a better understanding of the respondents involved. Based on this pilot test and previous replication studies (Golzio, Lalla, & Manni, 2014) the measurement scales were changed, using four thresholds instead of two thresholds as suggested in the original assessment (Weick & Sutcliffe, 2011). This decision increased the range of options, permitting a more detailed interpretation of the opinions of the respondents.

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As a final result, the survey consisted of eight sections (see also Appendix), using standard Likert scales. Each scale is directed to measure a specific area of mindfulness which contributes to the capability of the organization to discover and manage unexpected events (P), whereas the first three sections determine the need for mindfulness (M). The following sections had been included in the survey: The organization's mindfulness (M1), the organization's vulnerability to mindlessness (M2), where mindfulness is most required (M3), preoccupation with failures (P1), reluctance to simplify (P2), sensitivity to operations (P3), commitment to resilience (P4) and deference to expertise (P5). Each scale consisted of a different number of items ranging from seven to twelve items. Sections M3 and P6 contained a standard Likert scale from 'totally disagree' to 'totally agree'. The other sections contained a self-anchoring Likert scale from 'not at all' to 'a great deal'.

The global score of a section, as adopted from Golzio et al. (2014) is given by the sum of the values of the single items, $X_s = \sum_{i=1}^{I_s} X_{si}$, where I_s is the number of items in the section s. For each section, four thresholds were defined, demarcating five outcomes: very low, low, medium, high and very high. For example, section M1 has nine items and generates X_1, which ranges from 9 (number of items in the scale multiplied by score 1) to 45 (number of items in the scale multiplied by score 5). If X_1 is higher than 36, the organization has a very strong mindful infrastructure for high reliability. If X_1 is between 28 and 36, the organization has a strong mindful infrastructure for high reliability. If X_1 is between 19 and 27, the organization is on its way building a mindful infrastructure for high reliability. If X_1 is between 10 and 18, the organization has a weak mindful infrastructure for high reliability, and if X_1 is lower than 10, the organization should consider how it can immediately improve its mindful infrastructure for high reliability. The internal consistency of the scales was evaluated using Cronbach's α with a threshold of $\alpha \geq 0,7$ (Kaplan & Saccuzzo, 1997).

Hypotheses

The central hypothesis of the authors was that although many asset-intensive organizations operate in lower risk environments and deal with less complex systems compared to 'traditional' HROs, they can benefit from a mindful infrastructure for high reliability to manage uncertainties as a result of an increase in the complexity of physical assets in Industry 4.0. Therefore, based on the assumption that asset-intensive organizations, in general, operate in lower risk environments, the authors expected to find lower scores on the five principles of HRO. Furthermore, the authors expected to observe a positive relationship between the five principles of mindfulness and asset performance.

RESULTS

This section presents the results of the survey. The sample of the survey included active members of the NVDO. The survey was administrated by the NVDO and had been accessed online by 133 respondents After removing outliers and other inconsistencies, 90 surveys were fully completed. The first part of this section includes the results of the general questions and the second part comprises the 8 sections on assessing organizations' mindful infrastructure for high reliability. For illustration purposes, some

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typical examples have been included from the Netherlands Railways (NS), which can be considered as an asset-intensive organization.

In general, 6 out of 8 sections proved to be reliable in terms of internal consistency (Cronbach's $\alpha \geq 0,7$), indicating that two sections need further considerations when optimizing the survey.

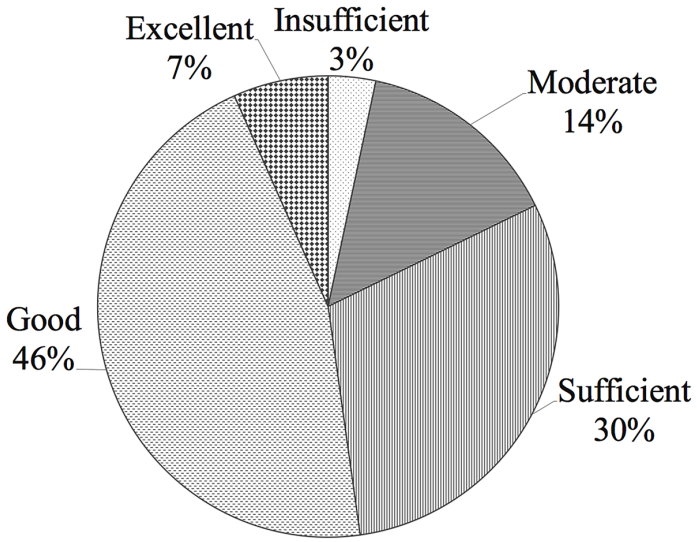
The results of the general section showed that 46% of the respondents were active in the process industry. Other respondents were engaged in sectors like food and pharma, building and construction, infrastructure, fleet and manufacturing. 24% of the respondents were employed in large organizations with more than 2.000 employees, and 60% of the respondents were directly involved in the role of asset owner, asset user, asset manager or service provider. 40% of the respondents were indirectly involved, mainly as a consultant.

Figure 4 shows the results of the perceived asset performance. 14% of the respondents perceived their asset performance as moderate, while 46% of the respondents perceived their asset performance as

Table 1. Internal consistency of the eight survey sections

Section	Cronbach's α
The organization's mindfulness (M1)	0.83
The organization's vulnerability to mindlessness (M2)	0.53
Where mindfulness is most required (M3)	0.60
Preoccupation with failures (P1)	0.82
Reluctance to simplify (P2)	0.90
Sensitivity to operations (P3)	0.83
Commitment to resilience (P4)	0.88
Deference to expertise (P5)	0.83

Figure 4. Perceived asset performance



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good. 3% of the respondents perceived their asset performance as insufficient. The question related to the Overall Equipment Effectiveness (OEE), one of the key performance indicators for production, was not fully understood by all respondents. 46% of the respondents were unable to answer this question.

The following subsections summarise the results of the areas of mindfulness, which determine the capability of asset-intensive organizations to discover and manage unexpected events. The items of each section can be found in the Appendix.

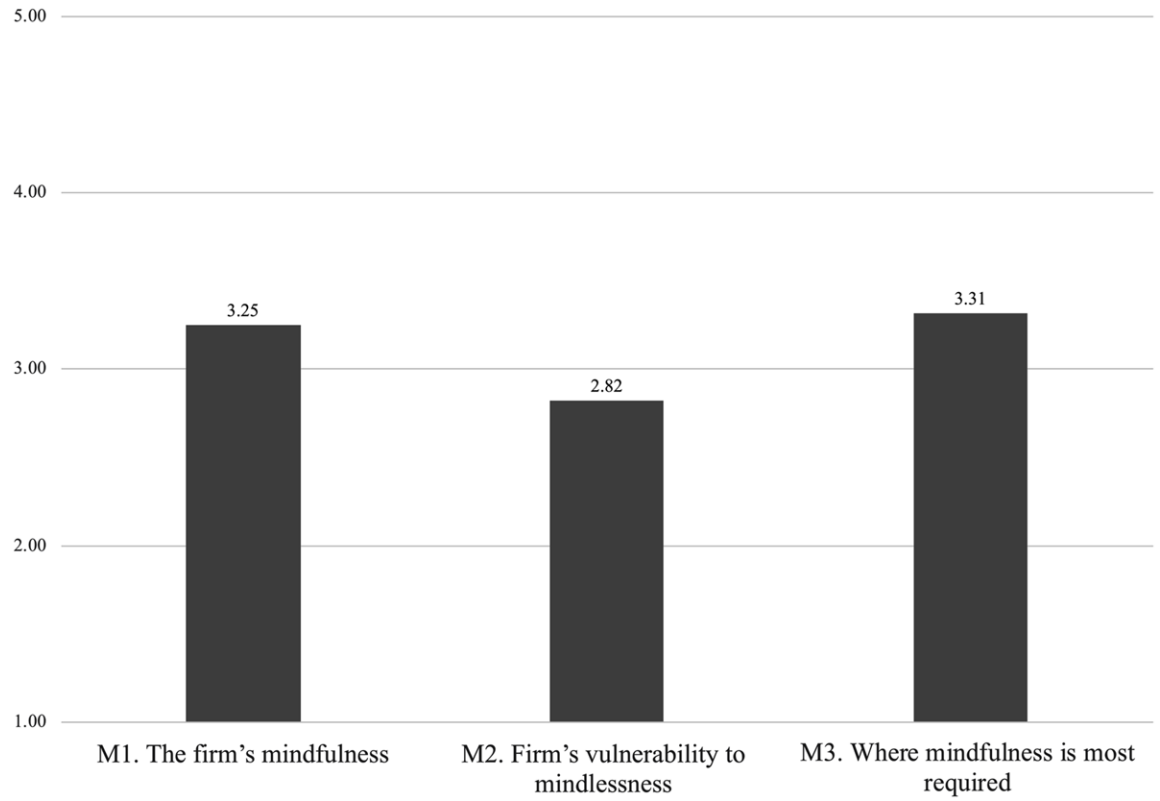
The Need for Mindfulness

The first three sections include the results which determine the need for asset-intensive organizations for a mindful infrastructure for high reliability, although they operate in lower risk environments compared to HROs. Figure 5 includes the mean scores of the sections M1-M3 based on a 5-point scale.

The Organization's Mindfulness

The first section (M1) can be considered as a starting point for assessing the organization's mindfulness, and it will provide insight into whether people are conscious of potential problems and issues and how open they are in finding out. The internal consistency of the scale was high with $\alpha = 0.83$. Results showed that the percentage of answers above the threshold of 28 was high (66%), indicating a strong

Figure 5. The need for mindfulness (mean values on a scale from 1 to 5)



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mindful infrastructure for high reliability based on nine items in this section. Nevertheless, the analysis also showed that three items with a mean value of $\mu \leq 3.0$ need further attention from asset-intensive organizations. These items concern the identification of events (26% of the respondents), the specification of events (27% of the respondents), and the understanding of events (22% of the respondents). A typical example from the NS is the need for the rolling stock control centre to gain a thorough understanding of the events that caused failures to a train in operations for the right diagnosis and repair. Is it, for instance, technical failure, or is it the unfamiliarity of the train driver that may have caused the disruption?

Vulnerability to Mindlessness

The organization's vulnerability to mindlessness (M2) assesses how strong people tend to ignore the disruptions that unexpected events cause. The internal consistency of the scale is low with $\alpha = 0.53$ based on 8 items in the scale. Results showed that the percentage of answers below 24 was 41%, indicating that 59% of the asset-intensive organizations have a potential for vulnerability to mindlessness and have the tendency to ignore disruptions caused by unexpected events. Two items need particular attention with a mean value of $\mu \geq 3.0$ (reversed scale). The first item is that people are expected to perform their jobs in a particular way without deviations (46% of the respondents). This makes them vulnerable in responding to unexpected events in operations. For example, sticking to the standard railway schedule will contribute to a reliable performance up to the point where unknown failures occur. Then railway operations will adapt the schedule to absorb the failures to return to the original railway schedule. The second item of vulnerability is caused by severe production pressures (time, costs, growth, profits, or other) on people's work (38% of the respondents).

Where Mindfulness Is Most Required

This last section describes where mindfulness is most required (M3). The items in this section support organizations to start thinking of ways where to improve the capacity for mindfulness. The scale consists of 9 items and has an internal consistency of $\alpha = 0.60$. Results confirm the assumption that asset-intensive organizations operate systems which are less complex and tightly-coupled compared to HROs. 83% of the answers are above the threshold of 27, indicating that in these organizations, mindfulness is less critical due to lower perceived complexity. Nevertheless, analysis also showed that two items with a mean value of $\mu \leq 3.0$ need further attention to strengthen the capacity of mindfulness. The first item is the need for the coordination of working activities (56% of the respondents agrees on this item). The second item concerns the necessity to do things right the first time because work processes cannot always be corrected. 59% of the respondents agree, indicating that for many work processes, there is no opportunity for corrections. The term "First time right" has also been introduced in the maintenance department of NS. It refers to a standard way of working to prevent recidivism by preparing, diagnosing and repairing rolling stock the first time right when it arrives in the maintenance depot.

In summary, 83% of asset-intensive organizations operate in lower complex and tightly-coupled systems, 66% is conscious about potential problems and issues, and 59% of the organizations have a potential for vulnerability to mindlessness. The following sections indicate possible directions for improvements based on the insights to which extend current practices of asset-intensive organizations incorporate the five principles of mindfulness.

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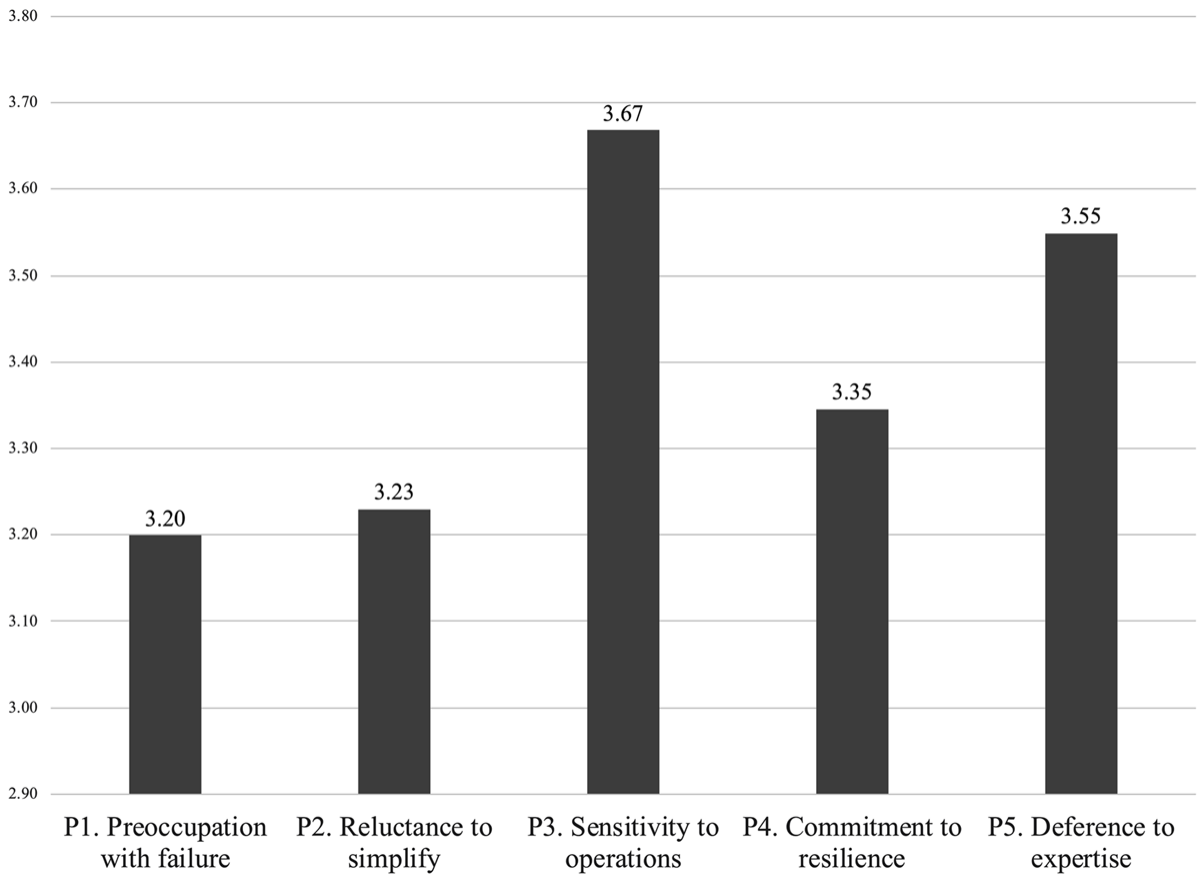
The Five Principles of Mindfulness

This section includes the results of the five principles of mindfulness (P1-P5). Figure 6 shows the mean scores of asset-intensive organizations on a scale from 1 to 5, indicating the average rating for asset-intensive organizations compared to HRO's.

Preoccupation With Failure

Preoccupation with failures (P1) refers to HROs' constant preoccupation with potential errors and failures. The items in this section determine the degree to which asset-intensive organizations have a healthy preoccupation with failure. Asset-intensive organizations need a strong preoccupation with failure to anticipate possible failures of their critical assets. The scale consists of 10 items and has an internal consistency of $\alpha = 0.82$. 31% of the answers were below the threshold of 27, indicating that almost a third of the organizations focus more on success than on failures. Results showed that near-misses were often (61%) regarded as successes that show the organization's capability to avoid disaster rather than failures that reveal potential dangers. Imagine a mechanic in a maintenance workshop, who just managed

Figure 6. The five principles of mindfulness (scale 1-5)



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to avoid an accident while repairing a pantograph. By pro-actively sharing his experience (near-miss) with other colleagues at other workshops, he contributes to the identification of potential dangers which increases the preoccupation with failures of the organization. Enabling the mechanic to share his experience easily would promote a more reliable culture in the organization.

Reluctance to Simplify

Reluctance to simplify (P2) relates to HROs' ability to collect, analyse and prioritise all warning signs that something may be wrong and avoid making any assumptions regarding the causes of failure. Seeking out reluctance to simplify, means that organizations want to find how the system socializes people to make fewer assumptions, notice more, and ignore less. Keep it simple is an established management paradigm in practice but does not always contribute to the reliability of the organization. If reality is complex, a simple representation may not be a fair reflection of reality anymore. The internal consistency of the scale was high with $\alpha = 0.90$. Results showed that the percentage of answers above the threshold of 37 was high (54%), indicating a strong focus on collecting, analysing and prioritising warning signs, based on 12 items in this section. The nature of the work, including diagnosing and analysing possible asset failures and applying root cause analysis, may be an explanation for this result. Nevertheless, the lower average score on the item of valuing sceptics within the organization ($\mu = 2.6$) indicates that asset-intensive organizations need to improve organizational conditions for appreciating sceptics.

Sensitivity to Operations

Sensitivity to operations (P3) refers to the ability to obtain and maintain the bigger picture of operations that enables organizations to anticipate potential future failures effectively. Diagnosing sensitivity to operations helps organizations appraise how prepared they are to prevent the accumulation of small events that can grow into bigger problems. The section consists of 9 items, and the internal consistency of the scale was high with $\alpha = 0.83$. Results showed that 10% of the answers are above the threshold of 36, indicating a very strong ability to avert the accumulation of small events into bigger problems. 84% of the responses are between 28 and 36, indicating a strong ability. Nevertheless, two items with a value of $\mu \leq 3.1$ on a 5-point scale can be considered for further improvements. The first item relates to the question of whether people are familiar with operations beyond their own job. Results indicated that 30% of the respondents consider this item as insufficient in their organization. Knowing how other experts and departments operate will increase individuals understanding of how (related) processes and procedures are executed and to what extent they contribute to operations. The second item is the question of whether managers constantly monitor workloads and reduce them when they become excessive. 26% of the respondents disagree, indicating the second area for improvement in this section.

Commitment to Resilience

Commitment to resilience (P4) is concerned with the ability of organizations to not only effectively anticipate errors but also to cope with and bounce back from errors and unexpected events. The capability for resilience, even if it is not exercised, aids diagnosis and detection of unwarranted simplifications

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and a cumulative trend in a series of errors. This section consists of 10 items, and the internal consistency of the scale was high with $\alpha = 0.88$. Results showed that the percentage of answers above the threshold of 31 was 76%. This indicates a strong commitment to resilience. A possible explanation for this high percentage is the high valuation of firefighting within asset organizations when things go wrong. Nevertheless, the continual devotion of resources to training and retraining people to operate the technical system should be taken into consideration for further improvements. Results showed that 21% of the respondents disagreed with this item. Technical systems will become more complex when information technology merges with operational technology. This will further increase the need for training, retraining and simulation. A better understanding of the system helps the organization to bounce back from errors and to cope with unexpected events. When introducing new trains, simulations are used to predict future performance and to identify possible failures to increase the response repertoire, which contributes to the resilience of the organization.

Deference to Expertise

Deference to expertise (P5) refers to deferring decision-making in case of emergencies to individuals with the expert knowledge to deal with a specific problem, irrespective of their status within the organizational hierarchy. This section consists of 7 items, and the internal consistency of the scale was high with $\alpha = 0.83$. Results showed that the percentage of answers above the threshold of 22 was 83%, indicating a strong ability to localize problems and limit spreads. Nevertheless, one item with a value of $\mu = 3.1$ on a 5-point scale can be considered to further strengthen the principle of deference to expertise. 23% of the respondents disagree that people in their organization typically "own" a problem until it is resolved. Ownership and clear responsibilities are essential for an adequate response in case of unexpected events.

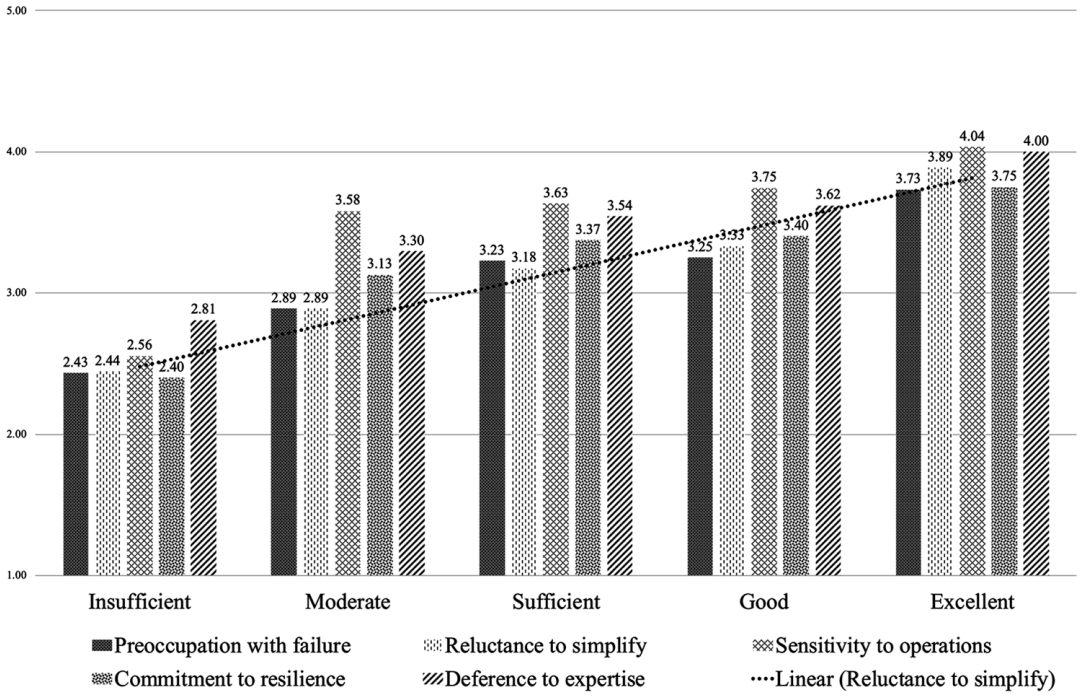
Asset Performance and the 5 Principles of Mindfulness

The Pearson correlation coefficient is a measure of the linear correlation between two variables X and Y. It has a value between $+1$ and -1, where 1 is a total positive linear correlation, 0 is no linear correlation, and -1 is a total negative linear correlation. The hypothesis was that asset-intensive organizations with a strong mindful infrastructure for high reliability would achieve a higher reliable performance of physical assets. Figure 7 illustrates the correlation between asset performance (horizontal axis) and the five principles of mindfulness as perceived by the respondents. The five principles all have a positive correlation with the asset performance, and all the correlations have a sig. (2-tailed) value of less than .05. Because of this, it can be concluded that there is a statistically significant correlation between asset performance and the five principles of mindfulness, taking into consideration that the population is based on a sample of 90 respondents. Pearson's r is the highest (.447) in the correlation with the performance and the principle of reluctance to simplify. The lowest Pearsons' r value was found (.363) in the correlation between asset performance and the principle of preoccupation with failure.

Investing in a mindful infrastructure for high reliability, especially when facing more uncertainty as a result of more complex systems in the fourth industrial revolution, will positively contribute to the reliable performance of physical assets.

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Figure 7. Relation between asset performance and the 5 principles of mindfulness



DISCUSSION AND IMPLICATIONS

The results of this study were presented and discussed at the annual conference of the NVDO in October 2017 with approximately 80 participants from asset-intensive organizations. This section includes a summary of the discussions at this conference to emphasize the relevance of this research and its implications for practitioners. By discussing statements using an online voting tool, further insights were gained to what extent practitioners expect the unexpected in their own organization and if they may benefit from adopting the principles for a mindful infrastructure. Based on the survey results, 5 statements were selected by the expert team consisting of both practitioners of the NVDO and academics from the University of Twente for discussion:

- The first statement raised was endorsed by 98% of the participating voters (39 out of 40) which stated that the complexity is not related to the technology, but to the organization. More awareness (section M1-M3) about the importance of organizational reliability, besides the technical reliability of the asset, to respond to increasing complexity, is therefore essential.
- The second statement was defined as “management is unaware of the issues and problems in operation”. This relates to the principle of sensitivity to operations (section P3) and was confirmed by 27% of the voters (10 out of 37). The existing gap between management and operations is well discussed in literature but remains an important challenge for organizations.
- Expect the unexpected also implies a certain strategy to respond in case of unexpected events (section P4). 40% of the voters (15 out of 37) lacked a strategy to manage the unexpected, while

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77% of the voters (30 out of 39) confirmed the statement that they need to pay more attention to the unexpected in their organization.

- One of the identified items that needs further consideration relates to the question of whether people are familiar with operations beyond their own job (section P4). 58% of the voters confirmed that people in the organization are not familiar with other working processes beyond their own job.
- Rewarding people for the identification of issues and problems contributes to the principle of preoccupation with failure (section P1). 55% of the voters (18 out of 33) confirmed the lack of rewarding issues and problems within their organization.

In summary, participants of the conference confirmed to a large extent the results as presented in this chapter and endorsed the idea to adopt HRO practices when seeking reliable performance.

CONCLUSION

The purpose of this chapter was to operationalise the HRO concept in the asset management domain, to measure to what extent the HRO principles are recognised at asset-intensive organizations and identify possible correlations between HRO principles and higher asset performance. In general, results revealed that the HRO principles could be operationalised to the domain of asset management and showed the extent to which the practices of asset-intensive organizations incorporated the five principles of mindfulness. Results showed a strong link between the overall asset performance and the five principles of mindfulness to manage the unexpected and maintain a relatively error-free performance.

The main hypothesis was that although asset-intensive organizations operate in lower risk environments compared to HROs, they can benefit from a mindful infrastructure for high reliability to manage higher levels of uncertainty a result of an increase in the complexity of physical assets due to the fourth industrial revolution. Results confirmed that the majority of asset-intensive organizations currently operates in an environment with lower complexity and less tightly-coupled systems compared to HROs. Nevertheless, only 66% of the organizations are conscious of potential problems and issues, and 59% has a potential for vulnerability to mindlessness. The survey results indicated that the HRO principles are recognised but also identified several items that need further management attention to strengthen the capability of asset-intensive organizations to discover and manage unexpected events. The results showed that there is a positive relation between asset performance and the five principles of HRO (P1-P5), indicating that adopting practices of the 5 principles of a mindful infrastructure for high reliability will benefit asset-intensive organizations in achieving reliable performance. Given these results and the expected increase in complexity in the fourth industrial revolution, asset-intensive organizations should consider adopting practices from HROs to strengthen their mindful infrastructure for high reliability.

The generalizability of this research is limited to asset-intensive organizations but may provide clear directions for organizations in other domains as well. Specifically, those organizations who face more and more uncertainty due to an increase in the complexity of their systems. Future research will be performed in the context of the introduction of new critical physical assets. High levels of uncertainty (e.g. teething problems) characterise critical asset implementations and organizations need to prepare consciously to expect the unexpected when seeking reliable asset performance.

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KEY TERMS AND DEFINITIONS

Asset-Intensive Organizations: Asset-intensive organizations such as utilities, heavy engineering, pharmaceuticals, and transportation rely on physical assets that are expensive, complex, and have a major impact on organizational performance.

Commitment to Resilience: Is concerned with the ability of HROs to not only effectively anticipate errors but also to cope with and bounce back from errors and unexpected events.

Deference to Expertise: Refers to the ability of HROs to defer decision making in case of emergencies to individuals with the expert knowledge to deal with a specific problem, irrespective of their status within the organizational hierarchy.

High Reliability Organizations: High reliability organizations (HROs) are a subset of high-risk organizations designed and managed to avoid accidents in complex, tightly coupled systems.

Preoccupation With Failure: Refers to HROs' constant preoccupation with potential errors and failures.

Reluctance to Simplify: Refers to HROs' ability to collect, analyze, and prioritize all warning signs that something may be wrong and avoid making any assumptions regarding the causes of failure.

Sensitivity to Operations: Refers to the ability to obtain and maintain the bigger picture of operations that enables HROs to anticipate effectively potential future failures.

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APPENDIX

Figure 8. Survey items adopted from Weick and Sutcliffe (2011)

M1 - Assessing the firm's mindfulness	**P2 - Reluctance to simplify**
1. There is a sense of susceptibility to the unexpected throughout the organization	1. People around here take nothing for granted
2. Everyone feels accountable for reliability	2. Questioning is encouraged
3. Leaders pay as much attention to managing unexpected events as they do to achieving formal organizational goals	3. We strive to challenge the status quo
4. People at all levels of our organization worry constantly about misspecifying events	4. People feel free to bring up problems and tough issues
5. People at all levels of our organization worry constantly about misidentifying events	5. People generally deepen their analyses to better grasp the nature of the problems that arise
6. People at all levels of our organization worry constantly about misunderstanding events	6. People are encouraged to express different views of the world
7. We spend time identifying how our activities could potentially harm all our stakeholders	7. People listen carefully, and it is rare that someone's view goes unheard
8. There is widespread agreement among the firm's members on what we don't want to go wrong	8. People are not attacked when they report information that could interrupt operations
9. There is widespread agreement among the firm's members about how things could go wrong	9. When something unexpected happens, people spend more time analyzing than advocating for their view
	10. Skeptics are highly valued
M2 - The firm's vulnerability to mindlessness	11. People trust each other
1. Exceptions rarely arise in our work	12. People show considerable respect for one another
2. We encounter the same kinds of situations and problems day after day	
3. People in this organization have trouble getting all the information they need to do their work	**P3 - Sensitivity to operations**
4. People are expected to perform their jobs in a particular way without deviations	1. On a day-to-day basis, there is always someone who is paying attention to what is happening
5. People often work under severe production pressures (time, costs, growth, profits, or other)	2. Should problems occur, someone with the authority to act is always accessible to people on the front lines
6. Pressures often lead people to cut comers	3. Supervisors readily pitch in whenever necessary
7. People have little discretion to resolve unexpected problems as they arise	4. People have discretion to resolve unexpected problems as they arise
8. Many people lack the skills and expertise they need to act on the unexpected problems that arise	5. During an average day, people interact often enough to build a clear picture of the current situation
	6. People are always looking for feedback about things that aren't going right
M3 - Where mindfulness is most required	7. People are familiar with operations beyond their own job
1. Work is accomplished through a number of sequential steps carried out in a linear fashion	8. We have access to a variety of resources whenever unexpected surprises crop up
2. Feedback and information on what is happening are direct and simply verified	9. Managers constantly monitor workloads and reduce them when they become excessive
3. The work process is relatively well understood	
4. The work process does not require coordinated action	**P4 - Commitment to resilience**
5. We can directly observe all the components in our production process	1. Resources are continually devoted to training and retraining people to operate the technical system
6. There are many different ways to produce our product or service (for example, items can be rerouted, schedules can be changed , and parts can be added later if delays or shortages occur)	2. People have more than enough training and experience for the kind of work they do
7. There is a lot of slack in our work process	3. This organization is actively concerned with developing people's skills and knowledge
8. In our work process, things don't have to be done right the first time because they can always be corrected	4. This organization encourages challenging "stretch" assignments
9. There is a lot of opportunity to improvise when things go wrong	5. People around here are known for their ability to use their knowledge in novel ways
	6. There is a concern with building people's competence and response repertoires
P1 - Preoccupation with failures	7. People have a number of informal contacts that they sometimes use to solve problems
1. We actively look for failures of all sizes and try to understand them	8. People learn from their mistakes
2. When something unexpected occurs, we always try to figure out why our expectations were not met	9. People rely on one another
3. We treat near misses as information about the health of our system and try to learn from them	10. Most people have the skills to act on the unexpected problems that arise
4. We regard near misses as failures that reveal potential dangers rather than as successes that show our capability to avoid disaster	
5. We often update our procedures after experiencing a near miss	**P5 - Deference to expertise**
6. If you make a mistake it is not held against you	1. People are committed to doing their job well
7. People report significant mistakes even if others do not notice that a mistake is made	2. People respect the nature of one another's job activities
8. Managers actively seek out bad news	3. If something out of the ordinary happens, people know who has the expertise to respond
9. People feel free to talk to superiors about problems	4. People in this organization value expertise and experience over hierarchical rank
10. People are rewarded if they spot potential trouble spots	5. In this organization, the people most qualified to make decisions make them
	6. People typically "own" a problem until it is resolved
	7. It is generally easy to obtain expert assistance when something comes up that we don't know how to handle

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Chapter 10
Anticipation of Problems in Innovative Projects Based on OTSM-TRIZ:
Operative Algorithm to Assess Resources and Solutions in Project Development - Innovative Projects Based on OTSM-TRIZ

Christopher Nikulin
Universidad Técnica Federico Santa María, Chile

Sabrina Estefania Nino
Universidad Técnica Federico Santa María, Chile

Constanza Céspedes Domínguez
Universidad Técnica Federico Santa María, Chile

Pablo Viveros
Universidad Técnica Federico Santa María, Chile

Raul Stegmaier
Universidad Técnica Federico Santa María, Chile

Niccolò Becattini
Politecnico di Milano, Italy

ABSTRACT

In this chapter, an integrated proposal is described to guide analysts and developers in identifying and selecting optimal alternative solutions in innovative projects. The integration is inspired by the theory of inventive problem solving, and specifically the recent evolution of the OTSM-TRIZ with a body of knowledge of risk analysis assessment. The authors propose a solution assessment indicator based on TRIZ-resources to anticipate a lack of resources when solutions are proposed. The solution assessment considers both risk assessment logic for evaluation and TRIZ resources for parameter classification and categorization. Finally, the solution assessment indicator aims to anticipate potential uncertainty by considering both qualitative and quantitative teamwork approaches. Moreover, this chapter presents a case study that involves a group of young designers and engineers working on a gripper design project, where the designers must develop a new product for a university laboratory.

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INTRODUCTION

The quest for efficiency and productivity in the current globalized environment, with fierce competition among companies, has motivated the development of methodologies to support the decision-making process, particularly in scenarios involving multiple variables or criteria for selection (Berumen, 2007). All industrial projects require a clear definition regarding the expected requirements and goals to achieve successful project results. Indeed, industries in the next decade will need to address new challenges based on different constraints, owing to the highly dynamic environments characterizing the current global market (McKinsey Global Institute, 2012). The drivers that motivate industries to change are firstly derived from internal company reasons, encouraged by the need for product and process improvements (Ziv-Av and Reich, 2005). Secondly, they are caused by external "events" (such as changes in environmental or social policies), which directly affect the growth and internal processes of organizations (Jaffe et al., 2002). These issues are non-trivial tasks in anticipating emerging problems caused by changes (Nikulin et al., 2018). However, changes based on problems and constraints cannot be considered only as a negative aspect, and in this scenario, particular attention is dedicated to constraints (technical, economic, and organizational), owing to their potential role as triggers for generating creative solutions in different knowledge fields.

Despite the difficulties in dealing with company problems (in terms of quantity and the manner in which they are managed), it is worth mentioning that these problems also play a positive role for companies. They indirectly determine the performance of any system, as their existence represents an opportunity for improvement (Rahman, 1998), particularly for innovative companies that make use of creativity techniques to meet new requirements continuously. Given this premise, plenty of models are available in the literature to aid decision makers in predicting managerial risks and recognizing obstacles for strategic decisions, so as to prevent or at least mitigate their impact (Viveros et al., 2012; Barbera, 2012; Viveros et al., 2014). Nevertheless, these models fall short in properly understanding the consequences or potential limitations of technical solutions in practice. Moreover, their applicability to specific industrial contexts is not always feasible or effective. They do not consider distinctive features of firms, and for this reason, many different models exist in the literature (Braunscheidel and Suresh, 2009), which are fundamental for correctly identifying critical integration areas required to guarantee project effectiveness.

In general, when a project is initiated independently from a specific industry, the analysts or developers must define directions for the formal development of project tasks. The research purpose must be established; that is, what the project objectives are. Indeed, during the initial stages, project solutions focused on addressing a specific problem have to be described, as well as the complex scenario and the manner in which the investigation will aid in solving it. It is important to note that objectives must be clearly defined in order to avoid deviations in the research process. The objectives are the solution guide and must be congruent with the current situation during the entire process (Hernández, 2006).

In many cases, specific objectives are divided into detailed activities that support the main objective and thus plan the project execution. The activities are defined to fulfill the general and specific objectives in order to establish routes for the project execution (Nikulin et al., 2013). Furthermore, the activities need to be analyzed and their priorities clarified. Activities are grouped in order to generate stages of the project development process to understand the steps to follow quickly (Nikulin et al., 2013). Each stage must specify the activities required and resource availability in the process in order to achieve a successful project: the correct tools, time availability, and worker skills, among others (Nikulin et al., 2017).

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From a TRIZ perspective, resources are important in all project processes. Altshuller (1984) proposed a systematic analysis regarding the resources of industrial projects, with the aim of encouraging analysis and anticipation of availability in project development. Moreover, Muller (2008) proposed an extension of Altshuller's resource analysis to improve the analysis process in project management, which is a relevant contribution to understanding the boundaries of the project development process. From a risk analysis perspective, the failure probability increases when an industrial project has deficient planning and poor resource definitions. For example, SMED is a method that allows for anticipation and measurement of problems from activity execution, and is frequently used when activity repeatability is high, which is a completely different scenario from when analysts are faced with an innovation project. In other words, understanding the resources is relevant for project development in order to obtain successful results and avoid uncertainty during the process.

From the literature, it is evident that industrial projects based on innovation present high failure probabilities, and mainly lack methods that prevent future problems at the development rather than strategic level (Nikulin et al., 2017). The skill of visualizing and managing possible negative scenarios is important for avoiding mistakes during project development. In this context, Khomenko (2008) proposed OTSM-TRIZ, an evolution of the classical TRIZ, with the aim of providing instruments to improve the efficiency of problem-solving sessions in the case of non-typical and complex interdisciplinary problems (Cavalluci and Khomenko, 2007). This evolution allows for TRIZ to be an integral methodology used in new knowledge areas. However, TRIZ literature indicates a lack of quantitative-analytic techniques, which are necessary for the hierarchy and selection of appropriate solution routes in the project development process. In general, appropriate planning includes not only the details of activities, but also appropriate knowledge of methodology that allows for the assessment of different scenes with their risk possibilities. In simple terms, effective evaluations and decisions increase the probability of project success.

Based on these premises, the authors propose an operative algorithm integrated with the risk analysis technique for improving the development of innovative projects, using TRIZ logic. The operative algorithm is inspired in OTSM-TRIZ, or more specifically, the network of problems (NoP) analysis in combination with risk analysis theories and applications, which allows for comparison among the different scenarios/selections in the NoP. The proposed algorithm can be used for the collection and analysis of different requirements by integrating OTSM-TRIZ during the project development process, which allows analysts to generate ideas and solve problems based on scenario analysis. In this work, OTSM-TRIZ is applied to deal with non-typical and complex interdisciplinary problems, within scenarios of designing under constraints and different scenarios evaluated through quantitative/qualitative risk analysis, allowing for an understanding of the optimal decision selection. Moreover, a case study is developed to demonstrate usability of the proposed algorithm. The case study focuses on the design of a modular gripper for multiple applications, which must be useful for students to develop several experiments in a shorter time.

STATE OF THE ART

Reducing Risk in Project Development

The research activity described in this paper aims to address the managerial issues of designing and following a more structured approach to understanding internal or process changes when a project needs to be developed. The authors propose an analysis to address the following research challenges: i)

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understanding the different constraints (problems and limitations for solution development) emerging at different levels, which can limit the solution space, in order to improve company processes; ii) Identifying the main constraints that should be solved or faced during the solution process and their related integration into company processes; and iii) creating a more resilient solution, suitable to be adopted in company processes based on simple risk analysis, which should be an adequate result of strategic and technical decisions.

Kumar and Kumar (1992) as well as Ghodrati and Kumar (2005) explained that risk analysis should be considered as a systematic approach, in which the correct support and strategies should be defined. In project development, risk analysis should be designed and implemented in order to reduce project risks, while satisfying constraints on factors such as budget, productivity, and space (Diallo et al., 2009). In many cases, risk theory is used to support part of the decision-making context. Risk analysis is used for the decision-making process, by integrating cost/benefit indexes (consequences) and uncertainty assessment, frequently expressed by probabilities (Aven and Kørte, 2003). In more detail, cost/benefit analyses are often based on simplifying assumptions, and focus on certain consequences while ignoring others.

Project management decision research has developed specific methods during the past several decades, and a common aim of each proposal is resource optimization, whereby the objective function is usually related to business characteristics (Cohen 2005), constraints, and limitations (Aven and Kørte, 2003). Within theoretical or practical frameworks, approaches include analytic techniques depending on the hazard characteristics (Silvanita et al., 2011), the quality and quantity of lifetime information available (Diallo et al., 2009), the criticality index of the analyzed machine/system (Dekker et al., 1998), and environmental factors (Ghodrati and Kumar, 2005). Based on the aforementioned explanations, the decision-making process relating to project management is clearly a challenging task that involves economical, technical, and operational variables, which change according to the particular problem being analyzed, and is obviously conditioned by the objectives pursued in research.

Risk Analysis as Initial Assessment for Successful Projects

An integral approach to consider in risk analysis is related to both mathematical and physiological perspectives (Vlek, 1996), in terms of which risk definitions are discussed at great length in the literature. Examples of psychological (informal) definitions from Vlek (1996) include ‘‘lack of perceived controllability”, ‘‘set of possible negative consequences”, and ‘‘fear of loss”. While the mathematical aspect is relevant for obtaining quantitative information regarding risk to consider different scenarios to tackle, the qualitative aspect is essential for obtaining knowledge about the problem, considering the human and psychological aspects of a situation (Suddle and Waarts, 2003). Further examples of (psychological) risk definitions can be found in the survey by Vlek and Stallen (1980) (Libby and Fishburn, 1977). The simple mathematical relation of risk logic can be represented by the following expression (the most frequently used definition in risk analysis) (ISO 31000, 2002):

$$RISK = P \times C \tag{1}$$

In the above, R is the risk, P is the failure probability, and C is the consequence of the unwanted event. Kaplan and Garrick (1981) considered at least three main components in the risk definition: i) scenario; ii) probability of that scenario; and iii) consequence of that scenario. Kaplan and Garrick (1981) also suggested that one must take into account all hazards, which can be accomplished by summing all possible

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hazards (scenarios) (Suddle, 2009). Consequently, multiple scenarios (indexed) and their mathematical relations can be considered by the following equation:

$$RISK = \sum \left(P \times C \right) \tag{2}$$

From a technical point of view, the extent of the risks and effects of risk reduction measures can be described by a quantitative risk assessment (QRA), which provides a basis for rational decision-making regarding risks (Bedford and Cooke, 2001). A risk analysis generally includes the following steps: scope definition, hazard identification, modeling of hazard scenarios, estimation of consequences, estimation of probabilities, and estimation of risks (Viveros et al., 2015).

From a TRIZ perspective, risk assessment in terms of specific solution development appears not to have been addressed properly at present. Consequently, this research attempts to enhance TRIZ (specifically, OTSM-TRIZ) by using quantitative analysis in the NoP analysis.

OTSM-TRIZ and Risk Analysis for Project Development

The theory of inventive problem solving (TRIZ) aids engineers by decreasing the amount of trial and error when a problem situation requires creativity and invention to be solved (Altshuller, 1984). TRIZ is based on three main postulates developed by Altshuller: the objective laws of system evolution, contradiction states, and specific situation states (Khomenko and De Guio, 2007). Similarly, OTSM, a Russian acronym for "General Theory of Powerful Thinking", was developed to extend the efficient application of classical TRIZ to a variety of non-engineering fields, particularly the educational area. Over the years, it has also been developed further to deal with problematic complex interdisciplinary situations (Khomenko, Shenck, and Kaikov, 2006). In addition to providing formalized models of classical TRIZ, OTSM introduces new instruments for organizing complex problems according to a hierarchical structure, in order to identify the most critical issues (Nikulin, Graziosi, Cascini, Araneda, and Minutolo, 2013; Baldussu, Becattini, and Cascini, 2011). In the context of OTSM-TRIZ application, the NoP is the first stage of the problem situation analysis. It is dedicated to forming an overall understanding of problem situations in order to obtain a holistic problem framework (Khomenko, Shenck, and Kaikov, 2006). The NoP is a graph in which the nodes represent both the problem (Pb) and partial solution (PS), which is the initial solution for addressing the problem. The connections among these provide a hierarchical structure of the problem situation combined with various alternatives for its solution. The graph edges link the PS to both the originating problem and newly discovered problems (Baldussu, Becattini, and Cascini, 2011). The network of contradiction (NoC) is a subsequent interpretation of the NoP that integrates information regarding contradictory requirements. TRIZ has been successfully applied to project aspects, as in Vidal et al. (2015), Cherifi et al. (2015), Russo et al. (2016), and Feniser et al. (2017). Nevertheless, a deeper integration considering risk logic appears to be required.

OPERATIVE ALGORITHM FOR PLANNING BASED ON NoP

This operative algorithm is created based on the authors' experience, using OTSM-TRIZ and resource evaluation techniques according to risk scenarios when a project is developed. Each of these has proven

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to be an excellent tool for analyzing and solving particular problems. OTSM-TRIZ encourages comprehensive analysis by means of creative thinking, which is useful as an analysis framework. Scenario evaluation using NoP can be considered as a consistent analysis technique, which is particularly useful for detailed analyses of complex systems (Nikulin et al., 2018). Based on these characteristics and positive evidence regarding the quality of each tool, this novel evaluation proposal for NoP is demonstrated as a decision-making alternative, especially for the analysis of complex and multifactorial project situations, which require an understanding of successful possibilities. The main difference between this proposal and previous analyses in the literature is that this technique transversely covers the entire problem domain. It not only focuses on the NoP formulation, but also includes a comprehensive analysis of successful situations and problem contexts. These comprehensive characteristics are convenient when the final goal of an analysis is to generate action lines to develop a specific project, particularly when a lack of resources exists for overall execution. In other words, the authors present an integrated quantitative evaluation algorithm based on the Liker/maturation scale. The aim is to identify the risk grade in the different detail levels in the project development.

The case study involves a modular gripper that can be adapted to five different situations in order to decrease the time for changing tools in industrial robots, contextualized in a university research laboratory. The teamwork is conducted by a small team of young designers and engineers. The proposal allows for project assessments of diverse disciplines, with the aim of:

1. Understanding in detail the project context and its problematic situation;
2. Anticipating problems and solutions that can be generated in the project development;
3. Quantitatively assessing and comparing the development possibilities based on key parameters that support the project; and
4. Generating development plans for scenarios with poor resources and thereby knowing how to mitigate these independently of their evaluation.

Stage 1: General Description of Situation Based on System Operator

The aim of this stage is to generate an analysis of the context as a basis for future decision-making processes. In order to generate this analysis, it is necessary to work with part of a system operator (SO) model, which belongs to the TRIZ methodology and operates as a multi-screen approach to system thinking, in order to support the system evolution vision (Altshuller, 1979). The SO was presented by Altshuller as a tool that allows for modeling knowledge consistently with the system-based logic of creative engineers and designers, in order to support the replication of their effective manner of thinking (Altshuller, 1984). The SO is typically depicted as a 3 x 3 “screen” matrix, but is freely expandable to additional columns or rows, according to various exigencies. It organizes knowledge according to two main dimensions; therefore, it allows for a detailed analysis of the situation to be obtained at different levels, as well as the super-system, system, and subsystem (Altshuller, 1984; Nikulin et al., 2013). The SO model operates with the following logic:

- Determine the limitation(s) according to different contexts, as well as technical, economic, social, and environmental factors (De Guio, 2008).
- Identify the super-system, system, and subsystem affected by the limitation(s).

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- Identify the future, present, and final stages regarding this problem or limitation.
- Propose a general synthesis for each of the SO model windows (Figure 1).

The purpose of using SO in this stage is to realize optimal operational management, in order to organize the necessary transformations within the process to achieve a superior solution.

Consequently, the SO approach should also satisfy the following necessities for this research:

- Versatility and ease of application to different industrial processes;
- Scalability to different detail levels, so as to map the knowledge of different experts and stakeholders in the industrial process; and
- Capability of representing time dynamics with an evolutionary perspective on technology.

It is important to mention that, in Becattini, Cascini, and Nikulin (2013), the SO is presented as an appropriate model to organize expert knowledge for both the product and process at different system levels.

Stage 2: Available Resources (TRIZ) for Project Development Analysis

This step requires identification of the resources involved in or related to the system under analysis. TRIZ-based classification of resources represents the beginning of problem solving. Resource analysis as part of a TRIZ-based toolkit can be defined as a technique for directing creativity. This analysis is directly applicable to every type of problem situation (Moehrle, 2003). In TRIZ terms, a resource is anything in and around the system that is not being used to its maximum potential (Mann, 2002). All of the identified resources must operate in the correct direction and work together to achieve optimal solution results. One of the key findings of the TRIZ-resource was that the strongest solutions are based on both unwanted and harmful elements, which are transformed into useful resources inside or outside of the process. The role of resources is frequently discussed in strategic management (Mueller, 2005). Strategy is constrained by and dependent on the firm resource profile (Collis, 1991; Tallman, 1991), and from a resource-based viewpoint, the concept of strategy is considered as a "continuing search for rent" (Bowman, 1974). The major difference between resource understanding inside the fields of TRIZ and strategic management is the application of resources (Mueller, 2005). Resources are the basic unit of analysis (Grant, 1991b) and may be conveniently classified under several headings (Grant, 1991a; Hofer and Schendel, 1978). The benefits of this classification are known and understood with the real application of each resource to achieve optimal benefits in the design process. Furthermore, TRIZ resources are used to solve a problem (Mueller, 2005), extending the space solution by attempting to maximize its usefulness inside or outside of the system.

Table 1. System operator: the most common schema for simulating an effective manner of thinking (Altshuller, 1984)

LEVEL	PAST (year)	PRESENT (year)	FUTURE (year)
Supersystem			
System			
Subsystem			

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The aim of this step is to identify the available resources to be used in the following stage. The identification is realized based on TRIZ classification, which allows for understanding of the resource types in order to take advantage of each of these. This classification includes six resource types that are considered as the majority of a design project.

According to TRIZ methodology, the classification of resources can be described as follows.

- **Material:** Related to all types of raw material, semi-finished products, and manufactured materials; that is, technological equipment belonging to a production plant. Any type of manufactured product is catalogued as a resource.
- **Energy:** refers to any type of energy originating from inside or outside of the company; that is, the manner in which the company environment affects its continual running. Analysts can also consider human energy, in the case of using physical force.
- **Information:** Related to all types of perceptible data in the system. Data may include documents, books, papers, computers, videos, and images, among others. Furthermore, analysts can classify the information stemming from human resources when it contributes to knowledge and creativity.
- **Time:** Refers to any time intervals that are relevant to the system operation. The times are considered in the actual company situation and are related to factors such as work times, preliminary work, programmed work, parallel processes, pauses, and time availability.
- **Space:** refers to any space or place available to the company and its environment for executing the Development processes.

Stage 3: NoP as a Key Planning Technique

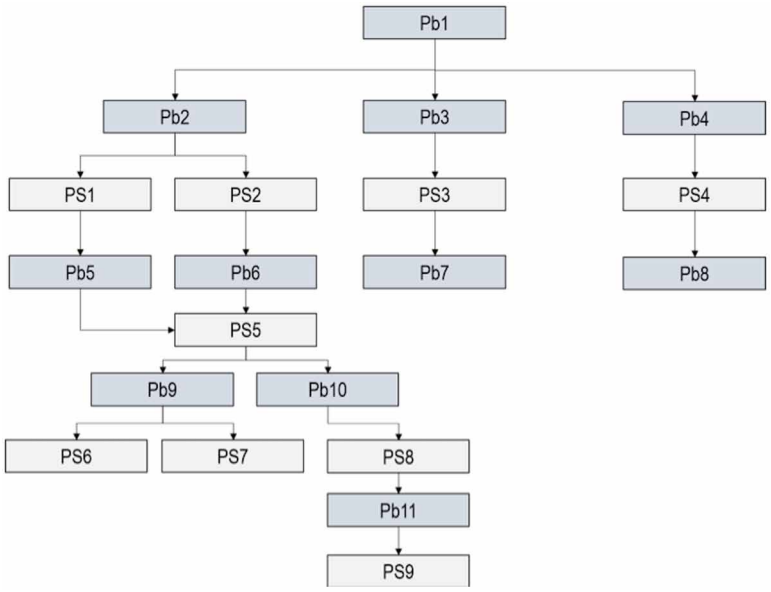
Along with the description of resources, it is necessary to define the available information in OTSM-TRIZ terms. This includes the definition of the main problem to be solved, or super-problem (Pb1), as defined by the element-name-value (ENV) model. This model will also be used for the definition of sub-problems, which should be solved in order to solve the main problem. When sub-problems arise, PSs should be defined that can make at least one positive contribution to the problem-solving process (Khomenko and De Guio, 2007; Khomenko, Shenck, and Kaikov, 2006). As mentioned previously, OTSM is the Russian acronym for the General Theory of Powerful Thinking and provides formalized models of classical TRIZ key concepts while introducing new instruments to organize complex problems according to a hierarchical structure, in order to identify the most critical issues (Baldussu, Becattini, and Cascini, 2011). NoP is an instrument that was mainly developed by Khomenko within the framework of the OTSM-TRIZ theory, with the aim of supporting engineers and designers in dealing with the initial steps of complex problem-solving activities (Cavallucci and Khomenko, 2007).

Firstly, it is necessary to model the problematic situation as an NoP. Several sub-steps characterize this task:

- **Analysis Stage:** Decompose the problematic situation, considering all the different process phases (from step 1) into more elementary problems, and repeat the decomposition iteratively until no further problems appear.
- **Synthesis Stage:** Where possible, using intuition and according to the team experience, to generate PSs for the elementary problems that currently populate the network.

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Figure 1. NoP, where Pb are the problems or sub-problems and PS are partial solutions
(Nikulin et al., 2013)



- **Evaluation Stage:** For each generated PS, identify new problems that may appear as a consequence of its implementation.

These three design stages can be repeated iteratively so as to achieve a more complete picture of the problematic situation.

Stage 4: Quantification and Assessment of Solution to Drive Project Development

In this stage, a novel assessment is proposed based on TRIZ logic in order to understand successful possibilities of an overall project analysis. For the solution quantification, it is necessary to assess the level of expertise/knowledge and resources available to address the main problem. The logic used for identification of these parameters is described below.

1. **Identify innovation parameters and constructs and interpret these towards reducing project development risk**. The objective of this logic is to redesign the constructs of the Innovation Capability Maturity Model (ICMM) model of Essman (2009) from a risk perspective. The characterization of its results and organizational support differ from the regular risk conditions and largely depend on the team that assesses the main problem to be solved.
2. **Identify relevant parameters and constructs for large applications in project development.** This involves narrowing the model to propose the most relevant parameters within the construction of assessing a large number of problem situations by using the same parameters. A first filter of constructs is conducted, omitting those constructs that fit well with the project development

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and planning, but not in a positive manner, in order to understand the lack of resources for project execution.

3. **Generate scenarios with interpretation towards project design and management.** In this step, the objective is to generate three levels of maturity that implicitly or explicitly design content as a relevant value for the development of the evaluated capacity of the project execution. The best practices (higher levels) refer to the highest maturity values within the model.

In detail, the format of each maturity scenario is inspired by Essman's model, and the maturity models are designed as follows. A basic level (1) with an ad-hoc value is reactive to circumstances that occur over time. An intermediate level (3) represents when the design practices and their management are already internalized processes, and can be diffuse and not formal, but the project already has a role available and is recognized within the assessed capacities. Finally, in level (5), the maturity levels, as support for the project development, are at a maximum, having a formal process and managing resources, with the aid of specialized human capital, and being an intrinsic resource of the organization to execute the project properly. Levels (2) and (4) are used as intermediate values between (1), (3) and (5), when developers assessment of the parameter does not match with any of the pre-stablished levels. Therefore, the use of Levels (2) and (4) is totally valid in the parameters assessment, thus obtaining real results in the assessment matrix.

The parameter analysis (PA) method has been proposed for cases requiring innovation (Kroll et al., 2001). PA focuses on the conceptual design process and consists of a descriptive model, based on observations of the design process and its development. The project concept space deals with "parameters", which in this context are functions, ideas, and other conceptual-level issues that provide a basis for anything that occurs in the configuration space (Weisbrod and Kroll, 2017). With this logic, the authors propose a novel classification of the main TRIZ resources in order to understand the successful possibilities of the project.

Analysts or developers must assess each of the proposed PSs based on five parameters: developer knowledge/experience (DK), system information (SI), process material (PrM), product material (PdM), and time needed (T). These parameters are associated with resource classification by TRIZ, because they allow for deep analysis of the building/development stage of the solution, as well as referring to certain real questions raised in the execution process.

Assessment using these parameters is performed for the first complex scenario that the engineers and designer must address. Each has its own description in order to understand its relevance, as well as all of the issues/resources incorporated into them. The assessment is based on these parameters because they represent each of the resources identified in the TRIZ classification but contextualized in the design and product development process.

The value level associated with a PS is known as the <Solution Assessment> and represents the possibilities of development without major issues using the elicited solution during the NoP.

Moreover, each PS under the same procedure must be valued using the same scale. In this case, more than one valued parameter may be identified (see Table 2). Each value assigned to each parameter is named according to previous nomenclature: <DK; SI; Pr; PdM; T>. The multiplication of parameters is known as <Solution Assessment-SA>, following the logic of risk analysis, whereby each parameter is essential for the project development. Finally, the goal is to determine which PS has a greater possibility of being addressed properly, according to the developer answers on parameters.

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Table 2. Scale measurement based on maturity levels

Parameter	General description	Level 1	L 2	Level 3	L4	Level 5
Developer knowledge/ experience (DK)	Developers know about activity-related topics and can create a real solution with their knowledge.	Poor knowledge and experience. The activity has never been developed for the analyst(s).		Some knowledge and, in certain cases, the activity has been developed.		Deep knowledge and experience. The activity has been developed frequently and regularly in practice. Unpredicted events are missed.
System information (SI)	Data compilation, images, and other information belonging to the system. Workers have access to the information for analysis.	The system suffers from a lack of information to develop the solution, and/or information access is difficult or impossible to obtain.		The system has sufficient information to be used for solution building, and/or information access may be limited.		The system includes the complete and necessary information to develop the solution or access to information is easy and rapidly obtained.
Process material (PrM)	Tools, implements, and equipment are available to develop the manufacturing or building process.	Tools, equipment, and implements are unavailable for use and/ or difficult to obtain.		Poor equipment, only a few tools and implements are available for the manufacturing process. Obtaining the equipment requires substantial time.		Equipment and all necessary tools for manufacturing are available and in good condition and/or equipment is easy to obtain in a short time.
Product material (PdM)	Materials (wood, steel, plastic, aluminum, etc.) that are transformed to obtain the final product.	All the required materials are unavailable or in a poor condition. Developers need to consider high acquisition times.		Only a few materials are available, in a good condition, or have fast and easy access.		All requested materials are available and have facility of use. In other cases, materials can be obtained in a short time.
Time needed (T)	The time considered in all development processes (analysis, design, manufacturing, quality assurance).	The time available for the solution development is less than that established in the planning. In other words, there is not sufficient time to develop an appropriate solution.		The time available for the solution is affordable and established in the planning.		There is a considerable amount of time for the project, far above that established in the planning. There is more time available than expected.

$$SA = DK \times SI \times PrM \times PdM \times T \tag{3}$$

As a result, each problem has a <Solution Assessment> by following the risk analysis logic as presented in equation 2. This indicator is useful for comparing the different PSs of the NoP.

Stage 5: Identify Execution Route in NoP

The decision-making scenarios can be constructed based on the PS routes, which are relevant to overcoming the main problem. A scenario represents a picture of the situation from a perspective determined by pre-selected PSs. The important point is that the scenario to be evaluated will clearly depend on the deciding agent, according to the developer skills and resources. These results can be expressed by means of illustrations, data graphs, and tables, among others. Figure 2 provides a simple representation of a potential route inside the NoP.

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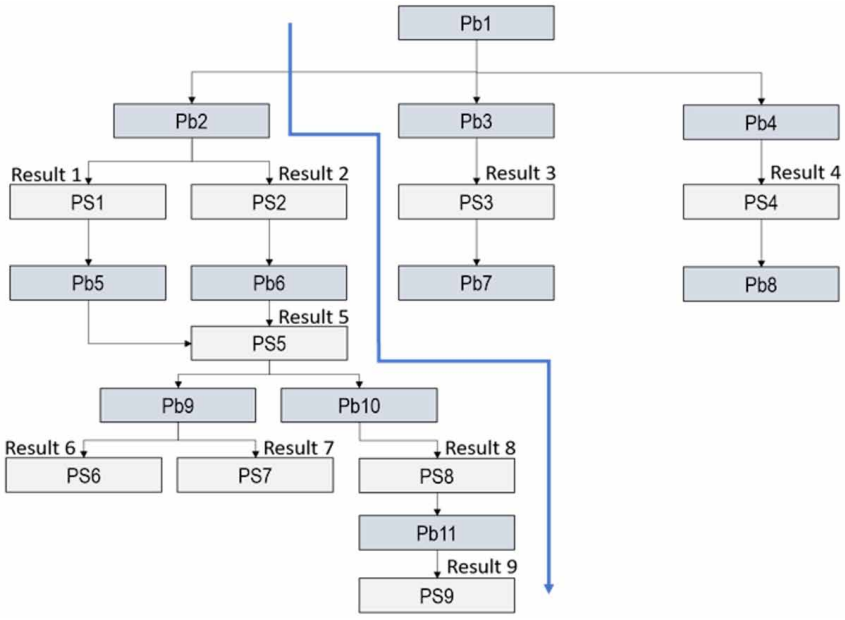
As a result of this step, information is obtained according to the variables under study and the hierarchical factors assigned in the execution. This type of analysis allows for a more rational understanding of the context and aids in simplifying the decision-making process. The scenarios can be displayed numerically, graphically, or in a combined manner. Finally, based on all of this information, decision-making is carried out, such as the generation of recommendations and action plans.

The final part of this step involves the creation of possible scenarios/routes by considering their relationships. For each PS that is identified and included in the solution framework, it is necessary to add the development master plan, and based on the information gathered from the previous steps, different tasks can be defined with their respective variables and PSs. It is important to consider that the number of scenarios should be sufficient to develop the project with unexpected issues to be solved. At this point, the list of tasks is set and ready to be implemented.

CASE STUDY

A real case study is presented in order to provide an example of the operative algorithm application, as well as estimate its applicability and viability within an empirical context. The case study was developed within the boundaries of the "Centro Integrado de Manufactura (CIMA) at Universidad Técnica Federico Santa Maria". The operative algorithm was applied to the design process for the development of a modular gripper. The aim of this case study is to exploit knowledge from engineers and design students in order to prototype a modular gripper, while anticipating major problems. This modular gripper operates based on five different sub-grippers simultaneously. The group consisted of two design engineers and two mechanical engineers.

Figure 2. NoP and example of solution pattern among potential PSs



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Stage 1: General Description of Situation Based on SO

Regarding the elicitation of process information, the main aspects of CIMA and industrial robots were collected intensively, considering different contexts and domains potentially affecting the student learning process (for example, for which activities students typically use robots). Moreover, the overall handling process was tackled from a fractal perspective, in order to understand which necessary grippers are currently present in the most critical laboratory (CIMA) activities. In order to improve readability and focus attention on problem management along with the application of the method, a set of three items per hierarchical level among the SO-level list are considered.

Three main rows characterize the hierarchical description level. The CIMA laboratory corresponds to the super-system, the definition of which appears to be in agreement with the objective of creating a modular gripper for a robot, which will be used in teaching activities. The robot is defined as the main system, and its phases as the subsystem. The specific aim is to understand the particular requirements according the types of robots used in student activities.

Stage 2: Available Resources (TRIZ) for Project Development Analysis

In the previous stage, the context was developed in order to understand where the principal problem is positioned, but at this stage the aim is to determine which resources are available in this context. The

Table 3. SO applied to case study

LEVEL	PAST (year)	PRESENT (year)	FUTURE (year)
Super-system – CIMA	a) Laboratory focused on manufacturing with computerized numerical control, robotics, automation, and rapid prototyping. b) Laboratory used by mechanical engineering department. c) Results obtained were basic and exhibited poor innovation. d) Laboratory with poor equipment.	a) Laboratory focused on manufacturing with computerized numerical control, robotics, automation, and rapid prototyping. b) This laboratory is used for certain courses in design engineering, industrial engineering, civil engineering and business. c) Several different prototypes are manufactured. d) Tools required are available for the manufacturing process.	a) Laboratory focused on manufacturing with computerized numerical control, robotics, automation, and rapid prototyping. b) All careers associated with design, manufacturing, and processes will use the laboratory in a complementary manner. c) New and modern tools are incorporated into the inventory. d) Additional courses will incorporate the use of this laboratory.
System – ROBOT	a) Few robots were used for work. b) Robots were antique. c) Robots had limited use. d) Robots were of high quality. e) Robots were not user-friendly.	a) Numerous robots are available for work. b) There are different types of robots. c) Robots are modern. d) Robots are used frequently and for new applications.	a) Several types of robots will be available. b) Robots will be new, modern, and use up-to-date technology. c) Robots will be used for new courses, in research projects, and for other personal aims.
Subsystem – GRIPPERS	a) Few tools were available for the manufacturing process. b) Grippers all had a similar function. c) Grippers were heavy and difficult to use. d) Gripper set-up was difficult and took a long time.	a) New grippers and different types are available. b) Grippers allow for manufacture of several prototypes. c) Grippers are lightweight. d) Grippers are user-friendly and set up time is shorter. e) Grippers operate with major effectiveness.	a) Grippers will be new, modern, and use up-to-date technology. b) Different types of grippers will be incorporated. c) Grippers will be lightweight and comfortable to operate. d) Grippers will operate with high efficiency and effectiveness. e) Grippers will have an automatic and fast set-up.

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resource analysis was carried out based on TRIZ classification, as explained in the previous section. Table 4 distinguishes the resources of the CIMA laboratory that are available to be used in the solution development process: those representing barriers not to be overcome in terms of exploitation (for example, because of unbearable cost increments) and those not fully exploited within the process, or of which further exploitation is acceptable. Moreover, the rows of Table 4 indicate the classifications according to energy, material, information, space, and time, as the identification of these resources in the laboratory was driven by means of these concepts.

Stage 3: NoP as a Key Planning Technique

This stage is focused on representing the relation between problems and PSs by means of the NoP of OTSM-TRIZ. The main problem to be broken down using the OTSM-TRIZ approach is as follows: the CIMA laboratory needs to build a modular gripper (Pb1). Taking this as an initial point, five main problems/PSs were identified and introduced hierarchically under the main problem in the graphic NoP representation. Continuing with this separation of the main problem, the NoP was constructed, and is presented in detail in Figure 3.

During the creative session, five gripper types appeared to be necessary for educative sessions in the laboratory: i) the suction gripper takes the seals and fixes them onto the gas gallon (laboratory experience: place cups in gallons using a pneumatic system); ii) the nut gripper loses the nuts of a fixation with other parts (laboratory experience: move and remove nuts in wheels automatically); iii) the polishing gripper generates a surface finish on the object (laboratory experience: improve quality surface using robots); iv)

Table 4. Simple resources classification based on TRIZ and relevant parameters as opportunities for solution development

RESOURCE	DESCRIPTION
Material	For the development of parts and pieces: o Machines: laser cutting machine, additive manufacturing machine, stereography, CNC router, hand tools, computer for modeling and simulation. o Materials: aluminum, acrylic, ABS, PLA.
Energy	o Electric energy for operation of machines and spaces. o Human energy for all execution processes.
Information	o Project requirements, initial problems for solution development, theses previously realized, compiled images of grippers. o Database on web regarding patents and other scientific referents. o Papers, documents, books, and journals on web or at university library. o Prior knowledge regarding design process methodologies. o Knowledge from expert at CIMA laboratory. o Information of robot (manual).
Time	o Work times in prototyping laboratory (laser cut, 3D manufacturing, handwork) o Gathering information, analysis, design, and manufacturing times. o Time considered in writing of the final document. o Analysis schedules with guide teacher. o Holidays and free days considered for rest.
Space	o Infrastructure/space of Universidad Técnica Federico Santa María (Product Design Engineering, laboratories, library, classroom)

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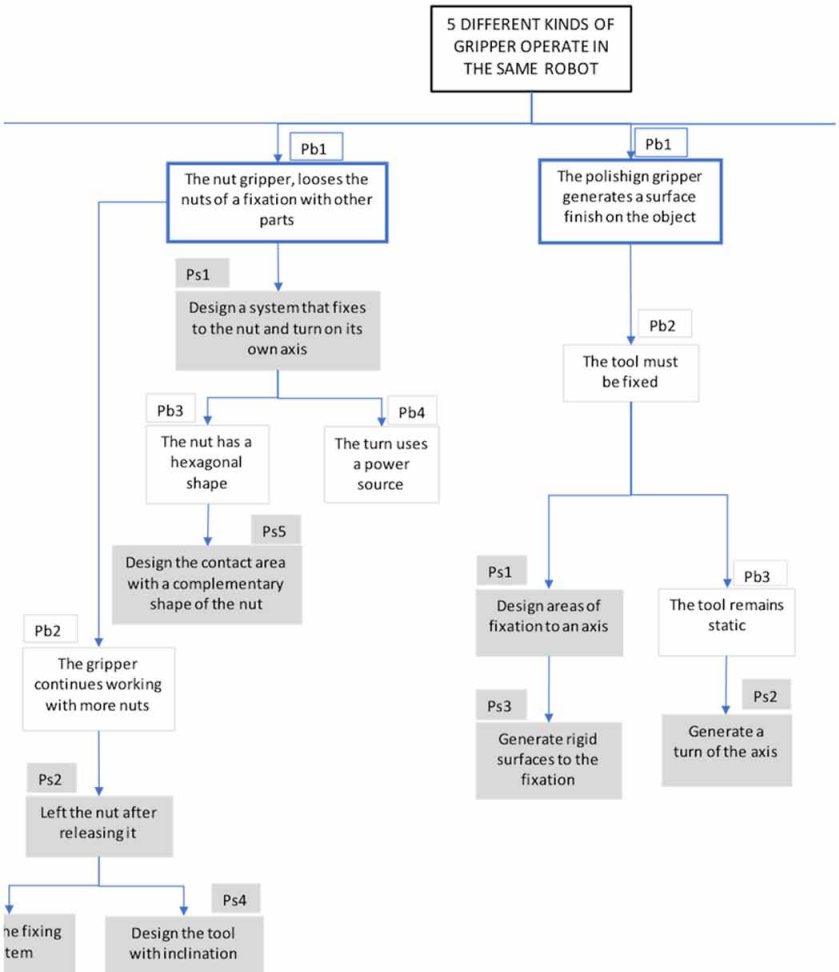
the gripper must grip, lift, and move the object (laboratory experience: simple movement of pieces); and v) the trajectory gripper records the path defined in the robot (laboratory experience: feedback robot).

Figure 3 is an extract of the main NoP who was developed with the main problem, which briefly describes the initial situation to be solved. Indeed, the principal problem was divided into five new problems according to the five different grippers that will be used and analyzed in depth. Figure 3 just shows three main problems as example to know how the NoP is developed. This continued with the identification of new possible problems and PSs.

Stage 4: Quantification and Assessment of Solution to Drive Project Development

From the PS obtained in the NoP during the previous stage, at this point, it is possible assess each PS based on the proposed maturity level. Effective development of the NoP allows for identifying a higher quantity of PSs, which means a greater amount of details for the final solution.

Figure 3. Main NoP to develop modular gripper for robot laboratory



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After organizing the problems and PSs into their corresponding routes for execution, each problem was classified according to its associated possibilities of being developed. In this case, the first step was to identify the main development routes and alternative solutions, if they exist. Likewise, the assessment of each solution was evaluated, identifying the risk affected by selecting a specific PS for the overall project. For the quantification of each solution, the first stage involved identifying the <Solution Assessment-value> using the aforementioned assessment scale that was previously defined. Finally, a valued problem matrix was created (see Figure 4), which is normalized in order to understand which solution is more plausible to execute proactively.

Stage 5: Identification of Execution Route in NoP

Following the previous analysis of the assessment of the identified solution, associated resources, and developer knowledge, the most appropriate strategy for the development process in the CIMA laboratory was selected.

The first step towards selecting the optimal strategy was transferring the normalized indicators of the <Solution Assessment-value> and the five values assigned in the assessment to each PS in the NoP. Thereafter, the assigned information allowed for detection of the PSs with major success indicators, as well as those with major uncertainty. Using this information, developers could select a specific route to approach the main problems in the solution development. Furthermore, the solution route selected could provide certain solutions with high uncertainty; nevertheless, it continued to be superior to the other routes. Moreover, the assigned values in the assessment allowed for identification of the weakest parameters that must be resolved in order to increase the success probabilities. Figure 5 illustrates the decomposition of one of the main problems of Figure 3, which was evaluated according the different proposed parameters.

DISCUSSION

The proposed algorithm aids in structuring and organizing information based on traditional problem identification, which is integrated with a problem-solving approach in order to improve the analysis and decision process based on novel assessment. During the case study, one of the main issues was related to knowledge, given that the team suffered from a lack of knowledge in developing grippers, and several proposed solutions were affected by these parameters. That is, in this case, the developers knew what they should do, but in practice, they did not know how to do it. Identifying this type of lack of knowledge was found to be useful to reinforce the group with people who have experience in gripper manufacturing. According to the proposed algorithm, it is important to include certain considerations regarding repeatability: the competences of the teamwork to develop the project and time consumption for developing the analysis may be high if the team members do not have previous experience using the OTSM-TRIZ approach. The decision process of the critical part or system can be supported by using additional decision assessment techniques, such as AHP. It is important to mention that solution assessment is largely dependent on teamwork skills to develop the optimal solution according to the initial problem; therefore, it is necessary for the designer/manufacturer who will develop the solution to evaluate which is the best

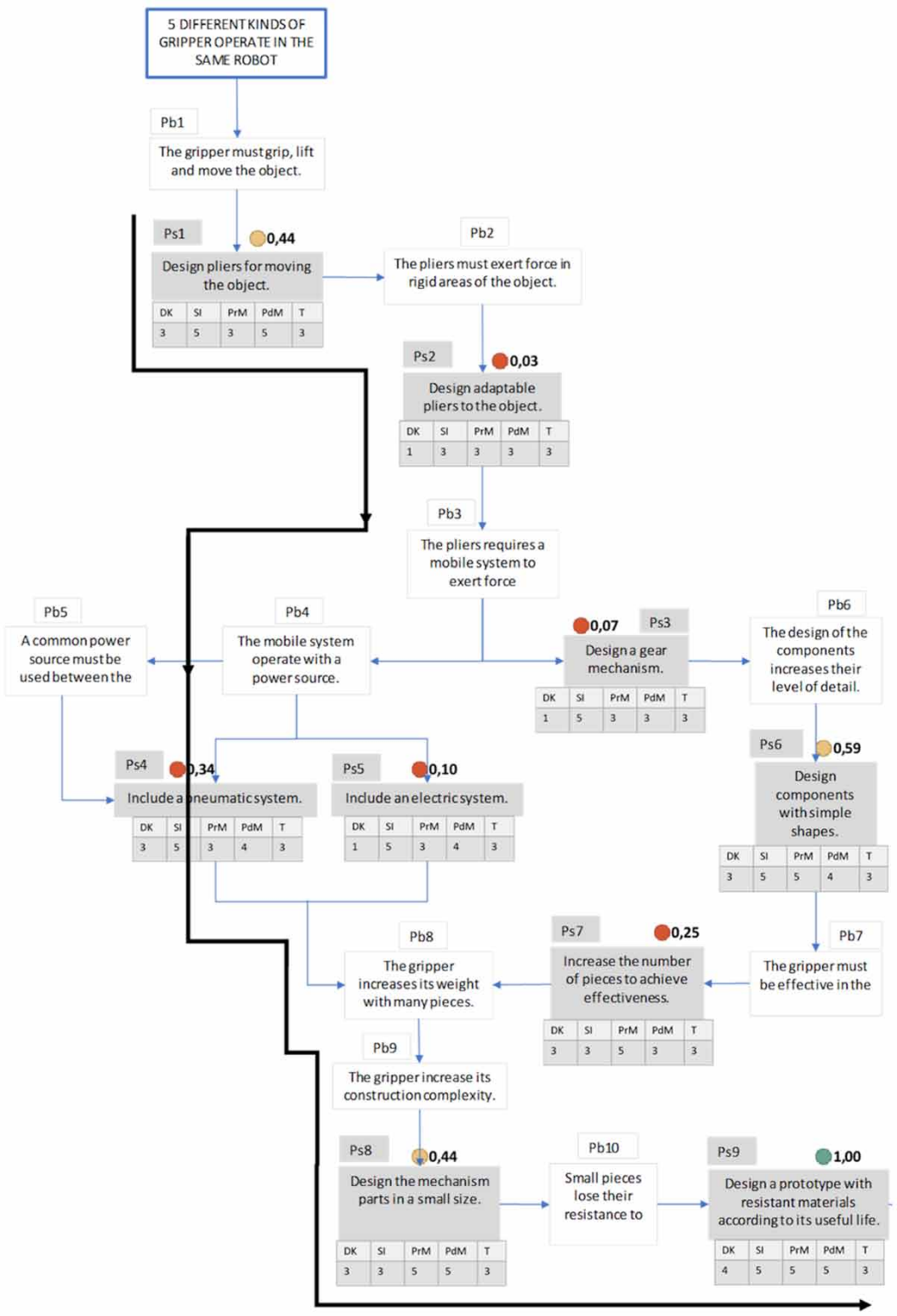
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Figure 4. Abstract of assessment matrix: PS of NoP

					ASSESSMENT PARAMETER						
KIND OF GRIPPER	Pb	PROBLEM	SOLUTION	PS	Developer knowledge/ experience	System information	Process material	Product material	Time needed	Solution Assessment	Normalized indicator
POLISHING GRIPPER	Pb1	The polishing gripper generates a surface finish on the object									
	Pb2	Requires a tool to polish the surface	Use a soft material tool to fulfill the function	Ps1	3	3	3	3	5	405	0,25
	Pb3	The tool works in a rotating way	Generate a turning axis that allows circular movement	Ps2	3	4	1	1	3	36	0,00
	Pb4	The tool must be set to perform the spin function on the shaft without releasing	Design fastening zones between the polisher and the shaft	Ps3	1	3	2	4	3	72	0,02
	Pb5	The axis of rotation must work from some source of energy	Design a pneumatic system	Ps4	3	5	3	4	5	900	0,59
			Design an electric system	Ps5	1	3	4	3	3	108	0,05
GRIPPER OF RELEASE NUTS	Pb1	The nut gripper, looses the nuts of a fixation with other parts									
	Pb2	The nut is fixed in the direction of rotation and released in the opposite direction	Design a turning system on its own axis	Ps1	3	4	2	3	3	216	0,12
			Design a contrary rotation to the fixing rotation	Ps2	3	3	4	3	3	324	0,20
	Pb3	The nut has an hexagonal form	Design the contact area with a complementary shape to the nut	Ps3	3	5	5	4	4	1200	0,80
	Pb4	It works with various nuts consecutively	Generate opening and closing of the contact area	Ps4	3	5	5	3	3	675	0,44
			Design a tool with inclination	Ps5	1	3	3	3	3	81	0,03
	Pb5	The nuts to be released have the same characteristics	Design the contact area with fixed dimensions	Ps6	3	5	5	5	4	1500	1,00
	Pb6	The axis of rotation must work from any source of energy	Design a pneumatic system	Ps7	3	5	4	4	3	720	0,47

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Figure 5. Example of routes to be executed based on OTSM-TRIZ NoP



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means of development based on its perspective with its capabilities. However, the proposed assessment aims to identify a lack of resources that are required to execute a project successfully. The educational project was useful for understanding the task distribution in a team of students, and can also be extended to a large number of developers.

CONCLUSION

The operative algorithm has been elaborated in order to guide the selection of the optimal project development route to follow when it is necessary to integrate new technical solutions. The operative generation was inspired by the theory of inventive problem solving (Altshuller, 1984) and OTSM-TRIZ, the aim of which is to provide instruments to increase the efficiency of problem-solving sessions in the case of non-typical and complex interdisciplinary problems.

Currently available integration models can aid decision makers in selecting the optimal compromise solution among several alternatives, but rarely guide the implementation stage in terms of the possible consequences or effects to take into account. The research described in this paper has a twofold objective: to define a more structured approach to solving the integration and execution of project development, avoiding compromise solutions, and to support decision makers in accomplishing this integration. An important prerequisite in defining the authors' method has been providing a decisional tool that is easy to use and understand, keeping the problem analysis traceable, and taking into account distinctive project features. An algorithm has been developed to guide analysts/developers in correctly approaching and solving integration issues: the OTSM-TRIZ resource analysis and NoP were applied to develop an efficient and reliable algorithm. Evaluation based on the TRIZ-resource is a useful analysis mechanism, which is necessary for understanding the effects of PSs on the selected decision and development, in addition to the fact that, in practice, decisions are generally made simply considering partial information, without thorough consideration of anticipated problems. The results of the case study were considered successful because it was not necessary to introduce invasive modifications to the OTSM-TRIZ logic. In fact, modifications were more focused on exploiting improved knowledge from the teamwork by using simple <Solution Assessment-parameters>.

The findings and lessons gained from the case study development and laboratory expert involvement, such as production and human resources managers, are of two types: the algorithm effectiveness and the usability level of the proposed approach. Regarding the algorithm effectiveness, although the obtained results were evaluated as effective, additional case studies should be planned to test the algorithm robustness. Regarding the approach usability and related assessment, further improvements can be made. Specifically, the authors consider this study as a first step towards building a software application capable of guiding the analysis of a planning process and manufacturing definition, following a systematic approach that aims to guide the analysis using each step, problem identification, and problem resolution.

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Chapter 11
Design Knowledge Development and Additive Manufacturing Systems:
How Does Design Knowledge Change With Design for AM?

Roderick Walden
University of Technology Sydney, Australia

Stefan Lie
University of Technology Sydney, Australia

ABSTRACT

The adoption of new technology is key for any manufacturer wanting to stay relevant as the world transitions to Industry 4.0. The advance of additive manufacturing (AM) technologies—an important element of Industry 4.0—has become part of a globally accepted reality. However, conventional design practice and knowledge generation inside a manufacturing firm must evolve. Technology-driven innovation must embrace knowledge-directed design work that is aimed at forecasting and utilizing the potential of new technologies. The chapter includes two projects, both of which were manufactured using additive manufacturing laser sintering technology. Analysis of the projects positions them at either end of a wider spectrum of product design practice that more aptly captures the way design and industry must operate for technology-driven innovation and Industry 4.0. A place for conventional design for manufacture remains though the case studies indicate differences in the setting of values to inform practice, requiring new methods for creating and managing design knowledge in the future.

INTRODUCTION

This chapter explores the potential impact on product design practice, due to the technological changes associated with a move additive manufacturing (AM) as a key part of Industry 4.0. The term Industry 4.0 refers to a revolutionary step in the level of organisation and control over the entire value chain involving the manufacturing industry. Industry 4.0 represents an unprecedented degree of system inte-

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gration between physical and digital worlds (Aljukic, 2017). The technological advance of an Industry 4.0 environment is a move toward self-aware, self-learning machines (smart manufacturing), creating a more open, flexible industrial network. Advanced (digital) manufacturing technologies such as Additive Manufacturing (AM), is central to this chapter. The networked industrial practice and integration of individualised customer requirements that contribute to define Industry 4.0 (Vaidya et al. 2018) can be functionally achieved through the optimisation of AM. Generally, the rapid technological change and innovation affecting production methods and consumption patterns drives forward the knowledge-based economy which places information and knowledge production at the centre of economic growth (OECD 2001).

Research provides appropriate ways of describing the connection between design practice and design knowledge based on conventional industrial situations, however technological change and the effect that's having on the conduct of design and manufacturing organisations requires a review of those descriptions and their applicability in technology-driven innovation. The research presented here considers product design practice for AM noting that as the scope of opportunity increases with the technological benefits of AM so does the need for design to become better equipped at developing new design knowledge. Development of design knowledge should be improved to enable product design to be agile and effective in its relationship with future systems of manufacture.

The chapter begins with a background section that describes the nature of design knowledge and highlights the importance of practice in the creation of design knowledge and the importance of 'values' in the conduct of that practice. Technology-driven innovation has been related to design and business by Verganti (2009) though his term is technology-push innovation. Verganti identifies in his research the importance for companies that hope to achieve competitive advantage to use design to integrate new technologies to 'push' toward 'radical' innovations that come not from market analysis but from a deeper understanding of meanings and values. Essentially, the pace of change and the risk of 'disruption' means that if companies rely exclusively on what 'the market' is telling them, then they are already well behind the competition. Design knowledge relies on values to direct practice particularly in the pursuit of 'radical' innovations through technology-driven innovation because there are few if any precedents (products or practices) to build upon. And design knowledge and values can only be developed through practice.

The chapter proceeds to provide descriptions of design practice that are more knowledge-intensive in nature such as *concepting* (Keinonen, 2006) and *research prototyping* (Matthews and Wensveen, 2015) to support an organization's ability to strategically forecast connections between emerging technology and emerging markets. Comparisons between conventional Design For Manufacturing (DFM) and technology-driven innovation serve to illustrate the way design practice must also change due to the way AM situates the production activity so 'close' to the end-user.

Two case studies are presented that demonstrate changes in the focus of product design work where AM has been the utilised production method. Both projects have been developed for manufacturing SMEs. AM is an intelligent production system considered to be an important part of the move to Industry 4.0 (Dilberoglu et al. 2017). As the level of sophistication and potential for application for AM steadily increases, technology-driven innovation as a design and manufacturing strategy is a key factor for the advancement of knowledge-based industries. The rationale for the study emanates from a concern for the product design industry and its ability to adapt to the pace of change associated with technology-driven innovation and Industry 4.0. The chapter seeks to demonstrate that the core competencies of product design practice hold true despite the significance of industrial-technological advances, though it requires

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practitioners to become more astute at managing the development of design knowledge. Additionally, and by extension of this, product designers must modify their practice to be knowledge-directed and technology-integrated to effectively and responsibly operate in advanced manufacturing environments.

BACKGROUND

Hoadly and Cox (2009) suggest that design knowledge may be less about 'answers' and more about 'methods that lead to answers'. They describe design knowledge as a type of meta-knowledge that links theory and practice through the creation of processes to deal with the underspecification, uncertainty and complexity of emergent phenomena. Importantly, they note that the development of design knowledge is in part driven by 'values' set by the 'designer' as part of an exploration of 'what should be' for the benefit of 'man' (referencing Aristotle's *phronesis*). Logically, as the world becomes more complex and as technology continues to advance, the scope for creative impact on the world increases. Given the disruptive nature of advanced manufacturing systems it's important to consider the responsibility of design in the development of, and contributions to, knowledge. The emergence of Industry 4.0 inevitably invites complexity that will impact design knowledge. Consequently, the question of how designers set and solve problems 'opens up' to challenge previously stable conventions precedents and drive innovation. Acknowledgement of the variability and irregularity of design outcomes and processes has led to the development of design models that propose structured relationships between the (assumed to be stable) underlying regularities in designs and designing. The Function-Behaviour-Structure (FBS) framework of design and designing (Gero & Kannengiesser, 2014) is one such approach. FBS framework identifies the interdependent variables of function ('what an artifact is for'), behaviour ('what an artifact does') and structure ('what an artifact consists of') as underlying values of all design to be coordinated and situated in design process. Engineering design may benefit from such models, but when the designer does not know what the artefact should be, or even *if* it should be, then an alternative position on values may need to be considered in a broader context.

Outside of the more predictable boundaries of conventional design for manufacturing, it will be the integrity of values that will bind technology-driven innovation strategy. The concept of 'values' in the development of design knowledge has been referred to in other design research such as subjective positions (primary generators) that drive conjecture and analysis (Darke, 1979); as a means of 'pre-structuring' by Hillier and Musgrove (1972) and as 'justificatory arguments' that bridge aspects of theory and practice (Lie, 2009). Design operating in a manufacturing environment that is rapidly advancing needs to contextualise, clarify and communicate its contribution in terms of practice in ways that the organisation can support.

Organisations may integrate knowledge both *of* and *by* design to address the challenges of technology adoption for Industry 4.0. It has been stated that "design is a capability, not a function" (Aman and Anderson, 2016) where knowledge integration can be achieved either *of* design or *by* design. Integration *of* design operates within its distinct capabilities (alongside other functions of the firm) in a more conventional way. And knowledge integration *by* design becomes an essential part of strategic management (2016). Industry 4.0 invites new technological advances that can flexibly adapt to customisation and lead to the creation very new products. Silberzahn and Midler (2008) identify that firms that create products for truly uncertain markets adopt a strategy that enables concurrent development of products

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and markets, as well as being flexible enough to "respond to new situations". It seems certain that companies operating comfortably in an Industry 4.0 environment manage technology-driven innovation with a capacity to integrate design capability both *of* and *by* design.

Traditional manufacturing industry typically positions design activity close to the production arm of the organisation. However, to develop a stable and effective means of innovative product development that can also be agile, design can also be used to forecast technological impact through *concept design*. Keinonen (2006) refers to *concepting* as a design function that is used to develop ideas that may or may not be the foundation of commercialisation but offers other forms of value such as exploring the application of technology, establishing a shared (corporate) vision, learning new design practices and for expectation management. Concept design should not proceed aimlessly, however. Emerging from academic design practice, research prototypes - prototypes typically unfinished and created for new knowledge enquiry rather than specifically for commercial reasons (Redström, 2017) - offer ways to utilise concept design for understanding technology. Research prototypes in academic design research proceed as a form of constructive design research (Koskinen, Zimmerman, Binder, Redström & Wensveen, 2011). Matthews and Wensveen (2015) describe four types of research prototypes - as an experimental component, a means of inquiry, a research archetype and as a vehicle for inquiry. Research prototyping and *concepting* may be thought about as knowledge-directed, meaning that this mode of design practice can be conducted to uncover new knowledge about how to design, what to design and how to drive innovation in Industry 4.0 environments.

Manufacturing SMEs are often identified as being flexible enough and agile enough to adopt technology-driven innovation, though they seem unable to manage the risk and cost associated with knowledge-directed (rather than exclusively commercially directed) design work (Rammer, Czarnitzki and Spielkamp, 2009). One advantage of AM is that design and production are brought close together, lending itself more favorably to exploratory and concept design work over conventional manufacturing. R&D support from university research units external to the SME is often sighted (and supported by Governments) as an option for companies under pressure to advance their technological and innovation competency. These arrangements must find ways to resolve the differences in incentives and orientation between university and industry practices (Bruneel, D'Este and Salter, 2010) and prototyping is one way that knowledge transfer can be effectively conducted.

The two projects that are analysed in this chapter, the bicycle crank arm and the Headistancer, serve as research vehicles to investigate the advantages of AM and the way design process may need to change in response to the demands of technology-driven innovation. Essentializing the role of design and design tasks remains a challenge (Dorst, 2016) particularly in relation to managing the transition to Industry 4.0.

The bicycle crank arm (see Figure 2) is a University Industry Collaboration (UIC) project, that as design research makes actionable *research prototyping* and by extension *design knowledge creation* accessible to industry. Viewed in this context, SMEs may feel more confident in strategically conducting the important work of experimental or 'concept' design. The bicycle crank arm is a project situated at the earlier concepting stage of the product development cycle. In contrast to this, the Visionsearch Headistancer (see Figure 4) is situated at the other end of the spectrum, where AM is used to produce end-use parts rather than research prototypes. The Headistancer is an example of addressing customisation and provides insights for SMEs considering Industry 4.0 technologies, such as AM, with a better understanding of how to potentially integrate them for end-use part production.

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PRODUCT DESIGN AND TECHNOLOGY-DRIVEN INNOVATION

Verganti refers to technology-driven (his term: technology-push) innovation in product design as a strategic approach to bring about, what he refers to, as a 'radical change' from conventional product typologies (2009). He goes on to state that this strategy is identified as being quite different from market-driven or user-focused design approaches that can only effectively deliver incremental improvements to conventional product typologies. Verganti further identifies a third strategy he calls design-driven innovation that incorporates both a technology 'push' and a shift in product 'meaning' - the emotional and symbolic attributes of product experience. The notion of innovation brought about through this so-called 'meaning change' which is dependent on a technology-driven design approach requires design to operate very much at the forefront of the product development process and not where it normally sits, in 'service' to manufacturing industry.

The authors see the role of the product designer expanding across the organisation in the future as a consequence of technological change associated with the integration of AM and the transition to Industry 4.0. Verganti's 'design-driven innovation' is essentially a strategy to explicate the relationship between design practice and business practice in a future industrial environment where competitive advantage can only be gained by organisations that can successfully create 'new markets' rather than exclusively rely on becoming leaders in existing ones. The role of product design practice inside an industry 4.0 organisation is not straightforward. The conditions that once guided product design practice are opening up. The profession must develop the ability to address complexity and uncertainty at multiple levels of the organisation. As Åman and Anderson (2016) indicate, organisations must adopt approaches to both the integration *of* and *by* design. This means product design must become better at conducting research, at setting values and developing (and cultivating) design knowledge to effectively contribute to technology-driven innovation.

As Hoadly and Cox (2009) suggest, design is more about methods than answers and, consequently, manages information and the development of new (design) knowledge through practice. *Practice* remains central to designs ability to solve problems, manage complexity and work through uncertainty. The problems of complexity and uncertainty as well as remaining competitive through technology-driven innovation may require new forms of design practice. The following section discusses the history of Design for Manufacturing which brought about the classic 'R&D' (Research and Development) model and the move to becoming design-led (technology-driven).

Description of Conventional Design for Manufacturing Process

The process of creating designs suitable for manufacturing predominantly relied on designing for moulds as the basis of making multiple repeats (Loy 2015). Designing parts so they can be manufactured in moulds and tools brings with it certain limitations. Injection moulding, for example, requires parts to have draft so they can be removed from the mould after moulding as well as a uniform wall thickness so the part shrinks evenly while it cools down. Injection moulding tools are also expensive to produce so complex geometry and undercuts on parts are avoided as much as possible. This typically means that product designers spend much of their energy on reducing complexity of parts, so they can be manufactured more easily, which in turn leads to a particular design process suited to established methods of manufacture. As a matter of fact, the profession of Industrial Design gets its name from this close relationship between industry and the designers that design for it. The two, design and industry, are so

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strongly connected that over the past 70 years DFM has developed into a sophisticated school of thought, which the majority of tertiary education Industrial/Product Design courses around the world have adopted. However as new manufacturing methods emerge, through Industry 4.0, this school of thought needs to adapt to new methods of manufacturing.

AM serves to illustrate this point well, because it does not require dedicated tooling, which means the geometry of a part can be highly complex and as long as the AM machine can print it, this complexity won't matter. AM, a significant form of advanced manufacturing, offers design freedom and is far more accessible than conventional manufacturing. Performance development of AM technologies is driven by improved digital capabilities including machine-machine and machine-user networks, artificial intelligence and automation. Given these emerging trends, the decisions about how a product should look and function may now be influenced quite directly by a vastly wider range of factors as the former restrictions dissipate and design practice becomes less 'insulated' by conventional production and commercialisation paradigms. This shift may present a problem for design and its ability to innovate.

Research from Cross indicates that as the scope of the 'problem space' expands opening up the possibility of an ever-increasing range of potential solutions, designers (particularly evident in novices) may more readily 'fixate' on particular conjectures at the risk of understanding the issues more deeply (2006). Design fixation has, however, been identified as intrinsic to design - an effective solution focused means of working through complex problems. Though it does raise questions about how designers rationalise design aims and objectives. Research by Hillier et al. published in the early 70's refers to the notion of 'prestructures' or 'problem prestructuring' which describes the way designers conceptualise or find a path through 'problem material'. Additionally, Darke (1979) refers to primary generators - subjective and deeply valued positions held by the designer, that enables conjectures for analysis. The question of values seems to become more and more relevant as we move from the relative predictability of systemisation and conventional manufacturing, toward the increasing complexity and potential associated with the design for advanced manufacturing.

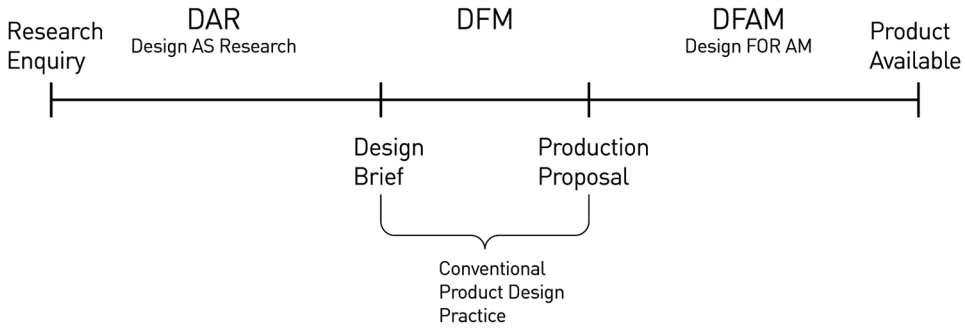
The Need for Technological Innovation in Manufacturing

Standards Australia notes that Industry 4.0 will create an environment for 'test bed' design and remote manufacture (2017). These are issues that have restricted the progress of Australian manufacturing in the past. The flexibility offered through software specific AI and rapid prototyping quickens the pace and lowers the cost impact of testing. It also means that 'testing' may be collaborative, investigative and speculative in nature with the support of external research units (such as academic research units inside universities) that are experienced in designing knowledge directed practice-based research that enables knowledge transfer.

For designers to be able to innovate through Industry 4.0 manufacturing methods, the design processes suited to DFM will not suffice. The previous section discussed the complexity of part geometry as one element in the design process that would need to adapt to suit AM. However, this extends much further into other realms that previously, under DFM, were not considered. For example, manufacturing methods linked to DFM are considered indirect manufacturing methods, in that the designer is not in control of the manufacturing process and shares the responsibility of the product they have designed with production engineers, distributors and retailers. On the other hand, Industry 4.0 manufacturing methods such as AM, are appropriate for low volume production runs, as well as various forms of customisation, as is the case with the example of the Visionsearch Headistancer. Furthermore, AM is considered a direct

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Figure 1. Product design knowledge needs to extend beyond the boundaries of DFM



manufacturing method, meaning that the product designer can be in control of the manufacturing of the part. This means that the product designer is now linked more closely to both the beginning of the process and the end of the process. For example, in the case of customisation it is likely that the designer will work directly with the people who will be using the product, which typically, with DFM is not the case. And when AM is used for the manufacture of end-use parts the designer will again be directly involved and responsible for the parts produced. Therefore, the designer's knowledge and understanding of AM processes, including material properties, appearance and how people will experience the product, must be extended and built to a level at which all those aspects can be considered holistically (Figure 1). So rather than simply considering material properties in isolation, a designer will consider all properties that will influence the performance of the product.

Future design practice must operate according to new models. Technology-driven innovation relies on management of knowledge transfer and the opportunity to decipher how the influx of new and complex chunks of information shall be integrated into the workflow of modern manufacturing organisations. Research strongly indicates that successful organisations cannot stay competitive by simply responding to market research - they must be active in the creation of new markets. A complex task in response to an ever increasingly complex world. Koskinen and Dorst (2015) suggest design organisations are required to develop more sophisticated methods of knowledge interpretation and curation to see further into the future than conventional practice allows. Further, they propose that a new (academic design) model that combines the capabilities of academic research practice with design practice may be a way to support design-led technology development - a 'D&R' model where "design is required to lead investment in research and technological development".

Considering the background research and the issues raised, the chapter continues in response to the questions: How might the role of product design change in an Industry 4.0, AM environment and; how may that impact product design practice?

THE CASE STUDIES (CRANK ARM AND VISIONSEARCH PROJECT)

Bicycle Crank Arm

The Product Design Program at the University of Technology Sydney conducted a University-Industry Collaboration (UIC) research project with the company Advanced Manufacturing Services (AMS). AMS

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Figure 2. Bicycle crank arm made from stainless steel by direct metal laser sintering



is a AM bureau specialising in selective laser sintering (SLS) in polyamide and direct metal laser sintering (DMLS) in metals including stainless steel. The project was set up as a research alliance to investigate avenues for innovation, concept directions for technology development, learn about technology and market opportunities, test competencies and improve brand image. Broadly, the aim of the project was to investigate the potential of AM technology across a range of application domains. The product types were selected on the basis of addressing wider questions about the relationship of product design with advanced manufacturing systems to ready ourselves and our industry partner for potential technological, social and (even) political disruptive change in the future.

One of the projects is the design of a bicycle crank arm for mountain bikes. In bicycle component design a key objective is to reduce weight while at the same time increase strength in order to improve performance. The industry typically uses high-end alloys, CNC machined or forged into shapes that are then post-finished for precision assembly. Stainless steel is a very strong and weather resistant material, but its weight normally precludes it as an option for bicycle components and as such parts are normally made from aluminium alloys or carbon fibre composites. However, in mountain bike cycling the bicycle is exposed to much higher levels of impact from debris and stresses than road cycling and therefore a more robust material such as stainless steel has been a consideration. Some companies have designed mountain bike components with stainless steel coverings over aluminium bodies but to make an entire

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part from stainless steel simply makes those parts too heavy for high performance cycling. Additionally, there can be problems associated with some (mechanically) assembled mountain bike components in terms of withstanding vibration and flex. To have a unified part made from one material is preferable in cases such as these, including the crank arm assembly.

Direct metal laser sintering has allowed the design of a completely unified stainless-steel crank arm assembly (Figure 2). Laser sintering has allowed for a unified spindle and ISIS (International Spline Interface Standard) feature as well as an integrated spider bracket (the multi-arm feature that connects to the chain ring assembly), printed in one operation. By consolidating these parts that would otherwise be separately fabricated and assembled together a sturdier design results, there is a reduction in material usage and complex production and assembly processes are eliminated. Normally crank arms are either solid shapes or hollowed-out forms (to reduce weight) and are forged using complex machine processes and tooling. Laser sintering permits an open structure that provides strength but removes bulk by adjusting and reducing wall thickness (Figure 3). These design advantages permit unique part geometry and allow a superior material such as stainless steel to be used.

Designing a bicycle component for end-use application using laser sintering has not been straightforward. Bicycle part design must comply with a number of standards and constraints (e.g. crank arm length, ISIS drive geometry and bracket pattern standards to name a few). These requirements become a boundary box within which one is free to explore the large range of geometry variations the technology offers. New mechanical performance testing may need to be adopted and the opportunity for customisation are all important considerations. Conceivably, there could be a developing relationship between bicycle component design and additive manufacturing technology for the production of end use parts in the future.

Figure 3. Part removed from the support material after printing, exposing the open structure. The honeycomb pattern reinforces a 'skin' whereby, computationally, the 'skin' can be adjusted, automatically adjusting the pattern structure according to certain set parameters.



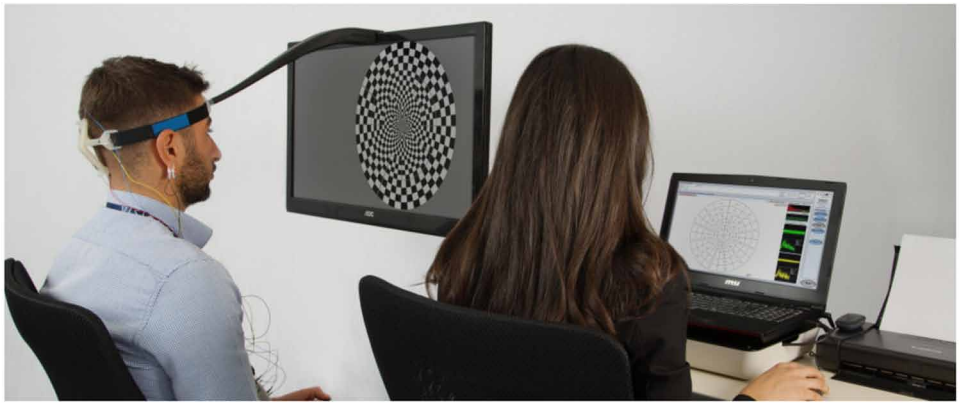
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The Visionsearch Headistancer

Visionsearch Pty Ltd is a company based in Sydney, Australia that distributes a computer-based system called VS+ which provides people suffering from certain vision impairments with tools that help them reduce or reverse sight degeneration. The VS+ system is not sold to individuals but rather to hospitals and therapy centres, so people who need to access it typically do so by visiting a hospital or therapy centre. The VS+ system is also used as a research tool in research facilities that specialise in specific vision-based afflictions. At the core of the VS+ system lies science and software that was developed by the Save Sight Institute, which is a research centre of the University of Sydney. The VS+ system is sold as a completely integrated solution including a computer, high resolution screen, EMG electrode cap, handheld control device and a Headistancer. When the VS+ system is in use the patient is seated in front of the screen with their eyes positioned and focusing on the centre of the screen. Through inputs on the handheld control device the patient is then required to react to cues displayed on the screen. While doing so it is imperative that the patient maintains the same distance from the screen and does not move their head. The Headistancer is attached to the center of the top edge of the screen and is the device that ensures the patient maintains their position and doesn't move (Figure 4). It does this by providing the patient with a place that they can gently rest their forehead against and through the tactile feedback know that they are the correct position.

The VS+ system is a high-end therapy and research tool and Visionsearch sell and install approximately 25 systems per year. As a consequence, any part of the system that is designed specifically for it, such as the Headistancer, is produced in very low volumes of approximately 25 units per year. The visual feedback of the VS+ system is of course provided by the screen but because screen technology is developing fast, Visionsearch purchases screens in bulk on a biennial basis. This means that every two years the screen changes, the consequence of which is that a new Headistancer needs to be designed and produced to suit the next screen. Due to this the Headistancer is now in its third incarnation with models designed and produced in 2014, 2016 and 2018. The combination of the two factors, namely, the

Figure 4. The VS+ system in use, the person to the left is a patient resting his forehead against the Headistnacer
(image courtesy of Visionsearch Pty. Ltd.)



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low production volume of 25 units per year and that the screen changes every two years makes AM in a polymer the ideal production method for the Headistancer. In the current climate, where industry 4.0 is at the forefront of many people's' minds, this may seem like a choice worth considering but initially, in 2013 when the first version of the Headistancer was under development, this was not the case.

Utilising 3D printing in a polymer for end-use part production was starting to get attention but was by no means an accepted method for production. The team at Visionsearch were familiar with the concept of AM and were speculating that it may provide a solution for them, but they were unable to conduct the work in-house because they lacked the necessary expertise. They investigated avenues of working with a consultancy but struggled to find one willing to experiment with AM as an end-use part production method. However, the team at Visionsearch did have experience in working with university research centers, such as the Save Sight Institute, and after some investigation collaborated with one of the authors, who is an academic design practitioner in Product Design at the University of Technology Sydney and conducts research into utilising AM in polymers for end-use part production.

HYPOTHESIS AND BREAKTHROUGH

Advanced manufacturing encompasses a range of technologies and processes. These technologies are a key component of Industry 4.0 as they offer opportunities and advantages that impact business models, products and value creation via digitally networked systems. Product design is wrapped up in this evolutionary shift and must be ready to adapt. It may be that conventional product design for DFM will continue to service manufacturing into the future. However, this chapter attempts to highlight two additional ways that product designers are increasingly going to need to operate.

Research prototyping is a research practice that investigates the potential of technologies at levels ranging from the pragmatic to the philosophical. Knowledge building through product concepting (that may be practiced through research prototyping) is valuable because it helps companies understand how technological advances and changes may affect them. It is argued that even small manufacturing companies need to integrate *concepting* as an essential part of their R&D strategy because they need to be prepared for the potential of unforseen disruption, which can be threatening to the point where it can put a company out of business. Companies therefore must engage with forms of concepting that deal with the relationship between technological development that are external yet potentially influential to their business, even if this seems counter to the core competencies that more fundamentally drive the company's commercial relevancy. If they cannot do this "in house", then it is possible to do it in collaboration with a university research unit.

The bicycle crank arm project is an example of a concept design as defined by Keinonen (2006). There may well be a commercial potential for a printed metal bicycle crank arm in the future, though our design objectives were not too focused on this concern. The design objective is not to arrive at a technical proposal for manufacturing a product for an existing market. The intention is to investigate *through* product design practice the scope, opportunities and challenges associated with the introduction of a new production technology, such as AM, with the potential to manufacture products with a range of performance advantages beyond what is currently possible. The start of the project begins with a 'research question' or set of questions that can best be answered through a design project and a research prototyping methodology. The goal is 'new knowledge'. Conducting the project this way - that is, really constructing the prototype(s) - instead of, for example, expert interviews or technology forecasting, en-

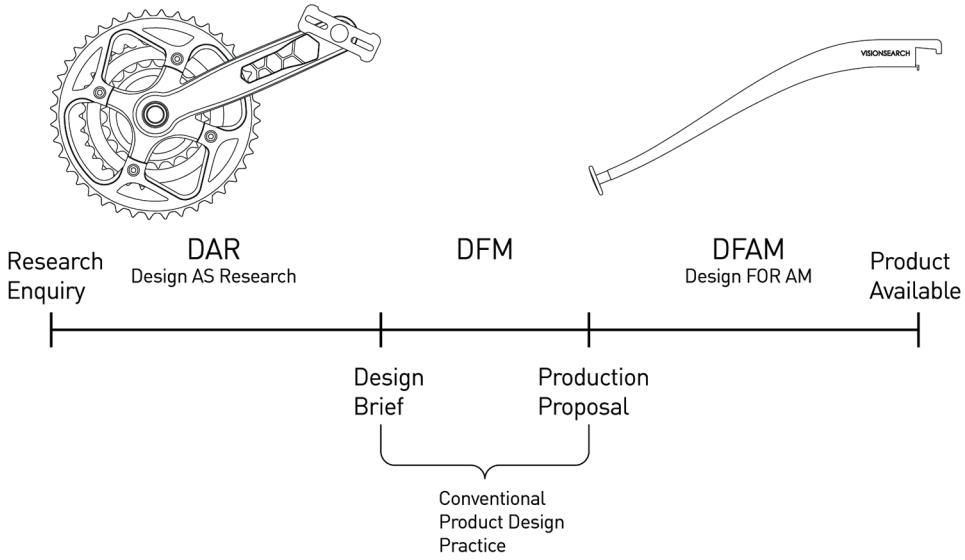
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gages the designers in practice enabling them to develop techniques and insights that can more explicitly inform their process. The case study is of a bicycle component although as an investigative project, it does not necessarily mean that it is only for a bicycle component manufacturer. It is a typology that suitably builds design knowledge related to new computer aided design practices, digitally networked teams, trans-disciplinary team design, part consolidation using AM, strength-to-weight ratio of AM metal parts, designing with geometric freedom and topology optimisation. Additionally, the crank arm, as a vehicle of investigation, sets up a series of advantages including that there are determinable benchmarks (conventionally manufactured high performance bicycle crank arms exist). There is a means of testing the result and the item embodies a suitable yet not overwhelming degree of mechanical complexity. Conceivably a design department may have a number of these kinds of projects running concurrently. The intention is to essentially build an *innovation agility* within the organisation and to continually hone the intellectual agency of the organisation in terms that are not exclusively reliant on a particular manufacturing technology or facility but based on more intrinsic and sustainable competencies. Projects of this type are intended to support the client or the business at a strategic level and to identify ways to set clearer and more targeted objectives in design briefs for DFM projects. They may also open up avenues for further research in technical fields, business and research alliances and help to verify future technology investments. The designers reach then extends to play a role in the research that must be conducted in Industry 4.0 companies, before DFM can be confidently and precisely engaged.

The Visionsearch project integrates product design in a different way. The Visionsearch Headistancer is a product that is manufactured as an end-use item using AM technology. Currently in use around the world, the design must be optimised for low-volume production and customisation. After the successful testing of the first prototype, this becomes the typical form and the product designers focus turns to the design of part modification sequencing and guidelines, information archiving and service aspects. As the customers system conditions change over time according to new software or screen designs new versions of the Headistancer need to be designed and made - an advantage of customisation previously unattainable in sophisticated materials and forms. In this case the designer remains connected to the client beyond completion of the initial design and forms a relationship with them whereby knowledge transfers with each engagement. Consequently, design knowledge is built within the designers own practice in a way that must be explicit (because the customers involvement in the process is crucial) and takes on a form so integrated that it forms part of the designers intellectual agency. In this particular case the design knowledge developed through a long-term engagement with Visionsearch is certainly in-part domain knowledge regarding the VS+ system and therapy tools developed by Visionserach. However, the knowledge developed is also strategic regarding AM parts modification techniques and efficiency of service in the delivery of customised designs for Visionsearch. The project provides insights into how product designers may build relationships with people and how their practice should transform from designing *for* someone to designing *with* someone. Furthermore, because the designer effectively acts as the manufacturer, via AM, the Headistancer illustrates how the designers reach must extend to encompass a better understanding of a product's holistic performance rather than solely its manufacturability and materiality. The authors understand this as an extension of the design process, meaning that the designers involvement starts earlier and ends later than with DFM. Product designers therefore need to develop strategies that will enable them to expand their knowledge base, so they can confidently operate on any point of this extended design process. As Industry 4.0 moves forward newly generated design knowledge

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Figure 5. The Bicycle Crank Arm and Visionsearch Headistancer are examples of projects that employ new forms of practice, generate new forms of design knowledge and new types of outcomes that contribute to the advance of industry in significantly different ways from conventional design for manufacture.



needs to be agile and adaptable to enable it to keep step with new technological developments and the challenges this brings with it.

As advanced manufacturing technologies, such as AM, become more capable and increasingly relied upon by industry, so too will growth of Industry 4.0. These projects demonstrate that product design practices have value and purpose as an instrument of research, in forecasting connections between developing technology and corporate strategy. As an active partner in the manufacturing space, design can help to ensure AMs full potential to service customer variations and design updates quickly and seamlessly. The following diagram (Figure 5) illustrates the predicted spectrum of product design concern in Industry 4.0 environments and places the Bicycle Crank Arm and Visionserach Headistancer at either end of the spectrum and outside of the conventional DFM practice 'zone'.

SOLUTIONS AND RECOMMENDATIONS

The case studies presented in this chapter present new ways for product designers to conduct their practice and develop design knowledge in an Industry 4.0 environment, with particular emphasis on Additive Manufacturing. The role for the product designer in a wider technology-driven innovation context can be seen as operating across a spectrum of enquiry from the very early stages of research and development cycle through to having a much closer and integrated role in manufacturing and customer / service delivery. The deliverables and values of these new roles is distinctively different from the conventional DFM model and for important reasons. Therefore, design for manufacture should not be replaced, but rather complemented by these other product design activities.

Each of the case studies demonstrate that there is a role for practice in these new roles. Previous research has shown that design knowledge is generated through the conduct of practice in order to deal

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with complexity and uncertainty of design problems (Hoadly and Cox, 2009). Although the focus of these new product design roles sitting at either end of the spectrum are different, the chapter hopes to show that they still proceed via the conduct of practical techniques - modified but not dissimilar to the familiar DFM techniques. There is still the construction of tangible elements through prototyped conjectures. The key difference in design knowledge development within these new roles, is the (defining of) values that guide this practice. These two projects, each of them conducted beyond the comfortable and predictable boundaries of DFM, must grapple on some level with deeper questions of *why* a design should exist and not simply *how* to design a thing. Here is where design models, such as Gero's FBS framework, may assume too much about the nature of the artefact at the time of designing (see Galle, 2009). The question of *why* can transcend the concerns of the 'organisation' and the commercial directives and security it pursues. It can, it probably should and perhaps in time naturally will, delve deeper by challenging the purpose of industrial practice in a much wider social, cultural and ecological context. This relates to Verganti's (2009) expression of *meaning* in products achieved through technological innovation. The Bicycle Crank Arm project, for example, raises questions about the possibility of computationally optimised, printed products replacing products that are more crafted in smaller companies by specialists and enthusiasts. To a large extent, this is already happening in the bicycle components industry. But how might AM disrupt that trend? It has the potential, if used appropriately, to empower smaller companies that want to remain flexible and culturally connected. AM can inspire digital craft - a crank arm that can be cosmetically altered to the customers specification, for example. Advanced manufacturing technologies and the networked environment that Industry 4.0 offers, opens up new commercialisation and service opportunities previously unavailable to business. Design should play a role in embracing these opportunities responsibly.

The result of this is that Industry 4.0 design work becomes more knowledge-intensive. The entanglement of theory and practice (the practices employed by the organisation) must constantly be critiqued and updated given the increase in complexity brought about by the rapid advance of technology and a more networked society. The case studies presented show that product designers working in these new roles, address these issues of knowledge integration, development and application through practice-based research. Construction of prototypes remains a central and common activity for product design, even when the project is about responding to a knowledge-directive or merging with production-service-system. As Koskinen et al. (2011) demonstrates, construction is a key part of design research. This suggests that designers that have attained a level of expertise in the DFM role may be able to move across into the new roles presented in this chapter.

However, as previously stated, DFM does not disappear. The type of practice and the focused work of designers operating in that restrictive space provides important moments of stability along the design spectrum within a constantly moving Industry 4.0 environment. The design work of the DFM space serves to link the work happening in the DAR (Design As Research) and DFAM (Design For AM) spaces by making actionable in the short-to-medium term, partially defined objectives set by these two design roles. Referring to Åman & Andersons (2016) research that suggests that there may be a need for knowledge integration *of* and *by* design, it is possible to see in the research presented here the case for these two modalities working side-by-side. DMF operates within its distinct capabilities with very clear objectives and constraints. This is predominantly knowledge integration *of* design, i.e. design practice is 'picked up and applied' to achieve specific, tangible and actionable outcomes to power the production operations of the organisation. DAR and DFAM to a much greater degree must integrate knowledge *by*

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design. That is, they must design their research processes and the activities within them. The organisation as a whole must adopt a *by* design approach to construct their entire R&D strategy.

FUTURE RESEARCH DIRECTIONS

Technology-driven innovation and knowledge for Industry 4.0 is challenging because companies must become more agile and technologies are developing and changing rapidly - sometimes promising more than they can deliver. The pace of technological advance suggests that design 'boundaries' will remain constantly ill defined, which can lead to volatility. In contrast to this DFM is clearly defined and its boundaries more easily established. It is well understood and provides a safe position to operate from. To deal with the volatility that Industry 4.0 presents, the knowledge created through a practice-based research approach, needs to be efficiently captured, recorded and coded so it is accessible and can be cultivated and applied to future projects. Implementing such a knowledge system would be a substantial undertaking that requires planning. To begin with, each individual researcher within a design research team could record their own practice-led research activity, ensuring that it is transmissible. Archer states that practitioner activity can count as research if, and only if, it accords with the criteria of research. He goes on to state that it must be knowledge directed, systematically conducted, unambiguously expressed and that its data and methods must be transparent and its knowledge outcome transmissible (1995). Once each individuals research knowledge has been recorded, it needs to be connected to the knowledge developed by other members of the team. Gaver and Bowers suggest doing this with an annotated portfolio which presents a basis through which to build connections between various different types of knowledge outcomes. An annotated portfolio, then, is a means for explicating design thinking that retains an intimate indexical connection with artifacts themselves while addressing broader concerns in the research community (Gaver & Bowers, Annotated Portfolios, 2012).

To test this in praxis, a research unit called IPD-R (Integrated Product Design - Research) at the University of Technology Sydney, is in the process of developing an Annotated Portfolio to capture the knowledge each team member develops while working on UIC projects. IPD-R supports SME businesses based in Australia to develop innovation strategies in connection with new product development. It is comprised of a team of four academic design practitioners who conduct research in product design and manufacture. The foci of the unit are aligned with the individual research directions of each team member; however, research activities are conducted collaboratively as a team. All projects IPD-R conducts are UIC projects, so there is always an industry partner involved. To develop their Annotated Portfolio, each IPD-R team member meticulously record their own practice-led research activity through annotated sketches, annotated photographs of models and prototypes as well as keeping a detailed activity journal. The team then select specific aspects of the project relevant to one team member's research direction and use that as a core element to connect to the work of other team members. The connections are based around themes the team had previously agreed on and included things such as "Usability", "Materiality" and "Maintenance". The process often involves pinning up the material on a pin board and gradually uncovering relevant clusters of research findings. The IPD-R team is currently experimenting with tools that will allow it to make the knowledge accessible so it can be cultivated and team members are able to apply it to future projects.

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CONCLUSION

This chapter broadly predicts two key new areas for product designers to apply their knowledge and practical skills in an Industry 4.0 environment. These are located on a spectrum of practice. The first, DAR, is situated in the formulation phase that essentially determines how technology may responsibly drive innovation. In this area of product design practice, designers work equally as researchers and respond to knowledge directives, that is, the goal is to verify ways forward for the organisation in a very complex world. The second, which for our particular study, is DFAM, is located at the other end of the spectrum, deeply integrated with manufacture and close to the consumer (the end-user). This area of product design practice calls upon the designer's expertise to respond to rapidly evolving changes in consumer needs and manage those insights, back through the organisation. Designers are concerned with the 'service' side of the organisation at this end of the spectrum. Case study projects are included to exemplify these two areas. The authors consider that the more familiar and conventional, DFM mode of practice will remain a key link between these two emerging modes of product design expertise. The chapter also seeks to demonstrate that research and understanding about the nature of design knowledge - how it integrates information and makes sense of uncertainty through practice - holds true in DAR and DFAM just as it does for DFM. There is however, evidence of a major difference between these two new areas of practice from DFM and that is in the way design sets and defines values to solve problems. There is an immense breadth of conceivable ways forward offered by the brilliance of advanced manufacturing technologies. New technologies such as AM will significantly impact how and why we make things. The growing interconnectedness of technology and society offered by new manufacturing systems requires a fresh focus on the setting and defining of responsible values, in the conduct of expanded design processes made explicit and transferable.

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Section 3

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Chapter 12
To Mine or Not to Mine?
Using Game Theory to Explain the Decision-Making Process in Asteroid Mining Investigations

Jesus Pedro Zamora Bonilla
Universidad Nacional de Educación a Distancia (UNED), Spain

Simone Centuori
Deimos Space S.L.U., Spain

ABSTRACT

Social studies of science have flourished within the last decades, making use of numerous intellectual tools from a high variety of academic fields in the social sciences and the humanities (sociology, anthropology, cultural studies, etc.). Game theory, however, has been one tool that has not been put to use too often, in spite of the obvious importance of strategic considerations in the negotiations between the relevant actors in research episodes. In this chapter, the authors illustrate the use of game-theoretical concepts and techniques with the analysis of a nascent research field: asteroid mining.

INTRODUCTION

Knowledge, and in particular scientific and technological knowledge, is usually the product of a complex social network in which innumerable agents interact. Even the lonely inventor or discoverer applies in her discoveries numerous items of knowledge she has acquired in the past through social interactions. The social study of science is a mature academic field since at least the mid 20th century, and has been approached from almost all branches of the social science: sociology, anthropology, political science, and obviously, economics. However, there has been a not easily understandable reluctance by part of most researchers in those areas to apply what some scholars consider to be the most nuclear intellectual tool in the social sciences: game theory (e.g., Gintis, 2009). As one of us has commented in other papers (Zamora Bonilla, 2006, 2007), this neglection has been particularly regrettable in the case of the constructivist sociologists of scientific knowledge, for, though the *interests* of the scientists and other social

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agents (and, in the case of authors like Bruno Latour, the 'interests' of the rest of other relevant things, which he calls 'actants') are considered by these authors as one of the major explanatory factors of the social situations they try to illuminate, they hardly take into account the problems and the possibilities associated to the *strategic decisions* that arise once we have more than one interacting agent, in particular the existence of several possible outcomes, not all of them being equally efficient for the agents, nor all of them equally constituting a possible equilibrium in the game that those strategies create. In particular, game theory allows to understand in an easy way some 'constructivist' conclusions that have created too much confusion and polemic in the last decades; for example, it gives a clear meaning to the notion that the epistemic value of the products of a research process may not be optimal, but showing that this does not amount to something as a complete rejection of the 'objectivity of science', for it simply means that getting an epistemically *better* output would have had some 'costs' for some agents that have preferred not to incur in them, if they have had the chance, but it does not entail that the output has no epistemic value (only that it does not have the possible *maximum* value... which is compatible with having a *very high* value). As the product of a 'social construction', scientific and technological knowledge has simply the quality level that the combination of the interests and possibilities of the engaged agents have allowed; being a 'social construction', hence, does not entail that, for example, a scientific theory is not a *good* theory as an item of knowledge, exactly in the same way as being a 'social construction' does not entail that a hospital is a *bad* hospital.

In this paper, we want to illustrate the capacity of game theory to make us understand in an interesting way the social processes of interaction that underlie the production of techno-scientific knowledge, by applying game-theoretical tools to a particular example. We don't pretend to develop something like a full-grown theory about the 'social construction of science', but just to offer an impression of how the application of these formal tools might look like. Of course, it is possible to apply them to other, very different aspects of research processes than those chosen by us. The essential thing to take into account is that, in order to understand a research episode from the point of view of game theory, we need to conceptualise it according to the following list of items:

- What are the (most relevant) *agents* (or 'players') involved in the episode.
- What are the actions, decisions, or *strategies* open to each agent.
- What are the results to which each combination of a strategy for each agent lead to, and how does each agent evaluate those results according to her own ranking of *preferences* (or, in the language of game-theory, her *payoffs*). The union of these three elements constitute the description of 'a game'.
- Taking the former into account, what combinations of strategies can be considered as reasonable outcomes by constituting an *equilibrium* of the game (basically, what economists call a 'Nash equilibrium', i.e., a combination of strategies such that no agent would prefer to choose another strategy, given what strategies have been chosen by the other agents). If the combination of strategies actually chosen by the real agents does not coincide with any of the ones the game-theoretic analysis has tagged, we should either revise our description of the game, or investigate if some non-rational factors have been operating (e.g., limitations to the information managed by the agents, or limitations to their rationality).
- Lastly, what are the normative properties of the outcomes: how 'good' are they from the agents' point of view, or from the point of view of other relevant actors.

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In the following pages, we shall apply this framework to the understanding of a particularly significant aspect of the creation of scientific and technological knowledge, namely, the very moment of constituting a new field of research, and we shall do it through analysing a case that is occurring right now: the nascence of 'asteroid mining'.

ASTEROIDS MINING

A particularly fascinating case of intersection between science and technology researches is certainly represented by the space exploration: the primordial attraction that we feel for the stars as human beings, the desire to understand where Life comes from and the aspiration to unlock the mystery of the universe, connect in the space sector with the state-of-the-art technology in a stunning attempt to push humanity beyond its limits, in terms of both knowledge and exploration capability.

And, in the space exploration domain, there is a very young area of investigation where this synergy between science and technology is especially coupled: the asteroids mining. Yes, "asteroids" and "mining", all in one sentence: something that immediately insinuates in our thoughts a science fiction aroma and that whispers to our mind images from books and movies. But this is not just science fiction: since February 2016, when Luxembourg government announced the intention to create a legal framework to define rights and responsibilities in the industrial mining of small celestial bodies, enthusiasm and scepticism have gone along together in the space sector (see JL Galache, 2016). The satisfaction for the money injection from international investment funds has lived together with the perplexity of those who, better than anyone else, are well aware of the technological and scientific challenge hidden behind the asteroid mining initiative. At the moment when this text is being written there are two US companies leading this new "Space Gold Rush" (Planetary Resources and Deep Space Industries) and the interest in their endeavour has done nothing yet but growing.

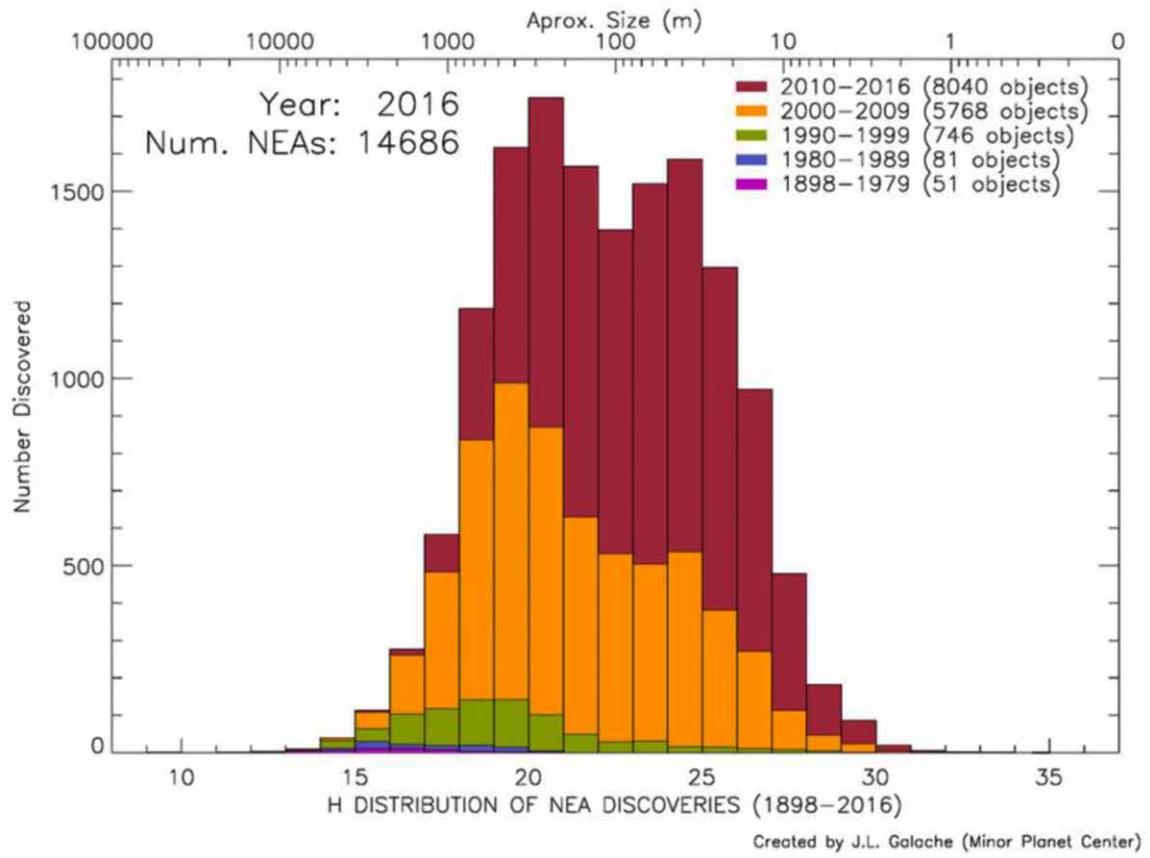
But, beyond the fascination and its dreams generating capability, does this initiative make sense at all at technical and financial level? The answer, of course, is not unanimous and we are certainly not talking about something that will concretize in the next few years. But the high money is raising its credibility, always keeping in mind that the next decade (at least) will be dedicated to fill the knowledge and technological gap that made the idea of mine an asteroid just impossible till yesterday. Let's see some figures.

The number of discovered asteroids has experienced an impressive increase since the start of 21st century: in Figure 1 it can be observed how the amount of known objects close to Earth (NEAs, Near Earth Asteroids), the most interesting ones from the mining perspective, has been multiplied by ten only since year 2000. So we can say that there are out there a sufficient number of potential targets.

Could then these asteroids be profitable? It depends of course on their composition (see De Meo et al., 2015 and Rivkin et al., 2014) and on the physical possibility to extract valuable materials from them (see Michel and Delbo, 2016 and Murdoch, 2016). Let's say from the very beginning that the main idea is not to bring those materials to Earth, because, except maybe for a utopic golden asteroid, there is no business case for that: it would be too expensive. The plan is rather to exploit the extracted materials directly in space, to build new infrastructure or to store all kind of useful resources such as oxygen, hydrogen, water etc. for the future exploration missions. Due to their weight, in fact, the cost to take these materials into space (i.e. to a Low Earth Orbit, abbreviate LEO) is extremely high, and then the possibility to have them already available in space could be highly lucrative. In the example illustrated in Figure 2, the profitability of a 50m asteroid is detailed, summing up 363B$ (yes, billions!) just as

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Figure 1. Near Earth Asteroids (NEA) as a function of their discovery date
(Credit: J.L. Galache, Minor Planet Centre, 2016)



**For a more accurate representation see the electronic version.*

saving in the transportation cost, so without considering the materials purchase in itself; these values are for a typical 50m, water-rich, C-type asteroid, as inferred from meteorite samples.

Of course this figure depends very much on the asteroid composition, which should be known in advance with a minimum level of detail, and it shall then be contrasted with the extraction cost. And here is where the chickens are coming to the roost: performing space mining means to carry out a space mission, and, whether it is a human or a robotic mission, not a standard one. At the moment this is extremely expensive because asteroids are not easy targets at all, as it is demonstrated by the fact that very few missions have been expressly dedicated to their exploration: NEAR Shoemaker (NASA, 2001), Hayabusa (JAXA, 2005) and Dawn (NASA, 2007 still ongoing). Asteroids are small bodies very far away from Earth: the high cost of reaching them is then combined with the complexity to orbit a spacecraft around them (see Vetrisano et al. 2016), due to the low and uncertain gravity attraction that they exert. If you add to that the fact that they could be rotating in a fast and/or uncontrolled way, it's easy to understand how hard is the technological challenge to manipulate an asteroid to mine it.

Different challenges are envisaged at technological level to realize the so called "In-Situ Resources Utilisation" (ISRU) with an asteroid:

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Figure 2. Materials extractable from a 50m class C asteroid and the price to take them to a Low Earth Orbit
(Credit: J.L. Galache, 2016)

Element	Mass (tons)	Price to LEO ($ billion)*
Water	21,000	57
Carbon	3,700	10
Iron	27,000	73
Magnesium	15,000	41
Nickel	1,500	4
Sulphur	6,300	17
Oxygen	43,000	117
Silicon	16,000	44

1. **Asteroids Manipulation:** The asteroid needs to be somehow manipulated to expose the material of interest. This could happen touching the asteroid or also contactless, depending on the extraction technique: the satellite could try to land on the asteroid, to grasp it with some mechanism, to impact it with a projectile or to heat it up to sublimate the contained water and break it up.
2. **Resources Extraction:** Several techniques envisaged for planetary ISRU are presented in literature to extract materials with the limited capabilities of space systems: carbothermic reduction (see Gustafson et al, 2010), reduction by hydrogen (see Linne at al., 2012), Molten regolith electrolysis (see Sibille at al., 2012).
3. **Handling:** Once the material is extracted, specific technologies are required to engage the material and start its processing, going from drilling to excavation, from transporting to conveying and sorting of the resource.
4. **Storage:** Finally, since it's highly possible that the extracted materials will not be used immediately, they will have to be stored without altering their properties for a potential long time in the hostile conditions of space environment.

Summarising, we can say that several challenges shall be faced to make asteroids mining feasible, challenges for both science and technology: the difficulty and the high cost of reaching an asteroid push toward a very careful selection of the candidate targets, and this shall rely on a robust scientific knowledge of what is being targeted. Then the approaching phase is not trivial at all, nor is the prospecting or the mining stage: dealing with an unresponsive object in a very low gravity environment definitely brings high uncertainties in the mission design and challenge our state-of-the-art technology and knowledge (see Centuori et al. 2016). And the answer to these challenges is not just on technology or science plate, but it is necessarily on both of them.

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As an attempt to provide responses to the asteroids miner's needs and questions, the ASIME ("Asteroid Science Intersections with In-Space Mine Engineering") conference has been organized in September 2016. ASIME has been conceived as a "focused two-day workshop of roughly 30 scientists and engineers seeks to provide an environment for the detailed discussion of specific properties of asteroids with the engineering needs of space missions with in-space asteroid utilization". The objectives of the workshop were to place scientific constraints about particular asteroid properties such as porosity, density, chemical elements, and volatile abundance as a function of asteroid type and further about specific asteroids. Moreover the conferences wanted to facilitate new collaborations and partnerships between the research and industry domains. The outcome of the conference has been summarised in the "ASIME 2016 White Paper: In-Space Utilisation of Asteroids: Answers to Questions from the Asteroid Miners".

Within the scope of the current publication, ASIME 2016 is then selected as a paradigmatic case of interaction between science and technology investigations, especially interesting due to the high innovation content intrinsically associated to the asteroids mining initiative. The framework of this conference is what we are going to take as the stage on which our game-theoretic reconstruction will be set.

THE GAME

The Players

Different players took part to ASIME conference with very different backgrounds, roles and objectives between them. Certainly with a certain degree of simplification, we can divide them into four different categories, which represent the typical high level players of a science-technology game:

- Science
- Industry
- Government
- Public opinion

Of course the boundaries between the different categories are sometime fuzzy and each category encloses a full world inside it; but moving into a more detail description of each of them we hope to provide a solid justification of this choice and to depict with more accuracy the game we dealing with.

Scientists

The scientists who participated in ASIME have very different backgrounds: participating in the conference meant the privilege to listen to talks given by the world top level planetary scientists, geologists and astronomers, like JL Galache, Simon Green, Marco Delbó, Naomi Murdoch, Patrick Michel or Andy Rivkin, just to mention the keynote speakers. Nevertheless we can say, as a general statement and as a first approach to the problem description, that several commonalities can be found in their objectives and strategies; because of that they can be grouped under the same category and then be described as a single player: the "*Science*" player that will be abbreviated in our graphical representation as *(S)*.

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A more detailed analysis would be certainly worth it to grasp all the behavioural nuances associated with the different backgrounds and the various areas of research of each of the scientist taking part in ASIME. However this would complicate too much this first analysis and it is then left as a suggestion for the future works on the subject.

Industry

As usually happens to engineers with respect to researchers, industry representatives who participated in ASIME were much less diverse than their scientists colleagues. However a significant line can be drawn dividing them in two groups: space miners on one side, and traditional space industry on the other. The distinction comes from the fact that they share the same objectives, which is true, but with different preferences and employing then different strategies:

- What we decided to call here "traditional space industry", and which will be abbreviated in the graphical representation as *(I)*, is represented by very well-established companies in the space sector, companies that have a consolidated track of project in the sector and with short term margin objectives. Smaller industries (like, for example, Qinetiq, SSTL, DEIMOS Space) and large space integrators of satellites (i.e. Airbus, Thales, OHB) belong together to this category: they could look very diverse, but we will see that their behaviour in this context allows describing them as a single player. An important remark is that the companies within this group participating to ASIME were all European firms.
- On the contrary, the "space miners" are very new companies with powerful investors behind them and which aim to develop a fully new technology to exploit the economic benefit of mining asteroids. Their objectives and strategies will then be very different from the other industries: instead of struggling for contracts and customers, their principal goal is to build up credibility to their investors by establishing a solid knowledge basis of asteroids exploitation and by developing the technologies needed to achieve this ambitious goal in a reasonable timeframe. It is proposed then to treat them as an additional and independent player, abbreviated in the graphical representation as *(M)*.

Government

The public sector also plays a critical role in this new research and technology field. It takes part to the game both through national representatives (i.e. the ministry of technology of Luxembourg) and through supranational actors such as space agencies (i.e. the European Space Agency) or the EU institutions (i.e. the European Commission). If we compare their behaviour we can say that they all share the same objectives and strategies, that is to finance basic research and industrial studies and development to foster a technological leadership in what is considered a strategical sector. Nevertheless they of course act at different geographical levels depending on their constitution.

In a first iteration of this analysis it is proposed to consider them as a single player, that rather than a real competitive player is a "game enabler" through its funding capability; it will be abbreviated in the graphical representation as *(G)*.

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Public Opinion

If the long term effects of a programme involving public funding want to be properly caught, some attention has to be dedicated also to the public opinion behaviour and to its effect on public institutions strategies: in fact, that has to be intended as the only counterbalance to government capabilities to fund R&D investments, but it is necessarily a response restricted to the long term effects and then very difficult to be modelled while attempting to describe a three days conference such as ASIME. As it shall be expected, the public opinion was in reality not represented at the conference, and the mentioned counterbalance was therefore missing. The result has been the acceptance of several appealing but expensive proposals to promote asteroids mining, like, for example, the launch of a dedicated space telescope for asteroids observation in the thermal (see Delbo et al, 2016) and infra-red frequency or the wide (and well deserved) support to ESA Asteroids Impact Mission (see Michel et al., 2016), which just three months after the conference was unfortunately rejected by the ESA Ministerial Council.

Due to its absence in ASIME and its impact only in the long term scenario, it is then proposed to leave the public opinion player aside this game modelling, and to consider it just as an external observer driving governments' long term strategies.

Players Summary

Four players are then selected to describe this game:

- Scientist (S)
- Traditional Space Industry (I)
- Asteroids Mining Industry (M)
- Governments (G)

The Player's Goals

Each player has, of course, different objectives or goals and it is important to correctly identify and rank them to then understand the possible strategic options available to each of them. To maintain the game description reasonable, three ranked objectives will be identified for the already described actors.

Scientists' Goals

As we have commented in the introduction, after the extended sociological critics to the scientific method elaborated during the seventies, the sociological constructivism has made it clear that scientists don't only pursuit epistemic objectives, but they take their decisions also to increase peers' recognition and economical funding of their work, amongst other 'social' or 'non-epistemic' goals. Nevertheless, as it is argued in Zamora Bonilla (2002, 2009), it is reasonable to assume that the norms regulating the behaviour of researchers are designed so as to make the pursuit of epistemic goals a primary (though not exclusive) motivation in science. To simplify, we shall consider the following three goals of scientists:

1. **Knowledge:** It represents the aim to satisfy the scientist's desire of increasing our knowledge of nature (epistemic goal)

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2. **Recognition:** This is the aspiration to obtain recognition of his/her work by his/her peers and become then a reference in his/her field of study (social goal)
3. **Funding:** The real life goal, that is the need to receive funding to support his/her research and then having the possibility of satisfying the first two objectives (economic goal)

Space Industry's Goals

Traditional industries can have different missions and organisations, but if they don't generate profits they are not sustainable. This is as simple as it is. Once this first goal is accomplished, then company mission comes into play, and we can say that an engineer working in the space sector will certainly ask to the genius of the lamp to see some device he has worked on flying in a real mission; this wish can be summarised, in a more general way, as the wish of implementing technology and it has interesting similarities, sociologically, to both scientists' knowledge and recognition desire. Finally, a company has to look for the future, and will then be interested in strategically positioning itself on the market to keep its business and mission alive also in the future.

The three identified objectives for the traditional space industries are therefore described as:

1. **Profit:** It cannot be forgotten that generate profit it is the main purpose of any private company (economic goal)
2. **Technology:** Engineers live to produce devices, this is both how they satisfy their aspiration of generating knowledge that contributes to humanity's wellbeing (epistemic goal) and how they obtain recognition by their peers (social goal)
3. **Positioning:** A company can reduce the profit it obtains from a certain activity in view of a foreseen strategical advantage expected in the future via a market positioning (strategic goal)

Asteroid Miners' Goals

The asteroids mining companies are private firms, so, in principle, they should be subject to the same goals described for the traditional space industries. Nevertheless their mission is somehow different, especially when considering the horizon time of the expected investments benefit: it is clear that, when planning the asteroids mining business, nobody expects real profits in the short term, so the benefit goal is somehow distorted as it is moved to the long term objectives, while, in the short term, it is replaced by the need of develop a new breakthrough technology or, at least, to obtain an advantageous positioning in the space mining market.

The three space miners' objectives are the defined as:

1. **Technology:** That is the key goal to give the company the most strategic asset and advantage with respect to the competitors (strategic goal)
2. **Positioning:** In a very reduced market, it is fundamental to establish oneself in a dominant positioning and to maintain it (strategic goal)
3. **Benefit:** In the long term, also space mining companies are needed to generate benefit to be shared with their investors (economic goal)

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Government's Goals

In the context of this analysis, public institutions basically aim to promote the leadership of their beneficiaries (territorially defined) in terms of knowledge and technologies. They also need to somehow respond to the public opinion instances, but, as already anticipated in the previous section, this aspect will not be considered in the context of the current study.

The government objectives are then defined as a twofold goal at the same level of interest:

- **Knowledge:** To position the beneficiary country (or countries in case of EU) in a leadership position within the research community (strategic goal)
- **Technology:** To provide the beneficiary country (or countries in case of EU) with the means to achieve breakthrough technologies (strategic goal)

The Players' Strategies

To pursuit its objectives, each player can put in place several moves that can be summarised here in a schematic way as:

1. The possibility to partner with other players or to compete against them
2. The option, not available to all players, to fund activities internally or to grant financing to other players. This is a key feature of techno-science investigation because their research areas are usually highly innovative and then not directly market profitable, needing then dedicated investments to cover this gap.

We will start the strategies description from the government and the space miners, since they are, thanks to their financing capabilities, the game enablers from the economic point of view.

Even with this simplified description, the game will already become complex enough to be difficult to handle, but the proposed separation among partnerships and financing strategies will open the door to valuable game solutions without oversimplifying its complexity.

Government Strategies

When we talk about advanced techno-science investigation, the government is the main game activator. Very innovative research and technology developments have very often to rely on public funding to take place, especially in their initial steps: the game would be immediately over if the funding was suspended when market profitability is still far to come.

The government strategies are then defined by the possibility to grant money or not to the players which can satisfy its goal by generating knowledge or technology. These strategies are:

1. **Finance Both Science and Industry to Obtain Both Knowledge and Technology:** this is what every public institution in principle wants, because it would guarantee both its objectives. of course real life put limits on funding capabilities and this strategy is not always possible.
2. Finance only science to obtain only knowledge. When the available budget is not sufficient to fund both of them, the government could decide to finance either only science or only industry. In this

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first case the priority is given to basic research, maybe because the considered research domain is considered still immature to provide a working technology and it is preferred to first consolidate the scientific knowledge of the area.

3. Finance only industry to obtain only technology. We are again in a scenario with limited budget availability, but this time the priority is given to industry: the technological maturity of a certain device is considered enough advanced to deserve public funding to complete its development process and to achieve higher technology readiness levels.
4. Do not fund anybody (and, of course, obtain nothing). This is definitely a worst case scenario for the techno-scientific investigation: the considered area of research is not judged strategically interesting by public institutions and it is abandoned.

Asteroid Miners Strategies

The asteroids miners can play a double game: they could both play the financing game, by funding science and/or industry to obtain knowledge and technology, and they could partner or compete with other space miners. In general they will not be interested neither in partnering nor in competing with scientists and/or traditional space industries, because they have very different priorities, as presented in the previous section.

For what concerns the financial game, they can very much act as the government granting money or not to the players which can satisfy its goal by generating knowledge or technology. But, differently from governments, they can also decide to develop themselves certain areas of investigation, especially the technological ones. The miners' financial strategies can therefore be described as follow:

1. Finance both science and industry to obtain both knowledge and technology. As for governments, if sufficient budget is available, the space mining industry can subcontract development activities to both science and industry.
2. Finance only science to obtain only knowledge. Differently from governments, this scenario is more likely to happen for space mining industry, because these firms could very much interested in developing themselves the technology needed for asteroids mining, since this would increase their independence from other industrial players.
3. Finance only industry to obtain only technology. As a counterpart of option "b", this is an unlikely scenario for space miners' financing strategies, because it would mean to give up both advances in science knowledge and independence at industrial level. Nevertheless it is far to be an impossible option, because asteroids mining requires such complex technologies, needing such long development times, that it could be worth it to rely on external and consolidated providers.
4. Do not fund anybody (but, maybe, still obtain something). This is a much desired option for the asteroids miners, but only if governments have already covered the financing in the areas of interest. If that is not the case, this scenario would leave space miners with open gaps in science and/or technology.

On the other hand the space miners can also play the partnership/competence game, deciding if they want or not partners with other miners:

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1. Compete with other miners to pursuit better market positioning. At the moment when this text is being written, only two players are present as space miners, and the most probable scenario is the one where they compete against each other.
2. Partner with other miners to increase their funding capability. A strategical alliance between two competitors would certainly increase their financing capabilities and this could be critical for some very complex technologies. This option is more probable in an extended market than in the case of few players.

Space Industry Strategies

Traditional space industries can also play a twofold game, having both the possibility to decide if partner or compete with scientists and other industries, and the capability to invest money for internal research to then obtain a better market positioning.

From the financial point of view, nevertheless, industry has more reduced options than government or miners, because they don't have any interest in funding other players. The industry financing strategies are then:

1. Internal funding to obtain a better market positioning. If certain technology is considered profitable in the long term, a company could decide to dedicate part of its benefit to develop such technology, with the hope of positioning itself as the market leader for that technology exploitation.
2. No internal funding to pursuit higher profits. A private company investment is always done at the price of reducing the company's profits, which is the primary goal for each private firm. Therefore it is not unlikely that industries decide not to invest money, even for promising technologies, if the economic conditions do not allow them to do that.

But industries also have to take another very important decision when facing public or private competitions for contracts: they have to structure a team to maximize both the chances to win and the future project profit. These two goals are usually contradictories because contract award probabilities are generally higher for industrial consortiums covering different areas of expertise, but the benefit is of course higher if the profits have to be split with less partners. Furthermore, industries have the possibility to partner both with other companies and with science teams: in the second case there is no market conflict, because industries and scientists usually cover different areas of expertise and pursue different goals, but when assessing the possibility to partner with industries, a private company has always to evaluate the partnership impact in the other industry market positioning, to avoid give it advantages for future competitions.

Considering then the possible combinations of the described options, the partnership strategies available to industries are:

1. Compete with both scientists and industries. In this scenario a private company decides to participate alone to a competition: its chances to win could be lowered by this decision, but, in case of award, the profit will be 100% for the company
2. Compete with scientists and partner with industries. In this case a 100% industrial consortium is built up, leaving aside scientific teams; it could be the case of competitions for a pure technological development where the theoretical basis of the activity is already very well consolidated.

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3. Partner with scientists and compete with industries. This is a very probable scenario for techno-science projects: the industrial and scientific teams complete each other with a net split of responsibilities that is beneficial for both of them, without helping competitors positioning in the market. Usually in this scenario the industrial team take charge of the project management and of the biggest money share.
4. Partner with both scientists and industries. If a very complex competition has to be responded, a bigger team could be needed to cover a wider set of expertise areas. This is not all an unlikely scenario, and it is very typical in European Commission H2020 programme.

Scientists Strategies

Differently from all the other players, scientists do not usually manage any internal funding to finance their activities, relying only on external grants. Their strategies are then reduced to the possibility to partner or compete with other scientists and/or industries. As for the industries a decision has to be taken assessing the increase in the award possibilities against the share of funding and, more important, against the obtained peers' recognition. When a scientific article has to be written, the competition to be first author of the publication has an important part in the decision making process and in the partnerships selection.

The available strategies for scientist are then defined as:

1. Compete with both scientists and industries. A scientific team decides in this case to not form any consortium and try to keep for itself both the entire project funding and the full research recognition.
2. Compete with scientists and partner with industries. The scientific team talks to some industrial partner to establish a collaboration to participate in the competition. It has the additional advantage to leave the project management (not at all interesting for them) to the industry and it has no internal competitors in the future results disclosure.
3. Partner with scientists and compete with industries. If a certain competition requires diverse and pure scientific competences, two scientific teams can establish a partnership without involving any industrial partners.
4. Partner with both scientists and industries. As already described for industries, this is the case of complex projects, such as EC H2020, that requires big teams of both scientific and industrial members.

Payoffs

For the partnership strategies of each player, the payoffs are evaluated to then build in the next step the game matrices. This exercise is limited to the partnerships aspects and it is then not extended to financing one because that is rather a game enabler than a strategic choice: it will then be directly treated in the next section with the "tree" technique instead that with the matrices one. As already anticipated in the previous sections, this choice will allow having a much more manageable game both for the authors and for the readers.

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Scientists' Payoffs

According to the strategies and the objectives described in the previous sections, the payoff matrix for the scientists could be defined as shown in Figure 3.

1. Compete with both scientists and industries means working in isolation and it then reduces the amount of knowledge that can be acquired, while increasing the peers' recognition and the funding share.
2. Compete with scientists and partner with industries increases the chances of developing new technologies and to validate the group theories, while the price of working with industry always means accepting a reduced share of funding.
3. Partner with scientists and compete with industries is worst in terms of peers' recognition, because it implies to share the glory, but it is certainly advantageous in terms of knowledge and it could also be good as funding share (scientist partners are not as greedy as industry ones)
4. Partner with both scientists and industries is certainly good in terms of knowledge but it is definitely not in terms of peers' recognition and the funding share.

The same options are ranked in the Figure 4.

Space Industry Payoffs

In the same way the space industry payoffs matrix would be as illustrated in Figure 5.

Figure 3. Scientists payoff matrix

SCIENTISTS	objective		
Strategy	knowledge	recognition	funding
Compete (S), Compete (I)	BAD	GOOD	GOOD
Compete (S), Partner (I)	GOOD	GOOD	BAD
Partner (S), Compete (I)	GOOD	BAD	GOOD
Partner (S), Partner (I)	GOOD	BAD	BAD

Figure 4. Scientists payoff matrix ranked

SCIENTISTS		objective		
RANKING	**Strategy**	knowledge	recognition	funding
1	Compete (S), Partner (I)	GOOD	GOOD	BAD
2	Partner (S), Compete (I)	GOOD	BAD	GOOD
3	Partner (S), Partner (I)	GOOD	BAD	BAD
4	Compete (S), Compete (I)	BAD	GOOD	GOOD

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Figure 5. Space Industry payoff matrix

SPACE INDUSTRY	objective		
Strategy	profit	technology	positioning
Compete (S), Compete (I)	GOOD	BAD	BAD
Compete (S), Partner (I)	BAD	GOOD	BAD
Partner (S), Compete (I)	GOOD	GOOD	GOOD
Partner (S), Partner (I)	BAD	GOOD	GOOD

1. Compete with both scientists and industries means, also for industry, working in isolation and it then reduces the possibilities to develop new technology and to obtain interesting market positioning, while increasing company's profit.
2. Compete with scientists and partner with industries increases the chances of developing new technologies but at the price of reducing the profit and sharing the new technology with competitors, which means renouncing to strategical positioning.
3. Partner with scientists and compete with industries is definitely the most rewardable option for industry, since it could simultaneously satisfy all its objectives. The absence of direct industrial competitors guarantees both the market positioning and good profits (even if certainly somehow lower than in option "a"), while the support form a scientific team offers better chances of developing new technologies.
4. Partner with both scientists and industries is certainly good in terms of technology and, depending on the team structure, it could also be satisfactory for positioning, but it is definitely not rewardable in terms of profit.

The same options are ranked in the Figure 6.

But the case where space industry decided to internally fund technology investigation shall also be analysed, because, in this case the payoff matrix would be different (see Figure 7).

1. Compete with both scientists and industries means, again, working in isolation but now the technology developments are guaranteed because of the internal funding and so it is, as a consequence, the market positioning. All goals are accomplished for this option

Figure 6. Space Industry payoff matrix ranked

SPACE INDUSTRY	objective		
Strategy	profit	technology	positioning
Compete (S), Compete (I)	GOOD	BAD	BAD
Compete (S), Partner (I)	BAD	GOOD	BAD
Partner (S), Compete (I)	GOOD	GOOD	GOOD
Partner (S), Partner (I)	BAD	GOOD	GOOD

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Figure 7. Space Industry payoff matrix with internal funding

SPACE INDUSTRY		objective		
RANKING	Strategy	profit	technology	positioning
1	Partner (S), Compete (I)	GOOD	GOOD	GOOD
2	Partner (S), Partner (I)	BAD	GOOD	GOOD
3	Compete (S), Compete (I)	GOOD	BAD	BAD
4	Compete (S), Partner (I)	BAD	GOOD	BAD

2. COMPETE with scientists and partner with industries has the same payoff presented in the case of no internal funding.
3. Partner with scientists and compete with industries in case of internal funding means pay twice the investment price, once in terms of financing the internal technology development and once by funding also the scientist work. This option loose then the profit goal.
4. Partner with both scientists and industries has the same payoff presented in the case of no internal funding.

The strategies ranking then changes if industry needs to use its internal funding (see Figure 8).

Asteroid Miners Payoffs

The asteroids miners' partnership strategies are very simple and lead to a rather trivial payoff matrix, which is here presented only for the sake of completeness (see Figure 9).

Figure 8. Space Industry payoff matrix with internal funding ranked

SPACE INDUSTRY	objective		
Strategy	profit	technology	positioning
Compete (S), Compete (I)	GOOD	GOOD	GOOD
Compete (S), Partner (I)	BAD	GOOD	BAD
Partner (S), Compete (I)	BAD	GOOD	GOOD
Partner (S), Partner (I)	BAD	GOOD	GOOD

Figure 9. Space Miners' payoff matrix

MINING INDUSTRY	objective		
strategy	technology	positioning	profit
Compete miners	BAD	GOOD	GOOD
Partner miners	GOOD	BAD	BAD

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1. Compete with other miners could be bad in the short term technology developments, but it is certainly the only reasonable long term strategy in a market with very few players.
2. **Partner With Other Miners is the Other Way Around:** It provides good short terms results at the price of scarifying the long term goals. This strategy shall be reconsidered in the future in case a considerable number of new players came into this market.

Government Payoffs

Government does not have any partnership strategy and then any payoffs matrix.

RESULTS

The results presentation will be done in two steps:

1. Firstly it will be presented the result of the financing analysis, presenting the game options through the "tree" technique.
2. Secondly the partnership game matrices will be illustrated

Games in tree-form are solved by the algorithm known as 'backwards induction': at each final – right-most– node, those choices that give a lower level of satisfaction or 'utility' to the relevant player are deleted, and then we proceed to the next player's choice by considering the utility she gets when the player in the deleted option has made her choice. Games in matrix-form are solved by looking the 'Nash equilibria': in each column, we look for the choice that the player in the rows would make if that column were chosen by the other player, and we select that (or those) row(s); we repeat the analysis by starting with the rows and looking for the column player's choices. Nash equilibria (there can be more than one) are those boxes that are selected in this way by both players.

Financing Analysis

This is a preliminary and necessary step in the techno-science investigation because the studied technologies are generally too immature to be directly sold in the market in a short timeframe. Therefore they need financial support either from public or private institutions; otherwise they would just not be sustainable. This is what in ASIME conference has been identified as the "Science Knowledge Gap" (SKG) focusing then the attention more on the scientific contribution than on the technological one.

In the specific instance of the space mining the principal investors will be the governments or the space miners themselves which can fund industry and/or scientists; as already discussed, also the private space industry can decide to put some money into the game by the mean of internal funding of technology research. The full tree of possible options is then depicted in Figure 10.

Nevertheless it is very likely that the space miners' funding will finance only the uncovered areas by the governments, and that the private space industries will authorise internal funding only if they do not receive other money. The tree would then be simplified in the following structure of 9 branches (see Figure 11).

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Figure 10. Financing game: complete tree

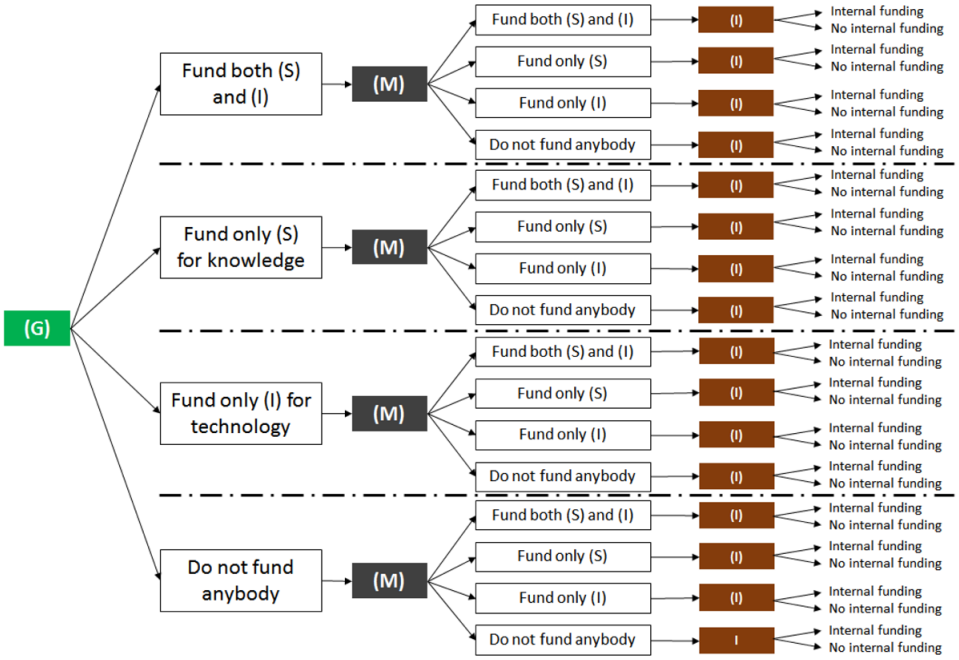
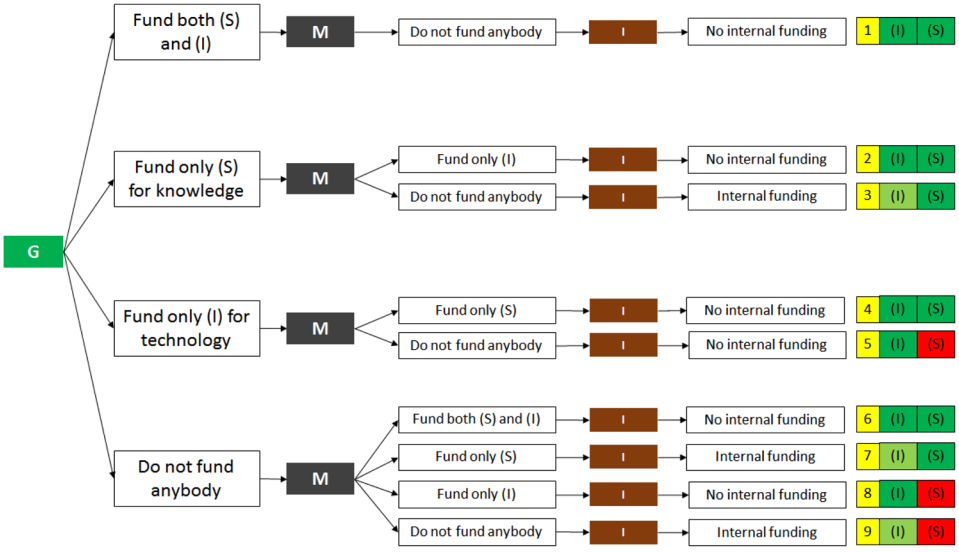


Figure 11. Financing game: reduced tree



**For a more accurate representation see the electronic version.*

In this figure a number is assigned to each branch and with green/red colours it is indicated whether industries and science receive funding or not: the main difference between these two players is that industries can always have funding because they have the possibility to access to internal financing (in the figure light green instead of dark green), while scientists are exposed to the risk of not having money

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to perform their research (red). In this case the techno-science game is considered to be over, because both industry and science are needed.

But let's go through the different branches one by one:

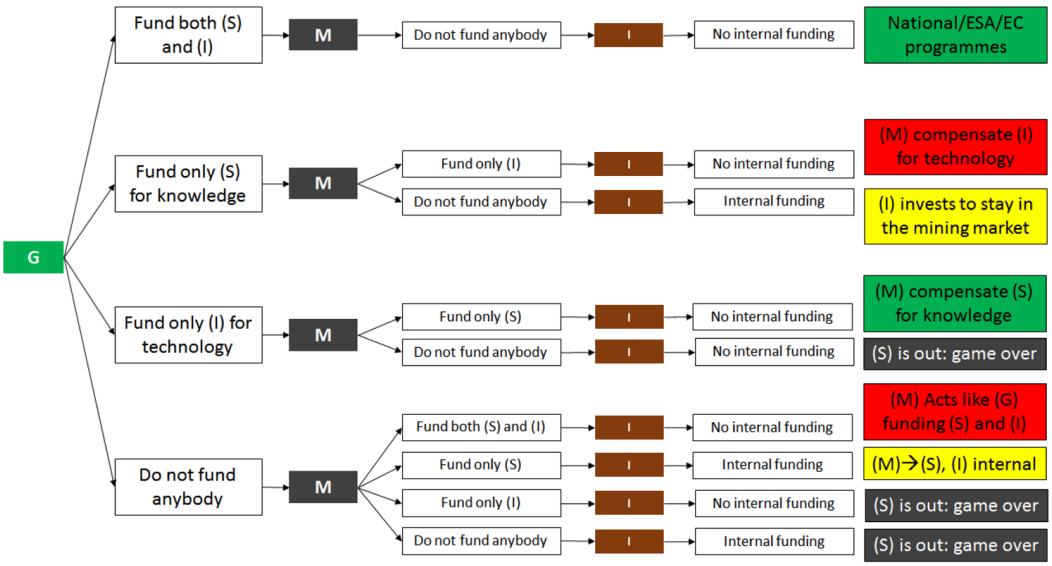
1. All funding from government: very likely scenario as in ESA or EC projects (i.e. H2020)
2. Scientists receive funding from government and miners sponsor industries: very unlikely scenario since miners would probably try to develop technologies themselves
3. Scientists receive funding from government and industries accede to internal funding to stay in the space mining market: possible scenario
4. Governments fund only industries (i.e. ESA programmes) and miners fund scientists to cover the "Science Knowledge Gap" (SKG): very likely scenario and one of the possible ASIME outcome.
5. Science has no funding: techno-science game is over.
6. Miners act like governments and fund both science and industry: very unlikely scenario.
7. Miners pay scientists for knowledge, and industries accede to internal funding to stay in the space mining market: possible scenario
8. Science has no funding: techno-science game is over.
9. Science has no funding: techno-science game is over.

The same information is graphically presented in Figure 12.

If we then prune the more unlikely and the game over branches, four scenarios remain active:

1. **Funding Scenario 1 (Highly Possible):** Governments fund both science and industry
2. **Funding Scenario 2 (Highly Possible):** Governments fund industry and miners fund scientists

Figure 12. Financing game: reduced tree with results



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3. **Funding Scenario 3 (Possible):** Governments fund science and industry uses internal resources to stay in the mining market
4. **Funding Scenario 4 (Possible):** Miners fund science and industry uses internal resources to stay in the mining market

Partnerships Analysis

As expected, the most complex and interesting partnership analysis is the one describing the interaction between science and industry. This game matrix is in reality double, as we have seen in the section dedicated to 2.4.2. Space Industry payoffs, since different payoffs appear whether the space industry is making use of internal funding or not (see matrices from Figure 5 to Figure 8). Following then the results obtained in the previous section on the financing analysis, we can configure a twofold game:

1. The funding scenario 1 or 2 game, that is the most probable one
2. The funding scenario 3 or 4, that is possible but not very likely.

In the first case the science-industry game matrix is shown in Figure 13.

The game theoretical analysis of this matrix shows that there are two possible Nash equilibria: the combination of strategies in column 1 and row 3, on the one hand, and the combination of strategies in column 3 and row 2 (e.g., if "Space Industry" chooses the first column, then the third row is the best strategy for "Scientists", and viceversa). However, as it is straightforward to see, the second of these equilibria (column 3, row 2) is better for both players than the first one (technically, it is "Pareto optimal"). Hence, to the extent that the players can agree beforehand a solution, they will tend to choose the second equlibria. However, the difference in value between both equilibria are not very high for the player "Scientists", so there would be a chance of seeing that "column 1/row 3" were chosen, if, for example, scientists had adopted in the past a strategy that commits them to mutual partnership, and then "Industry" should have to adapt to that situation. Nevertheless, since in practice there is ample room for negotiation between the players, it is much more likely that they end implementing the optimal outcome: the partnership between scientists and industry, each of them contending with their direct competitors.

Figure 13. Science-industry game matrix without industry internal funding

Funding Scenario 1/2	SPACE INDUSTRY							
SCIENTISTS	Compete (S), Compete (I)		Compete (S), Partner (I)		Partner (S), Compete (I)		Partner (S), Partner (I)	
Compete (S), Compete (I)	SCIENCE recognition funding	INDUSTRY profit	SCIENCE recognition funding	INDUSTRY technology	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE
Compete (S), Partner (I)	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE	SCIENCE knowledge recognition	INDUSTRY profit technology positioning	SCIENCE knowledge recognition	INDUSTRY technology positioning
Partner (S), Compete (I)	SCIENCE knowledge funding	INDUSTRY profit	SCIENCE knowledge funding	INDUSTRY technology	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE
Partner (S), Partner (I)	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE	SCIENCE knowledge	INDUSTRY profit technology positioning	SCIENCE knowledge	INDUSTRY technology positioning

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The situation becomes much more complex if industries have to rely on their own financing: the new game matrix would be shown in Figure 14.

In this case we have three possible Nash equilibria: "column 1, row 3", "column 3, row 2", and "column 4, row 2" (the two last ones are equilibria, in part because, if Scientists choose row 2, then the Industry is indifferent between playing column 3 or 4. Now also the situation is more complicated because no one of the three equilibria is a Pareto optimum: the Space Industry would prefer the first one, though scientists would prefer some of the two last ones. This means that the solution of the game, and hence the final outcome of the negotiations, is more undetermined than in the case depicted in fig. 13. However, since the difference in valuation for Scientists between the three equilibria is not too big, the most likely outcome is that the players agree to adopt the first equilibrium (column 1, row 3").

CONCLUSION

Taking advantage of the proposed analysis, some conclusion can be extracted contrasting the obtained results against ASIME outcome. From the conference wrapping up (described in Amara Graps et al., 2016), two different sets of conclusions can be extracted, one more related with the technical aspects of the workshop and the other one associated with the economical aspect of space mining investigation.

The technical needs identified by the conference participants are mainly focused in addressing the so-called "Science Knowledge Gap" or "SKG": as it shall be expected, the first steps of a new research field aim to clarify all the unknown aspects of the subject and to cover the correspondent knowledge gap. This is clearly illustrated by two needs identified during the conference: the demand for a dedicated telescope to map asteroids as potential mining targets and the need of new physical measures to characterise them in view of their mining exploitation (i.e. through thermal inertial instead than through light curves). Both of them are science needs but they both entail very complex technological challenges, like the design of new instruments or even the planning of dedicated space missions: therefore, even if the emphasis is put on the science knowledge, the technological component is here a predominant factor for the future activities definition and a "T" should be added to the SKG acronym to consider it (i.e. "Science Knowledge and Technology Gap", SKTG). In the light of the techno-science epistemology

Figure 14. Science-industry game matrix with industry internal funding

Funding Scenario 3-4	SPACE INDUSTRY							
SCIENTISTS	Compete (S), Compete (I)		Compete (S), Partner (I)		Partner (S), Compete (I)		Partner (S), Partner (I)	
Compete (S), Compete (I)	**SCIENCE** recognition funding	**INDUSTRY** profit technology positioning	**SCIENCE** recognition funding	**INDUSTRY** technology	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE
Compete (S), Partner (I)	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE	**SCIENCE** knowledge recognition	**INDUSTRY** technology positioning	**SCIENCE** knowledge recognition	**INDUSTRY** technology positioning
Partner (S), Compete (I)	**SCIENCE** knowledge funding	**INDUSTRY** profit technology positioning	**SCIENCE** knowledge funding	**INDUSTRY** technology	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE
Partner (S), Partner (I)	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE	IMPOSSIBLE	**SCIENCE** knowledge	**INDUSTRY** technology positioning	**SCIENCE** knowledge	**INDUSTRY** technology positioning

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previously portrayed, it is thus critical to properly describe the interaction between science and industry as an essential component of the space mining sector characterisation; the analysis illustrated in this text through the game theory approach could then be considered as a meaningful contribution to understand this new vibrant area of investigation.

The second critical aspect is the economical one and two questions shall be answered on this: who paid for ASIME organisation? And what is the economic strategy envisaged by the conference participants? Both questions lead us to the financing analysis presented in the previous sections. The conference sponsors have been both public institutions (Government of Luxembourg and ESA) and the space mining industries (Space Resources and Deep Space Industries): this is fully expected in the light of techno-science epistemology, where the optimal strategy has already been identified as the collaboration of science and industry, having either governments or miners' (or both) investing to cover the SK(T)G. Moreover the envisaged economic strategy largely rely on the promotion of activities funded by public institutions programmes (mainly ESA and EC), which are identified as the necessary techno-science enablers until the market profitability gets closer in time; but here the conference participants reckoned without their hosts, as we have already pointed out in § "2.1.4. Public opinion." Another important result is the consequence of deficient governments and miners' funding: in this case we have seen how industry would have to use its internal resources and that this would lead to a different game. The risk of this game is to kill the science-industry collaboration, something that could be a feasible (and sub-optimal) solution of the game, but that, epistemologically, would prevent the techno-science development resulting in a dead-end for the space mining.

To summarise, a complex model has been defined to describe the multifaceted science-industry interaction typical of techno-science; this model has been successfully applied to the fascinating and concrete case of ASIME conference to demonstrate the range of its validity. Moreover, the proposed analysis allows concluding that ASIME shall be considered as a first step in the asteroids mining research and industry construction, a step that privileged the science gap over the technological one. A more important role of technology shall be expected in the future, leading to more complex interactions between science, industry, miners' and governments.

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Chapter 13
Innovation in Scientific Knowledge Based on Forecasting Assessment:
A Case Study on Automotive Spare Parts Demand

Ignacio Aranís Mahuzier
Universidad Técnica Federico Santa María, Chile

Pablo Viveros Gunckel
Universidad Técnica Federico Santa María, Chile

Rodrigo Mena Bustos
Universidad Técnica Federico Santa María, Chile

Christopher Nikulin Chandía
Universidad Técnica Federico Santa María, Chile

Vicente González-Prida Díaz
University of Sevilla, Spain & Universidad Nacional de Educación a Distancia (UNED), Spain

ABSTRACT

This chapter presents a study of forecasting methods applicable to the spare parts demand faced by an automotive company that maintains a share of nearly 25% of the automotive market and sells approximately 13,000 parts per year. These parts are characterized by having intermittent demand and, in some cases, low demand, which makes it difficult for such companies to perform well and to obtain accurate forecasts. Therefore, this chapter includes a study of methods such as the Croston, Syntetos and Boylan, and Teunter methods, which are known to resolve these issues. Furthermore, the rolling Grey method is included, which is usually used in environments with short historical series and great uncertainty. In this study, traditional methods of prognosis, such as moving averages, exponential smoothing, and exponential smoothing with tendency and seasonality, are not neglected.

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RESEARCH PROBLEM

The sale of automobiles has experienced a sustained increase in the case of the company under study, thus escalating the sale of spare parts. For the company under study, the spare parts and accessories business is a key development area and is one of the important factors for maintaining the competitiveness of the current market share. Table 1 summarizes the main characteristics of the brand under study and the company, which markets various brands.

The administration of these parts and accessories is becoming increasingly complex owing to the constant growth in the volume of automobile sales in our country Chile (Asociación Nacional Automotriz de Chile A.G., 2017). The large number of cars in circulation only escalates the demand volumes of a variety of spare parts. This must be addressed as efficiently as possible while maintaining high levels of service, as the sale of original spare parts and the ability to respond promptly to demand have a great strategic impact on customer loyalty. The studied brand marketed 2,808 spare parts in the year 2017, of which only 9 are selected for analyzing the performance of the forecasts for the different types of spare parts.

It is necessary to obtain forecasts that reduce the uncertainty of future demand and that facilitate the adjustment of inventory levels to realize greater efficiency, thus reducing the current forecast error while applying a moving average method.

Forecasts are vital for every company—whether they belong to the manufacturing, business, or financial fields—and are necessary in administrative and managerial decision making. In the field of accounting and finance, forecasts provide the basis for budget analysis and planning. Marketing strategies are involved in sales staff decisions and the introduction of new products, which vary according to the sales forecasts. In turn, the production area makes capacity, function distribution, and operator decisions based on periodic forecasts obtained from the organization's commercial area (Chase, Jacobs, & Aquilano, 2006).

Generally, the spare parts industry faces a common problem, namely, intermittent demand and its variability (Syntetos & Boylan, 2001).

Some important demand patterns are explained in Table 2.

Table 1. Main characteristics of the brand and company under study

Market share of the company under study	20%–25%
Participation of the brand under study within the company	15%–20%
Annual car sales	10,000–13,000 units
Annual spare parts sales	300,000–320,000 units
Total employees	3,000–3,500 people
Software used	SAP

Source: Own elaboration based on the company's database (Company under study, 2017).

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Table 2. Recurring demand types in the spare parts demand series

Demand pattern	Description	Causes	Source
Intermittent demand	Items for which a significant proportion of the time demand is zero.	Low number of customers and/or low order frequency.	(Dunsmuir & Snyder, 1989) (Bartezzaghi & Verganti, 1995)
Irregular demand	Behavior that the demand has when it comes into existence.	Heterogeneity of customers' requests. The requests of each client vary in size.	(Syntetos A., 2001) (Bartezzaghi & Verganti, 1995)
Lumpy demand	Low demand for items with high variability and a large proportion of time when there is no demand.	Owing to specific replenishment decisions, lot-sizing rules, or even over-reactions of judgment	(Hahn & Leucht, 2015) (Bartezzaghi & Verganti, 1995) (Syntetos A., 2001)

LITERATURE REVIEW

This section outlines the methodologies that are used in this study to improve the performance of the method currently used and the studied advantages and disadvantages of implementing new techniques by observing their behavior according to various performance indicators, which are detailed in subsection 4.2.

Forecasting Methods

Time series analysis is based on the premise that it is possible to predict future events with some degree of accuracy based on past events, that is, the historical demand. This is made possible by observing a number of patterns that may occur, such as seasonality, trend, or cyclicality, while causal forecasts involve the use of linear regression techniques or more complex techniques for determining the relationship between the demand for a good and an underlying factor in the environment (Chase, Jacobs, & Aquilano, 2006).

Moving Average

The method currently used by the company under study is the simple moving average, which does not fall or rise rapidly when the demand is regular and may prove to be the best option for eliminating random errors (Chase, Jacobs, & Aquilano, 2006). There is a conflict in selecting the periods, as selecting a large number of periods will provide a more uniform prognosis, which would not be an advantage in the case of a trend for which a low number of periods is more beneficial. However, the inclusion of weights for each period can produce better performances, and such weights can be found empirically (Chase, Jacobs, & Aquilano, 2006).

Simple Exponential Smoothing

Another method, which is one of the most widely used and is an integral part of almost all forecasting software, is the simple exponential smoothing (hereafter SES) method. This method is frequently used by wholesale companies, retailers, and service agencies. The SES method is thus named because every step taken in the past reduces the importance of demand in $\left(1-\alpha\right)$ (Chase, Jacobs, & Aquilano, 2006). Here, the constant α determines the uniformity of the forecast and the ability to respond quickly to dif-

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ferences between the actual demand and forecast made in the previous period, as a value close to 1 would result in a forecast that simply replicates the actual demand of the previous period, while a value close to 0 would replicate the previous forecast (Pindyck & Rubinfeld, 2000).

Trend Adjusted Exponential Smoothing

When a trend exists and the SES is applied, the forecast will always be below the real demand. Thus, this method includes the effect of the trend and the smoothing factor for the trend β (Pindyck & Rubinfeld, 2000).

Holt–Winters Exponential Smoothing

Finally, in the method of exponential smoothing with trend and seasonality (hereafter SHW), the effect of seasonality is included or captured using the seasonality smoothing coefficient γ. In addition, the frequency of this seasonality should be estimated (Pindyck & Rubinfeld, 2000).

Croston Method

A relevant pattern in the demand for spare parts is the intermittency with which it occurs, and there can be a significant number of periods without demand (Syntetos & Boylan, 2001). The Croston method (hereafter CR) is focused on these problems (Hemeimat, Al-Qatawneh, Arafeh, & Masoud, 2016). This method consists of two stages: the first stage consists of an exponential smoothing method for the calculation of the demand forecast, while the second stage consists of the calculation of the average length of the interval between demands (Croston, 1970-1977), which is represented by the following model.

$$\hat{S}_{t+1} = \begin{cases} \hat{S}_t, & siD_t = 0 \\ \left(1-\alpha\right)\cdot \hat{S}_t + \alpha \cdot D_t & siD_t > 0 \end{cases} \tag{1}$$

$$\hat{K}_{t+1} = \begin{cases} \hat{K}_t, & siD_t = 0 \\ \left(1-\beta\right)\cdot \hat{K}_t + \beta \cdot K_t, & siD_t > 0 \end{cases} \tag{2}$$

where $0 < \beta < 1$ and $0 < \alpha < 1$

Finally, the forecast is defined as follows:

$$Y_{t+1} = \frac{S_{t+1}}{K_{t+1}} \tag{3}$$

where K_t is the actual length of the interval between the last non-zero demand and the current period, and $\hat{K}_t$ represents the predicted value of the interval length.

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Syntetos–Boylan Approximation

Syntetos & Boylan (2001) showed that the CR was significantly biased. This bias resulted in problems with the CR with the accuracy of its forecasts being even worse than those of the traditional forecasting methods (Syntetos & Boylan, 2001). Thus, a $1-\alpha/2$ deflator is introduced, which is multiplied with the result of Equation (3); this is an approximation that would eliminate the bias of the CR.

Teunter–Syntetos–Babai Method

Finally, the Teunter method follows the same approach as the two previous methods, although it differs because it updates the demand probability estimate for each period, in contrast to the CR or SBA methods, where the interval is only modified once a demand exists (Equation (1)), while the demand estimate remains unchanged (Teunter, Syntetos, & Babai, 2011).

$$\hat{S}_{t+1} = \begin{cases} \hat{S}_t, & si\, D_t = 0 \\ \left(1-\alpha\right)\cdot \hat{S}_t + \alpha \cdot D_t, & si\, D_t > 0 \end{cases} \tag{4}$$

$$\hat{P}_{t+1} = \left(1-\beta\right)\cdot \hat{P}_t + \beta \cdot P_t \tag{5}$$

$$\hat{Y}_{t+1} = \hat{P}_{t+1} \cdot \hat{S}_{t+1} \tag{6}$$

Rolling Grey Method

Another method regularly used for data series where uncertainty and information scarcity is present, is the Grey method (Wu, Yang, & Liu, 2014). This method is based on probability theory. Huiru & Sen (2016) and Xiangyun, Hongqin, Yun, Yujun, Yujun, & Lueling (2014) demonstrated the good performance of these forecasting methods by forecasting the annual load capacity and trends in tourism respectively. Its modification, the rolling Grey (hereafter RG) method, makes use of the most recent data for the elaboration of forecasts and data that can be updated when a defined forecast horizon is reached. Remarkable differences from the Grey method can be found in the study conducted by Huiru & Sen (2016).

Aggregate, Disaggregate, and Intermittent Demand Approach

One method that allows the problem of intermittency to be confronted is the aggregate, disaggregate, and intermittent demand approach (hereafter ADIDA) method, which consists of the demand aggregation over a certain number of periods—bimonthly, quarterly, quarterly, quarterly, and half-yearly. This is expected to reduce the intermittency, and a forecast is made for the next period in aggregate form, from which it will then have to be disaggregated using the best methods available (Nikolopoulos, Syntetos, Boylan, Petropoulos, & Assimakopoulos, 2011). Two methods can be used in terms of the aggregation

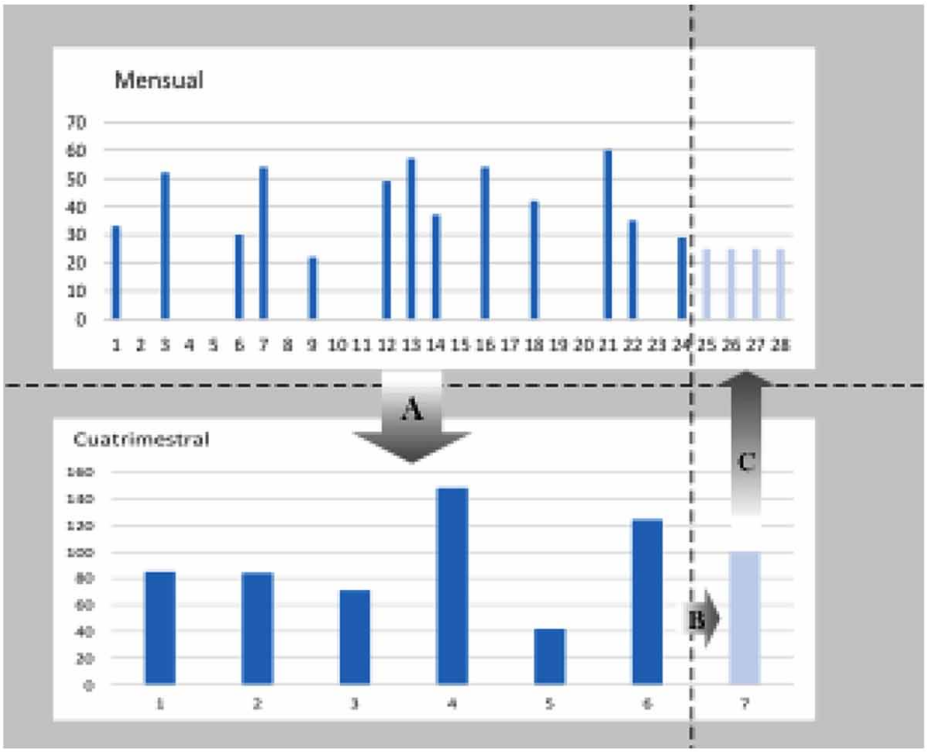
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form: the overlapping and non-overlapping methods. In the non-overlapping method, the historical demand is divided into a number of blocks, each of which is arranged sequentially, i.e., a block starts just after the period after the previous block ends. In the overlapping method, while the blocks have the same length, for each period of time that is advanced (which may be less than the length of the block), the last observation is eliminated and a new observation is included (Nikolopoulos, Syntetos, Boylan, Petropoulos, & Assimakopoulos, 2011). This method is illustrated in Figure 1

The steps for this method are listed below:

- The length of the selected aggregate block, either overlapped or not overlapped, is selected as shown in Figure 1 (process A).
- A forecast method is selected to estimate the next aggregate period for the case shown in Figure 1(process B).
- An appropriate method of disaggregating the predicted block is considered, which is related to the distribution of the demand observed throughout the series (process C). An example is presented in Figure 1
- The above process is repeated for different levels of aggregation, while observing which level allows for more accurate forecasts.

Figure 1. Scheme of the ADIDA method with the processes involved
Source: (Nikolopoulos, Syntetos, Boylan, Petropoulos, & Assimakopoulos, 2011)



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Autoregressive Integrated Moving Average

Autoregressive integrated moving average (ARIMA) methods are prognostic techniques that model certain non-stationary random processes, which have two main components: the presence of a moving averages process with a self-regression process.

Thus, the ARIMA method consists of a process of moving averages of order q, where each observation Y_t is generated by a weighted average of random disturbances with a number of lags q. In addition, it consists of a self-regression process of order p, where the current observation Y_t. is generated by a weighted average of past observations with p. lags along with a random disturbance in the current period. In addition, in the case of a non-stationary series, the series must be differentiated one or more times until a non-stationary transformed series is obtained, such that, in the case of a stationary series, the process is simply modeled using an ARIMA$\left(p,q\right)$ model. In the case of a non-stationary series, the time series is said to be an integrated self-regression process of moving average order $\left(p,d,q\right)$, or simply an ARIMA$\left(p,d,q,q\right)$ (Pindyck & Rubinfeld, 2000).

$$\phi\left(B\right)\Delta^{d}Y_{t}=\delta+\theta\left(B\right)\varepsilon_{t} \tag{7}$$

If the time series has a seasonal component, this process can be added to the ARIMA modeling process explained above, by designing an ARIMA model that includes both the relationships between the years as well as the intrannual relationships. In this manner, and as in the differentiation of stationary processes, the Y_t observations are differentiated in a period s. Thus, the seasonal component of the period s is eliminated (Brockwell & Davis, 2002).

Thus, if d and D. are integers, then Y_t is a seasonal ARIMA$\left(p,d,q,q\right)$X$\left(P,D,Q\right)_s$ process with period s if the differentiated series $Y_t=\left(1-B\right)^{d}\left(1-B^{s}\right)^{D}Y_t$ is a causal ARIMA process. Thus, the seasonal ARIMA process is defined as follows:

$$\phi\left(B\right)\varnothing\left(B^{s}\right)\left(1-B\right)^{d}\left(1-B^{s}\right)^{D}Y_{t}=\theta\left(B\right)\theta\left(B^{s}\right)a_{t}\ . \tag{8}$$

Willemain, Smart and Schwarz Method

In statistics, the estimated point of a parameter θ is defined as a unique number that can be considered as a sensitive value of θ in order to determine this estimator by determining the appropriate statistic and calculating its value based on the sample obtained (Devore, 2008).

The form of the estimator $\hat{\theta}$ can be sufficiently complicated such that standard statistics cannot be applied to obtain these estimators in all cases. This is how the Bootstrap method was introduced by Efron (1979). This method allows the creation of a "pseudo-data" with replacement samples from individual observations.

The non-parametric approach or the Bootstrap approach for forecasting allows the reconstruction of the empirical distribution for the historical data. The Willemain, Smart & Schwarz method (*WSS*) is

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an advanced form of the Bootstrap method that captures the autocorrelation between demands and can reproduce values that did not appear historically. The main problems appear if the Bootstrap method is applied without making any modifications (Willemain, Smart, & Schwarz, 2004). This is how a modified Bootstrap method was developed by Willemain, Smart, and Schwarz in 2004. With the objective of forecasting the spare parts demand in various industries, this method addresses three main problems in intermittent demand behavior: autocorrelation, frequent repetition of values, and relatively short series of historical data (Willemain, Smart, & Schwarz, 2004).

Binomial Method

In an experiment, in order to state that there is a binomial probability distribution, the following requirements must be met.

- The experiment itself consists of a series of smaller sub-experiments called trials, where n must be set before the experiment.
- Each trial may result in only dichotomous values that we call successes or failures.
- The tests are independent of each other, and thus, any results obtained in a test do not affect the results of the others.
- The probability of success is constant from one trial to the next and is indicated by p.

An experiment for which these constraints are met is called a binomial experiment, and the following expression can be used to represent it (Devore, 2008).

$$b\left(x = k; n, p\right) = \binom{n}{k} {P_E}^{k} \cdot {P_F}^{n-k} \tag{9}$$

The forecasting method described by Callegaro, Faccio, & Sgarbossa (2009) provides a forecast comprising two additive terms of demand, wherein a model is proposed in order to facilitate forecasting the demand for spare parts that can be used in various applications. The number of spare parts required is analyzed according to their probability of failure, which is not under study here.

Performance Indicators

The method of determining which forecasting method is better varies according to the assumptions and requirements made for each of them. In other words, "no single measure is universally best" (Silver, 1998). However, in practice, an evaluation of forecasts is made based on a single type of error measurement—the most commonly used are the mean square error (*MSE*) and mean absolute deviation (*MAD*) (Wallstrom & Segerstedt, 2010). The MSE, in contrast to the MAD, is sensitive to atypical demand values and loses sensitivity with small errors (Chase, Jacobs, & Aquilano, 2006), thus "stretching" the difference between the forecast and demand. Although these indicators are widely used, they can bias the prognosis when they are used in the case of intermittent demands (Rasmussen, 2004). One method of solving these problems is to apply a modified form of the two previous indicators, which can be defined as $MSEn$ and $MADn$. These indicators make an accumulation of the forecasts in which there is

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no demand to compare them with the demand when it exists, while increasing the result according to whether it is the $MSEn$ or $MADn$ and accumulating the forecasts again until another period with demand is observed (Wallstrom & Segerstedt, 2010). The symmetric mean absolute percentage error ($sMAPE$) and mean absolute percentage error ($MAPE$) measurement methods, which measure the mean absolute error as a percentage, allow the accuracy comparison of spare parts forecasts with various levels of demand. While the above error measurements measure the forecasts accuracy, there are also indicators that facilitate identifying types of bias in the forecasts. The CFE_t , for example, captures the accumulated value of the errors up to period t ; thus, one would expect an unbiased forecast to show values of this indicator close to zero, and furthermore, the number of times it is positive would have to be similar to the number of times it is negative (Wallstrom & Segerstedt, 2010). The number of shortages (NOS) indicator is responsible for capturing this last situation, as it indicates the number of times that the CFE_t is greater than zero over the planning horizon, while the $NOSp$. measures the previous indicator as a percentage, which is a value that should be close to 50% . in unbiased forecasts (Wallstrom & Segerstedt, 2010).

Furthermore, the indicator PIS_t (periods in stock) enables the delivery of a fictitious idea of the condition in which the stock levels would be with the used forecasts. This indicator measures the total amount of time each item would be in stock following the forecasts made (Wallstrom & Segerstedt, 2010).

nother indicator that provides relevant information regarding the forecasts bias is the tracking signal (Ts). There are a series of models for determining the tcking signal, which are used for providing tools to identify anomalies in forecasts in a timely manner while providing relevant information for decision making (Sabeti, Al-Shebeeb, & Jaridi, 2016).

The method developed in Brown (1959) is the one that is commonly used, wherein the tracking signal is defined as the cumulative sum of the errors (CFE_t) over the mean absolute deviation (MAD_t), and the tracking signal can be calculated for each predicted period. According to Brown (1962), a modification is introduced, in which the MAD_t is calculated using a smoothing process with a smoothing coefficient that is to be determined. As shown by Trigg (1964), this method of determining the tracking signal has some disadvantages, one of which is the case wherein the tracking signal goes beyond the control limits—a scenario in which, it may not return to within the control limits even if the forecasts return to normal. It also presents complications if the forecasts are extremely accurate, as in these cases too, an unnecessarily high tracking signal can be obtained. Trigg (1964) introduces a modification into the Brown method (1962) to develop a smoothed tracking signal, wherein the smoothed error (e_t) is divided into the smoothed MAD , which is simply the smoothed absolute error. Trigg and Leach later introduced a softened adaptive tracking signal, thus improving the performance of the tracking signal. This method makes use of an exponential smoothing model for the tracking signal with a variable response rate, which depends on the current value of the tracking signal (Trigg & Leach, 1967). The purpose of this method is to design a tracking signal that reacts quickly when the forecast escapes the control limits, thus increasing the value of α and increasing the weight of recent observations. Once the forecast has returned to normal, the value of α is reduced until it reaches normal values. However, according to Ravi (2014), it was concluded that the Ts tracking signal may allow an unbiased forecast to be indicated as an unbiased forecast, thus introducing a modification, which depends on the amount of historical data, to the conventional form of the tracking signal.

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Little is known about the distribution of the tracking signal and the nature of the deviation. The problem, as noted by Alstrom & Madsen (1996), is that in a forecast calculated as a linear combination of past observations, correlated errors are produced. In this study, this situation is avoided by proposing overestimated values of the standard deviation and, therefore, an overestimated value of the control limits.

Finally, indicators such as the BP and relative geometric root mean square error ($RGRMSE$) measure, in some manner, the performance of one forecast in relation to another. The BP shows the percentage of times one forecast involved a smaller error than another. While the $RGRMSE$ indicator expresses, in some manner, the extent to which the evaluated forecast is better than the baseline forecast, thus providing a method to measure this magnitude (Wallstrom & Segerstedt, 2010).

METHODOLOGY

The methodology comprises selecting the relevant stock-keeping units (SKUs) for the company and establishing, based on them, the study of the performance of the various forecasting methods addressed in this research.

The methods under study correspond to extrapolation models, that is, models based on historical data. Thus, this section presents a study of the incorporation of models such as SES, trend and seasonal exponential smoothing, as well as simple moving averages. This section also presents a study of the possible incorporation of the *CR* model and its modifications, in addition to the Grey method. Methods such as ARIMA and ADIDA are not taken into consideration owing to the short length of the historical series with which they work, and probabilistic methods are not taken into consideration, as they do not provide a point estimate of the demand. However, they do provide valuable information regarding the demand distribution and could be helpful in an extension of this study into the analysis of the supply policies of the company.

In this manner, and with the objective of studying the most relevant SKUs, an SKU is selected from each previously defined cluster—these clusters categorize the items according to their intermittency, variability, and size of demand. Thus, the study of the forecasts is conducted using nine SKUs to identify the forecasts and parameters that allow the MAD of each SKU to be reduced to a greater extent.

Finally, the proposed forecasting method is compared for each item with the base method (moving averages) and the advantages and disadvantages of the new method are noted while evaluating the various dimensions in which the performance of the forecasts is measured.

ANALYSIS AND RESULTS

Spare Parts Under Study

The spare parts for this study were selected in order to represent each of the clusters. These clusters were prepared based on those spare parts that showed movement in 2017. These clusters were developed by classifying the spare parts according to the average sales levels, and the variability of the spare parts and their intermittency over a defined period of time. The form of categorization used in studies such as Williams (1984), Eaves (2002), Syntetos, Boylan, & Croston (2005) and Boylan, Syntetos & Karakostas (2008) is used when categorizing the spare parts in this study.

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Table 3 shows the characteristics of each spare part that are considered relevant for this study, where a distinction is made between spare parts that have a month without demand and those that do not have months without demand throughout their series. The consideration of the other characteristics is more complex as they are codependent.

It is important to clarify that intermittency is a relevant characteristic for the study of spare parts demand, which has been studied and measured in the research described above. In this study, it was decided to measure it as the number of months throughout the year when the demand for spare parts is zero.

Case Study: Current Forecasting Method

The company under study uses a simple form of forecasting in which a moving averages forecast is applied to all the spare parts without making any discrimination between them. The period selected to make this forecast depends on the availability of information. Thus, if there is no period with zero demand in the last three periods, a moving average of three periods is used. While if there is a period with demand equal to zero, the last six periods are evaluated; if there are five periods with demand greater than zero, a moving average of six periods is used. In the event that the latter condition is not met, a moving average with a variable period is used, wherein the period is the interval between the first observation and the month prior to the forecast.

Thus, of the total of nine spare parts studied, the forecasts of five were obtained using a moving average of three periods, while the forecasts of the remaining four were obtained using a moving average with a moving period. The results thus obtained are as follows (see Table 4).

Table 3. Spare parts selected for the study along with their average monthly sales, coefficient of variation, and intermittency

Spare parts	Mean sales (units)	CV	Intermittency
Head bolt	6.0	1.3	7
Carpet clip	13.3	1.4	6
Belt	1.2	0.8	4
Vial	18.4	0.7	3
(PE) Pollen filter	145.8	0.2	0
(PE) Air filter	389.5	0.1	0
Air bag	593.8	1.1	0
Rear right retainer	6.4	0.5	0
Cleaning pen	8.3	0.7	0

Source: Own elaboration based on the company's database (Company under study, 2017).

Table 4. Performance of the moving average method implemented by the company

MSE	MAD	Ts	MSEn	MADn	sMAPE	NOSp	PIS_sob	PIS_sub
443,244	532	0	443,533	538	53%	52%	1,134	-5,481

Source: Own elaboration based on the company's database (Company under study, 2017).

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The forecasts used for the MAD imply a cost of $\$264,358$ out of an average total monthly sale of $\$421,978$, which indicates that the cost of imprecise forecasts represents 63% of the total monthly average sale.

Proposed Method

In this section, the incorporation of various forecasts into each SKU is studied. These were selected to represent each of the clusters comprising a total of $2,808$ spare parts. In this manner, the forecast is obtained for each item along with its respective parameters, which will facilitate the reduction of the MAD to a greater extent.

This exercise comprises an optimization process for each spare part, wherein the function to be minimized is the MAD, the variables are the parameters using which each model is constructed, and the constraints act on these same coefficients. The optimization program to be used is the Excel Solver tool with the evolutionary algorithm.

The methods proposed for each spare part are listed in Table 5, where it can be observed that it is only necessary to use two types of forecasting methods: the *SHW* and *RG* methods.

In this way, $coeff\#1$, $...coeff\#3$ represents the values of the different parameters with which each model is constructed. In particular, $coeff\#4$ is the seasonality parameter of the *SHW* method.

It is possible to emphasize that for each one of the spare parts that present intermittence, the RG or SHW method has been assigned over the traditional methods that deal with items with intermittent demands, such as the CR, *SBA*, and Teunter methods.

Table 6 shows the performance of the methods selected in the proposal according to the various indicators. Thus, with a cost associated with the MAD of $\$163,531$, while the mean square error is $134,929u^2$, the mean absolute error is 308 units, while the mean percentage symmetric error is 41%. A NOSp value of 49% is observed, which practically indicates that the number of times demand is overestimated. When the number of times demand is underestimated by forecasts, it is implied that there is no bias in the application of the forecasts. In addition, the amount of time for which the spare parts remain in overstock, which is measured fictitiously using the PIS_{sob} indicator, shows that over the plan-

Table 5. Methods assigned to each spare part under study along with their respective coefficients

Spare part	Method	Coeff #1	Coeff #2	Coeff #3	Coeff #4
(PE) Pollen filter	RG	5.0	1.0		
(PE) Air filter	RG	6.0	6.0		
Air bag	SHW	0.7	0.2	0.6	2
Vial	SHW	0.0	0.3	1.0	2
Carpet clip	RG	4.0	1.0		
Rear right retainer	SHW	0.0	0.3	0.0	3
Cleaning pen	RG	6.0	3.0		
Belt	SHW	0.0	0.0	0.7	2
Head bolt	RG	6.0	5.0		

Source: Own elaboration based on the company's database (Company under study, 2017).

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Table 6. Performance of the proposed method according to the various indicators studied

MAD_cost	MSE	MAD	Ts	MSEn	MADn	sMAPE	Nosp	PIS_sob	Pis_sub
$ 163,531	134,929	308	6	135,106	315	41%	49%	354	-1,049

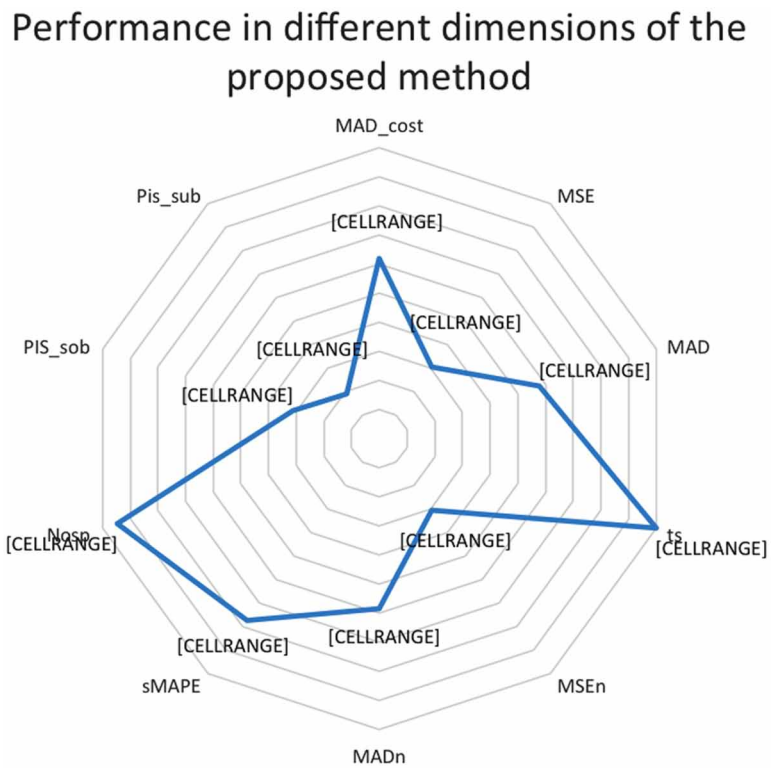
Source: Own elaboration based on the company's database (Company under study, 2017).

ning horizon there are $354\left[units\ /\ period\right]$, while the number of periods in which each part was out of stock is $1,049\left[units\ /\ period\right]$. Finally, it is important to note that the number of points outside the control limits increased by six points, and thus, this indicator must be taken into consideration in the final analysis.

On implementing this mix of forecasts, a notable improvement can be observed in each of the indicators with the exception of Ts, which represents the number of times the forecasts have escaped the limits of control.

The dimension in which the greatest improvement was observed is the PIS_{sub} indicator, which shows that the quantity of spare parts that would remain out of stock throughout the 12 months is reduced by 81% with respect to the method used by the company. Meanwhile, the MSE, PIS_{sob}., and MSE show improvements of close to 70%. The MAD as well as its modified value (MAD_n) show an improve-

Figure 2. Comparison of the proposed method with the moving averages method



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ment of almost 42%. Another relevant indicator is the $sMAPE$, which shows an improvement of 23% with respect to the value obtained using the moving averages method. Finally, with respect to the cost associated with the value of MAD, an improvement of 38% is observed with respect to the baseline.

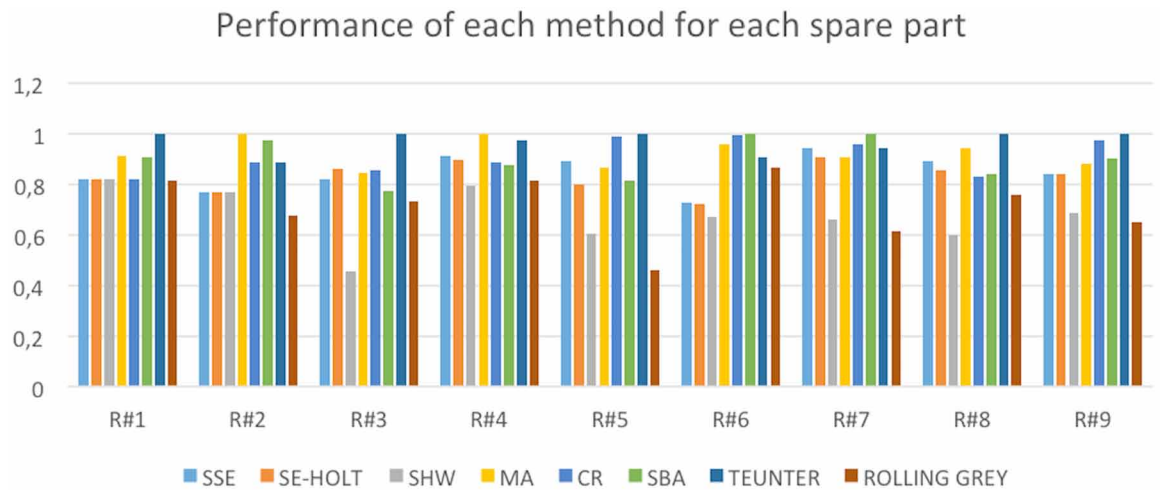
Despite the general improvement obtained in the performance of the forecasts on implementing the new prediction models, a worsening was noted in the tracking signal. It was observed that the points that escape the control limits increased. This represents 5.55% of the total points predicted, and this problem was only observed in the case of three of the nine spare parts studied.

Finally, Figure 3 shows the performance of each forecast according to the MAD for each of the forecasts. For each spare part, the value of the MAD is subject to and normalized according to the maximum MAD. value found for each part. Thus, it is observed that the SHW and RG methods generally have the best performance when measured according to the MAD, and there are notable differences from the other methods of prognosis.

DISCUSSION AND CONCLUSION

In this study, it was revealed that the moving averages method does not provide the best performance in terms of any of the measurements used as indicators. In contrast, the SHW and RG methods were found to reduce the MAD to a greater extent—reducing the total MAD. by 42%—while reducing the magnitudes of the other performance indicators. The PIS_{sub} method experienced the greatest reduction and improved by 81%. with respect to the value obtained on applying the moving averages method, which shows that the total amount of time that each spare part would remain out of stock decreases drastically. Decreases were also observed in the MSE, MSE_n, and PIS_{sob} indicator which were reduced by approximately 70%. Another relevant indicator is the $sMAPE$, which shows that the average percentage

Figure 3. Obtained for each optimized forecast method for each of the spare parts under study (standard values)



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symmetrical error is 41%, which reflects an improvement of 23%, and the costs associated with variability—which is measured as the cost of the replacement by the MAD obtained from it—was reduced by 38%. Finally, it was found that the value of NOS_p was 49.2%, which indicates that the demand is practically underestimated in the same time that it is overestimated, which suggests an impartial behavior of the forecasts. The only disadvantage encountered in implementing these new forecasts was the number of points that escaped the tracking signal; six points escaped the control limits, which represents $5.5\ .\ \%$ of the total predicted points, as compared to no point that escaped in the base situation. It is to be expected that as the forecasts become highly accurate, the values of the tracking signal could increase and escape the limits of control (Trigg D., 1964).

Some reflections on the possible improvements that can be made to this study are presented below.

The possibility of incorporating a longer time series could be evaluated ch that more elaborate forecasting methods such as the ARIMA method, for which it is generally suggested to work with samples greater than 50 observations. On the other hand, the ADIDA method, by agglomerating the demand of a certain number of months, would imply working with time series smaller than the 6 observations, which is not believed to be beneficial.

In addition, it could be beneficial to vary the objective function for the development of methods and the determination of their coefficients. In this study, the MAD was established as a target, and the performance of the forecasts could be studied as they are determined under other circumstances such as minimizing the MSE, the number of points that escape the control limits, or the PIS.

Finally, it is important to bear in mind that this research was performed on the basis of only nine spare parts, which is an unrealistic consideration owing to the large number of items currently marketed (Méndez Giraldo & López Santana, 2014). Therefore, identifying the best individual forecasting methods becomes impractical, and it is necessary to define general forecasting methods for each cluster. Thus, an extension of this research may involve determining methods of forecasting for general application to clusters. While the definition of clusters is also a complex task because a number of characteristics are to be evaluated, the number of groups and their cutting limits must be defined.

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Chapter 14
Decision Making for Energy Management in Smart Grid

Vira Shendryk
Sumy State University, Ukraine

Olha Boiko
Sumy State University, Ukraine

Yuliia Parfenenko
Sumy State University, Ukraine

Sergii Shendryk
Sumy State University, Ukraine

Sergii Tymchuk
Kharkiv Petro Vasylenko National Technical University of Agriculture, Ukraine

ABSTRACT

The chapter discusses the problem of energy management in Smart MicroGrid. The strategies of Smart MicroGrid energy management and objectives of Smart MicroGrid operation have been analyzed. The chapter emphasizes the potential of information technologies implementation to achieve energy management goals and provide a description of energy management information system which is used for MicroGrid planning and operation. The information flows which are used for making decision on Smart MicroGrid energy management have been analyzed.

INTRODUCTION

Nowadays there is a trend of Industry 4.0 concept's implementation in manufacturing and production. It involves the usage of intelligent technologies to increase the degree of automation and digitization of these processes. Industry 4.0 solutions are intended to improve operations efficiency, productivity, product quality, inventory management, asset utilization and environmental sustainability.

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In the Industry 4.0 development, energy management and energy efficiency overall have taken center stage. The rising of energy costs and strict environmental regulations cause the growing need for increased efficiency in the use of resources and make energy-efficient solutions essential. So, the significance of technology-driven innovations intended to energy saving such as Smart Grid is growing.

Smart Grid is not just a compilation of smart meters or other electric devices. It is rather a series of technologies that allow government and companies to integrate, interface with and intelligently control all these innovations. As the technology evolves, the Smart Grid will allow a two way flow of electricity and information that is capable of monitoring everything from power plants to customer preferences and individual equipment.

Smart Grid is intended to provide real-time data about near instantaneous balance of energy supply and demand. Managing the data used to operate and maintain the Smart Grid system requires data analysis and decision making support tools to achieve the reliability of the energy network by easing peak demands and improving energy efficiency.

One of the ways to increase the energy efficiency of Smart Grid implementation is its integration with renewable energy sources (RES). The planning and operation of renewable energy based Smart Grid requires development energy management tools which are information systems for decision support of planning the optimal structure of renewable energy system and analysis energy production and consumers' energy demand.

The Chapter will cover the wide range of the investigation of the state of the subject field "Decision making for energy management in Smart Grid". It will focus on determination the relevance of renewable energy based Smart Grid implementation. It will explore existing approaches to energy management of Smart Grid and analyze information flows in Smart Grid. The IT solutions for making decision support on Smart Grid planning and operation will be presented.

The chapter is organized as follows. In background section the current state of Industry 4.0 concept implementation for energy management is given. The overview of Smart Grid as a part of Industry 4.0, the analysis of energy management strategies of renewable energy based Smart Grid, the identification the uncertainty and risks in decision-making at management of information flows in the Smart Grid, the description of existing methods and intelligent solutions which can be applied in the Decision Support System for planning and operation of Smart Grid are presented in next sections.

BACKGROUND

Over the last years technical, economic and market transformation of the electric power sector connected with development concept of renewable energy Smart Grid have accelerated around the world. It is caused by growing energy demand in developing and emerging economies and trends in energy saving. Many countries have begun to respond to the challenge of power grid change. Consequently, new markets for both centralized and distributed renewable energy are emerging in all regions. Usage of renewable energy sources aims to meet a higher share of energy demand and provide reducing pollution and fuel poverty. According to Renewables Global Status Reports of REN21, renewable energy has growing in capacity and production for last several years. The estimated renewable energy share of global electricity production for recent fifteen years year is shown in fig.1 (Energy Efficiency Market Reports, 2002-2017).

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Renewable energies, such as wind and solar energy, have technical properties that make them better than more traditional forms of power generation (Renewable Energy and Electricity, 2017). First, their maximum output fluctuates according to the real-time availability of wind and sunlight and such fluctuations can be predicted in advance. Second, they are modular and can be deployed in different types of grid. Third, wind and sunlight are available almost everywhere, so do not requires transportation to place of energy generation.

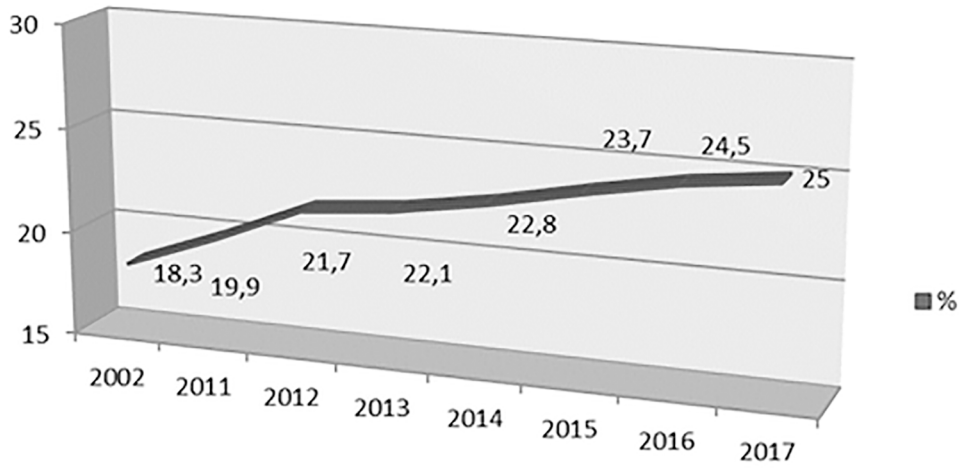
The world is getting more connected and the needs of customers are becoming more demanding and dynamic. Today energy producing needs to design and produce more innovative and energy-efficient approaches to stay competitive.

The successful development of energy grid based renewable energies has stimulated new requirements to the energy supply and its distribution. It requires Smart Grid implementation, as well as recognizing and managing them in an integrated fashion. Thus, Smart Grid should be gradually evolving towards global energy interconnection in a new generation of the fourth industrial revolution called Industry 4.0.

Industry 4.0 is an emerging trend in manufacturing, which integrates cyber and physical systems for smart design and manufacturing – has the potential to transform the way that energy grid will be designed, operated and managed in the future. One of the key characteristics of Industry 4.0 is the digitization of manufacturing processes. This transformation can offer opportunities for energy saving – for example, through the optimization or replacement of specific technologies, the application of new software tools that also offer energy optimization functionality.

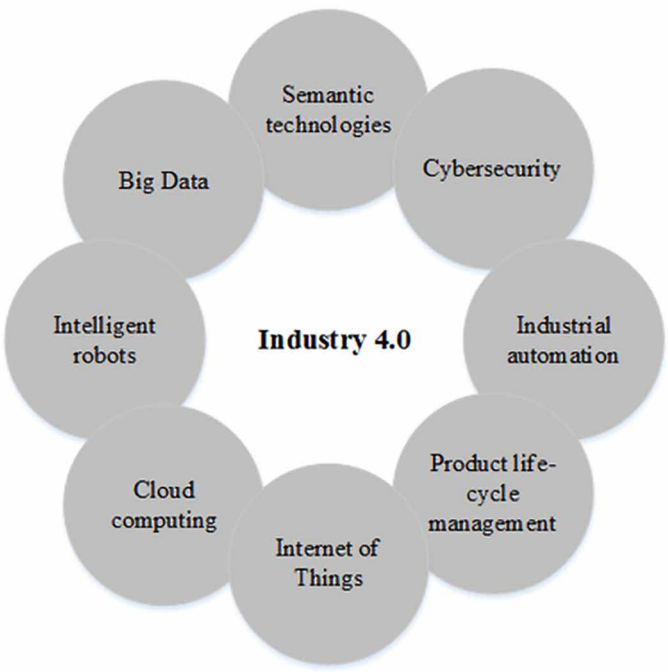
The term Industry 4.0 often referred to as the fourth industrial revolution, it aims to merge the real and virtual space through cyber-physical systems to achieve maximum autonomy and efficiency. Industry 4.0 allows a paradigm shift from "centralised" to "decentralised" production, a reversal of the logic of production process thus far. There are many studies that describe the basic components and enabling technologies of Industry 4: (Kagermann, Helbig, Hellinger, & Wahlster, 2013), (Mario, Tobias, & Boris, 2015), (Posada et al., 2015), (International Electrotechnical Commission, 2015), (Rojko, 2017), (Vaidya, Ambad & Bhosle, 2018). Based on it we distinguish Industry 4 as a collaborative network that combines eight key parts, namely cybersecurity, intelligent robots, industrial automation, IoT, cloud computing, product life-cycle management, semantic technology and big data analytics (Figure 2).

Figure 1. Estimated renewable energy share of global electricity production, in 2002-2017



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Figure 2. Building blocks of industry 4.0



One of the key characteristics of Industry 4.0 is the digitization of manufacturing processes. It can increase the profit in the industrial manufacturing. Also this transformation aims to use energy resources more efficiently. It can offer opportunities for energy saving – for example, through the optimization or replacement of specific technologies, the application of new software tools that also offer energy optimization functionality.

Figure 2 shows a relation between SF and customers in Industry 4.0. The Smart Factories provide the customers with smart products and services, which are connected via IoT technology. Then, the smart factories will collect and analyze data coming from the smart products and applications. This analysis helps the factories to define customers' behaviors and needs, and as a result to provide them with new and more sustainable products and services. One of the most promising part of Smart Industry in recent years is Smart Grid development. Energy sector tends to extreme development through world energy crisis.

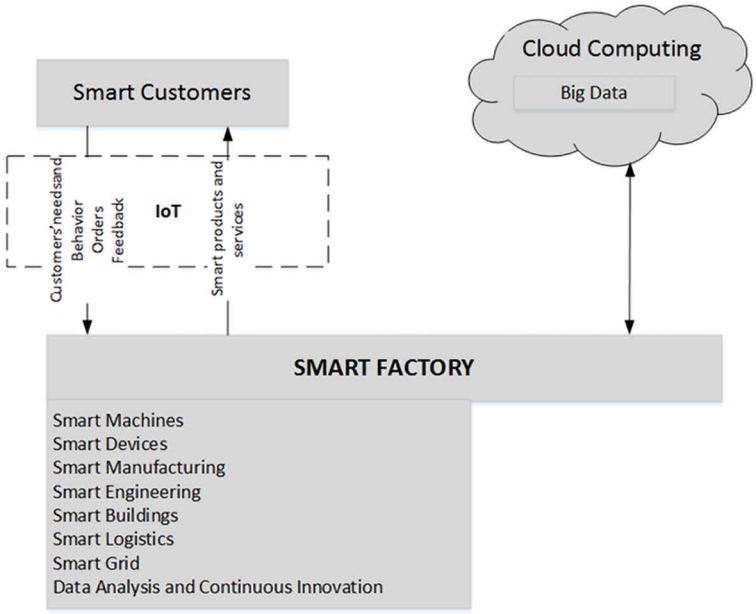
According to The German Federal Ministry of Education and Research (German Federal Ministry of Education and Research, 2018), the key part of Industry 4.0 where Industry 4.0 is needed to be implemented is the Smart Factory (Figure 3). The focus is on the ability of the systems to perceive information, to derive findings from it and to change their behavior accordingly, and to store knowledge gained from experience. To do it in Smart Factories (SFs) are used key technologies are listed above. Intelligent production systems and processes as well as suitable engineering methods and tools will be a key factor to successfully implement distributed and interconnected production facilities in future Smart Factories.

Smart Factory can realize flexible manufacturing through integration communication process, computing process, and control process to meet the industrial demands (Chen et al., 2018).

In Smart Factory energy infrastructure is implemented as Smart Grid. It is one of the most effective ways of providing the energy-saving technologies through the Industry 4.0 concept.

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Figure 3. The interaction between smart factories and customers in industry 4.0



SMART GRID AS A PART OF INDUSTRY 4.0: OVERVIEW AND INFORMATION SUPPORT

Smart Grid implementation in the frame of Industry 4.0 concept aims to bring expenses reduction with energy saving, as in cases where there are large intervals between productions.

The key features of Smart Grid are:

- Digitization of the energy sector.
- Using renewable energy sources.
- Hard coal, Oil, Nuclear phase-out.
- Use new transmission and distribution grids.
- Use Storage Banks.
- Unbundling, trading, many new players, new products, etc.
- Vastly increasing collection and flow of data.

There is no one common definition of Smart Grid. According to (Smart Grids Strategic Deployment Document, 2018) Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies. IEEE defines the Smart Grid as the concept of a fully integrated, self-regulating and self-healing power grid, which has a network topology and includes all sources of generation, transmission and distribution networks and all types of electricity consumers, managed unified network of information and control devices and systems in real-time (Hoang, 2018).

According to (Roncero, 2008) the key features of Smart Grid may be distinguished: self-healing, incorporates and empower the user, tolerates security attack, offers power quality enhancement, accom-

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modates various generation sources, fully supports energy market, optimizes asset utilization and reduces the expenses for system operations and maintenance.

Smart Grid in Smart Factories can be divided into parts, named MicroGrid (MG). Thus, Smart Factories will get information that is more specific from small neighborhoods to satisfy their needs.

Thus, the key idea of a Smart MicroGrid is integrating and coordinating operations of all grid consumers, they can be large power plants or small production units. This is caused by introducing the big part of interconnections in the power grid and more intelligence for automatic decision with measurements from the power grid. Consumers and active households can make decisions based on the actual electricity price. The main benefits of smart MGs can be broken into three parts (Enerbäck, & Nalin Nilsson, 2013):

- Lower environmental impacts.
- Higher reliability. It will be able to automatically respond and prevent faults in the grid (Moslehi, & Kumar, 2010).
- Lower operational cost or economy. End consumers will have the opportunity to coordinate the peak consumption and sell RES produced electricity.

Firstly, it is needed to define the architecture of Smart MicroGrid. Such grid is a small grid which is operated as the part of a large power grid or independently, and can manages their own energy conversion, storage and recycling. The Smart MicroGrid consists of smaller power sources, which typically generate from 1kW to 1MW and they are located near to the consumers to provide the electrical energy. The typically MG includes distributed energy resource (DER) units with both distributed generation (DG) and distributed storage (DS) units and the different types of the end consumers of electricity (Menniti, Pinnarelli, & Sorrentino, 2009). The DER is the source of electric power that is not directly connected to a bulk power transmission system (The Institute of Electrical and Electronics Engineers, Inc., 2011).

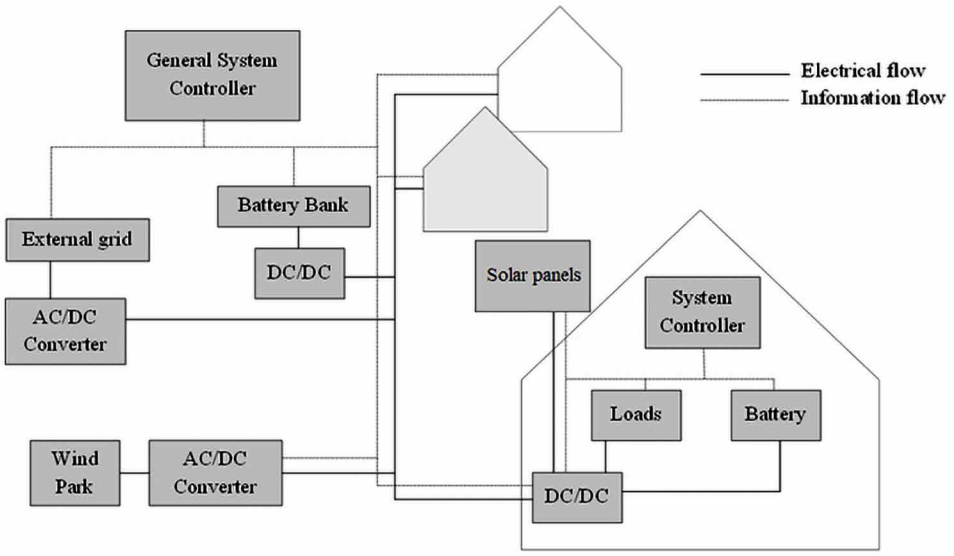
According to IEEE Guide (The Institute of Electrical and Electronics Engineers, Inc., 2011) there are next domains of Smart MicroGrid architecture: Bulk generation, Transmission, Distribution, Customer, Control and Operations, Market and Service Providers domains. The each of these domains plays a role in the operation of the electrical power systems and consists of different entities, which are connected by special interfaces.

Let's consider the typical small distributed power system, consisting of an array of buildings are equipped with photovoltaic panels, joint wind turbines and energy storage bank, and also there is a connection with an external power grid. The System Controller makes decisions using this information to be sure in not violated of internal grid conditions and using the micro generation units in an effective way. A schematic idea of the interactions in Smart MG is presented in Figure 4 (Shulyma, Shendryk, Baranova, & Marchenko, 2014). On this schema use next reductions: AC – alternating current; DC – direct current.

As it is clearly illustrated on the Figure 4, there are two flows in Smart MicroGrid: electrical and information; the last is directly linked with controllers. According to main idea about system stable reliability, firstly, it's important to build adequate distribution between sources based on electrical flow. It is necessary to plan in detail the structure of the future grid. Information flow support is provided by the management of a power system using Smart Grid technologies. In Smart Grid from point of view of Industry 4.0 it is necessary to control both information and electrical flows. And here important to notice that control of information flow helps to control electrical flow. To control them it is necessary to use different energy management strategies.

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Figure 4. A schematic idea of smart microgrid



RENEWABLE ENERGY BASED SMART GRID: GENERAL CONCEPT AND ENERGY MANAGEMENT STRATEGIES

Continuous growth of the share of renewables in centralized and decentralized grids requires an effective approach to grid management making full use of smart grid technologies. Smart Grids play a significant role in the transition to a sustainable energy future with renewable energy in several ways (Smart Grids and Renewables: A Guide for Effective Deployment, 2013):

- Providing smooth integration of high shares of variable renewables.
- Supporting the decentralized energy production.
- Creating new business models through enhanced information flows, consumer engagement and improved system control.
- Providing flexibility on the demand side.

Smart Grid technologies in combination with renewable energy sources upon conditions of appropriate supporting policies and regulations are essential to transform the electricity system and create the grid infrastructure to support a sustainable energy development. Smart Grids can facilitate the integration of different renewable energy providing grid planning and operations with high reliability.

Application of Smart Grid technologies aims to overcome regulatory, economic, stakeholder and technical barriers and challenges associated with power generation from renewable energies.

Regulatory barriers relate to poor or insufficient policy and legislation. Smart MicrogGrid implementation requires clearly defined regulatory instruments to select zones for it installation, clear regulatory instruments associated with RES integration into main power system, regulatory instruments for planning electricity transmission generated by Smart MicrogGrid. Countries have formulated numerous policies,

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directives and standards to Support Renewable Energies and MicroGrid development and overcome regulatory barriers following the particularities of their national energy policies (Ali et al., 2017).

Economic barriers are connected with effectively managing the cost of renewable energies integration into power grid and ensuring appropriate incentives to attract appropriate investments (Colas, Lu, Lazarov, François, Kanchev, 2012).

Stakeholder barriers are caused by trouble gaining the trust of local consumers to actually implement the Smart MicroGrid in their area due to the complexity of the microgrid concept and difficulty understanding of ecological and financial benefits (Soshinskaya, Crijns-Grausa, Guerrero, Vasquez, 2014). Moreover, these benefits possible only with proper comprehensive MicroGrid planning and managing of MicroGrid operation. Therefore energy management actions should be implemented on each stage of Smart MicroGrid development and application.

Technical challenges can be identified as necessity to realize tools for managing variability of energy demand during the continuous balancing of the power system in conditions of uncertainty, and balancing supply and demand during insufficient or excessive generation in surplus situations.

Smart Grid solutions emerging to address the technical challenges of renewable energy integration listed above include (Camacho, Samad, Garcia-Sanz, Hiskens, 2011):

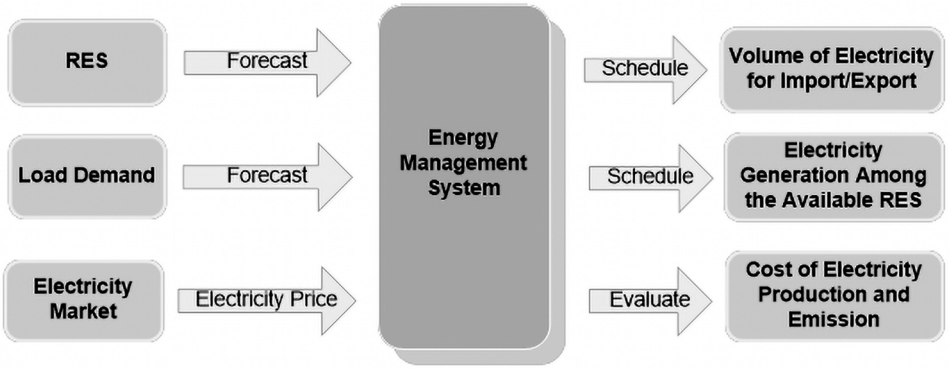
- Tools of demand forecasting – can allow system operators to better predict customers energy demand and manage renewable energy variability and uncertainty.
- Tools of dynamic line rating identification – can allow grid operators to receive real-time information about transmission line capacity and as a result extract more value from existing lines, reducing the need for costly grid upgrades.
- Smart meters – can help to monitor excess renewable energy generation, reducing the need for renewable energy distribution.
- Smart inverters and other advanced power controls – can reduce the need for significant grid transmission and distribution upgrades, thus reducing costs on renewable energies projects.
- Grid-scale storage – can help to reduce the need for additional transmission capacity.
- Behind-the-meter storage -can help absorb excess power generation, reducing the need for distribution upgrades.
- Energy management system (EMS) - provide real-time, high-resolution visibility and control of power grid.

These tools, technologies and applications are broadly used in Smart MicrogGrid to ensure its stable, reliable, and efficient operation. Consider more detail the MicroGrid EMS which analyzes information flow to control electrical flow in order to balancing and optimizing the electricity flow in real time depending of electricity demand. Implementation of Smart MicrogGrid EMS is compulsory required to achieve all goals of using RES in power generation. The overview of energy management system for Smart MicroGrid is shown in Figure 5.

Generally, the input data for EMS of Smart MicroGrid are the forecast values of load demand, the needs in renewable energy resources for certain period in future and the market price for electricity. The main functions of such system are to manage the power and the energy between sources and loads into the Smart MicrogGrid to make a schedule of energy generation and to evaluate the cost of energy production and emission. Long-term energy management of Smart MicroGrid includes the management of energy sources dependency of the prime source, environmental impacts and cost of generation, the

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Figure 5. The overview of energy management system for smart microgrid



management of controllable loads, the provision of an appropriate level of power reserve capacity according to the electricity market and the load. Short-term energy management of Smart MicroGrid is applied for power balancing and includes the voltage regulation and the real time power dispatching among renewable energy sources (Advanced Architectures and Control Concepts for More Microgrids, 2009).

Approach of Smart MicroGrid energy management differs from energy management of traditional power systems that addressed to manage uncertainty of load demand by controlling supply. The main task of Smart MicrogGrid energy management is to achieve energy balance by implementation direct and indirect mechanisms to control demand response and load. However, uncertainty on the supply side in such system must also be managed (Camacho, Samad, Garcia-Sanz, Hiskens, 2011).

The energy management technique for Smart MicrogGrid, which should be provided on the demand side, is called demand-side management. It is designed to modify the consumer's level of energy usage in order to benefit the overall grid operation, by avoiding the formation of high peak loads. Demand-side management aims to ensure demand balance in real-time. Also it ensures the development the distributed grid of power generation and can improve system reliability and reduce capital costs associated with electricity transmission (Reddy, Kumar, Mallick, Sharon, Lokeswaran, 2014), (Energy Efficiency Program Impact Evaluation Guide, 2012), (Palensky, Dietrich, 2011).

Energy management strategies for Smart MicrogGrid operation can be classified into two broad categories: the rule-based and the optimization-based strategies. The basic methods which may be applied under these strategies are given in Table 1.

The rule-based energy management strategies can cope with the various operating modes of Smart MicrogGrid. The rule-based strategies are developed using engineering experience and analysis the efficiency charts of MicroGrid operations and its components functioning. It is relied on the following main principles (Kanwar, Hidalgo Rodriguez, Appen, Braun, 2015):

- Renewable energy sources are primarily used to supply the loads.
- Load is supplied with priority order: at first – from renewable energy sources, at second – from battery energy storages, at third – from public distribution grid.
- Battery energy storage only discharged when the renewable energy sources and grid are not sufficient to produce electricity.
- Battery energy storages are charged during off-peak hours from the first available energy source.

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Table 1. Smart microgrid energy management strategies

Energy Management Strategy	Type	Applied Methods
rule-based	fuzzy	• predictive • adaptive • conventional
	deterministic	• state machine • power follower • thermostat control
optimization-based	global optimization	• linear programming • dynamic programming • genetic algorithms • metaheuristic algorithms
	real-time optimization	• robust control • model predictive • decoupling control

- Storages are used in priority order according to their operating costs (cheapest one first.
- Electricity is only sold to the distribution grid in case of excess renewable energy production and charged storages.

The optimization-based strategies of Smart MicrogGrid energy management can be provided under several objectives such as economic, technical, environmental and combined objectives. These objectives differ from each other by objective function of optimization the MicroGrid operation and constraints which are given in Table 2 (Fuhs, 2009).

Comparison of application the rule-based and operation-based strategies for Smart MicroGrid operation which is presented in (Kanwar, Hidalgo Rodriguez, Appen, Braun, 2015) has shown that the difference can be noticed during off-peak price periods. While the rule-based strategy leads to storage charging at the beginning of off-peak period, the optimization-based strategy delays the charging to avoid unnecessary self-discharge losses. As a result, the energy management using rule-based strategy may cause additional load peaks due to storage charging. To solve this problem the model of predictive control in the frame of operation-based strategy can be applied.

Table 2. The objectives of smart microgrid operation

Objective	Objective Function	Constraints
economic	to minimise total costs regardless of network impact/ performance	• distributed generation physical limits • energy balance
technical	to minimise power losses, voltage variation, and device loading	• grid voltage and loading • distributed generation physical limits • energy balance
environmental	to minimize emissions (do not exceed determined emission quota)	• distributed generation physical limits • energy balance
combined	multi-objective function of optimal distributed generation taking into account all economic, technical, and environmental factors	• grid voltage and loading • distributed generation physical limits • energy balance

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Energy management techniques should be implemented via application advanced information and communications technologies to achieve energy management objectives in the stages of Smart MicroGrid planning and operation.

IT-BASED SOLUTIONS AND APPROACHES FOR PROVIDING ENVIRONMENTALLY SUSTAINABLE ENERGY NETWORKS

Information technologies (IT) plays a vital role in achievement the sustainable development goals, one of them is to ensure access to affordable, reliable, sustainable and modern energy. The rapid development of IT-based services and systems offer the possibility for deep transformation of the energy sector. IT contribute to energy saving and increasing efficiency through smart appliances in infrastructure and manufacturing. Energy management information systems enable to change energy-use behavior and reduce consumption by scheduling loads based on supply.

The key potential impacts of IT in the energy sector are listed below (Sustainable Development Goal for Energy and Information and Communications Technologies, 2015):

- Automation of energy network operation.
- Ability of real-time gathering data of energy indicators for further analysis to assess progress and identify improvement needs.
- Development of energy demand analysis and forecasting techniques.
- Providing a communications network to increase electricity supply quality and system resiliency.
- Providing approaches to metering, advanced demand and supply management.
- Increasing flexibility of existing electric grids with improved management of power flows.
- Enhancing control of distributed generation systems based on renewable energy sources.
- Providing approaches to identify and manage energy efficiency efforts.
- Raising consumer awareness of energy efficiency and sustainable energy consumption.
- Enhancing decision-making processes for energy infrastructure development.

The main common possible information systems directed to achieve the capabilities of the energy system based on the concept of Smart Grid are: distributed monitoring and control system (DMCS), energy management information system (EMIS), home energy management system (HEMS).

The DMCS system as a rule achieves real-time monitoring of MicroGrid operation, has report functions, can alarm when parameters are beyond the limits and controls each distributed generation unit of MicroGrid supporting the required energy supply mode.

The DMCS system provides control functions are listed as the follows (Wang et al., 2015):

- Host storage integrated control and battery management system control - control battery stacks and support voltages.
- Running and load control - can control the installed equipment except batteries.
- Distributed generation control - includes start, stop, control and operation mode switching.
- System control - control the overall operation of the system and display operating states of each device.

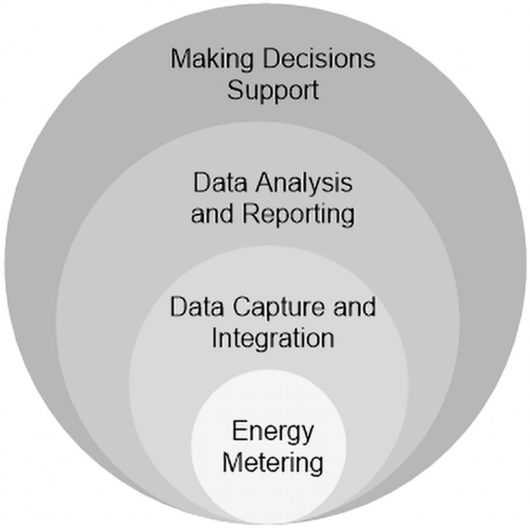
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Monitoring and control hardware and software are integrated in MicroGrid system. The DMCS system manages it to reach stable MicroGrid operation. The control of MicroGrid operations may be centralized and decentralized. The supervisory control and data acquisition (SCADA) system as one type of middleware used in intelligent monitoring platforms is used for centralized control of MicroGrid. It provides control over a Smart MicroGrid that contains inverters, batteries, generators such as solar panels, wind turbines with power meters (Li, Jiang, Wang, Dong, 2017). The processed data are stored in database tables and can be displayed in the web pages. Multi-agent systems (MAS) can be applied for decentrilized or distributive control of MicroGrid. An agent-based approach to MicroGrid control is capable of achieving multiple user-defined objectives in real-time. It is aimed to optimize the power demand towards additional constraints such as emissions concerns, fuel availability and cost, weather conditions, the spot-market price of electricity (Colson, Nehrir, Gunderson, 2018). Energy Management Information System (EMIS) is a performance management system that provides relevant information that makes energy performance visible to different levels of an organization, enabling to plan, make decisions and take effective action to manage energy. The various business processes that can be support by EMIS are shown in Figure 6 (Energy Management Information Systems, 2010).

An effective EMIS should the continuously provide these operations in order to result in optimized MicroGrid performance. EMIS generally includes the following key components: technical components such as meters and sensors, hardware, network equipment, communication channels, software components for information flows processing, which may contain subsystems for data monitoring, storage, visualization, analysis and decision support. Analysis must include implementation of forecasting methods and optimization techniques and prepare data for making decisions on MicroGrid planning and operation.

Home energy management system (HEMS) is intended to control energy consumption on the demand side. HEMS can provide consumers with information about how they use energy in the home, remotely via a smartphone or web service and/or offer prompts to modify consumption (Lamoureux and Reeves, 2016).

Figure 6. EMIS operations



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When implementation EMIS and HEMS systems for decision making support in Smart MicroGrid it is necessary to adhere to ethical values such as privacy and autonomy affect the acceptance of the system by end users. Personally identifiable information, monitoring data of energy usage must be protected and applied only in the interests of service users. The actions of Smart Microgrid operation are automated and human autonomy is removed, as well as the goal for decision-making may satisfy an entire network rather than a certain consumer in the system. In such systems autonomous decision-making should guarantee individual benefit for end user.

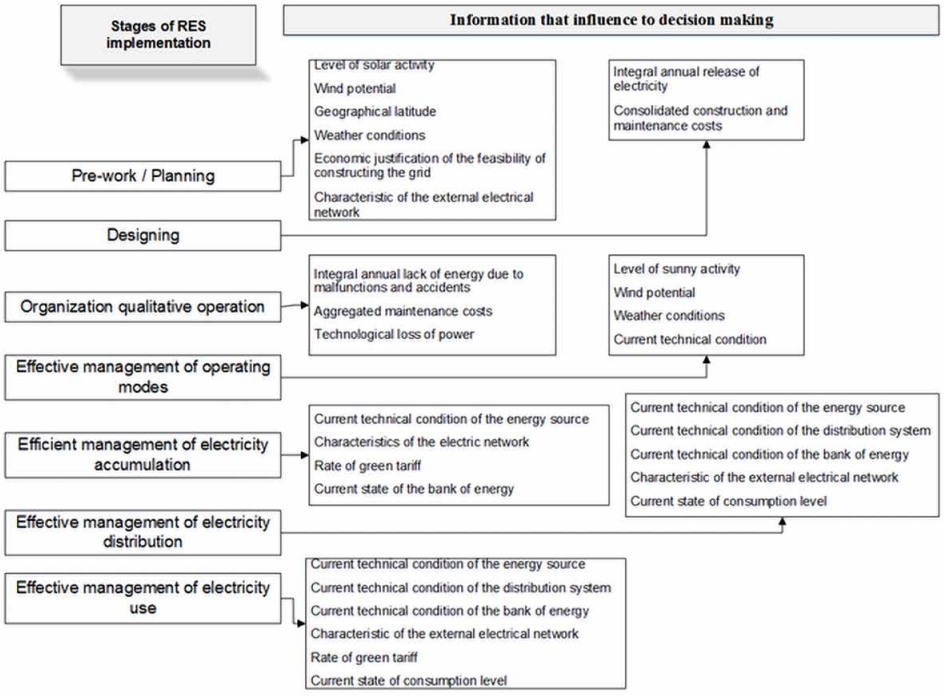
The example of HEMS system provides privacy and security is SEMIAH system (Gjosaeter, Ulltveit-Moe, Kolhe, Jacobsen & Ebeid, 2014). In this system the data storage is organized using cloud-based services where leakages of sensitive information are controlled thus ensuring privacy policies. In decentralized MicroGrids the solution to ensure privacy, grid safety and security is Privacy-preserving Energy Transactions (PETra) builds on distributed ledgers. It is based on such techniques for anonymity as mixing services and onion routing (Laszka, Dubey, Walker & Schmidt, 2017).

To solve decision making support tasks for MicroGrid energy management it is necessary to analyse information flows are discussed below.

ANALYSIS OF INFORMATION FLOWS FOR MAKING DECISION ON ENERGY MANAGEMENT IN SMART RENEWABLE ENERGY GRID

In general, the information that influence to decision making in dependence of stages of RES implementation into the grid, is presented in Figure 7.

Figure 7. Information that influences decision-making on energy planning and management



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Let's consider in detail the process of planning the structure of the MG and manage its operation. These processes require the collection of relevant data, presenting them in a form suitable for decision-making, development of appropriate planning models structure the grid and control the use of which can increase the efficiency of decision-making at the planning stage and ensure the efficiency of the grid. When planning the structure of the MG it is necessary to solve several tasks connected with selection of the MG alternative structures and their evaluation (Shendryk, Shulyma, Parfenenko & Shendryk, 2017).

Support for decision making on the selection of components of the grid in the general case contains five interrelated steps (Figure 8).

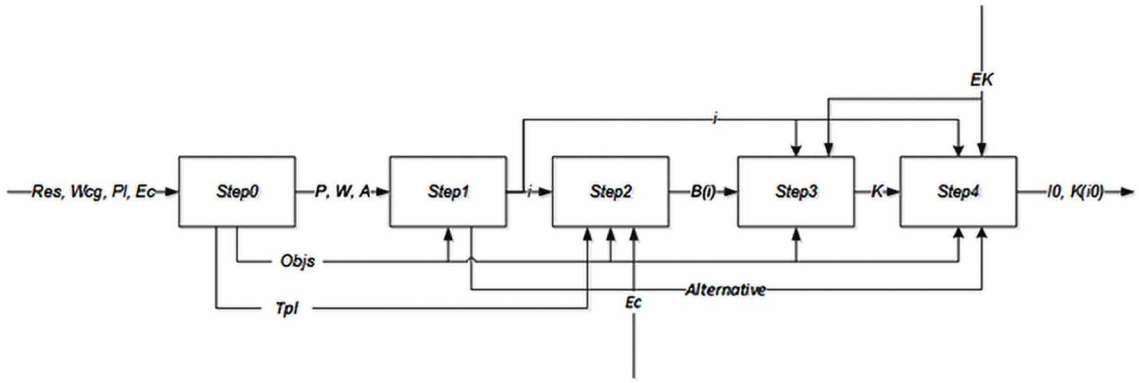
There is a plurality of data on available installation RES on the market (*Res*), weather conditions (W_{cg}), power consumption (E_c), available distribution networks (*Pl*), to which is planned to connect the grid. As a result, in the first stage the data sets about solar panels (P), wind turbines (W), storage batteries (A), which is available on a market and the throughput capacity of the external network (Tpl) and weather conditions (Objs) are formed. Based this data the decision on planning the grid's structure will make.

At the second stage, a set of alternatives of the grid is formed, which can be implemented based on the collected data (Alternative). For each alternative structure technical and economic indexes (*B (i)*) for forming the estimating criteria for an alternative solution are defined. The final stage is the evaluation of alternative structures by the set of criteria and the choice of the optimal structure of ($K(i_0)$). Also to the decision-making process when forming a set of criteria and evaluating alternatives can influence the knowledge of experts (*EK*).

One of the components of the decision support process during grid structure planning is the process of collecting and pre-processing information. At the stage of planning the structure of the grid, it is necessary to ensure the collection of data on the type and characteristics of its constituent parts (solar panels, wind turbines, rechargeable batteries). Also it is needed to collect data on factors are influencing into the generation of electricity (weather, geographical conditions), the needs of the households in electricity, the capacity of the external energy system. The collected data allow us to form a set of possible structures of the grid and to evaluate their efficiency.

During the process of collecting and pre-processing information, it is necessary to consider how exactly the weather data are collecting: hourly, daily, etc. It is also necessary to determine where and how often the data on existing RES installations are collected.

Figure 8. Scheme of the process of choosing the structure of the energy grid with RES



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A review of existing approaches of data collection in energy planning and management systems is presented in Table 3 (Shendryk, Shulyma, & Parfenenko, 2017)

Figure 9 depicts a typical scheme for the process of information collection and processing, which is carried out in solving planning and energy management tasks during energy supply of buildings with RES. Based on data on table 1 this scheme is corresponds to rule-based Energy Management Strategy.

In the planning process, in accordance with the proposed scheme, when data are extracted, they are checked for correctness and get preliminary processing. As a result, the database contains information on the worst weather conditions in the area based on the indexes such as temperature, wind speed, cloudiness and the sunrise day duration. Also, to the database is putted that information about the RES which is necessary for further calculation.

From consumers or sensors is getting information on consumption at the households. Experts provide information on the evaluation of the technical and economic parameters of alternatives. In such way a knowledge base may be formed. Using the knowledge can be used during forming optimal solutions for choosing the structure of the grid.

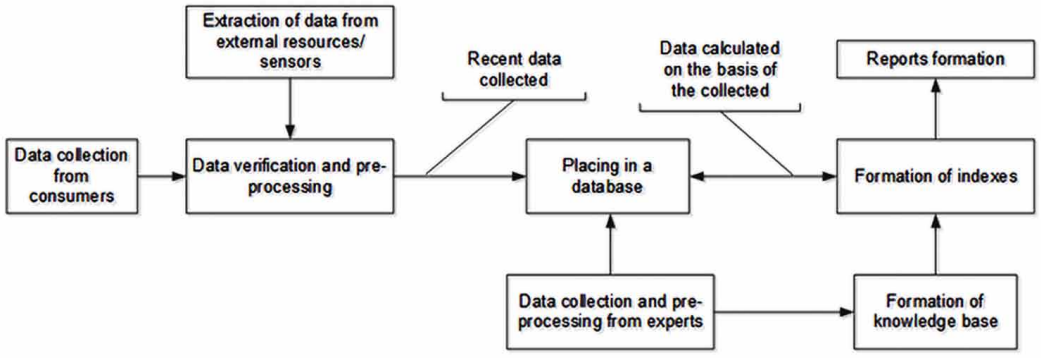
As a result of this approach, the set of alternative structures of the energy grid, as well as their technical and economic parameters, sets of evaluation criteria are formed. In result a multicriteria environment is formed. In environment it is necessary carry out a general assessment of the effectiveness of alternatives and formulate decisions on choosing the optimal one.

During energy management process, according to the proposed scheme, the input contains information on weather conditions, consumption, structure of the power system, and at the output we get information about which mode of operation of the grid to choose in order to maximize the benefits of its work under the influence of external factors.

Table 3. The approaches of getting data

Data on RES equipment	Data on weather conditions	Data on consumption
• Manually • Parser technology	• Parser technology • Weather sensors	• Manually from consumers • Sensors counters

Figure 9. Scheme of the process of information collection and processing when planning energy supply of buildings with RES and energy management



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The factors that determine the maximum benefit include the maximum sales that depend on maximum generation of electricity and, consequently, deviation index of electricity quality.

Deviation of index of electricity quality (IEQ) of the limits set by the standards, conditions worsen as the operation of electrical networks and consumers. Therefore, the values of the power quality index can serve as the initial information for decision making in the control systems of hybrid electric grids within the framework of Smart Grid technology.

The indexes of electricity quality deviation of the normalized values impair the conditions of operation of electrical power supply companies and electricity consumers, and could lead to significant losses, both in production and in the domestic sector. Therefore, the correct assessment of indexes of electricity quality is quite acute and pressing problem.

To date in assessing the quality of electrical energy used classical deterministic methods that do not take into account the uncertainty of information, all this leads to an incorrect use of the equations, conditions, and balance sheet ratios. Therefore, the representation of the IEQ in fuzzy form and integral development of the IEQ is an urgent task. In addition, uncertainty makes it possible to quantify the quality of the measurements. According to the latest international standards in the field of metrology and standardization of the basic assessment of the quality measurement results is recommended to consider its uncertainty (Tymchuk, & Miroshnik, 2015).

For decision making in assessing the IEQ it is more expedient to use the theory of fuzzy sets, rather than the classical methods of probability theory as a fuzzy representation gives a simple description of the object and, consequently, increase the speed of making decision. In addition, the application of fuzzy mathematical description allows to use for mathematical models with the results of measurements expertise and assessment, presenting them in the form of fuzzy numbers, membership functions and distribution functions of options.

This approach involves the implementation of the number of steps. At the first stage, the fuzzification of the norms of IEQ is carried out. This is done on the basis of regulatory documents. Norms of quality are conveniently represented as fuzzy intervals with the trapezoidal membership function. At the second stage fuzzification of IEQ is carried out. This is done on the basis of measurements. Usually, the measurement results are presented in the form of a histogram of the quality index. This histogram can be taken as a membership function of the fuzzy set of measurements after normalization. However, to simplify further operations, it is convenient to convert a fuzzy set of measurements into a fuzzy number with a triangular membership function. At the third stage, an assessment is made of the correspondence between the fuzzy indicator and the fuzzy quality standard. This correspondence can be estimated from the intersection of two geometric figures. The first figure is formed by the membership function of the norm of the IEQ, and the second by membership function of the IEQ itself. On this basis, it is possible to introduce a fuzzy concept of the indicator's compliance with the accepted quality standard. The membership function of this concept can be defined as the ratio of the indicated intersection to the area of the figure formed by the membership function of the IEQ. As a result, a lot of fuzzy estimates of quality indicators are formed.

From the point of view of the decision-making system, it is rational to have not a group of different types of quality indicators, but a single integral indicator. The fuzzy form allows you to combine different in physical nature indicators in one integral indicator.

Since operations on fuzzy sets uniquely projected on the operation of their membership functions, then form a single indicator of the fuzzy concept of "electricity quality" can be quite simple (Tymchuk, & Miroshnyk, 2014).

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For example, using the logical operation of crossing the quality measures, it may be represented as follows

$$EQ = \bigcap_{i=1}^{N_{EQ}} EQ_i; \quad \mu_{EQ} = \min_i \left(\mu_{EQi}\right),$$

where NEQ – the number of considered indicators of quality, μ_{EQ} - the membership functions of integral quality indicator.

Then μ_{EQ} we can assume a generalized indicator that assesses the quality of energy by the number in the range [0, 1].

However, different types of loads are not equally sensitive to power quality indicators. Therefore it makes sense to form an integral quality index for different types of load. To characterize the quality of electric energy with generalized index there are the following types of loads: lighting, motors, heating appliances and devices with microprocessor control units.

For example, the values of integral quality indices of electricity can presented in the form of:

- For the motor load:

$$\mu_{EQ} = \min\left(\mu_{\delta U_s}, \mu_{K_U}, \mu_{K_{U(n)}}, \mu_{K_{2U}}, \mu_{K_{0U}}, \mu_{\Delta f}, \mu_{\Delta t_P}, \mu_{K_{rU}}\right),$$

- For lighting load:

$$\mu_{EQ} = \min\left(\mu_{\delta U_y}, \mu_{\delta U_t}, \mu_{P_t}, \mu_{K_{0U}}, \mu_{\Delta t_P}, \mu_{U_{imp}}\right),$$

- For devices with microprocessor control units:

$$\mu_{EQ} = \min\left(\mu_{\delta U_t}, \mu_{P_t}, \mu_{K_U}, \mu_{K_{U(n)}}\right),$$

where δUs - steady voltage deviation; δUt - scope voltage changes; Pt – flicker; KU(n) - coefficient of n harmonic component of voltage; K2U - coefficient of voltage asymmetry by reverse sequence; K0U - coefficient of voltage asymmetry by zero sequence; Δf - frequency deviation.

Therefore, if we know the type of load, it is possible to consider only the IEQ, which have a negative effect on the operation of a particular electroreceivers.

The proposed method makes it possible to assess the degree of conformity of quality standards, as well as to monitor changes in the quality of electricity even if the major parameters are within the permissible values, to analyze the dynamics of change IEQ and identify proactive measures to normalize the EQ. Thus, using the generalized indicator of the quality of electrical energy, being aware of the type of load you can determine the degree of influence of poor electrical energy mode of operation, the service

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life of specific groups of consumers, as well as the additional electrical energy losses. This information can be used in making decisions on the management of Smart MicroGrid.

In presented above it was examined major ways of assessing information influencing to making effective decision during Smart Grid planning and its operation. Based on these data it was identified the criteria that are fundamental to planning and operation.

MULTISCALE DECISION-MAKING IN SMART GRID: RISK AND UNCERTAINTY DURING MAKING DECISION

The planning, simulation, operation, and control of electrical energy systems involve information and phenomena that is naturally associated with temporal, spatial, and scenario dimensions. Each one of these dimensions has specific scales and granularity requirements associated with relevant system behavior. The planning, safe and optimal operation, management of Smart Grid is a multi-dimensional and multi-scale problem.

In general, multi-scale processes are physical, engineering, biological, or social processes characterized by coupled phenomena that occur in disparate spatial and temporal scales (Grijalva, 2011).

Usually, interactions at all scales affect the ultimate behavior of the complete system. Multiscale modeling and analysis considers the following units (Guenard, Legendre, Boisclair, & Bilodeau, 2010):

- A set of models that provide a consistent description of phenomena.
- Simulation methods that combine steady state and dynamic scale interactions in model.
- Efficient computational analysis, optimization, and control methods.
- The uncertainty overcoming.

The first challenge and need for Smart Grid multi-scale analysis is to determine what the new relevant models build, how likely these new models are to remain contextually relevant in the future, and their important characteristics.

Multi-scale decision making is a growing area in multi-scale optimization. The aim of which is to develop a generalized statistical formalism that describes a large variety of complex systems in an effective way. As a result the entire system is optimized while considering the interaction between the scales by means of coordinated information.

We observe that Smart Grid customers are faced with a multiscale decision-making problem along at least two the directions: energy planning and energy management, based on set of criteria. The challenges that occur during these processes are listed on Figure 10.

Risks have significant impact to making decision in the operation and control of smart grid. They influence on a quality of making decision, thus they should be taken into account. The risk is present in both the design of an energy grid and its daily operation. By appropriately sizing the grid and minimizing the risks from energy economics, the smart grid's owners and investors will be able to maximize their savings while ensuring higher levels of energy security and reliability. To analyze risks in smart grid operation, uncertainties should be formulated. To handle uncertainty, robustness of proposed models to changing conditions should be considered as an objective. Uncertainties which occur may be divided into two classes that have been named "random" and "non-random" (Buygi, Balzer, Shanechi, & Shahidehpour, 2004). Examples of each class are presented in Table 4.

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Figure 10. Criteria of optimal decision-making

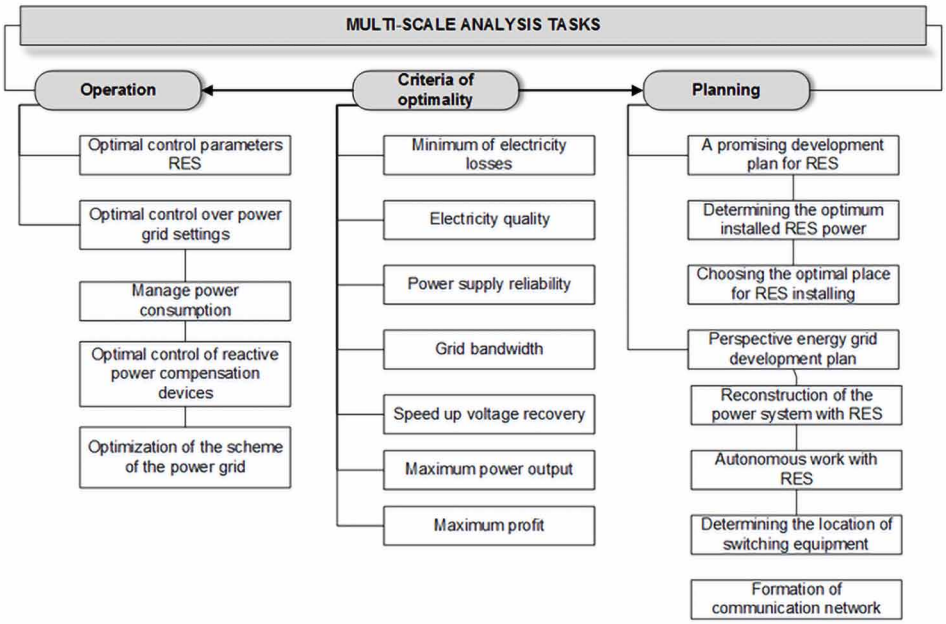


Table 4. The classes of uncertainties

Uncertainty class	Examples for Energy Sector
random	Energy prices Component prices Component outages
non-random	Weather condition shift Load forecasts Technological leaps Policy changes Extreme events

The former occurs repeatedly and can be captured by fitting probability functions to historical data. The latter uncertainties do not occur repeatedly; therefore, their statistical behavior cannot be derived from historical data, but they may have great impact.

When non-random uncertainties are occurred, there are a set of decision approaches that do not involve probability that may be used (Ryan, McCalley, J& Woodruff, 2011):

1. Decision makers may focus on the worst case and seek to minimize damages that would result if this case happened - this is a minimal approach.
2. Minimax approach is an opposite approach, in which the decision maker optimizes over each different future, then calculates the damage for a particular decision and future as the difference between the objective function values in that future between the given decision and the optimal decision for that future. As a result, the decision with the smallest value of maximum damage is selected.

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3. Robust optimization. Decision maker seek the intersection of all constraints generated by an uncertainty set are considered. The size of uncertainty set determines in what way resulting solution can be implemented.
4. Stochastic programming problems that include chance constraints. In this case, some constraints are required to hold only with a specified probability rather than for all realizable scenarios. This is particularly relevant for electric grid planning because it is one way to model service level requirements.
5. Approximate dynamic programming has been proposed as a way to use heuristic ideas from artificial intelligence applied to dynamic programming to address problems with a large number of decision variables.
6. Scenario-based planning. This approach provides an opportunity to simulate some of the sources of uncertainty and to purposely insert extreme, important cases. The use of time scales enables the creation of plans that take into account the fact that there will be future uncertainties.

The main risks when MicroGrid planning and operation are the follows (Jones, 2015):

- Standard risk exposures for installed equipment - wind storms, lightning strikes etc. These risks should be being taking into account by modeling MicroGrid operations in emergency mode.
- Weather risk caused by weather volatility. Reducing this risks requiers developing models to examine the influence of weather threats on MicroGrid reliability.
- Microgrid performance risk caused by the lost load. It needs to be analyzed for each risk of load interruption. The primary risk variable for this model is total lost operational time.

Due to diversity of the risks and their nature the MicroGrid performance risk assessment is the combination of several analyses for different threats.

Despite presented above risks and uncertainties in making decision in the operation and control of smart grid, there is a group of risks connected public perceptions of smart grids.

To research this issue T. Krishnamurti et al. (2012) propose to involve three interrelated approaches:

- Normative analysis of the decision context under consideration. It was presented above in this section.
- Descriptive research into how individuals actually view and make those decisions;
- Prescriptive interventions attempting to bridge the gaps between the normative ideal and the descriptive reality.

Let consider as descriptive research with what risks and uncertainties individuals deal when planning smart grid and describe possible prescriptive interventions to each type of risks.

- Technological issue. People consider smart grid introduction as changing lifestyles. There is a gap between those developing the technology and those who actually use in homes. As a variant of solving this problem can be proposed to use modelling to understand the ‘fit’ of consumers to proposed technologies.

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- The complexity of planning and operation of smart grid. Here can be noticed that smart technologies need to be invisible to the consumer. To provide it the technologies should be self-learning and be more intelligent.
- Interoperability between appliances and/or consumers. Appliances except talking to each other should not interfere with each other. As a variant to control and testing it some companies involve consumers to check it. Thus, there is a special mechanism, when a consumer can testify that service works in a right way. It can be done to reassure consumers.
- Reliability of smart grids. Despite whole intellectuality of system consumers want to have right to control it in unintended consequences (e.g., turning off energy). So in smart grid operation should be provided an opportunity of having a manual control.
- Privacy and security. Consumers consider privacy as the most challenging risk to smart grid introduction. There is a leak of confidential information about a consumer's daily routine. Thus, the whole system should have physical security, that it cannot be hacked or compromised.
- Cost of smart grid. Consumers concern over the costs of different aspects of smart technology. The cost of installation emerges as a primary barrier. In addition, repairs and maintenance of installation seem as costly and complicated. Thus, consumers want to see potential cost savings as substantial.

Presented above list of public concerns can serve as information background during decision making in planning and smart grid operation.

In recent years in order to minimize risks and eliminate uncertainty informational support systems for the operation and management of the grid have being developed. This is one of the key actions of the Smart Grid concept implementation as part of Industry 4.0.

INFORMATION SYSTEMS FOR ENERGY MANAGEMENT IN RENEWABLE ENERGY BASED SMART GRID

Informational support for the operation and management of the grid is providing by using appropriate information systems. Let's consider these systems separately by their purpose.

When planning the structure of the grid, it is important to get not only the result of the optimal structure, but also get a consolidated analytical information about the energy and economic parameters of the power system, as well as recommendations for the choice of structure, etc. One of the most suitable approaches to do it is using decision support systems. That can differ by variety of planning tools, models, and procedures are used to account for emerging issues and attributes of energy systems.

According to Ramachandra (2009) the Decision Support System (DSS) is an interactive system, which can produce data and information, in some cases, contribute to the understanding relating to this subject area in order to provide useful assistance in solving complex and ill-defined problems. The use of DSS in planning the structure of the grid allows formulating recommendations for choosing the optimal grid structure and characteristics of its components in conditions of uncertainty, taking into account the factors of influence on the needs of electricity, the characteristics of the external power grid, the characteristics of the grid installation areas and weather conditions. Depending on the number and type of RES that are used, there are three directions for the development of the DSS for their use in planning energy supply

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of buildings. The first one uses one type of renewable energy source to produce electricity, the second - several, the third one combines the sources of thermal and electric energy.

Existing DSSs differ in their functional capabilities: use different approaches to multicriteria assessment, calculation of technical parameters of installations; as well as a way of presenting data. Input parameters of the calculation may have an interdisciplinary character, and relate to meteorology, geography, architecture, urban engineering systems, and others.

To assess a wide range of available tools, distinguish the DSS in the following categories:

- Systems for determining the optimal type of RES in the region (Hunt, Bañares-Alcántara, & Hanbury, 2013), (Shchur, & Klymko, 2014).
- Systems for studying performance and choosing the optimal design of the energy system (Elhadidy, 2002), (Celik, 2002), (Nehrir, LaMeres, & Venkataramanan, 2000), (Lazarou, Oikonomou, & Ekonomou, 2012), (Sabirzianov, Kubkin, & Soldatenko 2011), (Deshmukh, & Deshmukh, 2008).
- Systems for predicting generation and consumption of electricity (Ai, Yang, Shen, & Liao, 2003), (Hunt et al., 2013).

In addition, DSSs differ depending on which strategy of energy management is implemented:

- Systems using dynamic modeling (Gomaa, Seoud, & Kheiralla, 1995), (Barbato, Capone, & Carello, 2014), (Hunt et al., 2013).
- Systems with analytical models (Ai et al., 2003), (Elhadidy, 2002), (Celik, 2002).

Also special mechanisms can be used for decision-making (Barbato et al., 2014), (Hunt et al., 2013); systems can combine several methods for decision-making: linear programming, dynamic programming, multi-criteria methods, etc.

Table 5 provides an overview and comparison of DSS that are commonly used by experts during planning stage of buildings energy supply with RES.

As it clearly illustrated the listed above DSS do not cover the entire complex of tasks that arise in the decision-making process when planning the structure of smart grid. Thus, there is a lot of variety tasks that should be solved.

As an option of solving some tasks, it can be presented an architecture of such DSS that can cover some unsolved tasks during planning stage. Figure 11 shows a diagram of the interaction of the main components of a decision support system for planning energy buildings with showing connections between constituent parts.

Information inside DSS goes through five stages:

1. Data collection and its processing. At this stage, collects data on the weather conditions in the area, electricity consumption in the household, available on the market of RES installation, geographic location, and expert information. Knowledge of experts is used to form a knowledge base.
2. Based on gathered data a set of possible grid`s structures is formed.
3. Forming technical and economic indexes of each alternative, that in output transforming to evaluation criteria.
4. On this stage, using previous result and expert knowledge calculate value of qualitative and quantitative criteria, as well as the weight of criteria.

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Table 5. Comparative characteristics of DSS

DSS	Solarius PV (Solarius PV, 218)	RET-Screen (RETScreen, 2018)	PVSyst (PVSyst. Photovoltaic Software, 2018)	Hybrid2 (Hybrid2 Software, 2018)	HOMER (The HOMER Pro microgrid software, 2018)
User friendly	+	-	-	-	+
Level of expert knowledge of decision maker	Not high	Not high	Not high	Extremely high	High
RES type	Solar panels + Diesel generator + Storage batteries	Solar panels + Diesel generator + Storage batteries	Solar panels + Diesel generator + Storage batteries	Solar panels + Diesel generator + Wind turbines + Storage batteries	Solar panels + Wind turbines + Storage batteries
RES Scenario-based modelling	-	-	Solar panels + Storage batteries	Solar panels + Wind turbines + Storage batteries	Solar panels + Storage batteries
Getting access to database with weather data	Only solar irradiation data	Only solar irradiation data	Only solar irradiation data	Only solar irradiation data	Only solar irradiation data
Analysis of the economic scenario	-	+	+	+	+
Analysis of the energy scenario	-	-	+	+	+
Ability to enter user data on consumption	+	-	+	+	+
Ability to enter data on specific types of RES	-	-	-	-	-
Reports forming	+	+	+	-	+
Connect to external databases	-	-	+	-	+

5. On the last stage, alternatives are evaluated according to the optimization scenarios (energy losses, price, and energy surplus). In addition, the optimal configuration is determined, and a feasibility study is formulated in relation to the choice of the optimal structure of the grid.

Thus, decision maker receives recommendations as reports about optimal energy grid structure. This report includes information about type of RES, its characteristics, price, other.

Information workflows operate by appropriate subsystems. Presented above DSS consists of five interconnected subsystems whose functionality is presented in Table 6.

Presented DSS is the first step to cover all tasks that occur during planning stage. Such system can be improved on direction to combine it with the appropriate information system that manage work of real energy grid. To do it, it is necessary to determine how can works such information system for energy management.

During creation an appropriate information system for energy management, the work can be divided into parts, e.g. which represent logical systems, which reflect the capabilities of the energy system. The

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Figure 11. The common DSS architecture

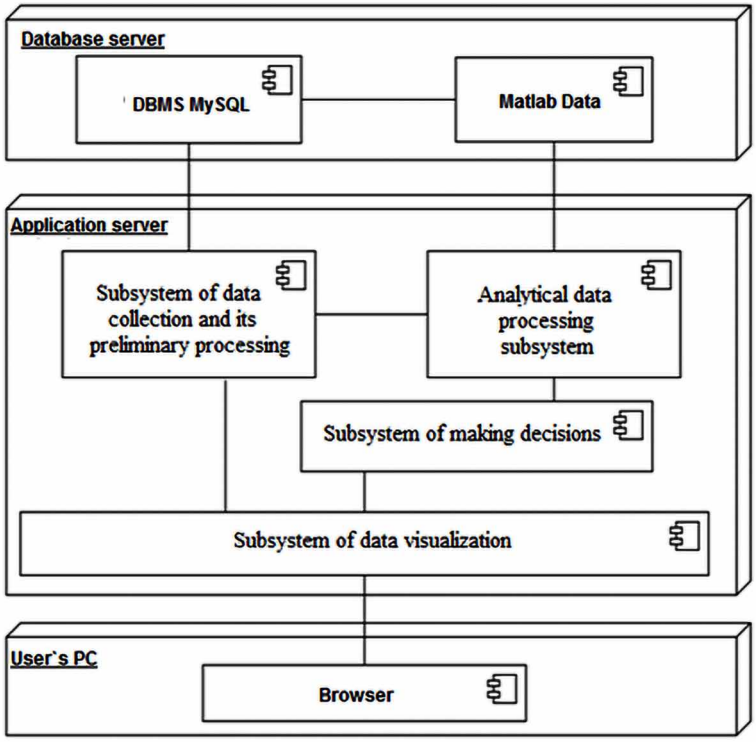


Table 6. Short description of DSS subsystems

Subsystem	Brief description / Actions to be performed	Input Data	Output Data
Subsystem of data collection and its preliminary processing (SCP)	Collection of information on weather conditions, technical and economic indicators of equipment on the Internet. Data is stored in SQL tables and used in other modules.	Data that is collected from the weather forecast web-site, web-sites with RES, user input data	Hourly weather data, the characteristics of RES installations, consumption in the household, external network parameters
Analytical data processing subsystem (SAPD)	Determination of alternate structures of energy grid, their technical and economic parameters using Matlab, determination of criteria sets.	Output data of the SCP	A set of alternative structures of the energy grid, a set of criteria
Subsystem of making decisions (DM)	Estimation of alternative design solutions, final formation of optimal solution.	Output data of th SAPD	The list of ranked alternatives with their characteristics
Data storage subsystem (SDS)	Formation of database based on data from SCP and SAPD	Output data of th SCP, DM and SAPD	Processed data of SCP, DM and SAPD
Subsystem of data visualization	The web interface is used to provide users with access to the system and a solution that is a feasibility study for the optimal version of energy grid with the indication of the type and number of RES installations, and also the user receives a list of alternative solutions closest to the optimal.	Data from the database that the user asks	Tables and graphs on a web page

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work of these logical systems can be represented as sub-systems in entire information system. The Figure 12 shows the possible structure of information system for energy management.

Presented on Figure 12 is the set of possible parts of Smart Grid that can be managed separately. They represent logical systems, which reflect the capabilities of the energy system (Massel, & Bakhvalov, 2012).

All listed logical systems should work in accordance with scheme of energy use or supply in the suggested smart grid architecture. Operational logic of smart grid is presented as pseudo code in Figure 13 (Pakštas, Shulyma, & Shendryk, 2016).

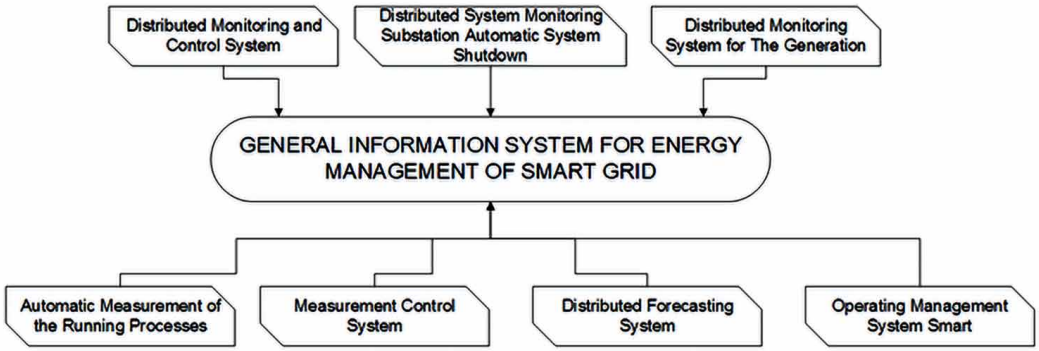
Here for simplicity are omitted instant discrete values of times, requested powers, priorities as well as costs and only generalized value of requests from individual households to HRES for satisfying domestic/industrial use is used (RH). Also, conditions such as "UNTIL Tx = 0" shall be understood as repeated generation of the request during specified period. In this pseudocode EPG means external grid. RBC is the request from batteries to smart grid or EPG via controller (PGS) for recharging. RHP is the request from smart grid via controller to EPG for purchasing extra energy Egp energy for satisfying domestic/industrial use (i.e. in a case of low common generated energy from solar (Es), wind (Ew) and those part what is hold on batteries (Eb). RGS is the request from the smart grid via PGS to EPG for selling of the surplus energy. RGB is the request from the EPG via controller to smart grid for buying of the surplus energy.

To realize the operational logic of smart grid properly inside each sub-system can be used different techniques. They can be divided into three main approaches, which can use a variety of tools (Shendryk et al., 2017). The main characteristics of these approaches are presented in Table 7.

To implement agent-based modeling approach whole system can be divided into some sub-systems, which are called agents (Nwana, 1996). Agents are characterized by the ability to cooperate, autonomously act and the ability to learn. Dynamic model's simulators are used to describe and analyze the behavior, ask "what if" questions about the real system, and aid in the design of real systems (Tisue, & Wilensky, 2004). Network simulators are used to support domain-specific functionality such as support for sensor networks, wireless ad-hoc networks, Internet protocols, performance modeling, photonic networks, etc.

Combination of these approaches can help to build an appropriate information system that can be used to manage work of real energy grid. It is a complex task that require to do deep analysis that relate both management and combining with planning.

Figure 12. The logical system of smart grid



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Figure 13. The operation logic of smart grid

```
REPEAT
GET(RH)                                  -- Get total energy request
IF (Eb ≤ Ebmin) OR                       -- If battery low OR
        ((Ebmin < Eb < Ebmax)                    -- battery good
                AND (RH=0))                              -- AND no other requests
        THEN (RBC(Ec,HRES);                      -- then generate charging request
        RH := RH + Ec)                           -- and adjust total request RH
Ea := Ea1 – SOLD(EPG)                    -- Available power minus already sold
IF RH ≤ Ea THEN USE(Ea,RH)               -- If enough then use Ea to satisfy RH
IF RH > Ea THEN Ea := Ea + Eb            -- If not enough then add battery
IF RH ≤ Ea THEN USE(Ea,RH)               -- If enough then use Ea to satisfy RH
IF RH > Ea THEN RHP(RH-Ea,Tp,EPG)        -- If not enough then request RH-Ea
IF RHP(OK) THEN BUY(RH-Ea) UNTIL Tp=0    -- If OK then buy extra RH-Ea during Tp
IF Ea > RH THEN RGS(Ea–H,Ts,EPG)         -- If ∃ surplus then offer it to sell during Ts
IF RGS(OK) OR RGB                        -- If sell accepted or ∃ request for surplus
        THEN SELL(Ea–RH) UNTIL Ts=0              -- then sell surplus to EPG during Ts
IF CHARGING(FINISH) THEN RH:= RH–Ec      -- If charged then adjust total RH
UNTIL STOP
```

Table 7. Short description of approaches implemented in information system for smart grid management

	The agent-based modeling	Dynamic model's simulators	Network simulators
To represent a work of logical systems	Operating Management System Smart Distributed Monitoring and Control System.	Distributed System Monitoring Substation Automatic System Shutdown. Distributed Monitoring System for The Generation. Automatic Measurement of the Running Processes. Measurement Control System. Distributed Forecasting System.	Distributed Monitoring and Control System.
The major field of use	IoT in the smart grid work	Modeling of structure and the dynamics of complex systems.	Network connection between sensors in the smart grid
Tools	REPAST, NetLogo, JADE, Cormas, AnyLogic	NEPLAN, MATLAB, PSS NETOMAC & SINCAL, VTB	OPNET, GloMoSim, QualNET, OMNeT++

FUTURE RESEARCH DIRECTIONS

According to the presented study of the features of decision making for energy management in smart grid with RES, there is the problem of creation appropriate information system, which allows combine presented planning system with appropriate system for energy management.

Therefore, future research directions can be focus on determination the appropriate functional models, which can be used in such tasks. During construction the general information system, it is necessary to improve planning tasks in accordance to management in next direction:

- The monitoring system should use sensors for gathering information on regional weather conditions, geographical data, and energy consumption data. It allows conducting operational control of changes and can be used in both planning and management sub-systems.

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- The systems should use the common information database. It allows giving the best recommendations for the construction of smart grid in accordance to automatically adjust the power supply.
- The models of energy consumption in planning should use real scheme of operational logic the same as in management system.

The presented above tasks its shows only small direction of future research. In general, it is complex and much bigger task.

CONCLUSION

According to analysis the current situation of the features of decision making for energy management in smart grid with RES, this Chapter captures the state of information support in energy management. It can be the solid source of comprehensive reference material in the related research field.

It was studied the broad range of topics and material to identify the actual problems of the determining the place of a smart grid in the Industry 4.0, as well as feature of renewable energy based smart grid, energy management strategies in smart grid, analysis of information flows for making decision on energy management, risk and uncertainty during making decision on energy management and information systems for energy management in renewable energy based smart grid. It can be concluded, that there are the many disparate ways of solving listed problems.

The research results can serve as a basis for work on the construction of an Information System, which allows manage the work processes in Smart Grid and receiving summary information about the grid.

Concerning before construction stage of Smart Grid with RES as efficient tool of we propose the decision support system for planning the general structure of Smart Grid with RES. Thus, it can be achieving the energy efficiency of Smart Grid construction through the implementation of this system.

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KEY TERMS AND DEFINITIONS

Decision Support System: An interactive system that can produce data and information and, in some cases, contribute to the understanding relating to this subject area in order to provide useful assistance in solving complex and ill-defined problems.

Energy Management Information System (EMIS): A performance management system that provides relevant information that makes energy performance visible to different levels of an organization, enabling individuals and departments to plan, make decisions, and take effective action to manage energy.

Industry 4.0: A collaborative network that combines eight key parts, namely cybersecurity, intelligent robots, industrial automation, IoT, cloud computing, product life-cycle management, semantic technology, and big data analytics.

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Microgrid: A localized group of electricity sources and loads that normally operates connected to and synchronous with the traditional centralized electrical grid (macrogrid) but can also disconnect to "island mode" – and function autonomously as physical and/or economic conditions dictate.

Multi-Scale Process: Physical, engineering, biological, or social processes characterized by coupled phenomena that occur in disparate spatial and temporal scales.

Renewable Energy: An energy that is collected from renewable resources, which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat, etc.

Smart Grid: The concept of a fully integrated, self-regulating, and self-healing power grid, which has a network topology and includes all the sources of generation, transmission and distribution networks, and all types of electricity consumers managed into a unified network of information and control devices and systems in real time.

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Chapter 15
Application of MSTAM Methodology in Project Management:
A Case Study of ITF Robotic Automation R&D Project

Siu Cheung Ho
City University of Hong Kong, Hong Kong

Kong Bieng Chuah
City University of Hong Kong, Hong Kong

ABSTRACT

Innovation technology development and commercialization are not new, but this is a hot topic in this decade in Hong Kong. The relevant researches are focused on two dimensions from research and development (R&D) technologist perspective (supply-side) and industry user perspective (demand-side). This is a part of the author's engineering doctorate thesis. The thesis title is "An Analysis of the Determinants of Innovation and Technology Fund (ITF) R&D Projects Commercialization in Hong Kong's Logistics and Supply Chain Industries." A pilot implementation case study has been conducted and tested, and the MSTAM methodology are workable for ITF R&D project deliverables commercialization to the industry.

INTRODUCTION

This is the first attempt to investigate how to effective and efficiency to develop the project management mechanism for helping the R&D Technologist and Industry to solve the gap from the idea generation, apply research, development, technology implement and adoption to the market. For the traditional ITF R&D project operation mechanism has many monitoring procedure and operation step to examine the R&D project progress. But the mechanism may be ignored the R&D deliverable whether apply to the Industry in suitable time, need and fulfill the expectation of Industry User and R&D Technologist.

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Complicated and long project time schedule are the key issues affect the enabling technology to the Industry. This research study aims at linking with both supply-side and demand-side together to balance their requirement and expectation. A pilot implementation has been conducted the MSTAM (Market, Science, Technology, Application and Market) methodology in an ITF R&D project.

This research study aims to develop a new project management model to have a good grasp of factors influencing R&D project commercialization through a multi-perspective methodology. It is a good reference for all R&D personnel to manage the R&D project in Hong Kong. The proposed model and project management framework can be used to examine which factor can be generated the additional value into the R&D project and solve the basic problems of ITF R&D projects for increasing the ITF R&D projects commercialization rate opportunity to the market. In order to solve the foundation problem of ITF R&D projects commercialization to the Hong Kong's Logistics and Supply Chain Industry. A Seed Research Programme project has been selected to prove that using MSTAM methodology is an effective tool to increase the adoption rate of R&D projects deliverables to the Industry.

BACKGROUND OF ITF R&D PROJECT

ITF R&D projects are divided into 4 projects categories (ITSP 2017 & ITC 2015) such as 1) Seed Research Programme; 2) Platform Research Programme; 3) Collaborative Research Programme; and 4) Public Sector Trial Scheme. The detail is given as below.

1. **Seed Research Programme:** This programme is a foundation of ITF R&D project, under R&D Centres which are exploratory new technology concept and provide the foundation for future application to next step to another R&D projects such as platform research programme, collaborative research programme, and public sector trail scheme programme.
2. **Platform Research Programme:** All platform projects require industry sponsorship from at least two private sector companies which covers at least 10% of the total project cost during the project period. The companies should not be related to the lead applicant by ownership or management. Sponsorship can be in the form of cash, in-kind contributions, or a combination of the two. The IP rights generated from the project will be owned by the lead applicant, which can be a R&D Centre or a designated local public research institute. However, in the case of R&D Centre projects, wherein the university undertakes most of the R&D work, the R&D Centre may be free to negotiate with the university regarding ownership of the IP rights. Platform Research Programme applications are normally solicited (via "Call for Proposals") twice a year.
3. **Collaborative Research Programme:** For collaborative projects, the industry co-applicant should cover no less than 50% of the total project cost (or no less than 30% in the case of R&D Centre projects) during the project period. Industry co-applicants can be one of the following; a private sector company incorporated in Hong Kong under the Companies Ordinance (Cap. 32), an industry support organisation, a trade and industry association, or a professional body with the capacity to enter into contracts. The IP rights generated during the project may be owned by the industry co-applicant if it has contributed 50% or more of the total project cost during the project period. If this is not the case, the lead applicant should be the owner of the IP rights. Collaborative Research Programme applications are accepted throughout the year.

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4. **Public Sector Trial Scheme**: The aim of this programme is to facilitate and promote the realization and commercialization of R&D results generated through ITF projects. The ITF funding scope has been extended to cover the production of prototypes/samples and the conducting of trial schemes in the public sector. The prototypes/samples and the trial schemes should aim to facilitate the development of new products not currently available on the market. The use of samples/prototypes and trial schemes is confined to the public sector, which includes Government bureaux and departments, public bodies (e.g. Hospital Authority, Airport Authority, etc.), non-profit trade associations, charitable organizations, etc.

In order to solve the foundation problem of ITF R&D projects commercialization to the Hong Kong Logistics and Supply Chain Industry. A Seed Research Programme project has been selected for pilot implementation to demonstrate whether the proposed MSTAM methodology is supportive to transfer the developed technology into the market in the best situation.

In order to enhance the commercialization success of ITF R&D projects to the Hong Kong's Logistics and Supply Chain Industry, a Seed Research Programme project has been selected for case study. It will demonstrate the proposed model, MSTAM, elements and hypotheses are feasible.

ENABLING TECHNOLOGY OF ITF R&D PROJECTS APPLY IN HONG KONG'S DIFFERENT INDUSTRIES

Refer to Ho and Chuah 2018, the developed technology of ITF R&D project can be applied in different industry of Hong Kong such as E-lock system applied in Logistics and transport sectors, RFID baggage system for Hong Kong's Airport operation, and e-cheque payment method for e-Commerce sector etc. Table 2 is brief of the ITF R&D project application in different Industries of Hong Kong.

PROBLEMS OF ITF R&D PROJECT COMMERCIALIZATION

This section examines specifically the main problems of ITF R&D project commercialization in Logistics and Supply Chain Industry of Hong Kong. Figure 1 shows the basic ITF R&D project concept from the building up of knowledge to market use, starting from the basic research, applied research, and experimental development technology development commercialization. Basically, ITF R&D operations process has 3 stages: 1) starting at science base for initial development, 2) generic technology stage to

Table 1. ITF R&D funding projects

Project Type	Sponsorship	ITF Fund
Seed Research Programme	0%	100%
Platform Research Programme	10%	90%
Collaborative Research Programme	50%	50%
Public Sector Trial Projects	0%	100%

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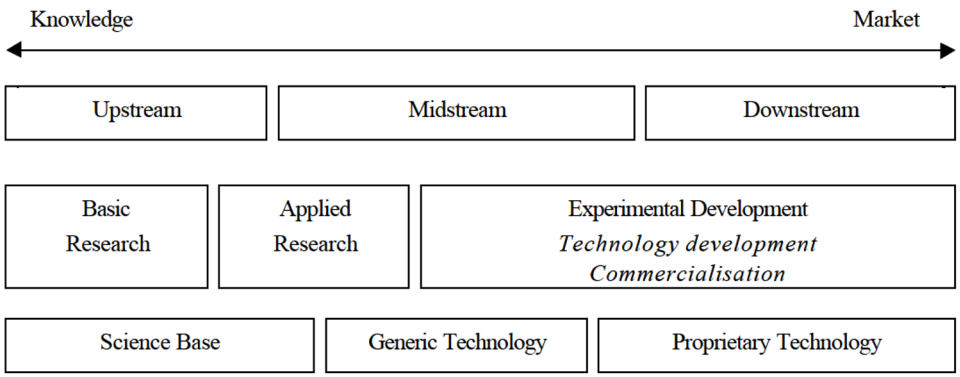
Table 2. Enabling technology in Hong Kong's different industries



develop a prototype of the product or technology, and 3) the final stage is to finalize the proprietary technology to the application. (ITC 2015)

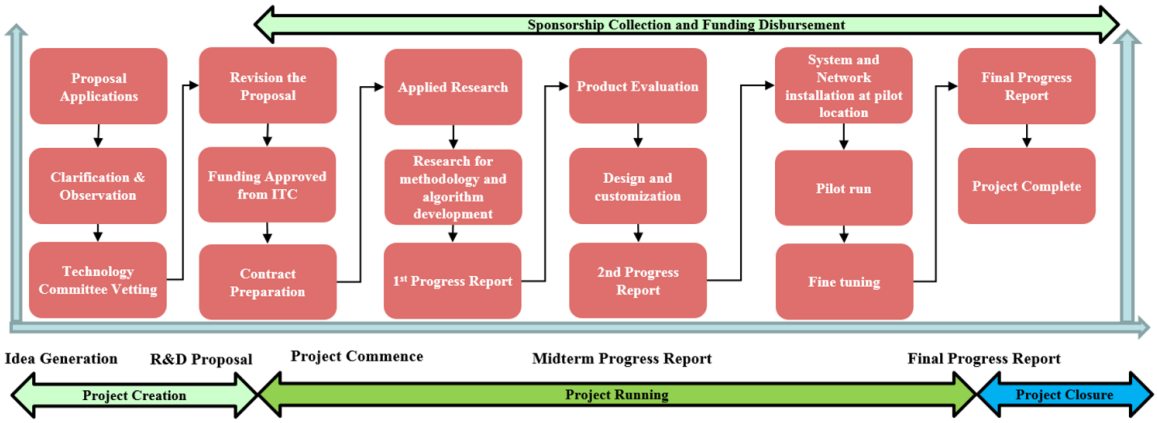
As noted in the previous section, there is a low rate of commercialization of extremely R&D deliverables in the Hong Kong's Logistics and Supply Chain Industry in the past ten years. Figure 2 escribes the general ITF R&D project operation process from idea generation, R&D proposal submission, proposal vetting, ITF R&D project commencement, product development, and project completion. In this current operation framework, the administrative operation process/steps in the different phases are for monitoring whether the whole project schedule and project milestones are fulfilled. If one operation tasks in the project period cannot be aligned, it will let the project go to a dilemma situation.

Figure 1. The research development spectrum



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Figure 2. Current ITF project operation flow



In order to ensure the ITF R&D projects complied to approved project deliverables in the proposal, a set of step by step instructions and operation tasks complied by lead applicant to help the project team carry out complex R&D work operations to achieve efficiency and quality R&D deliverables. In current ITF R&D project, many operation processes and steps to monitor whether ITF R&D project are kept on track and matched with proposal. The follow example is a normal R&D project schedule from proposal submission to project commercialization.

For example, a typical time line would be:

1. Proposal submission : 1 Jan 2015
2. Vetting date: : 1 Mar 2015
3. 1st Comment from ITC (Technical) : 1 Apr 2015
4. 1st Comment from ITC (Administrative) : 15 May 2015
5. Project commencement date : 1 July 2015
6. Project progress report : 1 July 2015 to 30 Jun 2017
7. Project completion date : 30 Jun 2017

In general, the normal lead time of ITF R&D platform project (LSCM 2017), the operation process from proposal submission to project completion is around 2.5 years. In many cases, R&D project has many critical issues influence the project progress. The normal ITF R&D platform project duration is started from proposal stage to project completion stage. The normal project duration schedule is around 2.5 to 3 years (For 18 month project or 2 year project). Also, many ITF R&D projects need to be post-poned. In average the project extension is over 5 months. Some projects will be completed over 5 years or more. The project issues that commonly affect the ITF projects are summarized below:

Problem 1: Control and Time Issue - Long Period of Time for Approval in Proposal Stage

ITC will provide some comments for project team to update the proposal before approval. The project team needs to explain the question in detail and resubmit the R&D proposal to ITC. The classification normal

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lead time for each inquiry is around 2-3 weeks. In some cases, it may have more than 20 time inquiries and questions in the proposal stage. Therefore, the project commencement date would be postponed.

Problem 2: Time and Control Issue – Project Development Process Is Too Long (From Proposal Stage to Project Completion Stage)

Due to the long project period, many supporting companies didn't have patience to wait the R&D project completed after 2 to 3 years or longer. If a project was required to be deferred the project completion date, the project period would increase one or two times than originally expectation of industry sponsors. The project postponement was caused some sponsors decline to support the ITF R&D project. This issue would affect the whole project operation and cash flow disbursement.

Problem 3: Quality Issue – R&D Project Deliverable Cannot Match Against Industry Demands

High investment cost, long lead time and R&D project deliverables performance may not fulfill the industry expectation and market need. Industry is not willing to use unknown value product (R&D technology deliverables) in their enterprises. ITF R&D project deliverables commercialization and adoption would be affected.

Problem 4: Communication and Motivating Issue - Misunderstanding of the Project Expectation Within Each Stakeholder in the Project

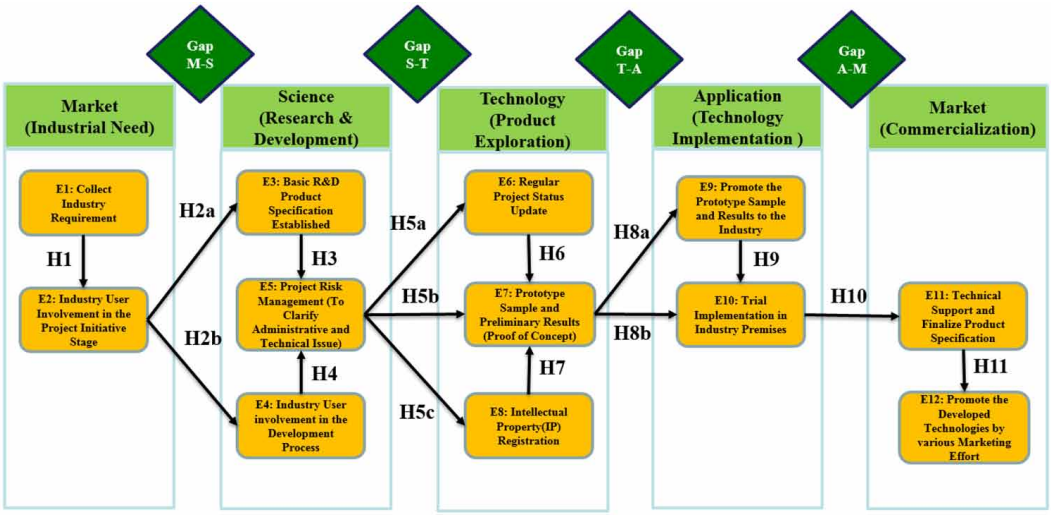
All R&D projects involve various stakeholders such as industry sponsors, supporting parties (e.g.: product demonstration and pilot testing), R&D technologists, HK government, and industrialists. They have different expectations in different stages of R&D projects. For example: proposal stage, interim result and final result. There're some gaps amongst in the ITF R&D projects, if the expectation and understanding are different, it will affect the project operations such as sponsorship collection, project planning and execution, data collection, and trial implementation. The project resources are fixed and cannot be changed once the R&D project has been approved by ITC. Therefore, interactive communication and risk response planning from R&D proposal stage to project commercialization stage are necessary. This can be crucial for project success.

Ho and Chuah 2017 & Ho and Chuah 2018 proposed a MSTAM model, and its associated propositions and hypothesis for enhancing the commercialization success of ITF R&D projects to the Hong Kong's Logistics and Supply Chain Industry. The detail is shown in Table 3 and Figure 3.

The developed model is tailor made for ITF R&D project from market need, science, technology, application to commercialization in the market. In between the gaps and the key factors in the ITF R&D process that have been defined for measuring the performance and helping to develop the propositions and hypotheses to guide all stakeholders to easy follow.

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Figure 3. MSTAM model



RESEARCH AIM, OBJECTIVES, AND SCOPE

This research focuses to explore new application of ITF R&D project monitoring mechanism for enhancing the R&D project deliverables commercialization to the Industry. This research summarized the previous research finding from R&D Technologist and Industry User through the quantitative and qualitative survey methodology from the key stakeholders from supply side and demand side in the ITF R&D ecosystem in Hong Kong. The value of the study is to find out which critical factors can enhance ITF R&D project progress and eliminate the gap between supply side (R&D Technologist-Technology Push) and demand side (Industry User - Application Pull). A MSTAM methodology is piloted in an ITF R&D project to demonstrate it is workable.

Research Aim

This paper aims to address the commercialization issue of ITF R&D project in Hong Kong's Logistics and Supply Chain Industry. This is the first attempt of the multi-perspective study to bridge the gaps from idea generation, R&D and subsequent technology implementation and adoption by Industry. The Industry is facing extremely challenge in this dynamic business environment. To increase the competitive advantage of the company, R&D technology is a good tool for the company survives and creates the core advantage in the company.

For the traditional ITF R&D project operation mechanism has many monitoring procedure and operation step to examine the R&D project progress. But the mechanism may be ignored the R&D deliverable whether suitable apply to the industry in a reasonable time, need and fulfil the expectation of Industry and R&D Technologist. Complicated and long project time schedule are the key issues affect the R&D technology transfer to the industry. Industry need and R&D technology applied research may need to be aligned

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Table 3. ITF R&D Projects development elements and hypotheses

Proposition	Description	Hypothesis	Description
E1	Collect Industry Requirement at the R&D Initial Stage	H1	Industry requirement collection can be helped to develop the R&D projects
E2	Industry User Involvement in the R&D Project Concept Development Stage	H2a	Industry user provides real market situation to help the R&D technologist explore the new idea of R&D project
E3	Basic R&D Product Specification Established in Science Stage of Research and Development	H2b	Industry user involve in the R&D projects in the project initial stage, it can speed up the R&D development process
E4	Industry User Involvement in the Development Process	H3	Create a basic R&D product specification in the R&D project initial stage; it can help all stakeholders easy to know the R&D deliverables
E5	A Gatekeeper Identifies the Project Risk in Advance for Clarifying Administrative and Technical Issue in the R&D Project (Project Risk Management)	H4	Industry user participates in the R&D projects; it can enhance the project value of the R&D deliverables
E6	Regular Project Status Update and Unification Schedule Management	H5a	Regular project status update of the R&D project, it can reduce the communication issue among all stakeholders
E7	Prototype Sample and Preliminary Results (Proof of Concept)	H5b	The preliminary test result and prototype sample can help the industry user easy to understand the product for future commercialization and adoption
E8	Pre-Intellectual Property (IP) Registration	H5c	In the R&D project initial stage, I believe that define project risk in advance such as administrative and technical issue, it can eliminates the risk of project failure
E9	Promote the Prototype and Results to the Industry	H6	The preliminary results and prototype sample of the R&D product can help the industry user easy to know and how to use the R&D deliverables
E10	Trial Implementation in Industry Premises	H7	Intellectual Property (IP) registration can protect the rights of the developer and facilitate further commercialization
E11	Technical Support and Finalize Product Specification	H8a	The promotion activity can attract the industry users to know the R&D product value for commercialization
E12	Promote the Developed Technologies by Various Marketing Effort	H8b	The R&D project trial implementation in the real industry premises, it can help the industry user to adopt the R&D deliverables
		H9	Technical support of R&D technologist can help the industry user easy to adopt the R&D deliverables in the company
		H10	Clear and detail R&D product specification can speed up the industry user to adopt the R&D deliverable
		H11	Clear marketing plan can promote the R&D deliverables to the market effectively.

Research Objectives

This study aims to identify and evaluate a way to enhance/enable the commercialization success of ITF R&D projects in Hong Kong's Logistics and Supply Chain Industry. This research further aims to develop and apply a novel project management model to increase the rate of commercialization opportunity of ITF R&D project in the Hong Kong's Logistics and Supply Chain Industry, the qualitative and quantitative data will be collected from R&D technologist and industry user. A comprehensive analysis

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will be conducted and tested in a case study. The objectives are to find out solutions to solve the commercialization issue of ITF R&D project. It uses the multi-perspective to analysis how to align R&D technologists and industry users to develop and apply developed technologies to companies. This research investigates R&D technologists and industry user's perspective to study their concerns and expectations of ITF R&D project deliverables and how to align both parties in a systematic way.

Research Scope

The scope of research focuses on the ITF R&D project for Logistics and Supply Chain Industry of Hong Kong, and develops a novel project management and optimization mechanism to help the R&D Technologist to develop and transfer the R&D deliverables during the technological development process to the Industry effectively. To evaluate how effective and efficiency factors influencing R&D project technology adoption to the Logistics and Supply Chain Industry. This research identifies the critical issue influencing R&D product commercializes to the market. R&D project commercialization and adoption in this research is defined into two perspectives of R&D Technologist and Industry User. Successful commercialization and adoption of R&D project deliverables are defined as the whole R&D project completed, commercialized and adopted in the Industry. A pilot study will be conducted.

ITF R&D PROJECT DATA ANALYSIS (ANONYMOUS)

The funding programme for ITF R&D projects are funded by HKSAR's Innovation and Technology Commission (ITC) (ITSP 2017). The funding programme supports midstream/downstream R&D projects undertaken mainly by designated local public research institutes, R&D centres, industry support organizations, professional bodies, and trade and industry associations. ITC will provide financial assistance for the following four funding programmes: 1) Seed Research Programme; 2) Platform Research Programme, 3) Collaborative Research Programme, and 4) Public Sector Trial Projects (PSTS) (ITSP 2017 & ITC 2015). The data of ITF projects in Logistics and Supply Chain Industry has been collected from one of the R&D centres in Hong Kong. The total number of ITF projects is 99 based on the project period from 1 Mar 2005 to 30 Mar 2016. The project data summaries are listed in Table 4, 5, 6, and 7.

Seed Research Programme

This programme is a foundation of ITF R&D projects, under R&D Centres which are exploratory in new technology concept and provide the foundation for future application. Table 4 is the summary of ITF seed project. From 1 Mar 2005 to 30 Mar 20016, 3 seed projects commenced and the findings are 1) the total change request application is at 400%; 2) the total project extension was 7 months (around 2.33 months per project); 3) one sponsor dissatisfied the project results, and 4) the total number of companies involved in the project was 13 (around 4.33 companies per project) (ITC 2015; LSCM 2017)

Platform Research Programme

All platform projects require industry sponsorship from at least two private sector companies which covers at least 10% of the total project cost during the project period. The companies should not be

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Table 4. Analysis on SEED project of ITF R&D funding scheme

Project Number	Project Type	Approved Funding (Million)	Commencement Date	Completion Date	Change Request	Project Extension (Month)	Reduce Project Cost	Reduce Scope	Project Termination	User Dissatisfaction	Number of Companies Involved in the Project
P3	Seed	1.95	15/2/2016	14/2/2017	3	3	0	0	0	1	4
P6	Seed	2.80	15/12/2015	14/9/2016	0	0	0	0	0	0	5
P46	Seed	1.95	2/9/2013	31/12/2014	1	4	0	0	0	0	4
				Total	4	7	0	0	0	1	13
				Average	1.33	2.33	0.00	0.00	0.00	0.33	4.33

Remark: User dissatisfaction mean "Product quality dissatisfaction, Sponsors declined or Project Termination"

related to the lead applicant by ownership or management. Sponsorship can be in the form of cash, in-kind contributions, or a combination of the two. The Intellectual Property (IP) rights generated from the project will be owned by the lead applicant, which can be a R&D Centre or a designated local public research institute. Refer to Table 5 the findings for the platform projects are 1) the total change request application is 191 times (around 3.9 times per project), 2) the total project extension time is 369 months, (around 7.53 months per project), 3) the number of reduce project scope and cost are 8 and 10 times respectively (around 16% and 20% per each project), 4) the total user dissatisfaction is 26 (around 53% per each project), and 5) the total number of companies involved in the platform project is 433 (around 8.84 companies per project). The data is counted by 49 projects only, due to 6 out of 55 projects have not been recorded the relevant information and cannot be traced.) (ITC 2015; LSCM 2017)

Collaborative Research Programme

For collaborative projects, the industry co-applicant should cover no less than 50% of the total project cost (or no less than 30% in the case of R&D Centre projects) during the project period. The collaborative projects are listed in Table 6 and the findings are 1) the total change request application is 13 times (around 1.18 times per project), 2) the total project extension time is 25 months, (around 2.5 months per project – the number is based on 10 projects only), 3) the total number of companies involved in the platform project is 30 (around 2.73 companies per project), and 4) one project is terminated. The data is counted by 11 projects (exception for the project extension, due to one project is terminated.) (ITC 2015; LSCM 2017)

Public Sector Trial Projects

The aim of this programme is to facilitate and promote the realization and commercialization of R&D results generated through ITF projects. The ITF funding scope has been extended to cover the production of prototypes/samples and the conducting of trial schemes in the public sector. 30 PSTS projects have been initiated. The PSTS project summary is stated in Table 7 The findings are 1) the total change request application is 25 times (around 0.93 times per each project), 2) the total project extension is 84.5 months

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Table 5. Analysis on platform project of ITF R&D funding scheme

Project Number	Project Type	Approved Funding (Million)	Commencement Date	Completion Date	Change Request	Project Extension (Month)	Reduce Project Cost	Reduce Scope	Project Termination	User Disatification	Number of Companies Involved in the Project
P1	Platform	11.07	30/3/2016	29/3/2018	0	0	0	0	0	0	4
P11	Platform	6.50	12/10/2015	11/10/2017	4	0	0	0	0	4	7
P12	Platform	8.40	25/9/2015	24/9/2017	0	0	0	0	0	0	2
P13	Platform	5.26	22/9/2015	21/9/2017	0	0	0	0	0	0	4
P14	Platform	4.00	7/9/2015	6/9/2017	1	0	0	0	0	0	10
P15	Platform	5.50	1/9/2015	28/2/2017	2	6	0	0	0	0	1
P17	Platform	6.00	31/3/2015	29/9/2016	1	3	0	0	0	0	4
P18	Platform	5.40	30/3/2015	30/6/2016	1	2.5	0	0	0	0	5
P23	Platform	4.50	31/3/2015	30/6/2016	3	12	1	0	0	4	7
P25	Platform	13.50	15/1/2015	14/1/2017	1	9	0	0	0	0	1
P26	Platform	1.05	3/10/2014	2/4/2016	0	0	0	0	0	0	4
P32	Platform	5.82	5/1/2015	4/11/2016	4	12	1	1	0	2	5
P33	Platform	7.37	16/3/2014	15/7/2016	2	4	0	0	0	0	15
P40	Platform	10.34	15/3/2014	14/9/2016	1	6	0	0	0	0	10
P48	Platform	8.66	1/1/2013	30/9/2014	3	4	0	0	0	0	7
P49	Platform	9.00	1/1/2013	30/4/2015	3	4	2	0	0	3	9
P50	Platform	8.78	1/1/2013	30/6/2015	2	6	0	0	0	0	7
P59	Platform	8.94	12/6/2012	11/6/2014	3	6	1	1	0	1	13
P60	Platform	6.12	1/7/2012	31/12/2013	3	3	0	0	0	0	14
P61	Platform	3.86	16/4/2012	15/10/2013	2	3	0	0	0	0	9
P63	Platform	0.93	1/2/2012	28/2/2014	2	6	0	0	0	0	3
P64	Platform	11.00	15/9/2011	14/6/2014	5	12	0	0	0	0	7
P65	Platform	8.50	18/10/2010	17/7/2012	3	9	0	0	0	0	6
P66	Platform	11.40	1/11/2010	31/12/2012	4	6	0	0	0	0	13
P68	Platform	4.60	1/4/2010	30/6/2012	3	3	0	0	0	0	5
P70	Platform	9.85	4/1/2010	3/3/2012	4	8	0	0	0	0	15
P71	Platform	5.74	1/10/2009	31/12/2011	4	3	1	1	0	1	10
P72	Platform	4.93	1/10/2009	31/12/2011	4	9	0	1	0	1	11
P73	Platform	7.00	15/9/2009	14/9/2011	2	6	0	0	0	0	21
P74	Platform	4.11	16/7/2009	15/12/2011	3	5	0	0	0	0	5
P75	Platform	9.79	15/9/2009	14/7/2012	5	16	0	0	0	4	17
P76	Platform	9.87	1/9/2009	30/11/2011	3	3	0	1	0	0	8
P77	Platform	12.86	1/3/2009	31/8/2011	3	15	0	0	0	0	16
P78	Platform	9.10	1/10/2008	31/3/2011	5	6	0	1	0	0	20
P79	Platform	5.84	15/9/2008	14/12/2010	1	3	0	0	0	0	3
P80	Platform	4.04	1/9/2008	28/2/2011	6	6	0	1	0	1	9
P81	Platform	6.36	1/7/2008	30/9/2010	5	3	1	0	0	0	12
P82	Platform	9.00	16/5/2008	15/11/2009	7	3	0	0	0	0	17
P83	Platform	8.49	1/6/2008	31/10/2010	5	5	0	0	0	3	20
P84	Platform	12.85	20/5/2008	19/8/2010	6	9	0	0	0	0	13
P85	Platform	3.86	1/4/2008	30/6/2010	4	3	0	0	0	0	1
P86	Platform	1.97	20/8/2007	19/5/2008	1	6	0	0	0	0	0
P87	Platform	8.99	1/1/2008	31/12/2009	7	0	1	0	0	0	2
P88	Platform	6.96	1/8/2007	31/7/2009	4	6	0	1	0	2	5
P89	Platform	5.85	1/7/2007	30/9/2008	1	0	0	1	0	0	17
P90	Platform	10.00	1/7/2007	31/1/2009	3	5	0	0	0	0	15
P91	Platform	1.99	1/7/2007	31/12/2008	2	3	0	0	0	0	13
P92	Platform	5.99	1/7/2007	31/3/2009	2	3	0	0	0	0	8
P93	Platform	2.00	1/8/2007	31/12/2009	6	16	0	1	0	0	3
P94	Platform	4.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P95	Platform	6.50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P96	Platform	14.15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P97	Platform	10.50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P98	Platform	4.60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P99	Platform	5.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
				Total:	191	369	8	10	0	26	433
				Average:	3.90	7.53	0.16	0.20	0.00	0.53	8.84

Table 6. Analysis on collaborative project of ITF R&D funding scheme

Project Number	Project Type	Approved Funding (Million)	Commencement Date	Completion Date	Change Request	Project Extension (Month)	Reduce Project Cost	Reduce Scope	Project Termination	User Dissatisfaction	Number of Companies Involved in the Project
P2	Collaborative	1.45	14/3/2016	15/5/2017	1	6	0	0	0	0	1
P5	Collaborative	0.10	25/1/2016	24/7/2016	0	0	0	0	0	0	1
P24	Collaborative	4.90	31/3/2015	30/9/2016	2	-6	1	1	1	1	2
P38	Collaborative	0.43	31/3/2014	30/3/2015	1	0	0	0	0	0	1
P44	Collaborative	0.37	31/3/2014	30/4/2015	1	1	0	0	0	0	3
P45	Collaborative	1.35	18/11/2013	17/11/2014	1	1	0	0	0	0	1
P47	Collaborative	0.35	11/3/2013	10/1/2014	0	0	0	0	0	0	2
P58	Collaborative	1.20	1/7/2012	31/12/2013	1	3	0	0	0	0	3
P62	Collaborative	0.60	16/3/2012	15/3/2014	0	0	0	0	0	0	3
P67	Collaborative	0.44	1/3/2010	31/8/2011	2	6	0	0	0	0	6
P69	Collaborative	1.50	1/9/2009	30/4/2011	4	8	0	1	0	1	7
				Total:	13	25	1	2	1	1	30
				Average:	1.18	2.50	0.09	0.18	0.09	0.09	2.73

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Table 7. Analysis on PSTS project of ITF R&D funding scheme

Project Number	Project Type	Approved Funding (Million)	Commencement Date	Completion Date	Change Request	Project Extension (Month)	Reduce Project Cost	Reduce Scope	Project Termination	User Dissatisfaction	Number of Companies Involved in the Project
P4	PSTS	3.80	1/3/2016	31/8/2017	0	0	0	0	0	0	1
P7	PSTS	3.94	1/10/2015	31/3/2017	0	0	0	0	0	0	1
P8	PSTS	2.49	14/9/2015	13/3/2017	1	4	0	0	0	0	1
P9	PSTS	5.23	12/10/2015	11/2/2017	1	5	0	0	0	0	1
P10	PSTS	2.84	1/10/2015	30/9/2016	2	8	0	0	0	0	1
P16	PSTS	3.50	30/4/2015	31/7/2016	0	0	0	0	0	0	2
P19	PSTS	3.30	31/3/2015	30/9/2016	0	0	0	0	0	0	1
P20	PSTS	6.03	31/3/2015	30/9/2016	0	0	0	0	0	0	1
P21	PSTS	4.90	31/3/2015	30/7/2016	1	4	0	0	0	0	2
P22	PSTS	2.10	31/3/2015	29/9/2016	0	0	0	0	0	0	1
P27	PSTS	0.93	8/12/2014	7/3/2016	0	0	0	0	0	0	1
P28	PSTS	0.75	1/11/2014	2/11/2016	1	6	0	0	0	0	1
P29	PSTS	5.48	19/9/2014	18/9/2016	1	6	0	0	0	0	1
P30	PSTS	1.59	18/11/2014	17/5/2016	0	0	0	0	0	0	1
P31	PSTS	3.37	29/9/2014	28/5/2016	1	5	0	0	0	0	1
P34	PSTS	1.94	26/8/2013	25/9/2014	2	1	0	0	0	0	1
P35	PSTS	4.31	3/6/2014	31/1/2016	2	9	0	0	0	0	1
P36	PSTS	1.88	16/1/2014	15/5/2015	1	4	0	0	0	0	1
P37	PSTS	2.45	16/12/2013	30/4/2015	2	7.5	0	0	0	0	1
P39	PSTS	3.30	31/3/2014	30/3/2015	1	4	0	0	0	0	1
P41	PSTS	0.60	31/3/2014	31/3/2015	1	0	0	0	0	1	1
P42	PSTS	0.24	31/3/2014	31/12/2014	1	0	0	0	0	1	1
P43	PSTS	1.94	31/3/2014	30/3/2015	1	0	0	0	0	0	1
P51	PSTS	0.52	1/3/2013	30/9/2013	0	0	0	0	0	0	1
P52	PSTS	3.47	7/1/2013	6/7/2014	2	6	0	0	0	0	1
P53	PSTS	2.03	25/2/2013	24/8/2014	2	6	0	0	0	0	1
P54	PSTS	2.26	16/1/2013	15/12/2013	0	0	0	0	0	0	1
P55	PSTS	1.63	1/9/2012	28/2/2014	2	6	0	0	0	0	1
P56	PSTS	3.31	1/10/2011	30/9/2012	1	0	0	0	0	0	1
P57	PSTS	2.30	19/9/2011	18/12/2012	2	3	0	0	0	0	2
				Total:	28	84.5	0	0	0	2	33
				Average	0.93	2.82	0.00	0.00	0.00	0.07	1.10

(around 2.82 months per project), 3) two users dissatisfy the project result, and 4) the total number of companies involved in the project is 33 (around 1.1 companies per project).) (ITC 2015; LSCM 2017)

To conclude, the main findings are summarized in 4 issues as follow:

1. **Project Management and Control Issues**
   a. Frequency change request of ITF projects - The total number of change request is 236 times. The average is 2.54 times per project and the number is counted by 93 projects only, due to 6 out of 99 projects information has not been recorded.
   b. Termination of ITF project - 1 project was terminated (Project Number: P24)
2. **Project Quality Issue**
   a. Reduce project scope and project deliverables - 12 projects were reduced the project budget. The average percentage is 12.9% per total projects)
   b. Project deliverables are not matched with user requirement – 1 project is terminated and 30 projects was reduced project scope. The percentage of failure project and user dissatisfaction is 1.08% 32.25% respectively. (1/93 projects)

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3. **Project Time Issue**
   a. Postpone the project completion date - The total project extension is 485.5 months. The percentage of average is 5.22 months per project.
   b. Long project duration - Industry user didn't know the value of the product or system (R&D project deliverables) in the project period.
4. **Communication and Motivating Issue**
   a. The developed technology/product did not matched with the industry user's expectation - The total supporting companies are 509. There are 30 supporting companies dissatisfaction. The average percentage is 5.89%.
   b. The industry user is not happy with the developed R&D project deliverables.

CASE STUDY IMPLEMENTATION PLANNING

According to ITC 2015, the funding programme for R&D projects are administered by the R&D Research Centre and funded by HKSAR's ITC. The establishment of the Centre marks the realization of the concerted effort and enthusiasm on the part of the government, industry, academia and research institutes. The funding programmes for R&D projects are administered by the R&D Research Centre and funded by the HKSAR Government's ITC. The Centre focuses on supporting R&D projects that would increase the added value, productivity and competitiveness of the logistics and supply chain industries in Hong Kong. ITC will provide financial assistance for the following three funding programmes; 1) Seed Research programme; 2) Platform Research Programme, 3) Collaborative Research Programme, 4) Public Sector Trial Projects (ITSP 2017). Seed Research Programme is the foundation of ITF projects. These are more forward-looking and exploratory projects and aim to provide foundation work for future platform / collaborative projects. No industry contribution is required. Therefore, seed research project is the best suitable project for testing this approach. A Seed research project has been selected for pilot implementation. The project initial stage is started on May 2017.The project has been started on 16 Nov 2016 and the project completion date is 15 Nov 2017.

Data Collection Method

A comprehensive understand of R&D Technologist and Industry User concern and expectation, the data collection methodology had involved in a pilot Implementation and planning – A real case study implementation will be conducted to test and examine the deployment and MSTM methodology are workable or not.

Case Study Using MSTAM Methodology

To verify the proposed model, MSTAM, elements and hypotheses, a case study has been selected for testing the model. This was a seed project in a R&D Centre. The explanation of why select this case study, case study background, challenge, need of industry and detail of case study implementation approach were shown in detail in this chapter. Finally, the research results for the MSTAM application will be evaluated in the end of this section. The author was a role of organizational manager in this case

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study. He worked with the project team to manage the project. The case study work tasks, development process, and results were stated in Table 8.

CASE STUDY BACKGROUND

A Seed Research Programme project was selected for a case study. The idea generation of the project started in May 2016. The project proposal was generated on 5 May 2016. The project commencement date was started on 16 November 2016 and the project completed date was planned on 15 November 2017. The project period from preliminary idea to project completion, the using time was around one and half years.

This was a robotic automation R&D projects, it can be called the project as "*Project R*". The background of Project R is research automation and robotics technologies. It has been used and adopted in Logistic and Supply Chain Industry for a period of time. Nowadays, warehouses are facing new customer paradigm "big demand of small quantity but vast variety of options in products". This becomes ineffective to use robot to handle such products because of high programming overhead and lack of flexible manipulator technologies for robotic hands. To overcome aforesaid problems, an agility robotic system compiling with a hand (or end-effector) and eye (vision) co-ordination control is important to cope with different shape, size, colour, and stiffness objects in the same process. In this project, it aimed to carry out an explorative research investigation in designing a multi-camera vision coordination control system and a flexible end-effector applying to commercially available robotic arms. The deliverables were expected to be able manipulated objects in different shapes, colours, sizes and surface textures moving along conveyor belts. The developed technologies were foundations to a subsequent platform project titled "*Smart Warehousing for the E-commerce Industry*" which needed to handle numerous unstandardized items. (Reference: LSCM Publication (2018).

This project aims to investigate hand (end-effector) and eye (robot vision) co-ordination of the service robots for material / object handling. Robot hand and eye co-ordination are an important robotic process for automated devices or service robots to mimic human tasks. Fast and cost-effective visual sensors will be developed to improve service efficiency. This project is a new attempt to investigate various robotics enabling technologies such as hand (end-effector) and eye (robot vision) coordination, and robot vision module to improve service robots' efficiency and productivity for specific problems at large logistic hubs and workplaces (e.g. airport terminals).

CHALLENGE OF THE PROJECT

The technical challenge was to design a fully-automatic RFID label affixing machine to replace the current manual processes. The system has to meet the following features.

Reliable

It was difficult for the conventional vision systems to distinguish objects when their colour was similar to colour of the background and/or baggages nearby (for example black baggage on the (black) conveyor belt in this case), more reliable object detection techniques were needed.

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Fast / Accurate Response

In order to increase the system efficient, the speed would be increased after the automation, fast robot was necessary. Also, robot hand (end-effector) and eye (vision) co-ordination control was critical part in this project to minimize processing delay and provide fast/accurate response.

Insensitive to The Object Shape and Material

The objects handled could be in odd shape and/or made by soft material. It might be inefficient for common end-effectors to handle these conditions.

Problem in Hong Kong ‘s Logistics Hubs

Hong Kong International Airport (HKIA) receives over 30K~40K pcs of transit baggage daily. Each baggage was required to put an RFID tag for security check and identifications. Presently, it is a 100% manual handling process. But there is about 3% error. (i.e. >1,000 pcs of baggage are missing RFID tags.) Baggage could be in different shapes, colours, sizes, weight and made of different materials. As such, the RFID label fixing process automation by robot was a huge challenge for this R&D project.

This case study would use a RFID label affixing robot targeted for HKIA transit baggage loading bay as a trial. The current working environment was shown in Figure 4, the baggage was transferred on a conveyor belt and the workers stick a RFID label on the baggage when it passes by. The RFID label or tag is about 4 inches x 1.75 inches in size. In average, each line would handle approximately 400-500 pieces of transit baggage per hour.

Figure 4. HKIA transit baggage loading bay



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1. Bags Processing Load
    a. Bags Per Hour: Average = 215, Peak = 650
    b. Bags Per Day : Average = 5086, Peak = 6483
2. Speed of Conveyor Belt = 28 m/min (loading conveyor)
3. Width of Conveyor Belt = 1 m

Needs of Hong Kong's Logistics Hubs

HKIA would like to robotize or automate this process and aimed to reduce the error to minimal. The operation is 100% manual processing for a repeatable task; when the third runway was up running, daily baggage capacity was expected to be double (or more). For example: It might lead to more errors if existing manual process was kept going.

Implementation Approach and Detail

A case study of MSTAM model in ITF R&D project was started on 16 Nov 2016 and the project deliverables were finished on 15 Nov 2017. The main project deliverables were developed and demonstrated. It served to validate the MSTAM model application in the R&D Centre. The 12 elements implementation roadmap was tailor-made for the Project R. To further enhance the user experience, the project duration was extended for 2 months to let the user has more time to understand the project deliverables. The further enhancement of the R&D technology was discussed. This project extension was not affected the original project deliverables, budget, and additional resources. A trial of Project R was divided into 5 phases as follow. The case study detail was shown in Table 8.

Phase 1: Market (Industrial Need)

Organization Manager (OM) received the draft proposal from the project team dated on 5 May 2016. OM reviewed the whole proposal and provided the administrative and technical comment to the project team for updating the proposal, project deliverables, and project detail. The Project Team (PT) worked with Industry User (IU) to collect the user requirement to develop the draft technical specification of the project deliverables for all stakeholders easy to follow and verify the product and the project results, it could be quantifiable and measurable. Supporting Organization (SO), IU, and System Integrator (SI) pledged to support the project team to this R&D project before the project start.

Phase 2: Science (Research and Development)

PT worked with the SO, IU and SI to develop the basic R&D product specification for synchronizing the expectation of all stakeholder together. The project deliverables would be followed this preliminary product specification for development. OM reviewed the project proposal and provides the administrative and technical support to the project team to identify the problem in advance before project commencement. The potential project risk could be identified in advance before project vetting and approval. Most administrative and technical issue could be eliminated in the R&D project initial stage before project commencement. PT worked with IU and SI to perform the preliminary and simulation test in workplace

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of IU and SI. Figure 5 is the preliminary project schedule for the project. The project task and each project task duration were listed on the table to all stakeholders to know the same schedule for easy monitoring.

Phase 3: Technology (Product Exploration)

OM requested PT to provide the project progress report monthly to track whether the project milestones and deliverables had any deviation and issue in the project development period. A 3D modelling simulation platform (See Figure 6) had been developed to test the R&D product deliverables in a virtual environment to save the time, budget, manpower, and misunderstanding in advance. PT developed a prototype sample and installed in IU factory. The preliminary test results were positive. For the pre-Intellectual Property (IP) registration, OM worked with the Legal Team, Business & Project Development Team and Robotic Team (Project Team) to apply the patent application in the ITF R&D project initial stage to protect the rights of Intellectual Property of the project in advance.

Figure 5. Gantt chart for the pilot implementation

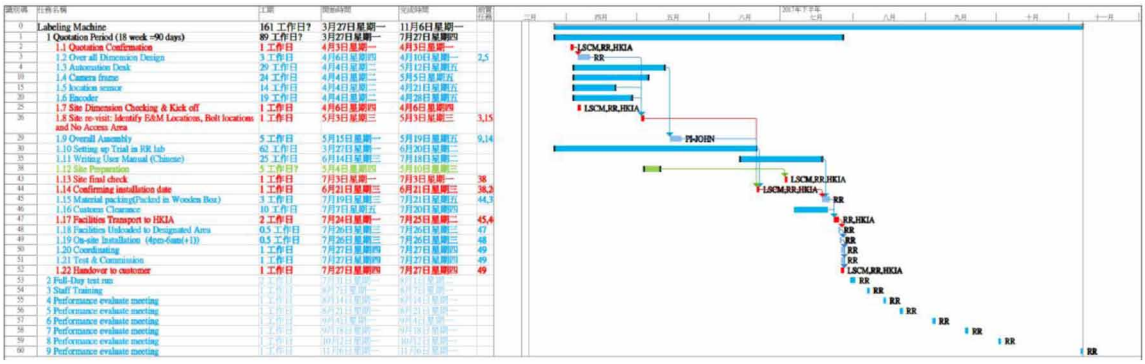
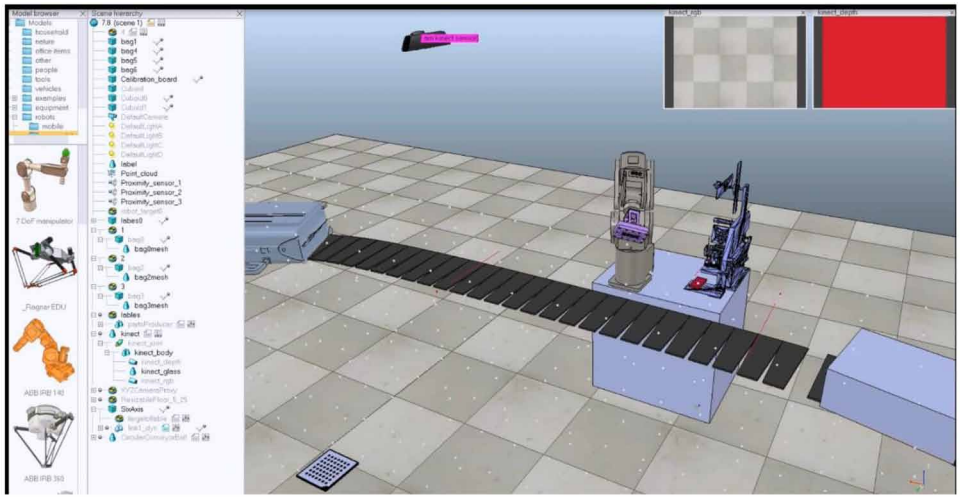


Figure 6. 3D modelling simulation



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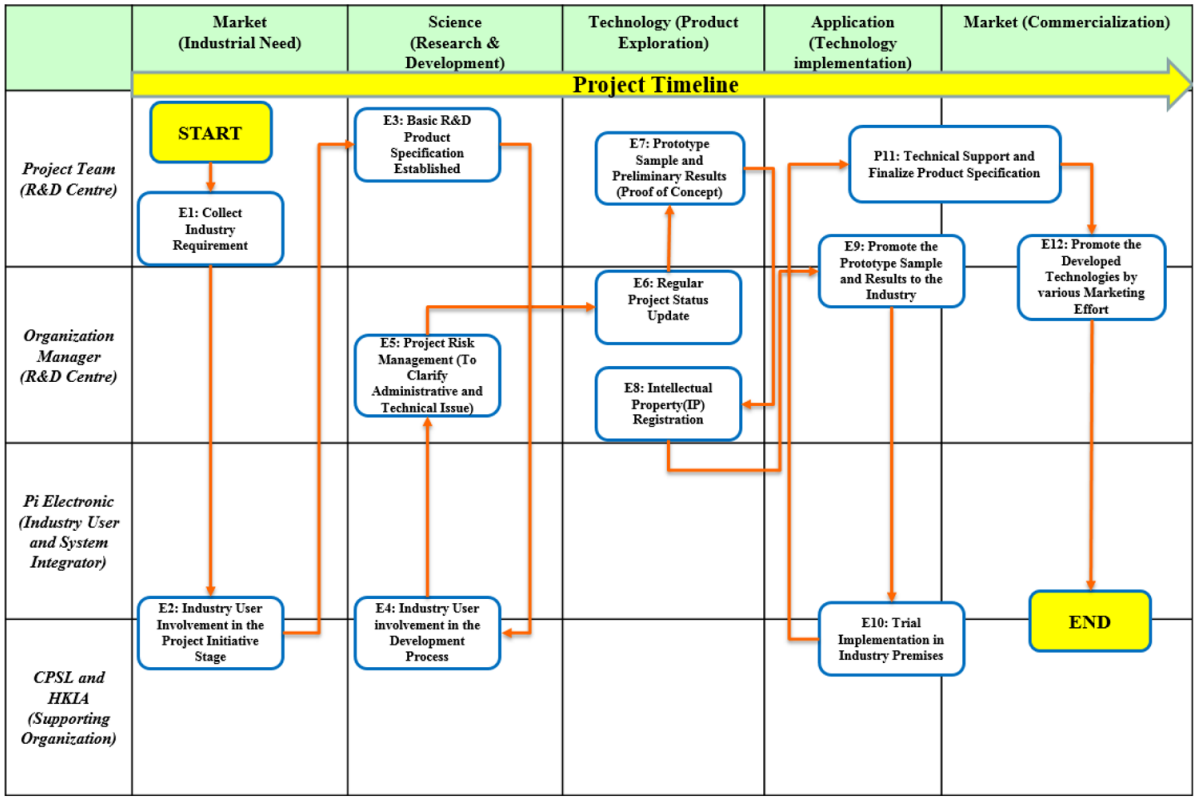
Phase 4: Application (Technology Implementation)

PT demonstrated the primary test results in Hong Kong International Airport (HKIA) Tecnovation Conference and Exhibition 2016 dated on 2 Nov 2016. Also, PT worked with Public Relations and Marketing team to publish an e-newsletter article to introduce detail of the R&D project deliverables to the industry. PT worked with pilot user to install the robotic automation system at HKIA for trial test. The trial results were positive and demonstrated the R&D deliverables to the public for attracting the IU's interest via the promotion activities.

Phase 5: Market (Commercialization)

PT provided the technical support to the IU and SI for technology transfer and pilot installation. The developed R&D project deliverables could be finalized and the product detail was listed in a document for helping the IU & SI to know how to use the robotic automation system. PT worked with the Public Relations & Marketing team to publish the news publishers to promote the R&D technology on various promotion channels such as newspaper, seminar, HKIA Tec novation Conference and Exhibition 2016, and LSCM summit 2017 etc. Table 8 was the detail break down of the project implementation approach and detail for the Project R. Figure 7 is the work flow diagram.

Figure 7. MSTAM methodology implementation roadmap of ITF R&D project



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Table 8. Case study implementation summary

Phase 1: Market (Industrial Need)					
Item	**Element**	**Date**	**Action**	**Description**	**Results (Hypotheses Test)**
E1	Collect Industry Requirement at the R&D Initial Stage	10-May-16	The project team discussed with supporting organization (CPSL and HKIA) to collect their expectation and requirement for product development.	1. Introduced the ITF R&D project idea to the industry user. 2. Collected the basic requirement from industry user.	CPSL and HKIA provided the supporting document and basic product requirement to the project team to support this ITF R&D project. **(H1 is supported)**
E2	Industry User Involvement in the R&D Project Concept Development Stage	29-Jul-16	The project team worked with a company (System Integrator and Industry user - Pi Electronic) to develop and test the basic function of the product in the China factory.	1. A basic simulation platform of software and hardware was assembled. 2. Some experiment was arranged to test the performance to prove whether the concept of R&D project is correct.	The project team, industry sponsors and SI were satisfied the preliminary test result. The preliminary data was tested and affirmative. **(H2a & H2b are supported)**
Phase 2: Science (Research & Development)					
Item	**Element**	**Date**	**Action**	**Description**	**Results**
E3	Basic R&D Product Specification Established in Science Stage of Research and Development	10-Aug-16	**Original Specifications** 1. A special-design picks and place end-effector 2. A multi-camera vision module 3. A hand and eye coordination prototype	1. The product specification was not concrete. 2. The project deliverables could not be measured and evaluated.	N/A
		11-Aug-16	**After Collected the Industry User Requirements Specification and Functional Specifications** **A) Specifications of the Hand-Eye Coordinator** 1. Closed loop embedded system: 64 bit microprocessor 2. I/O response: ≤100ms 3. Multi-thread processing capability 4. Power consumption: ≤80W 5. Operating temperature range: 0 ~ 55°C 6. Multiple camera connectivity 7. Data communication type: SPI, I2C or Modbus 8. Always ON (7/24) capability. **B) End-effector** 1. Suction loading: 20 ~ 100 gram 2. Supply pressure: ≥ 6 bar /85psi 3. Label size: ≥1 inch x 2 inch **C) Multi-camera vision module** 1. Multiple depth sensors to cover 2 or more sides of an object. 2. Each sensor's specification: 3. Resolution: >= 224x171 pixels 4. Depth max range: 3m. 5. FOV: Depends on lens. 6. The full system operates at controlled lighting environment	Basic user requirements specification and functional specification were developed.	Accountable and measurable product specification was developed. The project deliverables could be measured and quantifiable. **(H3 is supported)**
E4	Industry User Involvement in the Development Process	May 2017 to Nov 2017	The project team performed a primary test and simulation experiment in the Pi Electronic China factory. (Industry user & system integrator)	Pi Electronic provided the workplace, resources, equipment to support the project team to develop the project deliverables.	1. A primary results was positive and collected the data for further study 2. Reduced the error and development time. **(H4 is supported)**

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Table 8. Continued

E5	A Gatekeeper Identifies the Project Risk in Advance for Clarifying Administrative and Technical Issue in the R&D Project (Project Risk Management)	May 2017 to Sep 2017	The OM provided the administrative and technical support to the project team to identify the problem before project commencement. Project risk assessment could be identified in advance.	For example: budget items, project milestones, project deliverables, product specification, supporting document, detail cost break down and budget justification etc.	1. Reduced the communication time, misunderstanding, and duplicated work. All parties understanding were same in alignment. 2. Enhanced the product quality in the product initial development stage. 3. Eliminated the product development time 4. Alignment between R&D technologist and industry user **(H5a and H5c are supported)**
Phase 3: Technology (Product Exploration)					
Item	**Element**	**Date**	**Action**	**Description**	**Results**
E6	Regular Project Status Update and Unification Schedule Management	1st week of each month (From Nov 2016 to Jan 2018)	The OM checked with the project team the updated project status bi-weekly and ensured the project milestones were keep on track.	OM reviewed the response from the project team and evaluated the project status and results time by time.	1. Eliminated the project risk in advance. 2. Ensured the project progress was kept on track and alignment with R&D technologist and industry user. **(H5a is supported)**
E7	Prototype Sample and Preliminary Results (Proof of Concept)	25 Jul 2017 to 29 July 2017	The project team developed a 3D modelling simulation platform to test the product.	1. A 3D modelling simulation platform has been developed on 29 July 2017. 2. Some experiments and testing were performed in the China Factory.	1. The 3D modelling stimulation platform helps the R&D technologist and industry user easy to know the product. 2. Reduced the misunderstanding and communication issue. All people used same information for discussion. **(H5b and H6 are supported)**
E8	Pre-Intellectual Property (IP) Registration	Aug 2016 to Sep 2017	The OM worked with the Legal Team, Business & Project Development Team and Robotic Team to apply the patent application in the ITF R&D project initial stage.	The project deliverables detail, patent application method, time schedule, and proposed project deliverables specification, administrative and technical issues were clarified before patent application.	1. Faster the patent application time and patent filing process. 2. Until Dec 2017, the end effector of project deliverables was in patent pending stage. **(H7 is supported)**
Phase 4: Application (Technology Implementation)					
Item	**Element**	**Date**	**Action**	**Description**	**Results**
E9	Promote the Prototype and Results to the Industry	2 Nov 2016 & Dec 2016	1. The PT demonstrated the primary test results in HKIA Tecnovation Conference and Exhibition 2016 dated on 2 Nov 2016. 2. An e-newsletter article was posted for introducing the detail of the R&D project deliverables.	1. The PT set up a prototype of robotic automation system to show the R&D primary results to industry, government, and public sector. 2. A promotion article was listed out the detail of R&D deliverables and value to the industry by e-newsletter.	1. To attract more people to know the ITF R&D project deliverables 2. Simply the complicated technology to the industry user in a simple way and demonstrated the value to them for further adoption or commercialization. 3. Demonstrated the ITF R&D project deliverables to the potential users. **(H8a is supported)**

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Table 8. Continued

E10	Trial Implementation in Industry Premises	Early Sep 2017	The PT set up an automation robotic system is HKIA in early September 2017 for trial test.	The PT worked with trial user to install the robotic automation system at HKIA.	The Specification for the RGB-D vision module: Depth sensing: 640x480 depth solution Frame rate: 15FPS RGB resolution: 2048x1536 Pixel (3MP) The specification for the pneumatic end-effector for pick and place (baggage label): Shape: Rectangular Dimension: Length (104.5 mm), Width (43 mm), Thickness (0.3mm with the chip) Weight: 0.5125g RFID label sample photo:  The specification for the label affixing system: Place 12 to 15 label sticker to baggage per minutes Trial test results were positive. **(H8b and H9 are supported)**
Phase 5: Market (Commercialization)					
Item	**Element**	**Date**	**Action**	**Description**	**Results**
E11	Technical Support and Finalize Product Specification	Aug 2017 to Nov 2017	1. The PT provided the technical support to the IU and SI for technology transfer, system installation and trial implementation. 2. The PT finalized the R&D project deliverables in a document for helping the IU & SI to know how to use the robotic automation system. 3. The PT compiled a technical report to state the use cases and limitation of the proposed system for future industrial adoption.	1. The PT provided the technical support to IU and SI in the trial. 2. ITF R&D project deliverables specification had been developed.	1. Detailed product specification for potential users easy to adopt the developed technology had been developed. 2. To grasp the R&D deliverables in a short time. **(H10 is supported)**
E12	Promote the Developed Technologies by Various Marketing Effort	14 Sep 2017, 25 Sep 2017, 29 Sep 2017	The PT worked with Public Relations & Marketing team to work with the news publishers to promote the developed technology on the newspaper, seminar, and LSCM summit 2017.	The R&D technology results showed on LSCM summit dated on 14 Sep 2017 and newspaper dated on 25 Sep 2017 & 29 Sep 2017.	1. Received many inquiries for the robotic automation system from potential industry users after the promotion activities. 2. A few companies (including one supporting organization) was interested in commercialize the developed technologies The PT was being negotiated the commercialization plan with the potential users. 3. IU and SI were willing to apply a license and adopt the developed technology for further commercialization. **(H11 is supported)**

SUMMARY OF PILOT IMPLEMENTATION

To testify MSTAM methodology, an ITF R&D project pilot implementation was conducted. The pilot implementation is divided into 5 phases as Phase 1: Market (Industrial Need) Stage; Phase 2: Science (Research & Development) Stage; Phase 3: Technology (Product Exploration) Stage; Phase 4: Application

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(Technology Implementation) Stage; and Phase 5: Market (Commercialization) Stage. It demonstrates the MSTAM methodology in real case situation. The final results of the pilot implementation are supportive and positive. Table 8 is the detail break down of the project implementation approach and detail for the Project R. Figure 7 is the pilot implementation roadmap.

RESULTS AND ANALYSIS

A case study of *Project R* is studied to prove the proposed MSTAM model, and its associated elements, and hypotheses are feasible for enhancing the commercialization success of ITF R&D project to the Hong Kong's Logistics and Supply Chain Industry. The case study findings are summed up in Table 8. All project deliverables has been completed within the original project schedule. All project milestones, work tasks, budget are within the original proposal in order to enhance the user experience for helping the user to easily catch up the technology enabling in their corporate. By considering the aforementioned, 2 months project extension has been applied, defer the project completion date through 15 Jan 2018.

Refer to the Table 8, the research aims and objectives in Table 3 have been achieved. The results are supported in the case study. The determinants for R&D deliverables commercialization can be focused on 4 factors as time, control, quality and motivating. For the gap analysis of case study, the results of hypothesis 2a, 2b, 5a, 5b, 5c, 8a, 8b, and 10 are proved to solve the problem between each phase of the MSTAM model. The analysis detail is shown in Table 9. The detail of gap analysis for the case study is summarized in Table 8.

To conclude, the definition of commercialization success of ITF R&D projects in Hong Kong's Logistics and Supply Chain Industry is defined as the whole R&D project completed, the company starts of mass production, commercialized, licensed and adopted in the industry. In a case study, the trial user and system integrator were willing to apply a license and adopt the developed technology for further commercialization. The results support the MSTAM model, its associated elements and hypotheses are feasible.

DISCUSSION AND FURTHER ENHANCEMENT

It can be observed from the case study results shown that time factors, quality factors, control factors and motivating factors are the main critical factors affecting the ITF R&D projects commercialization in Hong Kong's Logistics and Supply Chain Industry. The results support the argument of past research, James Moultrie (2015), suggested that "*Design Demonstrator*" might to be taken a role of gatekeeper as multiple purposes in the innovation project early development stage to translate the scientific research progress from laboratory to the market. It can be aligned with the actual need of industry. Therefore, in order to enhance the commercialization success of ITF R&D projects to the industry, R&D technologist should strengthen the quality of R&D deliverables to fulfill the industry need and requirement for the core value of the R&D project. In the R&D project, it should have a role of gatekeeper or inspector to review the whole R&D operations process and correct it once the problem occurred.

Project risk response planning and identification before project commencement, it can captures the project risk interactions for predicting the bottle-neck point and high risk tasks of failure in the R&D

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Table 9. Case study summary of gap analysis of MSTAM model

Impact	Market to Science (M-S)		Science to Technology (S-T)			Technology to Application (T-A)		Application to Market (A-M)
	H2a	**H2b**	**H5a**	**H5b**	**H5c**	**H8a**	**H8b**	**H10**
Hypothesis	Hypothesis 2a: Industry user provides real market situation to help the R&D technologist explore the new idea of R&D project	Hypothesis 2b: Industry user involve in the R&D projects in the project initial stage, it can speed up the R&D development process	Hypothesis 5a: Regular project status update of the R&D project, it can reduce the communication issue among all stakeholders	Hypothesis 5b: The preliminary test result and prototype sample can help the industry user easy to understand the product for future commercialization and adoption	Hypothesis 5c: In the R&D project initial stage, I believe that define project risk in advance such as administrative and technical issue, it can eliminates the risk of project failure	Hypothesis 8a: The promotion activity can attract the industry users to know the R&D product value for commercialization	Hypothesis 8b: The R&D project trial implementation in the real industry premises, it can help the industry user to adopt the R&D deliverables	Hypothesis 10: Clear and detail R&D product specification can speed up the industry user to adopt the R&D deliverable
Quality Factors	Detail product specification was provided in the project initial stage	Eliminated the misunderstanding of the product quality	Eliminated the misunderstanding of the product quality in each product development period	Reviewed the prototype sample in advance and fine tuning	Risk assessment had been performed to identify the potential risk of ITF R&D project in the development period	Helped the IU cognition the benefit of the R&D deliverables	Guarantee the R&D deliverables in a high performance	Clear R&D deliverables specification to easy follow the developed technology by the Industry user
Time Factors	Reduced the misunderstanding and speeding up the development process	Development time can be reduced	Speeding up the development process	Reduced the technology transfer time to the industry	Identified the critical and bottleneck parts of ITF R&D project and solve those issues before project commencement	Through different marketing activities to launch the developed technology in a short time	Reduced the installation, testing and set up time of R&D deliverables	Improved the communication between Industry user and R&D Technologist. The installation and setup time can be reduced.
Control Factors	The R&D deliverables can be quantifiable and measurable	Improved the communication between demand side and supply side.	Monitoring the R&D deliverables are kept on track and schedule	Secured the R&D deliverables quality in user accepted level	Evaluated the key project milestones in each project period to ensure the R&D deliverables are kept on time and beneficial to the industry	Ensured the marketing activities are effective to launch the R&D deliverables to the market	Inspected all project milestones and deliverables are same as original proposal	Reduced the misunderstanding and installation time.
Motivating Factors	Motivated the IU to adopt the R&D deliverables	Motivated the IU interest to use the R&D technology	Provided the confidence to all stakeholders	Promoted the preliminary results to the industry in advance	Established a clear roadmap for all stakeholders to work in the R&D project process	Promoted the R&D deliverables to the Industry effectively	Real case demonstration to prove the value of the R&D deliverables	IU and SI were clearly known the R&D deliverables and how to use it in the firm
Final Results for Gap Analysis in Pilot Implementation	To alleviate the gap from Market stage to Science stage. **(Hypothesis 2a is supported.)**	To alleviate the gap from Market stage to Science stage. **(Hypothesis 2b is supported.)**	To alleviate the gap from Science stage to Technology stage. **(Hypothesis 5a is supported.)**	To alleviate the gap from Science stage to Technology stage. **(Hypothesis 5b is supported.)**	To alleviate the gap from Science stage to Technology stage. **(Hypothesis 5c is supported.)**	To alleviate the gap from Technology stage to Application stage. **(Hypothesis 8a is supported.)**	To alleviate the gap from Technology stage to Application stage. **(Hypothesis 8b is supported.)**	To alleviate the gap from Application stage to Market stage. **(Hypothesis 10 is supported.)**

project development processes in advance, so that the project failure risk can be eliminated. Chao et al. (2013) also agreed the risk response planning in large engineering projects to identify potential response action for optimizing the risk response plan once the problem occurred. W. K. Wan and S. Monsef (2012) proposed four distinct elements in the process of developing a new product; these are Planning, Development, Marketing and Commercialization. These elements can be applied in the ITF R&D project to support the MSTAM methodology. Developing a new high quality product faster to the market and at a lower cost, supplier contribution to the product development was essential. (Janet L et al. 1997) This helped collecting the multiple stakeholder perspective to explore the R&D product to the industry that make certain the developed technology is beneficial to the industry for increasing the commercialization opportunity.

To sum up the finding, a summary of operations comparison between current operations and applied MSTAM methodology in ITF R&D projects are listed in Table 10. There are 14 critical items and deployment of work tasks are difference. Comparing between current operations and applied the MSTAM methodology in the ITF R&D project, the results are shown in Table 10. The R&D technologist use the MSTAM methodology in the ITF R&D projects, the rate of adoption and commercialization opportunity to the market can be increased. The applications of robotics technologies will potentially help re-industrialize Hong Kong's Logistics and Supply Chain Industry and foster E-commerce Industry.

Table 10. Operation comparison between current operation vs applied MSTAM Model for ITF's seed project

Operation Comparison between Current Operation vs Applied MSTAM Model for ITF's Seed Project			
Item	**Description**	**Current Operation**	**Applied MSTAM Model**
1	Collect Industry Requirement at the R&D Initial Stage	No	Yes
2	Industry Sponsorship	No	No
3	Industry User Involvement in the R&D Project Concept Development Stage	No	Yes
4	Basic R&D Deliverables Specification	No	Yes
5	Project Risk Assessment in the Proposal Stage	No	Yes
6	Industry User Involvement in the R&D Process	No	Yes
7	Regular Project Status Update and Unification Schedule Management	No	Yes
8	Prototype Sample and Preliminary Results (Proof of Concept) in the Middle Stage of R&D Process	No	Yes
9	Pre-Intellectual Property (IP) Registration	No	Yes
10	Promote the Prototype and Results to the Industry	No	Yes
11	Trial Implementation in Industry Premises	No	Yes
12	Technical Support and Finalize Product Specification	No	Yes
13	Promote the Developed Technologies by various Marketing Effort	No	Yes
14	Further Enhancement of Project Deliverables	No	Yes
15	Developed Project Deliverables License to Industry	No	Yes

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Further Enhancement

To enhance the rate of developed R&D deliverables commercializing and productizing to different industry application, the project team discussed with potential users in the different promotion activities to collect their industry need for the project team to develop the extra function in another application. Figure 8 is the original design of the robotic hand of *Project R*.

In order to apply the developed technology in different application, the project team was taken the feasibility stamping application during Nov 2017 to Jan 2018 for exploring multi-camera vision module for stamping automation. The project team find tune the system and design, the tailor made stamping robotic hand module applied in the *Project R*. This was an extra function for this project and this additional function can help to extend the rate of adoption opportunity in the industry. Figure 9 is the modification of robotic hand. This stamping automation function (See circle in Figure 9) can be replaced the existing manual handling work in different industry.

Figure 8. Original design of robotic hand

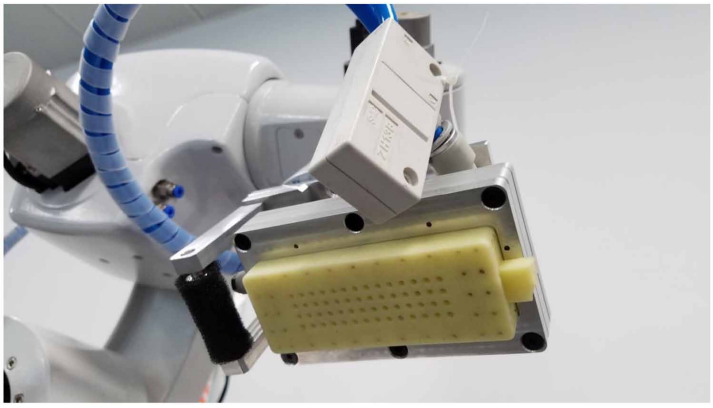
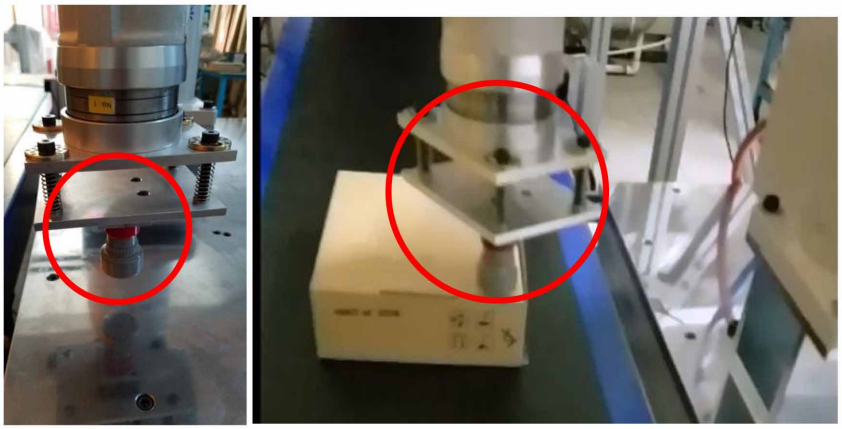


Figure 9. Improvement and modification of robotic hand



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Chapter 16
Data-Driven Decision Making to Select Condition-Based Maintenance Technology

María Carmen Carnero-Moya
University of Castilla-La Mancha, Spain & Universidade de Lisboa, Portugal

ABSTRACT

Condition-based maintenance (CBM) may be considered an essential part of the Industry 4.0 environment because it can improve production processes through the use of the latest digital technologies. The literature includes a large number of contributions on new techniques for diagnosis, signal treatment, analysis of technical parameters, and prognosis. However, to obtain the expected benefits of a vibration analysis program, it is necessary to choose the instruments and introduction process best suited to the organization, and so guarantee the best results using data-driven decision making in accordance with the needs of Industry 4.0. Despite the importance of these decisions, no relevant models are found in the literature. This contribution describes a fuzzy multicriteria model for choosing the most suitable technology in vibration analysis. The goal is to create a model that is easy for organizations to use, and which reflects the judgements of a number of experts in maintenance and vibration analysis. The model has been applied to a Spanish state-run healthcare organization.

INTRODUCTION

As described in OECD (2017), Industry 4.0 has to do with the application in industrial production of the latest digital technologies, generally interconnected, to achieve new or more efficient processes.

These new technologies include big-data analytics, cloud computing and the Internet of Things (IoT), and will involve a huge digital transformation in companies, affecting the whole value chain. This transformation could lead to benefits in products, processes and business models. However, logistic and support processes for production, which include asset management, could also be a target for the application of Industry 4.0, as they have a very important role in improving the productivity of industrial processes, and even in creating new services with high value added for the customer. For example, by

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setting up an automatic on-line predictive data acquisition system in an organization, sending the data instantaneously to the supplier of the critical device for remote analysis of the state of the equipment, allowing early detection of anomalies and faults which might diminish the quality of the product and affect productivity (Ferreiro, Konde, Fernández, & Prado, 2016).

Thus, condition-based maintenance can be seen to be an essential component of Industry 4.0 due to its ability to improve production processes by the use of the latest advances in digital technologies. For example, automatic learning can be achieved via the Industrial Internet of Things (IIoT).

The predictive maintenance software collects data which is transferred and analyses using predetermined rules and conditions. This automatic analysis provides a large quantity of data, which can be analysed by Big Data, allowing the company to be alerted to inefficiencies and future breakdowns in real time. The whole process requires automatic connection of all the data, both the process data and predictive data, and so an interconnection of the software used in the company is also needed, such as the Computerised Maintenance Management System (CMMS) or Enterprise Resource Planning (ERP).

This chapter describes a model for introducing advanced predictive technologies in industry, especially in the kinds of businesses, like health care organizations, which are very out-dated with respect to the energy, manufacturing, transport etc. industries with regard to the use of predictive techniques and the integration with on-line platforms for maintenance management. This favours:

- Adapting to demand for care services, providing the number of services requested, as assets are available at the time of need.
- Attending to patients with fewer delays, waits or cancellations of appointments due to unavailability of assets.
- More personalised attention to patients.
- More efficient use of resources.

Vibration analysis can be of great benefit to an organization. These benefits include improvements in availability of facilities and equipment, and in the quality of manufactured products and components, meeting delivery times, improvements in operational safety, reductions in maintenance costs (equipment and labour), reductions in inventory and energy consumption, as well as contributing to gaining and retaining ISO 9000, QS 9000, and other certifications, providing the ability to check the quality of maintenance activity, savings in machine replacements due to longer-lived machines, and improvements in business sustainability (reduction in material and human resources, avoidance of obsolescence of spares, decrease in pollutant spillage, protection of human resources from unexpected faults, etc.) (Bari, Deshpande, & Patil, 2015; Carnero, 2005; Carnero, Gónzalez-Palma, Almorza, Mayorga, & López-Escobar, 2010; Carnero, López-Escobar, González-Palma, Mayorga, & Almorza, 2015; Carvalho, Gomes, Schmidt, & Brandão, 2015; Charray, 2000; Jardine, Lin, & Banjevic, 2000; Mobley, 2001; Precup, Angelov, Costa, & Sayed-Mouchaweh, 2015). This all leads to an increase in profitability. Furthermore, manufacturers can now include diagnostic and prognostic services for the machinery they sell, which is seen as a competitive advantage.

Vibration analysis is the most commonly used predictive technique (Mahmood, 2011), as it is the most versatile, and can be applied to a wide variety of machines and diagnose a large number of faults and failures (Khwaja, Gupta, & Kumar, 2010). There is also the possibility of developing an automatic diagnostic system based on a pattern recognition technique or an amplitude modulation detector (Yang, 2015).

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Although there are many contributions in the literature on new techniques for diagnostics, prognostics or fault prediction related to vibration analysis, there are, nonetheless, important deficiencies in the matter of decision making for the introduction of predictive maintenance programmes. Therefore, this chapter describes an objective model built with the fuzzy Analytic Hierarchy Process (FAHP) for choosing the most suitable technology in portable vibration analysers. The goal is to create an easy-to-use model that takes into account the fact that judgements are often based on ambiguous, imprecise or inadequate information. The model includes judgements from various decision groups, experts in the field of vibration analysis. The model has been applied to a Health Care Organization.

This model could be applied by the managers, maintenance managers, engineers and scientists responsible for buying technology related to predictive maintenance, not only vibration analysis but also other predictive techniques such as lubricant analysis or thermography. This model could serve as an example in their decision process. Some criteria, weights, procedures, etc. could be applied or the model could be modified or updated with additional criteria to adapt it to the specific needs of each organization.

Furthermore, the technologies ultimately applied are selected through an advanced decision-making process which is not based on intuition or suggestions from the suppliers of predictive technologies; that is, they are based on data-driven decision making.

This chapter is structured as follows. Firstly, there is a literature review on the application of MCDA techniques in vibration analysis. Next is a description of the multi-criteria model for assessing vibration analysers, with special attention to its application to a Health Care Organization. Then come the conclusions, acknowledgements and references.

BACKGROUND

The choice of technology should take into account economic, technical, environmental, human resource and political matters. These questions may be addressed simultaneously by applying Multi-Criteria Decision Analysis (MCDA) techniques. Furthermore, these techniques allow the decision problem to be modelled objectively, by facilitating compromise solutions when the criteria clash (Munda, Nijkamp, & Rietveld, 1994) and enabling large quantities of data, uncertainties, relations, objectives, stakeholders, decision makers, etc., to be included in the model. All of which leads to better acceptance by management of the solution given by the model (Huang, Keisler, & Linkov, 2011).

There is an extensive literature on the state of the art in sensors and vibration analysis instrumentation (Harris & Piersol, 2002; Randall, 2011; Scheffer & Girdhar, 2004). There is an important lack, however, of models that enable technological decision making in vibration analysis. Selcuk (2016) describes the latest trends in the introduction of predictive maintenance, considering recent breakthroughs in information and communication technology, the internet of things and radio-frequency identifications. These new technologies allow remote maintenance and e-maintenance to be used in predictive maintenance activities in unsafe working environments and scattered locations.

The literature on MCDA techniques in predictive maintenance includes the following notable contributions. Carnero and Hidalgo (2003) describe a system which combines activity-based cost and AHP to assess the costs and benefits in a PMP. Carnero (2005) uses AHP with factor analysis to build a model that allows a choice of diagnostic techniques and instrumentation to be made in predictive maintenance when vibration analysis and lubricant analysis are applied independently, and when they are used together. Carnero (2006) develops an assessment system combining AHP and an expert rule-

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based system to analyse the feasibility of introducing a programme of predictive maintenance (PMP) and the organization's need for it. Carnero (2007) uses AHP to make the choice of the best predictive technique, from vibration analysis, lubricant analysis or the integration of both techniques. Decision making depends on the technological level of the PMP, there being four levels, from the simplest, which uses almost no instrumentation, to the most complex, which uses the latest developments in diagnosis for each technique. The model has been applied to companies including a petrochemical plant, a food business, a pharmaceutical company and a machinery manufacturer. A similar decision process is described in Carnero (2009), but with the addition of AHP, utility functions and discrete probability distributions. Holbert and Lin (2012) use fuzzy logic with the goal of carrying out diagnostic monitoring to data acquired from instrumentation within operating electric power facilities. Bana e Costa, Carnero, and Duarte (2012) describes a thermography-based audit of a PPM with the Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) approach. This audit allows the global state of the introduction of PMP to be obtained, as well as a valuation in the areas of strategy, control, technical aspects, etc. Sofuoglu and Orak (2015) apply regression models to determine the criteria weightings to be used in the model, built by the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) for chatter vibration prevention; the result is that number of revolutions and workpiece hardness are the most effective parameters. Nematkhah et al. (2017) presents a three-stage strategy for choosing the most suitable predictive technique, using a hybrid fuzzy DEMATEL-fuzzy ANP approach; next, the effectiveness of the predictive maintenance program is evaluated with a simple average weighting method.

DATA-DRIVEN DECISION MAKING MODEL TO SELECT CONDITION BASED MAINTENANCE TECHNOLOGY

The model described in this chapter uses FAHP to include uncertainty, vagueness or ambiguous situations in the judgements given by the decision makers. Also, the decision makers prefer to use linguistic expressions rather than a crisp number because it is difficult to give an exact value when giving judgements in the decision process (SeongKon, Gento, SangKon, & JongWook, 2011). Additionally, FAHP is able to divide complex decisions into a hierarchical system of elements, which makes decision making easier. The use of pairwise comparisons allows a ratio scale of measurement to be obtained, and so more precise information about the preferences of decision makers can be generated. FAHP has a system for assessing the consistency of judgements given by the decision makers (Liberatore & Nydick, 2003), and this technique can be easily understood by those responsible for making the final decision.

Structuring

The choice of decision criteria for the model made use of the literature recommending different areas to which attention must be paid when choosing technology for predictive maintenance (Ballesteros, 2014; Daza, 2007; Veldman, Klingenberg, & Wortmann, 2011). Information from suppliers of vibration analysers was also considered, as was the literature on the selection of policies and technologies not relevant to vibration analysis (Gossens & Basten, 2015; Ivlev, Vacek & Kneppo, 2015), and articles evaluating supplier selection (Chitcharoen, Kanthawongs, Wathanasuksiri, & Kanthawongs, 2013; Lee, Cho, & Kim, 2015).

The proposed criteria and subcriteria for vibration analyser selection are (Carnero, 2015):

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1. **Hardware characteristics (HARD): (**specifications common to all devices on the market, such as a tachometer and sensors for data acquisition, as they do not the field of choice for devices):
   a. Electrical and electronic parameters (ELEC). A series of characteristic parameters of vibration analysers is studied, such as: input type (acceleration, velocity, displacement, any non-vibration AC voltage integration (single, double full digital integration)), number of channels, dynamic range, frequency range, spectrum range, spectrum lines, speed range and signal/noise ratio.
   b. Computer parameters (INFO). A set of characteristics related to the computational features of the device must be considered, including: the processor, storage capacity of hard disk, storage capacity of RAM, communication/interface systems, and battery life.
   c. Diagnostic functions (DIAG). Functions that the analyser can perform are analysed, such as real-time FFT, waterfalls, envelope demodulation, spike energy, etc.
   d. Hardware utilities (HAUT). The existence of the following utilities in the device is evaluated: data acquisition in pre-programmed routes, the possibility of using cloud monitoring systems, lubrication control, sound pickup, impact tests, measurement in slower machines, noise analysis (thirds of octave) and the possibility of taking photos.
2. **Software Characteristics (SOFT):** This includes the subcriteria:
   a. Software diagnostic functions (SODF). These are functions that allow reliable diagnoses to be obtained, for example, representing trends in different parameters, advanced diagnostic tools for turbomachinery, time and spectrum signal analysis, etc.
   b. Software utilities (SOUT). These are utilities related to the management or programming of predictive activities, such as the capacity to be integrated with other predictive techniques, the possibility of managing the inspection routes, exporting to Excel, compatibility with different versions of Windows, solutions for multi-terminal network.
3. **Price (PRIC):** The purchase price of the analyser and the necessary instrumentation is evaluated, along with the support services generally included with the analyser.
4. **Human Resource Characteristics (HUMA):** This has two subcriteria:
   a. Ease of handling (EASE). This evaluates characteristics of the device which make it easier to use, such as being light, free of wires, and easy to handle during data acquisition and real-time diagnosis.
   b. Training required (TRAI). This subcriterion analyses the amount of training necessary to bring in a given analyser, taking into account the previous know-how in the organization.
5. **Reputation (REPU):** The testimonials or references obtained from other companies are very useful in the when choosing a technology supplier, together with a list of organizations that have introduced similar technology, the assessments of other users of the analyser, and the financial situation of the supplier (Lee et al., 2015).
6. **Service Level (SERV):** This criterion is divided into the following subcriteria:
   a. Warranty period and coverage (WARR). Both the length of the guarantee provided by the manufacturer and the quality of the cover are considered.
   b. Repair and calibration (REPA). This evaluates the capability of the provider to offer quick repair and calibration services, using a variety of standards and including a general check of the analyser, verifying measurements and adjusting calibration parameters, checking deviation from normal sensitivity of the accelerometer, checking the sensor cables, checking and changing the battery if it does not pass the performance checks.

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c. Support Service (SUPP). A support service is essential when purchasing a vibration analyser (Chitcharoen et al., 2013). These services should be set out in a Service Level Agreement (SLA). This subcriterion assesses two areas:
   i. Diagnosis and prognosis support (SUDP). This diagnostic service allows a second opinion to be taken, for example, on certain particularly complex faults, as well as on-site or remote support for problem solving, continuous access to knowledge data-bases with articles, interactive services, practical guides, etc., or training courses on vibration analysis.
   ii. Hardware and software support (SUHS). The quality of on-site, telephone, email, etc. support of the provider or manufacturer to solve problems related with the software which accompanies the vibration analyser is assessed, as is the provision of training courses on the working of the hardware and software.

d. After sales service utilities (AFTE). This subcriterion assesses the additional services provided by the supplier, such as: extension of the guarantee period, provision of spare equipment during reparation or calibration, flexibility in giving technical assistance, updates of the analyser and diagnostic software, hardware updates when new specifications, standards or laws appear that require them. Provision of tools Software as a Service (*SaaS*), etc.

7. **Remaining Useful Life of Technology (REMA):** The technology is analysed to see whether it is fully matured, and so is reliable, although it should be in the decline stage, likely to be replaced in the short term with other models of analyser.
8. **Adaptation to the Organization (ADAP):** This criterion assesses the capacity to adapt of the vibration analyser technology with respect to the hardware and software already used in the company. This includes:
   a. Compliance with safety (CSAF). The purchased device should be able to be used without risk in facilities with explosive atmospheres, and so should comply with current legislation on the matter in the country of use.
   b. Compatibility with data acquisition systems and maintenance management (COMP) already used in the organization. These systems use SCADA systems and Computerised Maintenance Management Systems (CMMS), as well as the possibility of using other data acquisition devices already used by the organization.

These criteria and subcriteria have the following important features; they are: concise, exhaustive, non-redundant, made operational with performance descriptors and independent.

The hierarchy of the multi-criteria model is shown in Figure 1.

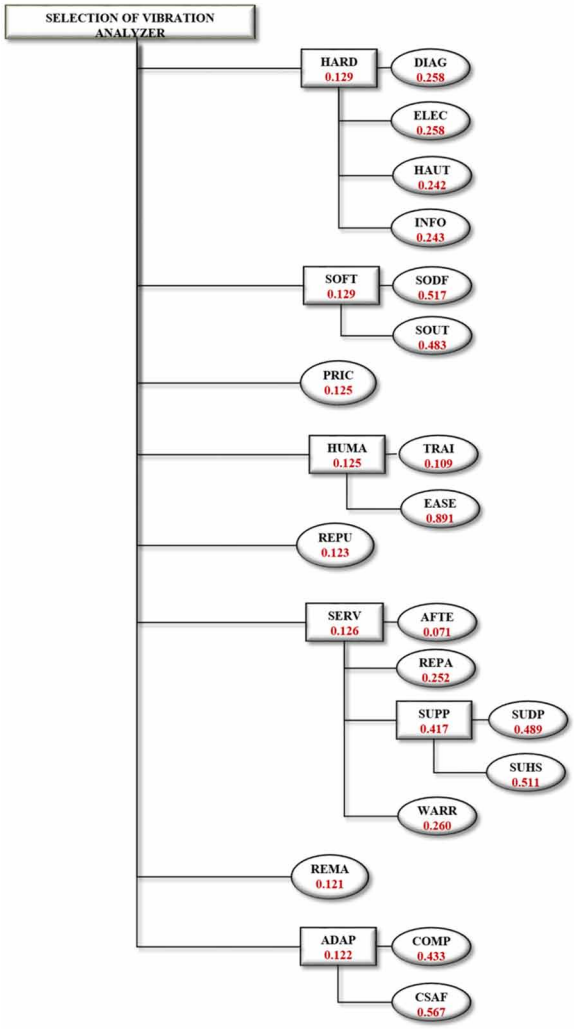
A descriptor has been defined for each subcriterion. A descriptor is an ordered set of possible impact levels which allows each alternative to be objectively evaluated (Bana e Costa, Correa, De Corte, & Vansnick, 2002). Most of the descriptors defined in the model are qualitative and constructed. Table 1 shows the descriptor associated with the criterion Training required as an example.

Weighting Process

The weightings of the criteria and of the scale levels for each indicator must be obtained from the fuzzy judgements matrix $\tilde{A}$. This matrix has as elements the fuzzy comparison values $\tilde{a}_{ij}$, which express the

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Figure 1. Hierarchy
(Carnero, 2015)



decision-maker's opinion about the relative importance of element *i* over element *j* at the same level of the hierarchy. The weightings between the criteria and the scale levels of each indicator are obtained from the fuzzy judgements matrix $\tilde{A}$ shown in Equation (1).

$$\tilde{A} = (\tilde{a}_{ij})_{nxm} = \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \ldots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & (1,1,1) & \ldots & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \ldots & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \ldots & (1,1,1) \end{bmatrix} \quad (1)$$

with

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Table 1. Scale levels of descriptor associated to criterion Training required

Level of performance	Scale levels
L1 (highest level of performance)	The organization has a previous model of the same manufacturer with software and hardware that have similar procedures. The analyser has automatic setup and an intuitive interface. It is adapted to allow fast data gathering by non-expert users with feedback. It has diagnostic tools such as colour codes to show test status, invalid or abnormal measurements, and machinery condition.
L2	The organization has a previous model from the same manufacturer with software and hardware that have similar procedures. The analyser does not have automatic setup and an intuitive interface. It is adapted to allow fast data gathering by non-expert users with feedback. It has diagnostic tools such as colour codes to show test status, invalid or abnormal measurements, and machinery condition.
L3	The organization has a previous vibration analyser, but not from the same manufacturer, although the software and hardware use procedures with some similarities. The analyser does not have automatic setup and an intuitive interface. Data gathering requires expert staff. It has diagnostic tools such as colour codes to show test status, invalid or abnormal measurements, and machinery condition.
L4	The organization has a previous vibration analyser, but not from the same manufacturer, although the software and hardware use procedures with some similarities. The analyser does not have automatic setup and an intuitive interface. Data gathering requires expert staff. It has diagnostic tools such as colour codes to show test status, invalid or abnormal measurements, and machinery condition.
L5 (lowest level of performance)	The organization has not previously used predictive maintenance. The analyser does not have automatic setup and an intuitive interface. Data gathering requires expert staff and does not have tools to control the validity of the data collected, nor automatic diagnostic tools.

Source: (Created by the author)

$$\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$$

and

$$\tilde{a}_{ij}^{-1} = (1/u_{ij}, 1/m_{ij}, 1/l_{ij})$$

for i,j=1, 2, …, n and i≠j.

To perform the fuzzy pairwise comparisons of $\tilde{A}$, three experts in vibration analysis were asked to evaluate the importance of the criteria and subcriteria using the fuzzy scale shown in Table 2.

The geometric mean is applied to aggregate the judgements of the three experts. Table 3 shows the pairwise comparison matrix of aggregated judgements of the three experts for the subcriteria of the Hardware characteristics criterion.

The value of the fuzzy synthetic extent with respect to the *i*-object $\tilde{S}_i$ is obtained by applying Equation (2) (Chang, 1996).

$$\tilde{S}_i = \sum_{j=1}^{m} \tilde{a}_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{a}_{g_i}^{j} \right]^{-1} \tag{2}$$

with $\tilde{a}_{ij}$ the triangular fuzzy number of the decision matrix $\tilde{A}$ with n objects and m goals.

The values of fuzzy synthetic extents for the subcriteria of Hardware characteristics criterion after applying a normalization process are:

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Table 2. Definition of fuzzy scale numbers

Linguistic scale	Fuzzy number
Equally important	(1,1,1)
Judgement values between equally and moderately	(1,2,3)
Moderately more important	(2,3,4)
Judgement values between moderately and strongly	(3,4,5)
Strongly more important	(4,5,6)
Judgement values between strongly and very strongly	(5,6,7)
Very strongly more important	(6,7,8)
Judgement values between very strongly and extremely	(7,8,9)
Extremely more important	(8,9,9)

(Zhu, Jing, & Chang, 1999)

Table 3. The pairwise comparison matrix of subcriteria of Hardware characteristics criterion.

	DIAG	ELEC	INFO	HAUT
DIAG	(1, 1, 1)	(1.260, 1.442, 1.587)	(1.260, 2.289, 3.302)	(2.289, 3.302, 4.309)
ELEC	(0.630, 0.693, 0.794)	(1, 1, 1)	(1, 1.587, 2.080)	(1.260, 2.289, 3.302)
INFO	(0.303, 0.437, 0.794)	(0.480, 0.630, 1)	(1, 1, 1)	(1, 1.260, 1.442)
HAUT	(0.232, 0.303, 0.437)	(0.303, 0.437, 0.794)	(0.693, 0.794, 1)	(1, 1, 1)

Source: (Created by the author)

$$\tilde{S}_{DIAG} = \left(\frac{1.042}{6.674}, \frac{1.337}{5.177}, \frac{1.620}{4.148}\right) = \left(0.156, 0.258, 0.391\right)$$

$$\tilde{S}_{ELEC} = \left(\frac{1.029}{6.674}, \frac{1.334}{5.177}, \frac{1.636}{4.148}\right) = \left(0.154, 0.258, 0.394\right)$$

$$\tilde{S}_{INFO} = \left(\frac{1.028}{6.674}, \frac{1.257}{5.177}, \frac{1.715}{4.148}\right) = \left(0.154, 0.243, 0.413\right)$$

$$\tilde{S}_{HAUT} = \left(\frac{1.049}{6.674}, \frac{1.249}{5.177}, \frac{1.703}{4.148}\right) = \left(0.157, 0.241, 0.411\right)$$

It is then necessary to calculate the degree of possibility between two fuzzy synthetic extents $\tilde{S}_2 = (l_2, m_2, u_2) \geq \tilde{S}_1 = (l_1, m_1, u_1)$ from Equation (3), and $V(\tilde{S}_2 \geq \tilde{S}_1)$ and $V(\tilde{S}_1 \geq \tilde{S}_2)$ must be calculated.

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$$V(\tilde{S}_2 \geq \tilde{S}_1) = hgt(\tilde{S}_1 \cap \tilde{S}_2) = \mu_{\tilde{S}_2}(d) = \begin{cases} 1, & if\ \ m_2 \geq m_1 \\ 0, & if\ \ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \quad (3)$$

where *d* is the ordinate of the highest intersection point between $\mu_{\tilde{a}_1}$ and $\mu_{\tilde{a}_2}$.

$V\left(\tilde{S}_{DIAG} \geq \tilde{S}_{ELEC}\right) = 1,$

$V\left(\tilde{S}_{DIAG} \geq \tilde{S}_{INFO}\right) = 1,$

$V\left(\tilde{S}_{DIAG} \geq \tilde{S}_{HAUT}\right) = 1,$

$V\left(\tilde{S}_{ELEC} \geq \tilde{S}_{DIAG}\right) = 1,$

$V\left(\tilde{S}_{ELEC} \geq \tilde{S}_{INFO}\right) = 1,$

$V\left(\tilde{S}_{ELEC} \geq \tilde{S}_{HAUT}\right) = 1,$

$V\left(\tilde{S}_{INFO} \geq \tilde{S}_{DIAG}\right) = 0.945,$

$V\left(\tilde{S}_{INFO} \geq \tilde{S}_{ELEC}\right) = 0.945,$

$V\left(\tilde{S}_{INFO} \geq \tilde{S}_{HAUT}\right) = 1,$

$V\left(\tilde{S}_{HAUT} \geq \tilde{S}_{DIAG}\right) = 0.938,$

$V\left(\tilde{S}_{HAUT} \geq \tilde{S}_{DIAG}\right) = 0.938,$

$V\left(\tilde{S}_{HAUT} \geq \tilde{S}_{DIAG}\right) = 0.992$

The values of fuzzy synthetic extents are compared and the degree of possibility of $V(\tilde{S}_j \geq \tilde{S}_i)$ is calculated using Equation (4).

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$$V(\tilde{S} \geq \tilde{S}_1, \tilde{S}_2, ..., \tilde{S}_k) = V(\tilde{S} \geq \tilde{S}_1)$$

and

$$V(\tilde{S} \geq \tilde{S}_2)$$

and

…

and

$$V(\tilde{S} \geq \tilde{S}_k) = \min V(\tilde{S} \geq \tilde{S}_i), \quad i = 1,2,...,k \tag{4}$$

Applying the subcriteria of the criterion Hardware characteristics gives the minimum degrees of possibility:

$$\min V\left(\tilde{S}_{DIAG} \geq \tilde{S}_i\right) = 1,$$

$$\min V\left(\tilde{S}_{ELEC} \geq \tilde{S}_i\right) = 1,$$

$$\min V\left(\tilde{S}_{INFO} \geq \tilde{S}_i\right) = 0.945,$$

$$\min V\left(\tilde{S}_{HAUT} \geq \tilde{S}_i\right) = 0.938.$$

If $d'(A_i) = \min V(\tilde{S}_i \geq \tilde{S}_j)$ for i,j= 1, 2, …, k; k≠j, the weight vector is given by Equation (5).

$$W' = (d'(A_1), d'(A_2), ..., d'(A_k))^T \tag{5}$$

Finally, W is obtained by normalizing W' .

In the example described, the resulting normalized non-fuzzy weight vector is $W\left(DIAG, ELEC, INFO, HAUT\right) = \left(0.258, 0.258, 0.243, 0.242\right)$.

Inconsistencies in the judgements given by the experts are quantified by the consistency index (CI) shown in Equation (6) (Saaty, 1980).

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{6}$$

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The consistency ratio (CR) is calculated from Equation (19), in which the random consistency index (ICR) is generated by a random matrix of similar dimension to that evaluated.

$$CR = \frac{CI}{ICR} \tag{7}$$

If CR is less than 0.05 for a 3x3 matrix, 0.08 for a 4x4 matrix and 0.1 for matrices of higher order, then the judgement matrix is consistent (Saaty, 2001).

In the fuzzy environment, the crisp value m_{ij} is used to calculate CI in each pairwise comparison matrix (Meixner, 2009).

The CR obtained by the matrix for the subcriteria of Hardware characteristics is 0.

A similar process was carried out for the criteria of the model, and the subcriteria of the other criteria, giving consistent results. The remaining weightings of the criteria and subcriteria can be seen in Figure 1.

SOLUTIONS AND RECOMMENDATIONS

The model described was applied in a Health Care Organization, where vibration analysis could improve quality of care considerably by reducing cancellations of diagnostic tests, visits, treatments and improving safety of patient care and of hospital visitors.

Eight vibration analysers were tested, three of which, from one supplier and two different manufacturers, are codified as A, B and C; one of these analysers is from another manufacturer and is codified as D, three analysers of different technological levels are from another manufacturer and are codified as E, F and G, and finally there is one model from a different manufacturer to all the others, codified as H. The brands and models of the analysers are not given, so as not to publicize a given brand and to guarantee the confidentiality of the study.

Each analyser was assessed by assigning it one of the scale levels available for each descriptor. For some analysers, the information is incomplete or imperfect for evaluating certain descriptors; this was solved by the use of probability distributions, allowing the model to be assessed using the most probable values. A Monte Carlo simulation was used to compute the uncertainty. 5,000 trials were applied and a random number seed of 10,000.

The statistical results obtained are shown in Table 4. The model produced the results, including the uncertainties, shown in Figure 2.

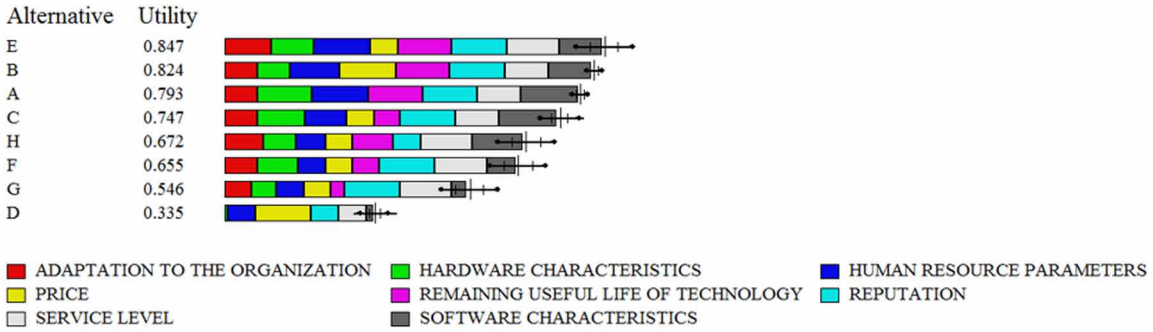
A sensitivity analysis was performed to guarantee the robustness of the model. This analysis modifies the weightings assigned to the model criteria coherently, in order to assess the changes produced in the ranking of vibration analysers. An increase and decrease of 5% was made to all the weightings of the criteria. There is no change in the ranking of analysers, with the following exceptions. There is a switch in the classification of analysers B and A when the weighting for the criterion Price is decreased to 9% or less (originally the weighting was 12.5%). Weightings of 9% and below are, however, considered too low for the criterion Price. There is also a switch in position between analysers H and F when the weighting of the criterion Remaining useful life of the technology is increased. There model is, therefore, robust, as in no case is the position of the analyser chosen as most suitable modified; furthermore,

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Table 4. Statistical results

Vibration analysers	Mean	Standard deviation	Median	Min	5%P	95%P	Max
A	0.792	0.012	0.793	0.776	0.776	0.809	0.809
B	0.823	0.012	0.824	0.808	0.808	0.841	0.841
C	0.747	0.027	0.747	0.696	0.705	0.790	0.798
D	0.337	0.017	0.337	0.289	0.304	0.365	0.372
E	0.842	0.045	0.847	0.784	0.784	0.909	0.909
F	0.650	0.045	0.655	0.592	0.592	0.717	0.717
G	0.541	0.045	0.546	0.484	0.484	0.609	0.609
H	0.667	0.045	0.672	0.610	0.610	0.735	0.735

Figure 2. Ranking of alternatives
(Carnero, 2015)



**For a more accurate representation see the electronic version.*

the full ranking of the alternatives is unchanged when the other weightings of the criteria are modified, with the two exceptions mentioned.

The results show that, although Price is something to be considered, it is not definitive when making a choice of vibration analyser, since an increase in price is compensated to an important degree by an increase in diagnostic capacity and support. It is also seen that the technological level is very high, and included in the latest analysers on the market are asset management systems, which provide full management of machinery, and not only fault detection and diagnosis. Automatic diagnosis and the inclusion of wireless utilities and a number of communication systems are matters that distinguish the latest analysers from those that have been in operation for some time.

FUTURE RESEARCH DIRECTIONS

Given that vibration analysers are devices that develop over time, as they incorporate the most recent diagnostic and IT advances, periodic updating of the criteria, and above all of the descriptors, would be

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necessary, so that these advances can be assessed, especially in their agreement with the latest advances in Industry 4.0.

This study included three experts who made objective evaluations of the criteria and subcriteria; however, it would be interesting to take into account the opinions of manufacturers and suppliers of analysers when setting these weightings.

CONCLUSION

Despite the importance that choice of technology has in guaranteeing the success of a vibration-analysis-based condition based maintenance program, there is a serious lack of models to help objectively with technological decision making. That is, there are deficiencies in the application of models related to data-driven decision making in the selection of condition-based maintenance technology, in the new environment of Industry 4.0.

This research shows a robust model for making decisions on the choice of most suitable vibration analyser in an organization. The model was built using FAHP, which allows uncertainties and ambiguities of the decision process to be included. Judgements of three experts in vibration analysis, maintenance and electronic devices were used to build the model. These judgements allowed the weightings associated with the criteria and subcriteria in the model to be obtained. The model provides objective evaluation of different models of vibration analyser thanks to the definition of descriptors with different scale levels which characterize a criterion or subcriterion from best to worst performance level.

This chapter is intended to contribute to the use by organizations of MCDA models which guarantee satisfactory decision making when acquiring vibration analysis technology. To this end, a case study is shown applying the model to a Health Care Organization, which generally do not include vibration analysis among their maintenance policies, unlike most processing and manufacturing plants. Different models of vibration analyser, from different suppliers and manufacturers, were evaluated according to the specifications found in the Spanish, and a full classification of alternatives was obtained. It can be seen that the top two analysers in the ranking have very similar utilities, and so the decision will be between one of these two alternatives. The benefits that come with its use can lead to more efficient processes and improvements in productivity, and they can thus have a big impact of the quality of care and on the end user of care services, the patient.

This model is useful not only for manufacturing and energy companies, processing plants and service companies, but also universities and research centres that need to purchase vibration analysers for teaching and research. For teaching and research, it would be necessary to adapt the weightings of the criteria and subcriteria to the needs of each organization, but the model would still be useful.

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KEY TERMS AND DEFINITIONS

Fuzzy Analytic Hierarchy Process: This is a multicriteria technique, based on AHP but using a range of values to incorporate the uncertainty, ambiguities, or indecision of the decision maker. Different methodologies have been developed for applying it (e.g., the algorithm designed by Van Laarhoven and Pedrycz, which is a direct extension of the original AHP method) and the Buckley method for incorporating fuzzy comparison ratios into the methodology. Other methodologies used are Chang's extent analysis method and Cheng's entropy-based fuzzy AHP.

Fuzzy Logic: A technique of computational intelligence introduced by Zadeh in 1965 used when the complexity of a decision is high and affected by the incomplete knowledge, uncertainty or vagueness which is characteristic of human judgements and thought. It represents knowledge, which is primarily linguistic and qualitative, by the use of fuzzy sets defined by a membership function and using fuzzy operators to perform mathematical operations.

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Maintenance: A set of technical and management actions carried out to operate, preserve, improve, and adapt machines and/or facilities in an organization over their whole life cycle, so as to contribute to achieving the goals set by the company at minimum cost.

Monte Carlo Simulation: A method for estimating uncertainty in a variable which is a complex function of one or more probability distributions; it uses random numbers to provide an estimate of the distribution and a random number generator to produce random samples from the probabilistic levels.

Multi-Criteria Decision Analysis: It is a part of operational research that uses multiple criteria in decision-making processes providing objective models to improve understanding of underlying decision processes within the systemic processes. Among the techniques included in this area are analytic hierarchy process (AHP), analytic network process (ANP), the family of techniques elimination et choix traduisant la realité (ELECTRE), technique for order of preference by similarity to ideal solution (TOPSIS), multi-attribute utility theory (MAUT), the preference ranking organization method for enrichment of evaluations (PROMETHEE), measuring attractiveness by a categorical-based evaluation technique (MACBETH), etc. Multi-criteria decision analysis techniques allow acceptable compromise solutions to be obtained when criteria are in conflict.

Predictive Maintenance: Also known as condition-based maintenance (CBM), this is based on the control of physical parameters (such as vibrations, temperature, water content of used lubricant, etc.) of a working machine that can be recorded, periodically or continuously, by a set of sensors to detect an abnormal situation, allowing necessary maintenance activities to be carried out before any failure occurs. The data obtained from the control of the parameters are analyzed to find a possible trend over time, which allows a prediction to be made about when the threshold values will be reached.

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Chapter 17
Decision Making in the Choice of Condition-Based Maintenance Techniques in a Subsidiary of a Petrochemical Company

María Carmen Carnero-Moya
University of Castilla-La Mancha, Spain & Universidade de Lisboa, Portugal

Francisco Javier Cárcel-Carrasco
Universitat Politècnica de València, Spain

ABSTRACT

Condition-based maintenance (CBM) may be considered an essential part of the Industry 4.0 environment because it can improve production processes through the use of the latest digital technologies, which allows improvements to products, processes, and business models. Nonetheless, despite this importance, there are no models or methodologies in the literature to assist in choosing predictive techniques and the level of complexity to be used in a given organization. This chapter describes a model for choosing the most suitable CBM technique to be introduced in a subsidiary of a petrochemical plant. The predictive techniques of vibration analysis, lubricant analysis, and a combination of the two were considered at three technological levels. The model was built using the measuring attractiveness by a categorical based evaluation technique (MACBETH) approach. The present model could avoid failures in these programmes when making decisions about the techniques and technologies most suited to the characteristics of the industrial plant.

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INTRODUCTION

Traditional maintenance strategies can reduce the overall productive capacity of a plant by between 5 and 20 percent. Unlike traditional corrective and preventive maintenance, Predictive Maintenance, Condition Based Maintenance (CBM) or Prognostic and Health Management (PHM) (Shin & Jun, 2015) can use the latest digital technology to increase the productivity of industrial plants. CBM is a maintenance technique in which physical parameters of a working machine are monitored, periodically or continuously, from a set of sensors, to analyse and compare data, which then allows decisions to be taken about the working and maintenance of the machine (Carnero, 2009).

Therefore, although CBM is not a new concept, the decrease in cost of digital technologies and the increase in the Digital Supply Network (DSN), have allowed CBM to be set up in a large number of organizations of different sizes and a variety of processes (Coleman, Damodaran, & Chandramouli, 2017).

CBM, therefore, has among its goals the development of diagnostic tools to identify a failing component and its failure mode and, prognosis aimed at predicting the remaining useful life of a component, or estimating the probability that a machine or component can still function before failure occurs (Jardine, Lin, Banjevic, 2006).

In any case, diagnosis is, in practice, used much more widely than prognosis (Heng, Zhang, Tan, & Mathew, 2009). Some of the literature considers CBM as a part of a preventive maintenance policy, since preventive actions are carried out depending of the performance of the parameter monitored.

CBM allows faults to be detected at an early stage, and so corrective action can be planned and programmed as best suited to the organization. Furthermore, diagnostic techniques are applied while the machinery is working, which allows for greater availability of equipment.

Thus, among the benefits of applying CBM in an organization are improvements in availability of facilities and equipment, meeting of delivery deadlines, improvements in quality of manufactured products and parts, improvements in staff and plant safety, reduction in maintenance, inventory and energy costs, availability of tools to check the quality of both internal and outsourced maintenance activity, increasing the useful life of equipment, improving company sustainability, as well as contributing to acquiring and retaining standards ISO 9000, QS 9000, etc, (Ayo-Imoru & Cilliers, 2018; Bari, Deshpande, & Patil, 2015; Carnero, López-Escobar, González-Palma, Mayorga, & Almorza, 2015; Carvalho, Gomes, Schmidt, & Brandão, 2015; Mobley, 2002; Precup, Angelov, Costa, & Sayed-Mouchaweh, 2015).

These benefits are more important in the Industry 4.0 environment, due to the following features (Köhler, 2016):

1. Real-time CBM. Production data from the machines and processes, together with sensor data, is taken in real time, using Industry 4.0 software. The resulting data can be seen by everyone, anywhere, on different devices and in the cloud.
2. Evaluation and flexible analysis. Data can be evaluated using highly customised algorithms, rules, or groups of experts, and the technician can apply expert systems without complicated IT know-how. Therefore, the software is adapted to the CBM necessities of each organization.
3. Targeted notification of experts. As soon as the software identifies the need for maintenance action in a machine, the information is sent automatically to the appropriate team by means of a digital ticket that includes all the relevant information. Once the maintenance task is finished, the ticket can be closed automatically and on line, updating the information related to the failure.

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Therefore, CBM can be considered a key element within Industry 4.0 due its capacity to improve the productive processes by the use of the latest breakthroughs in digital technologies, allowing products, processes and business models to be improved. However, there is a significant lack of objective models for making decisions related to the introduction of this technological maintenance policy.

A large number of predictive techniques exist (Edwards, Holt, & Harris, 1998). Vibration analysis is a technique that has now reached maturity in the marketplace. Large industrial plants have already introduced it, while small and medium enterprises are beginning to do so. Its applicability to rotating machines and their alternatives, which may be considered to be the most common in any industrial plant, together with its high diagnostic capacity, makes it the most versatile predictive technique.

Lubricant analysis performs a periodic analysis the state of certain parameters or components of the lubricant used, via physical-chemical tests, so as to monitor loss of quality in the lubricant and both external (water, dust, etc.) and internal (worn particles, lacquer, etc.). The test generally carried out include: viscosity, viscosity index, Total Acid Number (TAN), Total Base Number (TBN), infrared analysis, metal content, water content, particle count, etc. (Carnero, 2012).

Additionally, thermography monitors the presence of hot spots in electric cables, electric panels, engines and machines that may develop anomalous hot spots, either because of defects in the material or in the insulation (Díaz, 2007). For this reason, infrared energy emission is analysed, since all objects with a temperature above zero emit energy and, as infrared energy is that of shortest wavelength emitted its measurement requires special instruments.

Other predictive techniques control the process parameters, magnetic particles, penetrating liquids, radiography, ultrasound, control of corrosion, etc.

Nonetheless, the use of the wrong predictive technique may lead to economic loss, loss of time and resources, and would not prove beneficial to the availability of machinery or the industrial plant. The introduction of a CBM programme is often not based on strategic considerations, or is applied to unsuitable equipment, and so will have little effect on productivity (Manning-Ohren, 2015).

Although there is a very extensive literature analysing technical matters related to diagnostics, especially new techniques and parameters, the literature is deficient in contributions which analyse aspects of management concerned with the design and introduction of CBM programmes (Ayo-Imoru & Cilliers, 2018; Veldman, Klingenberg, & Wortmann, 2011;) or they focus only on a single piece of equipment (Koochaki, Bokhorst, Wortmann, & Klingenberg, 2011)

The model described in this chapter aims to formalise one of the decisions to be taken when introducing a CBM programme, the choice of a predictive technique. In this way, decision making is based on data, algorithms and rules within objective models in agreement with the characteristics of Industry 4.0. The aim is to generate decisions that can contribute to improving product, processes and business models. This will be done using the multicriteria Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) approach, considering nine alternatives including vibration analysis and lubricant analysis, applied in isolation at different technological levels, and also when used in combination.

The chapter continues with a review of the literature on integration of predictive techniques, and contributions to the management of CBM programmes. The next section describes the model for the selection of Condition Monitoring Techniques. It shows the results of applying the model to a subsidiary of a petrochemical plant. Finally, the future research directions, conclusions and references are set out.

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BACKGROUND

To determine the most suitable condition-monitoring technique, or combination of techniques, it is necessary to see whether the condition-monitoring technique is available, is cost effective and if the condition-monitoring technique can provide a numerical value of the relevant condition predictor when evaluating the data acquired (Saranga, 2002). Although vibration analysis can detect a large number of faults, it does not provide information on the state of the lubricant or areas of heat loss, and therefore a predictive maintenance programme should include several techniques (Mobley, 2002).

Vibration analysis is usually the main technique used within organizations, while lubricant analysis is usually outsourced due to high cost and the training necessary to carry it out (Mobley, 2002). This makes it difficult to integrate techniques.

Integrating two or more predictive techniques consists of acquiring data on those techniques, to correlate all the information, and obtain an early diagnosis of the root causes of failures, and predict their consequences for the machinery (Carnero, 2009). To the benefits obtained from applying a CBM programme with a single predictive technique, the following additional benefits of integrating techniques may be added:

- Increasing the number of machines included in the CBM programme. In industrial plants there are commonly different types of machinery, and applying a single predictive technique can limit the control of the state of all machines in the production line, or in a plant with continuous production.
- Exposing defects at an early stage of their development.
- Increasing the number of faults to be monitored, as some faults can only be analysed by one of the predictive techniques.
- Intensifying and perfecting the amount of information available about incidents to be given to those responsible for corrective action.
- Confirming diagnoses, by contrasting data from both techniques.
- Determining the root causes of failures.

40% of bearing failures can be diagnosed via lubricant analysis, 33% via vibration analysis, and the joint use of both techniques allows the remaining 27% to be detected. However, the simultaneous application of both predictive techniques does not necessarily mean they have been integrated. The instruments and computer applications used with each predictive technique usually come from different manufacturers, which makes it difficult to integrate the data.

On the other hand, the results are not always positive when the techniques are integrated. For example, problems of wear give contradictory results when using vibration analysis and lubricant analysis due to the smoothing effect caused by friction of the worn particles on the surfaces, reducing the level of vibration. This effect is prolonged to the point that clearance in the components is considerably increased, giving rise to a significant increase in the level of vibrations (Carnero, 2009).

Each predictive technique can detect a failure at different stages of its development. Lubricant analysis can detect a fault in the early stages of development, while vibration analysis can only do so when the breakdown has actually occurred. This is why lubricant analysis is associated with microscopic characteristics of a failure, and vibration analysis with macroscopic.

Among the literature which analyses decision making related to predictive maintenance programmes the following may be considered to stand out. Carnero (2005) sets out a model which integrates Analytic

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Hierarchy Process (AHP) and factor analysis in choosing diagnostic techniques and instrumentation in the CBM policy. The model is used in screw compressors in which vibration analysis and lubricant analysis are applied and assessed when they are used together. Factor analysis is applied to the information supplied by the quantitative diagnostic parameters, which eliminates redundant information. The quantitative information resulting from the factor analysis is complemented by the qualitative information provided by other diagnostic techniques. The most significant diagnostic techniques obtained from the factor analysis and the qualitative diagnostic techniques are the alternatives incorporated into an AHP model described according to the technological level. The model has been applied at four technological levels, depending on cost and diagnostic capacity. At level 0, the setup is carried out using control of sensitive variables. The cost is almost null and the diagnostic capacity is very low. At the highest level (level 3) the cost is very high because the most technologically advanced devices are used, such as water content in lubricant, content in wearing metals, spectral analysis, cascades, spike energy etc. and so the trend is towards the most appropriate predictive technique. Therefore, the alternatives considered at each technological level are very different, as are the weights obtained from the experts for each criterion. This ultimately produces four AHP models, one for each technological level, which have only the hierarchy in common. Therefore, it is not a matter of choice of maintenance policies, but of choosing between different diagnostic techniques included in CBM. Factor analysis is thus shown to be a useful tool for rationalizing the indiscriminate application of predictive diagnostic techniques. It is the first contribution to show integration between predictive techniques obtaining better results for the state of the equipment.

Carnero (2006) describes an assessment system which facilitates decision making on the introduction of predictive maintenance programs, especially in small and medium enterprises. This was done by assessing the implementation of a CBM policy through AHP together with decision rules and Bayesian tools. The hierarchical structure of the problem is set out taking into account different scenarios characterised by the variables of company size and productive processes. To guarantee the successful introduction of a CBM policy two objectives are assessed: the ability of the company to implement a CBM and the need for this policy in the company. The AHP hierarchy comprises two scenario variables, 47 criteria and these alternatives: to set up a CBM policy internally, to develop prior requisites for the setting up of a CBM policy, not setting up a CBM policy and outsourcing the policy. An incomplete hierarchy is used to apply a superior specificity in the making of a judgement because it is considered that the preferences must be modified in the different scenarios suggested. To integrate the results obtained from the criteria of ability to introduce a CBM policy and the need for such a policy, a series of decision rules have been defined following the methodology of experts in rule-based systems. A company may not have all the information that needs to be included in the model, and so it is suggested that the results obtained for companies with similar scenario variables be used, by applying Bayes theorem to the objectives analysed. The number of critical machines, which is considered crucial for the application of CBM (Carnero, 2006), has not, however, been used in the literature in a conclusive manner, with the exception of Carnero (2005), Carnero (2007) and Carnero (2009). These contributions make reference to the need to adapt the technological level in a company to the technological level of the maintenance applied.

Carnero (2007) uses AHP to choose the most appropriate predictive technique, from vibration analysis, lubricant analysis or the integration of both techniques. The CBM policy is characterised at four levels according to the technological level. Each company is characterised using four scenario variables: typology of critical machinery in the industrial plant, technological level of the productive process in the industrial plant, number of critical machines in the industrial plant and future behaviour of the company. The model has been validated in various companies belonging to different sectors such as petrochemical,

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food, pharmaceutical and machinery manufacturing. Carnero (2009) also chooses the condition monitoring technique to be applied, but using a multi-criteria utility function and AHP. Discrete probability distributions are obtained for each alternative and a Monte Carlo simulation is used to calculate the final utility of the alternatives. The characterization of the decision criteria in utility functions should be especially noted in this contribution, as well as the use of discrete probability functions associated to each alternative; to produce them the decision maker is asked to identify the most likely value of the variable under consideration.

It can be seen that although contributions in the literature on CBM are numerous, there is little research into decision making in the set up of this technological maintenance policy. Additionally, the models produced in this area are constructed with AHP, with the limitations inherent in this technique, and without fuzzy characteristics. In this chapter, the MACBETH approach has been used, which provides solid procedures for building each step of the model and gives more reliable results. Furthermore, the MACBETH approach allows different levels of precision to be included in the expert's judgements, therefore, uncertainty can be included without having to use a complex fuzzy multicriteria model.

Veldman et al. (2011) bring together the main assumptions regarding CBM found in the literature in the following postulates:

1. Processing companies apply more diagnosis than prognosis in their CBM programmes.
2. Processing companies also make extensive use of information systems and specialised software in their CBM programmes.
3. Processing companies make use of third parties for specialised CBM tasks.
4. Processing companies create autonomous organisational units in which the actual CBM tasks take place.
5. Processing companies make use of strict procedures to carry out their CBM programmes.
6. Processing companies use employee training for the proper execution of their CBM programmes.
7. Processing companies make sure sufficient domain-related knowledge is available for their CBM programmes.
8. The integration of domain-related workforce knowledge is critical for the success of diagnostic and prognostic tasks.

Koochaki et al. (2011) develop a simulation model to analyse the effects of production context using traditional performance indicators such as costs and availability of each piece of equipment, together with other metrics including line efficiency. The results show that CBM gives the best performance among maintenance policies in loosely coupled processes; however, in tightly coupled processes, CBM has a negative effective on the efficiency of line production as it increases equipment blockage and starvation states.

Shin and Jun (2015) analyses a series of aspects related to the introduction of CBM such as definitions, international standards, techniques and procedures. Several case studies are also presented.

Guillén et al. (2016) set out a framework for an effective management of the CBM programmes using different international standards including ISO 13379-1, ISO 13374 and OSA-CBM. They develop a template to integrate the data from the prognostic and health management techniques used to capture failure mode behaviour and to manage maintenance.

Carnero (2013) includes a survey on the introduction of CBM programmes in small and medium enterprises. It shows that only 22.9% of such companies have introduced a CBM programme. Most of

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these companies apply a number of CBM techniques simultaneously, and the most widely applied predictive techniques are vibration analysis (18.2%), lubricant analysis (18.2%), ultrasound (18.2%), process variables (18.2%), other predictive techniques (13.6%), engine current spectroscopy (4.5%) and thermography (4.5%). It should be noted that the goals identified when introducing the CBM programme is achieved in 62.5% of cases. Antosz and Stadnicka (2014) carry out a survey into technical infrastructure maintenance activities in large enterprises. The results show that, although preventive maintenance is the most widely applied maintenance policy, 30% of the surveyed companies indicate that they use continuous monitoring. Ayo-Imoru and Cilliers (2018) carry out a survey in a nuclear power plant to determine the strengths, weaknesses, opportunities, and dangers of applying CBM in this kind of plant. Among the weaknesses are the need for networks of expertise to provide technical support to the operators, a lack of procedures for choice of monitoring, diagnostic and prognostic techniques and equipment, the need for detailed technical knowledge of failure mechanisms, a cultural change to do with application, sensors that are radiation-resistant and long-lasting, and the need to develop strategies for the ideal placing of sensors to monitor the state of passive components.

Noman et al. (2018) carries out a literature review of the contributions most relevant to CBM. It underlines that when first applied the USA was the most represented country in the contributions about CBM; while today, there are numerous countries with research groups devoted to CBM in the USA, Europe, and Asia.

Therefore, the contributions which exist in this field are only based on surveys with no objective mathematical models, and with data provided by a very limited number of companies.

MULTICRITERIA MODEL TO SELECT CONDITION-BASED MAINTENANCE TECHNIQUES

The MACBETH approach (Bana e Costa & Vansnick, 1997) was chosen as the multicriteria technique to be applied, because it has a number of advantages, including:

- The possibility of including intervals in the judgements given.
- M-MACBETH software is available to apply the methodology.
- Validation of the results obtained from the judgements of the decision maker.
- Use of two reference levels in each criterion minimises inconsistency and produces more reliable, accurate and objective results from the decision process.
- It has a complete methodology which facilitates objective decision making.

Structuring of the Decision Criteria

The decision criteria were established by an expert in CBM who based them on past experience in the setting up of some CBM programmes in process plants, in the two techniques considered in this paper, and who also had experience in the integration of vibration and lubricant analysis. The expert knows the characteristics of the industrial plant analysed. Information supported by experience from other CBM Programme managers has also been considered, as has the literature about lubricant and vibration analysis.

A descriptor is associated to each criterion. A descriptor comprises a set of levels in a scale ordered in terms of attractiveness. To construct the linguistic scales in each descriptor, information from the

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literature has been considered (Carnero, 2012; McKone, & Weiss, 2002; Mobley, 2002) together with experience from one of the authors in setting up CBM programmes in petrochemical plants. Quantitative and qualitative descriptors were defined.

The decision criteria established are:

- **Future Behaviour of the Company (FB):** This considers the effect that strategic aspects of the company, such as investment opportunities, setting up of new production systems, or access to new technologies, will have on the expected results of the implementation. There is a strong relationship between this criterion and the possibilities of success in the setting up of a CBM programme. The technological and organizational situation, investment opportunities, etc., will determine the correct use of a specific CBM technique. The scale levels of the descriptor ordered from highest to lowest performance are:
  - L1 = Good. Favourable.
  - L2 = Neutral. Stable.
  - L3. Adverse.
- **Adaptation of the CBM Technique to the Technological Level of the Production Process in the Industrial Plant (AT):** This criterion analyses the degree of technological compatibility of the industrial plant with each of the alternatives. The scale levels of the descriptor defined for this criterion from highest to lowest performance are:
  - L1 = Good. High.
  - L2 = Neutral. Medium.
  - L3. Low.
- **Costs of the CBM Programme (CO):** This criterion is composed of the following subcriteria:
  - Investment cost (IC). It includes the costs of hardware and software required to set up a CBM programme. This cost depends on the technological level of the devices purchased and the number of machines included in the CBM programme, and so a normalised CBM programme with 50 critical machines was defined. The scale levels of the descriptor from highest to lowest performance are:
    - L1 = Good. €0
    - L2. Up to €600.
    - L3 = Neutral. Up to €12000.
    - L4. Up to €60000.
    - L5. €100000 or above.
  - Setting up costs (SC). This includes the cost of training personnel, of the external consultancy and the cost of personnel dedicated to the selection of critical machinery, to the design of routes of critical machineries, to the selection of points for acquiring data, etc., used during the set up. The scale levels of the descriptor from highest to lowest performance are:
    - L1 = Good. Up to €600.
    - L2. Up to €12000.
    - L3 = Neutral. Up to €30000.
    - L4. Up to €60000.
    - L5. €100000 or higher.
  - Maintenance cost (MC). This includes the cost of continuous training, development of diagnostics for the state of machinery, calibration, data acquisition, etc., spent per year. When

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developing the descriptor, a normalised CBM programme with 50 critical machines was considered. The scale levels of the descriptor from highest to lowest performance are:

- L1 = Good. Up to €6000.
- L2. Up to €60000.
- L3 = Neutral. Up to €120000.
- L4. Up to €240000.
- L5. Above €600000.

- **Diagnostic Features (DF):** This comprises the subcriteria:
  - Diagnostic quality (DQ). This subcriterion gives information about the quality of the diagnoses supplied by each alternative. The scale levels of the descriptor from highest to lowest performance are:
    - L1 = Good. Gives highly reliable diagnoses with sufficient notice of catastrophic failure to be able to plan preventive action well in advance, without materially affecting other components of the machine.
    - L2. Gives highly reliable diagnoses with sufficient notice of catastrophic failure to be able to plan preventive action well in advance, with only a very small effect on other components of the machine.
    - L3 = Neutral. Gives reliable diagnoses with sufficient notice of catastrophic failure to be able to plan preventive action well in advance, with only a small effect on other components of the machine.
    - L4. Gives fairly reliable diagnoses with sufficient notice of catastrophic failure to be able to plan preventive action well in advance, although other components of the machine are affected.
    - L5. Gives unreliable diagnoses with insufficient notice of catastrophic failure to be able to plan preventive action well in advance, and other components of the machine are seriously affected.
  - Diagnostic capacity (DC). This determines the number of failures that can be analysed with each alternative.
    - L1 = Good. Up to 50 failures.
    - L2. Up to 35 failures.
    - L3 = Neutral. Up to 25 failures.
    - L4. Up to 10 failures.
    - L5. Only one type of failure.
  - Diagnostic time (DT). This determines the length of time needed by the alternative to acquire the Predictive Maintenance data and provide a diagnosis.
    - L1 = Good. In 12 hours.
    - L2. In 24 hours.
    - L3 = Neutral. In 48 hours.
    - L4. In 96 hours.
    - L5. In 120 hours or over.
- **Level of Service (LS):** This criterion includes the following subcriteria.
  - Simplicity of use and maintenance of the instrumentation needed in the alternative (SU). The functioning of some CBM devices is difficult to understand, leading to obstacles or delays in the acquisition of data. The risks for the human resources that record the CBM data are also

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considered. The scale levels of the descriptor Ease of use and risk in use by human resources from highest to lowest performance are:

- L1 = Good. Easy application and no risk in use by human resources.
- L2 = Neutral. Medium ease in application and no risk in use by human resources.
- L3. Difficult application and no risk in use by human resources.
- L4. Difficult application and low risk in use by human resources.
- L5. Difficult application and medium risk in use by human resources.
- L6. Difficult application and high risk in use by human resources.

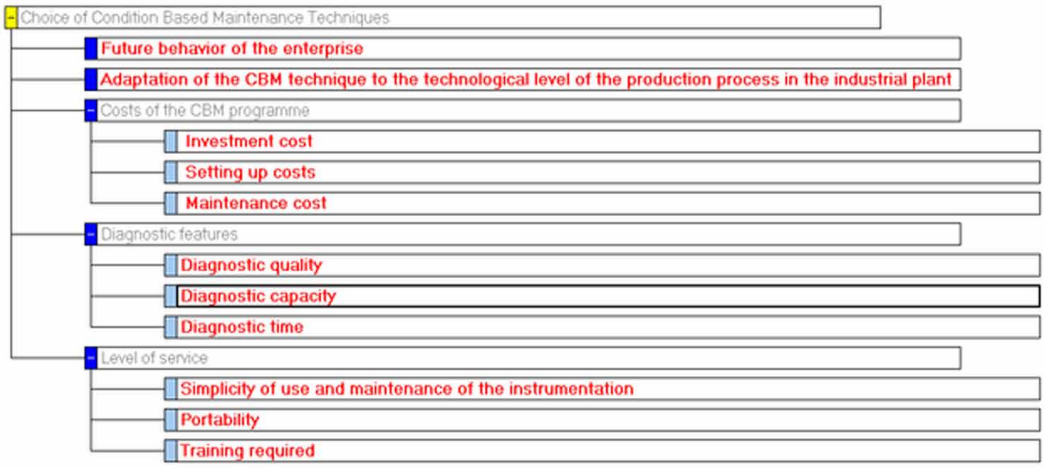
- Portability (PO). The greater the portability of the hardware, the better the application of the technology by the human resources. The scale levels of the descriptor, from highest to lowest performance are:
  - L1 = Good. Lightweight and no wires required. Easy to transport devices and sensors during data acquisition.
  - L2. Lightweight and no wires required. Not easy to transport devices and sensors during data acquisition.
  - L3 = Neutral. Lightweight and wires required for the sensors. Not easy to transport devices and sensors during data acquisition.
  - L4. Medium weight and wires required for the sensors. Not easy to transport devices and sensors during data acquisition.
  - L5. Heavy weight and wires required for the sensors. Not easy to transport devices and sensors during data acquisition.
- Training required (TR). The more training received, the better the human resources can adapt to this technology. The descriptor associated to this criterion is the Number and level of complexity of courses required in each Predictive Maintenance technique considered. The scale levels of the descriptor, from highest to lowest performance are:
  - L1 = Good. No courses required in any technique.
  - L2. A basic course required in one technique.
  - L3 = Neutral. One basic course and some advanced courses (continuous training) in one CBM diagnostic technique.
  - L4. One basic course and some advanced courses (continuous training) in some CBM diagnostic techniques.
  - L5. Continuous training in all CBM diagnostic techniques.

The MACBETH value tree or hierarchy structure is shown in Figure 1.

Ordinal scales are transformed into cardinal scales by means of value functions. A value function generated by the M-MACBETH software is representative of the decision maker's judgements (Bana e Costa & Chagas, 2004). The value function assigns value scores to the performance levels of a descriptor relative to the fixed scores of 0 and 100, assigned in turn to the good and neutral reference levels. To convert the different scale levels of each descriptor into a value scale, the expert is asked for qualitative judgements of differences in attractiveness between pairs of performance levels. The decision maker was asked to choose from one of the MACBETH semantic categories of difference in attractiveness: no, very weak, weak, moderate, strong, very strong or extreme; two or more consecutive MACBETH semantic categories can be used if the decision maker considers it appropriate. Each time the decision maker gives a qualitative judgement, the consistency of all the judgements is automatically checked

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Figure 1. MACBETH value tree
Source: Created by the authors



by M-MACBETH. The value function is generated by M-MACBETH from the linear programming of equation (1) (Bana e Costa, Ensslin, Correa, & Vansnick, 1999).

$$Min\left[v\left(x^{+}\right)-v\left(x^{-}\right)\right] \tag{1}$$

Subject to

$$v\left(x^{-}\right)=0\ \left(arbitrary\,assignment\right)$$

$$v\left(x\right)-v\left(y\right)=0,\qquad \forall x,y\in C_{0}$$

$$v\left(x\right)-v\left(y\right)\geq i,$$
$$\forall x,y\in C_{i}\bigcup\ldots\bigcup C_{s}\quad with\,i,s\in\left\{1,2,3,4,5,6\right\}and\,i\leq s$$

$$v\left(x\right)-v\left(y\right)\geq v\left(w\right)-v\left(z\right)+i-s',$$
$$\forall x,y\in C_{i}\bigcup\ldots\bigcup C_{s}\quad and\,\forall w,z\in C_{i'}\bigcup\ldots\bigcup C_{s'}$$
$$with\,i,s,i',s'\in\left\{1,2,3,4,5,6\right\}and\,i\leq s,\ i'\leq s'\,and\,i>s'$$

where x^{+} is at least as attractive as any other element of X, x^{-} is at most as attractive as any other element of X and $v\left(x\right)$ is the score assigned to element x of X.

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Figure 2 shows the value functions of the subcriteria Diagnostic quality, Diagnostic capacity, Diagnostic time, Simplicity of use and maintenance of the instrumentation needed in the alternative, Portability and Training required as an example.

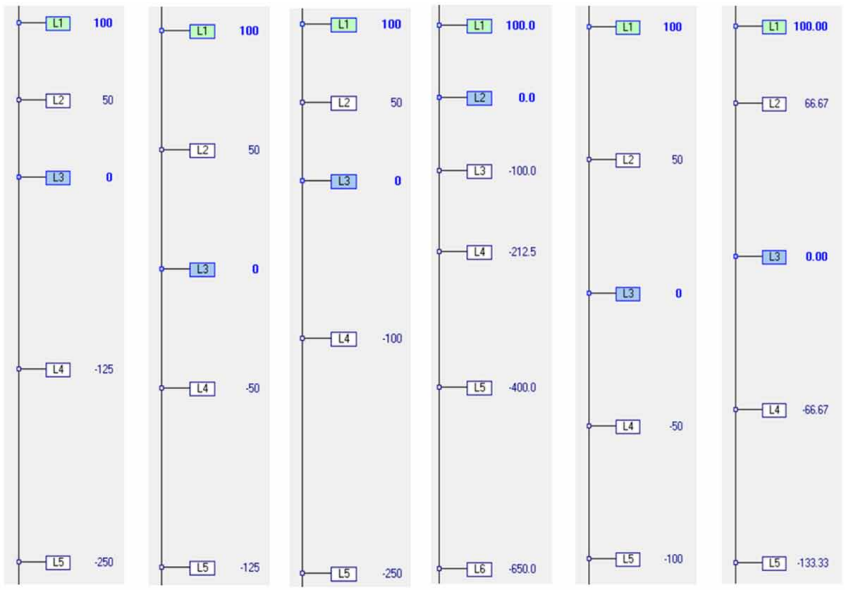
Weighting Process

To obtain weightings for the criteria, an alternative was defined that is at the neutral level for all criteria (or subcriteria). The expert was asked to give a qualitative judgement of the increase in overall attractiveness provided by a swing from the neutral level to the most attractive impact level, in each of the criteria, using the semantic categories: no, very weak, weak, moderate, strong, very strong and extreme. This provides an ordering of the criteria obtained in the MACBETH judgement matrix, from greater to lesser importance by rows and columns.

Next, the expert compared how much more preferable the change from the neutral to the good level is in the criterion Future behaviour of the company as opposed to the same change in the criterion Diagnostic quality. The expert answered, "very weak". The expert was then asked how much more attractive a swing from neutral to good would be in Future behaviour of the company than in Diagnostic capacity? The expert in this case was hesitant and gave the two consecutive categories "very weak-weak". The questioning process continues until the first row of the judgement matrix is completed. This process was repeated row-by-row until the weighted judgement matrix was completed (Bana e Costa & Chagas, 2004).

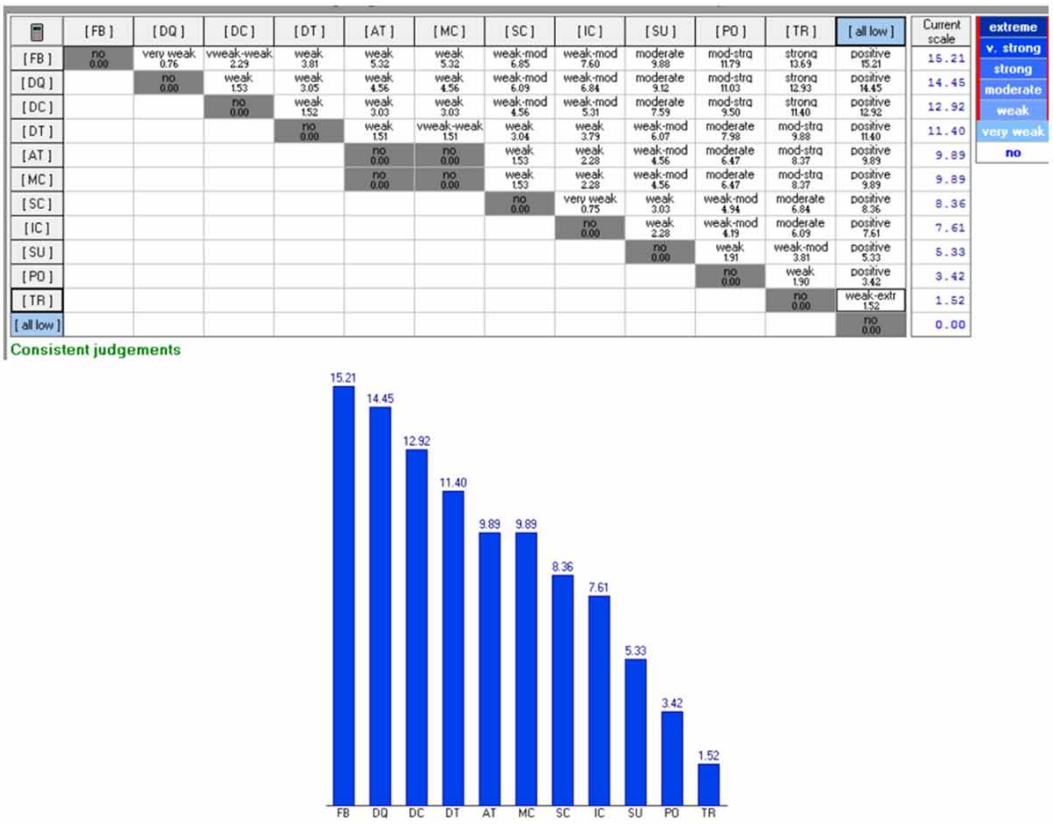
The judgements provided by the expert and the weightings obtained for the criteria or subcriteria are shown in Figure 3.

Figure 2. MACBETH value functions of subcriteria Simplicity of use and maintenance of the instrumentation needed in the alternative, Diagnostic quality, Diagnostic capacity, Diagnostic time Portability and Training required (from left to right)
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Figure 3. MACBETH judgement matrix and bar chart with weightings
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The consistency of each judgement given by the group was tested by M-MACBETH, and the judgements were shown to be consistent, as seen in Figure 3.

It was next necessary to validate the results. To do this, the expert was asked about the need to adjust the weightings interactively to obtain more suitable values. However, the expert agreed with the weightings obtained.

Alternatives

Four technological levels were defined, depending on the cost and diagnostic capacity (Carnero, 2004) which will serve to characterise the alternatives:

Level 0: Set-up is carried out using the control of sensitive variables. The cost is practically zero and the diagnostic capacity is very low.
Level 1: Elementary instrumentation, like vibrometers or devices for carrying out the crackle test are used.
Level 2: More sophisticated instrumentation, like vibration analysers, data processing software, or viscometers are used.
Level 3: The cost is high as sophisticated analysis machines are in use; diagnostic capacity is excellent.

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The alternatives proposed are:

1. Lubricant Analysis (Low Level) (LUB-LL).
2. Lubricant Analysis (Medium Level) (LUB-ML).
3. Lubricant Analysis (High Level) (LUB-HL).
4. Vibration Analysis (Low Level) (VIB-LL).
5. Vibration Analysis (Medium Level) (VIB-ML).
6. Vibration Analysis (High Level) (VIB-HL).
7. Integrating Lubricant and Vibration Analysis (Low Level) (INT-LL).
8. Integrating Lubricant and Vibration Analysis (Medium Level) (INT-ML).
9. Integrating Lubricant and Vibration Analysis (High Level) (INT-HL).

The alternatives are limited to nine because there are difficulties for human beings in analysing (comparing) more than 7 ± 2 items. Although the use of MACBETH, with perfectly defined scale levels and indicators, can solve this problem, because no direct comparison of alternatives is needed, as with AHP, only nine alternatives has been chosen.

SOLUTIONS AND RECOMMENDATIONS

The MACBETH model described in this chapter has been applied to a subsidiary of a petrochemical plant dedicated to the production of liquid petroleum gases obtained in the process of refining crude oil.

The manager of the plant filled out a questionnaire that enabled the specific state of the plant to be assessed against the descriptor scale. This was considered the most suitable way to incorporate the judgements of the decision maker, as the manager of the plant lacked the necessary knowledge of integration of CBM techniques and the time to design another decision process. The questionnaire asks for information about the number of total machines in the company, which of them are critical machines, and the quantity of machines of each type, number of total employees and number of maintenance workers, their qualifications and IT knowledge, existence of a Computerised Maintenance Management System (CMMS) in the company, and information about the record of failures of the machines, percentage of corrective and preventive activities carried out annually and information about cost and safety. Costs that the manager would be allowed to manage with the set up of a CBM, or requirements for the reduction of repair time are also asked about, among other questions.

The model has been applied to a specific company; since this model used data obtained from the manager of the company via a questionnaire. However, the industry has common characteristics related to the technology applied to the process, and requirements for availability, safety and cost and, therefore, the model can be applied to another company in the same industry, with prior adaptation to the specific characteristics of that company.

The process of assessing alternatives is based on the construction of an additive aggregation model represented by Equation (2).

$$v\left(A\right) = \sum_{i=1}^{n} w_i v_i\left(A\right) \qquad \sum_{i=1}^{n} w_i = 1 \quad w_i > 0 \tag{2}$$

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where A is the alternative that is being assessed, $v\left(A\right)$ is the global value of alternative A, $v_i\left(A\right)$ is the value of the impact of alternative A on criterion *i*, considering

$$v_i\left(\text{most attractive impact level on}\, i\right) = 100$$

and

$$v_i\left(\text{least attractive impact level on}\, i\right) = 0\,;$$

w_i is the weight of criterion *i*, and *n* is the number of criteria.

The MACBETH model obtains the ranking of alternatives shown in Figure 4. It can be seen that the recommended action is the setting up of a CBM programme bases on vibration analysis at a medium technological level. This means that a portable vibration analyser is recommended, able to carry out spectral analysis, waterfalls, tendency of global vibration value RMS (10– 1000 Hz), spike energy, harmonic tendencies, cepstrum, envelope, peak values, time signal analysis, form analysis and crest factors.

The results show a prevalence of vibration analysis over lubricant analysis. Additionally, the integration of vibration analysis and lubricant analysis in all the technological levels is below that of the other alternatives, with the exception of lubricant analysis at the high technological level. This is due to the complexity of integrating techniques appropriately, which requires highly-trained personnel and an increase in cost. This increase is due to the high cost of the devices used in lubricant analysis and the number of work-hours required to integrate the data and results obtained by the two techniques.

The technological level of the alternative chosen depends on the technological level of the industrial plant. The final classification of alternatives obtained through the method described in this article coincides with the expectations of the main decision maker.

However, according to the features of Industry 4.0, the company should begin with a portable vibration analyser and then evolve in the medium term to a continuous data-acquisition system, with data recorded automatically and stored in the CMMS, with capacity to launch alerts and alarms when the system detects any anomaly or malfunction.

A sensitivity analysis was carried out to assess the robustness of this decision under logical modification of the weights of the criteria and subcriteria. Figure 5 shows the results of the sensitivity analysis of the four most relevant criteria (or subcriteria) of the model. It is clear that a large increase in each of the criteria weightings would be necessary to change the first choice of alternative. Decreasing the weightings of these criteria would not modify the ranking of alternatives in any circumstances. The other criteria and subcriteria of the model exhibit similar behaviour.

FUTURE RESEARCH DIRECTIONS

The lines of future research involve obtaining weightings for the criteria and subcriteria from a decision group, in which the final weightings are obtained by consensus, for example by decision conferencing or by applying a geometric mean to aggregate the individual judgements.

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Figure 4. Ranking of alternatives
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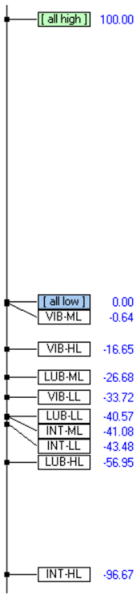
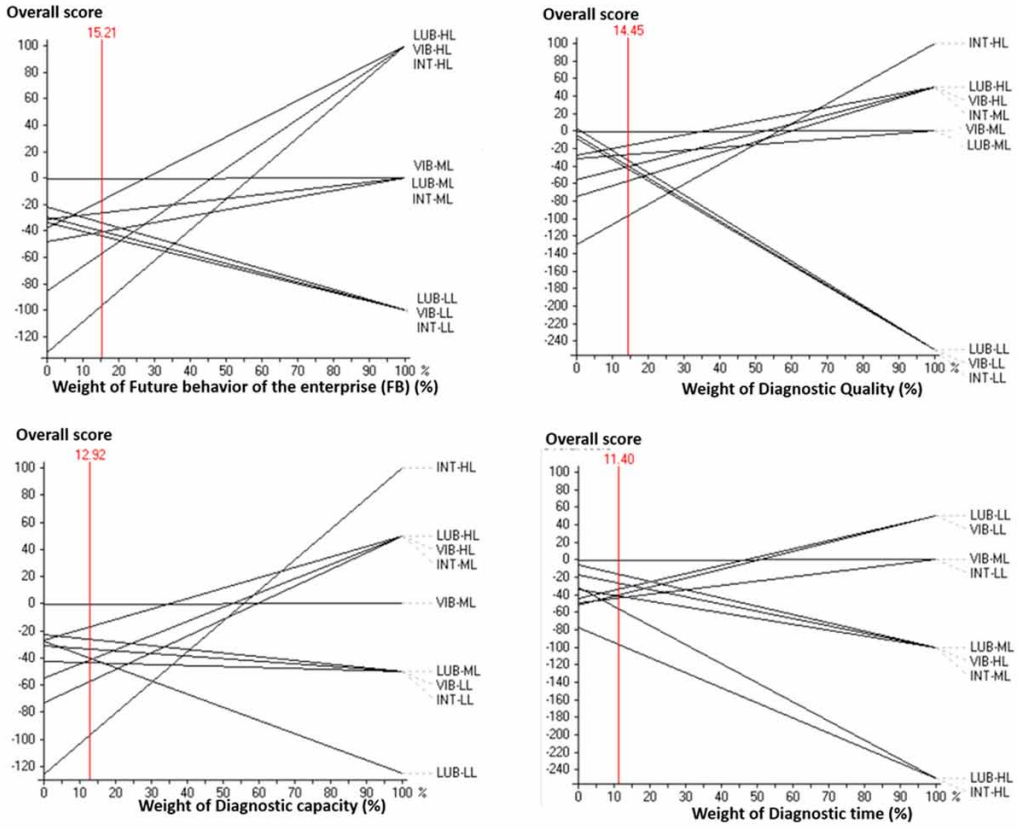


Figure 5. Sensitivity analysis
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It would also be useful to update the model from time to time, since the investment, setting up and maintenance costs change over time, and also new diagnostic tools are increasingly coming on the market, ever easier to use and adapted to the new necessities of the industry, especially in the new Industry 4.0 environment.

The model should be updated with additional predictive techniques like thermography, control of the process parameters, ultrasound, etc. depending on the characteristics of the facility and machines.

CONCLUSION

Despite the importance of the various aspects involved in introducing a CBM programme to achieving good results, the number of contributions analysing these matters is very small. This chapter describes a multicriteria model using the MACBETH approach to select the most appropriate predictive technique and technological level. The alternatives considered are vibration analysis at three technological levels (low, medium and high), lubricant analysis at three technological levels (low, medium and high), and the integration of both techniques at similar technological levels.

The model developed was applied to a subsidiary of a petrochemical plant dedicated to the production of liquid petroleum gases obtained in the refining process of crude oil, and gives as the most suitable alternative the use of vibration analysis at a medium technological level.

The model described could be applied to an organization of any size and in any field of activity, just by filling out a questionnaire about the specifics of the company. It would thus be of great use to maintenance managers or directors in any organisation. However, the director of the CBM should preferably give specific judgements allowing the weightings of the criteria and subcriteria to be calculated, as this would adapt the results even more closely to the organisation.

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KEY TERMS AND DEFINITIONS

Lubricant Analysis: Is a condition-based maintenance technique, which brings together a set of techniques for the monitoring of the physical-chemical of the lubricant. These techniques allow the state of the lubricant and the presence of contamination and wear in the machinery to be diagnosed.

MACBETH: Measuring Attractiveness by a Categorical-Based Evaluation Technique (MACBETH) is multicriteria decision-making approach created by Bana e Costa and de Corte in 1997. MACBETH only requires qualitative judgements of differences in attractiveness to obtain value functions by means of mathematical programming and weights for criteria. M-MACBETH software allows the hierarchy to be constructed, consistency checked, and judgements validated, value functions created, and sensitivity and robustness analyses carried out.

Vibration Analysis: Is a condition-based maintenance technique used in rotary and alternative machinery. The commonly used diagnostic techniques are measurement of total vibration in a broad or narrow frequency band, spike energy, envelopment or peakvue analysis, analysis of kurtosis or skewness, harmonic analysis, peak vibration synchronicity measurements, etc. This can detect disequilibrium, excessive clearance, problems with bearings and gears, electrical faults, etc. and is the most widely used predictive technique.

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Chapter 18
The Implementation of Nearly Zero Energy Buildings (nZEB) in Spain: Legislative Requirements and Policies

Elisa Peñalvo-López
Universitat Politècnica de València, Spain

Javier Cárcel-Carrasco
Universitat Politècnica de València, Spain

Manuel Valcuende-Paya
Universitat Politècnica de València, Spain

María Carmen Carnero-Moya
University of Castilla-La Mancha, Spain & Universidade de Lisboa, Portugal

ABSTRACT

The construction segment is an important economic sector in Europe, representing 9% of European gross domestic product (GDP) and providing approximately 18 million direct jobs. Construction activities that include renovation work and energy retrofits add almost twice as much value as the construction of new buildings, and small and medium-sized enterprises (SMEs) contribute more than 70% of the value added in the EU building sector. Furthermore, European legislation obliges member states to establish minimum energy efficiency requirements for buildings to achieve optimum levels of costs versus energy demand reduction. These requirements are reviewed every five years and represent categories of buildings based on their energy levels (demand and generation). This chapter analyzes the legislation associated to nearly zero energy buildings (nZEB) in Spain in order to identify the factors that will leverage their massive implementation.

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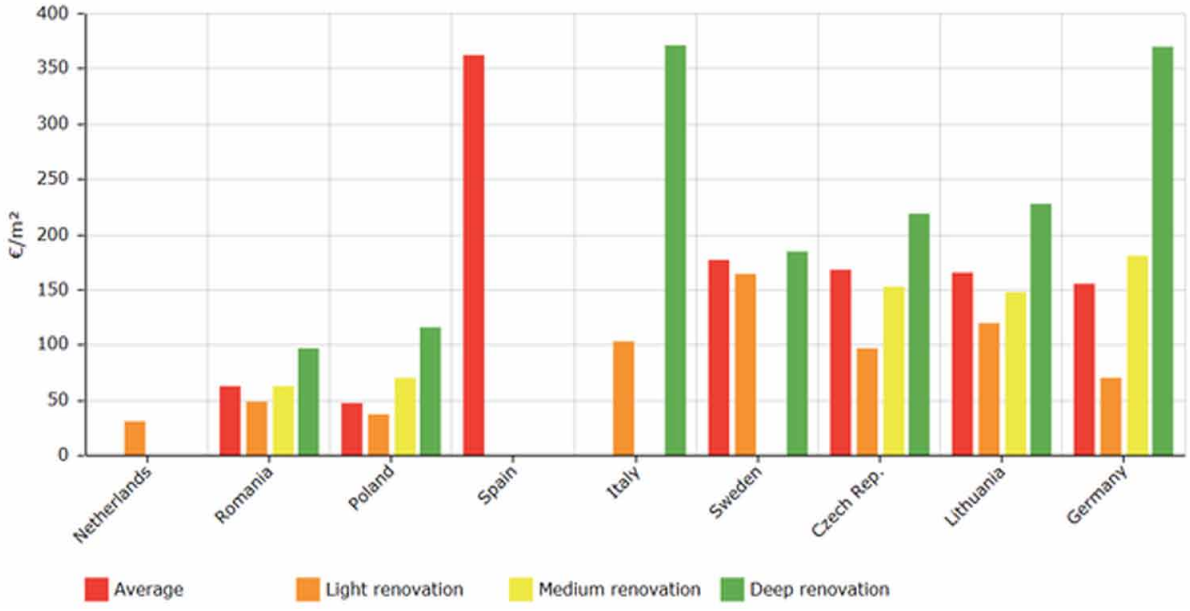
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INTRODUCTION

Construction is one of the most energy demanding segments in Europe composed in great extent by SMEs (JRC,2015). Based on this, on 30 November 2016, the European Commission published the '*Clean Energy for All Europeans*' documents (EUR-LEX, 2016), setting objectives for (a) energy policy (Annunziata et al., 2013; Kylili et al., 2015; Weißenberger et al., 2014; Cellura et al., 2015; Kurnitski et al., 2011), (b) use of renewable resources (Bonomo et al., 2015; Ferreira et al., 2016; Dabaieh et al.; 2016;), (c) energy efficiency measures and targets (Ferrara et al., 2014; Ascione et al., 2017)), and d) market design initiatives (Marszal et al; 2011; Panão et al., 2013; Ferrari et al., 2017). The released package includes the proposal on the revised Energy Performance Building Directive (EPBD) and relevant articles of the Energy Efficiency Directive (EED) (article 4 is moved to EPBD). The Energy Efficiency Directive (2012/27/EU) compels Membetr States to submit their National Energy Efficiency Action Plans (NEEAP) every three years, including energy efficiency strategies to achieve major energy savings in buildings. Specifically, in the case of building renovations, the directive encourages Member States to "establish a long-term strategy for mobilising investment in the renovation of the national stock of residential and commercial buildings, both public and private".

EPBD proposal sets renovation targets and minimum performance requirements for existing and new buildings (EUR-LEX, 2010) including for the first time the Nearly Zero Energy Buildings (nZEB) concept, which is defined as: "nZEB is a building that has very high energy performance, determined in accordance with Annex 1 of the EPBD. The nearly zero or very low energy required should be covered to a very significant extent by energy from renewable sources, produced on site or near-by" (SMD, 2014). It also defines the "cost-optimal level" as the energy performance level which leads to the lowest cost during the estimated economic lifecycle. Figure 1 shows the average cost for deep, medium and

Figure 1. Average cost of renovation by level in residential per m² (Zebra Project, 2016)



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light energy renovation of building across different countries in Europe. As it may be observed, Spain registers on the highest average cost in European residential sector, corresponding to 362.19€/m^2 (Zebra Project, 2016).

In addition, in 2009 the European Union defined the 20-20-20 targets regarding the reduction of CO_2 emissions, the increase in the use of renewables and the increase in the energy efficiency (de Gregorio, 2016). One of the main implementation strategies of this directive in the construction sector is the implementation of nZEB. The EU Directive establishes the need of each Member State to define a plan detailing the national, regional or local conditions which includes the definition of nZEB and introduces a numerical factor to measure the building use of energy, in kWh/m^2 per year (Cárcel et al., 2017).

In order to comply with this target, Spain adopted an energy efficiency obligation scheme based on a standardized negotiable energy savings certificate approach, which is flexible and straightforward enough to ensure that there is a high administrative burden for neither the obligated parties nor the regulatory body.

This programme is planned in two phases:

Phase 1: Royal Decree 235/2013 (MP, 2013) approving the basic procedure to certify the energy efficiency of buildings with the incorporation of the basic procedure for certifying the energy efficiency of existing buildings, also taking into consideration the experience of applying this law over the past five years. The Royal Decree sets out the obligation to provide the buyers or users of buildings with an energy efficiency certificate that must include objective information about the energy efficiency of a building and reference values such as minimum energy efficiency requirements or CO_2 emission. The Royal Decree sets out the obligation to provide the buyers or users of buildings with an energy efficiency certificate that must include objective information about the energy behaviour of a building and reference values such as minimum energy efficiency requirements, so that the owners or tenants of the building can compare and evaluate its energy efficiency.

In addition, the decree includes the obligation for all buildings constructed after the 31st December 2020 to be nZEB, this date is advanced to the year 2018 for the case of public buildings.

Phase 2: Official definition of nZEB to be approved by 2016-2017 so it could be applied, in a voluntary way, even before the normative is enforced both for public buildings (year 2018) and private ones (year 2020). On February 2016, the Royal Decree 56/2016 (MI, 2016) goes into force transposing EU Directive 2012/27/EU of the European Parliament and Council of 25 of October 2012, on energy efficiency in terms of energy audits, accreditation of service suppliers and energy auditors. This recently approved decree presents the nZEB concept as it is stated in the EU Directive 2010/31/UE, with no further details for its implementation or concrete requirement targets.

Directive 2010/31/EU, which repeals Directive 2002/91/EC, introduces new requirements concerning energy efficiency in buildings (Figure 2), forcing to issue an energy certificate representing energy efficiency profile of buildings to be constructed, sold or rented. In Spain, this Directive is transposed by Royal Decree 235/2013 of April 5, which repeals Royal Decree 47/2007 and regulates both new and existing buildings certification. The responsible entity of this transposition is the Spanish Ministry of Industry, Energy and Tourism, who entrusted the Institute for the Diversification and Saving of Energy (IDAE) to develop the official software for rating energy efficiency both for existing and new buildings, which are applicable throughout the national territory

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Figure 2. Objetivos marcados por las Directiva Europea 2010/31/EU de Eficiencia



Energética de Edificios (Ortega et al., 2014)

In Spain, in the field of social buildings, have been detected important barriers that complicate the definition of the concept NZEB and, consequently, the development of the corresponding legislation (IVE, 2015). In particular, the following barriers have been identified:

- **General Aspects:** There is difficulty in finding examples of social housing buildings in Spain with an energy rating of who could assimilate to what would be a building of nearly zero energy consumption.
- **Climate Aspects:** The countries of the Mediterranean area are characterized by warm climates and not extreme temperatures, allowing users to reduce energy consumption, but not to ensure thermal comfort temperatures, thus in many cases not they can pay their bills, especially in cases of energy poverty.
- **Legal and Financial Economic Aspects:** Priori users and professionals refuse to implement solutions or highly efficient systems, especially in social housing, arguing that they are too expensive, both in its installation and its maintenance.
- **Aspects of Transfer of Innovation:** Currently available on the market innovative solutions in energy efficiency to almost zero consumption building design, but there is an excessive slowness in the dissemination and implementation of the same.

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- **Social Aspects:** Difficulties of users for management and appropriate use of passive and active operation strategies of buildings from energy class type A problem compounded in the case of social housing have been identified.
- **Aspects of Information and Communication:** Consumers do not have enough information to study investment in energy saving and efficiency in a correct way. This fact is exacerbated because users do not have the detailed information on energy consumption of housing bills. Monitoring of buildings by means of automation and control that are friendly for users is essential. This misinformation makes that the citizen does not understand the cost-benefit ratio.

THE CHALLENGE OF THE CONSTRUCTION OF BUILDINGS NZEB

Main characteristic of low-consumption buildings is their demanded power, which should be equal to the generated in order to achieve a null balance (Hamdy et al., 2013; Hamdy et al., 2016). These buildings should produce at least the consumed energy of a whole year with in-situ renewable sources (Chastas et al., 2016; Congedo et al., 2015).

The European Union estimates that buildings correspond to 40% of its energy consumption and 36% of its greenhouse gas emissions (Ortega et al., 2014); therefore it is determined to reduce the environmental impact of the construction and maintenance of buildings. This is carried out by introducing the the definition of building nearly zero energy consumption or nZEB (Nearly Zero Energy Building), and requests their implementation at public facilities December 31, 2018, while it extends up to the same date of 2020 for private buildings. Optimal design of nZEB buildings is based on applying bioclimatic criteria for reducing the energy demand of the building, primarily taking into account the characteristics of orientation, compactness, insulation, sunscreens, natural ventilation, and controlled ventilation.

All EU member countries must establish its own definition of "nZEB building", according to their climate and local environmental characteristics since aspects such as vegetation, prevailing breezes, sunlight, or moisture may become strategic in constructions.

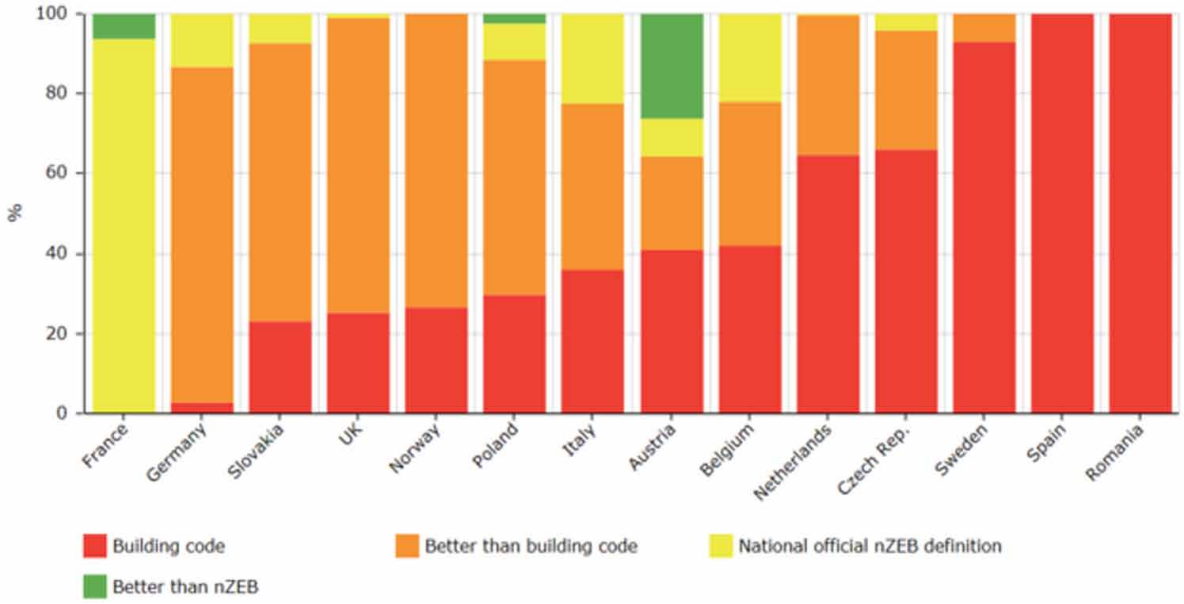
According to a technical report of the Buildings Performance Institute of Europe (BPIE) (WEB7), different countries have already agreed to its definition, being some of the main points of discussion the following:

- Thermal envelope (facades, roofs, windows, sill, etc.)
- Simulation of facilities
- Energy certification
- The main indicators to define a nZEB building.
- The methodology of calculation of energy consumption.
- The process to continue with existing construction.
- Project facilities (planes, memory, registry certificate, etc.).
- Follow-up, implementation and monitoring.

The construction of these buildings will provide a lot of economic and ecological benefits for our society. It will allow EU member countries significantly reduce CO^2 emissions to the atmosphere and to improve its energy efficiency. At the same time that stakeholders will develop technologically. Figure 3

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Figure 3. Distribution of new dwellings according to the nZEB (Zebra Project, 2016)



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shows the implementation of nZEB in several European countries, where it may be observed that Spain still has a major potential for improvement.

The Concept of NZEB Buildings in Spain

The necessary convergence of energy certification with the core document of energy saving (DB-I) of the Spanishe technical building code (CTE) and the regulation of Heating Facilities of Buildings (RITE), both updated in the year 2013, forced to the revision of the procedure used for rating the energy efficiency of the building. In addition, it was considered necessary to define a more flexible framework allowing to adapt certification to the permanent technical advancement and innovation occurring in the sector of the building in relation to energy efficiency. The most significant changes in the procedure of certification are the following:

- **Power Indicator:** Has been adopted as an indicator of consumption in the certification, the consumption of non-renewable primary energy.
- **Climatic Data and Rating Scales:** The climate data used for certification have been unified with those defined in the DB I for different climate zones. Also it has been suitably corrected the scales to adapt to new climates.
- **Factors:** It has been updated the factors established in the recognized document of RITE, CO_2 emission factors and coefficients of primary energy are implemented in the buildings certification procedure.
- **Replacement of Systems:** Technical substitution of systems have been modified to compel with the regulatory requirements established in the RITE.

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- **Ventilation Levels in Residential Buildings:** Ventilation levels have been defined more consistently with actual conditions of use in the residential buildings.

Also, the statistical treatment of the data contained in the certificates has been facilitated. New software tools generate a digital file in XML format that contains all data from the certificate, including the registration time. The new regulatory framework is detailed in the recognized documents for certification of energy efficiency "*Rating the energy efficiency of buildings*", "*Technical conditions of the procedures for the evaluation of the energy efficiency of buildings*" and the "*report of energy evaluation of the building in electronic format XML*", which are available on the Ministry website (MINETUR) (WEB8). Aslo, it may be found in this website the document regulating Heating Systems in Buildings (RITE) called "*Factors of CO_2 emission and coefficients of step to primary energy from different sources of final energy consumed in the sector of buildings in Spain*"(sap9), which are applicable from January 14, 2016. From this date on, regional communities only supports certificates generated by this version of the official software tool for energy certification.

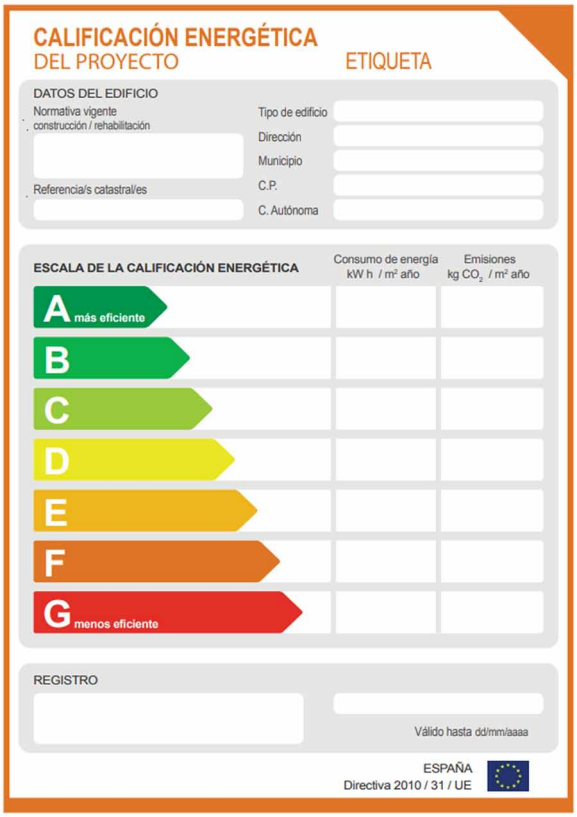
Some of the procedures for the evaluation of energy efficiency can be the following:

- General Procedure for energy certification of buildings in construction progress, existing and completed. The software tool is a computer application promoted by the Ministry of Industry, Energy and Tourism, through the IDAE, and the Ministry of Development, which allows to obtain the energy efficiency certification of a building, both in its construction and finished stage of the building. Software tool responds to two energy certification procedures:
- Simplified procedures for energy certification of existing buildings. CE3 and CE3X are computer tools used to obtain the certification of the energy performance of an existing building (Figure 4).
- Simplified procedures for qualifying energy efficiency of residential buildings. CERMA software, is a computer tool used to obtain, in a simplified manner, the energy efficiency rating of residential buildings.

Calculation procedures must conform to the conditions set out in this document and backed in the core document of energy saving (DB-I) of the technical building code (CTE). In this section, the documents deal with the procedures for calculating the energy consumption of a building. Both, detailed and simplified procedures have to calculate energy demand and energy consumption taking into account the hourly evolution of thermal processes, behavior of the facilities and the contribution of renewable energy sources. Besides, procedures should also consider the categorization of spaces in the building defined in the DB-HE, differentiating between living spaces and not living spaces, and distinguishing living spaces according to their internal load (low, medium, high or very high) and level of conditioning (conditioned or unconditioned). In compliance with the common general framework of the EPBD 2010/31/EC, procedures must also allow accounting the following aspects in relation to the energy performance of the building: (a) the real thermal characteristics of the building, including its internal divisions: 1) thermal capacity, 2) insulation, 3) passive heating, 4) elements of cooling, and 5) thermal bridges; (b) the installation of heating and hot water, and their insulation characteristics; (c) air conditioning installations; (d) natural and mechanical ventilation which may include air-tightness; (e) installation of incorporated lighting (especially in the non-residential area); (f) design, location and orientation of the building, including outside climatic conditions; (g) the passive solar systems and solar protection; (h) indoor climatic conditions, including projected indoor environmental conditions; (i) internal loads;

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Figure 4. Example of model project in Spain energy rating labels



((j) the positive impact of the following, when they become relevant: 1) local conditions of exposure to Sun and active solar systems, as well as other heating and electricity systems based on renewable energy sources; (2) electricity produced by cogeneration; (3) urban or central heating and cooling systems; (4) natural lighting.

CAPITAL COSTS TRENDS AND HOW THEY AFFECT THE NZEB RETROFIT IN DOMESTIC BUILDINGS

Complying with the obligations established by the European Directive 2010/31/EU and Delegated Regulation 244/2012, the Ministry of Development, together with the Directorate for Architecture, Housing and Planning, developed in June 2013 the report on cost optimal calculations and comparison with the current and future energy performance requirements of buildings in Spain (Ministry of Development, 2013). The report bases the analysis in four typical existing residential dwellings: two of them are single family and two multifamily, and estimates the optimal costs for NZEB implementation in Spain, considering the six climatic areas, from warmest to coolest (α A, B, C, D and E) (INE, 2001). The study uses the energy costs, taxes included, corresponding to real Spanish prices by December 2012 (AENOR, 2008)] in order to assess the costs (Table 1).

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Table 1. Overview of the energy price for the average household (AENOR, 2008)

Energy Source	Cost [€/kWh$_t$] (Year: 2012)
Home Heating Oil	0.096
Natural Gas	0.068
LPG	0.115
Electricity	0.209
Biomass[1]	0.046

In addition, considering other European initiatives, the following approximate costs have been identified (Table 2).

Barriers to the Realization of nZEB Buildings in Spain

Few important barriers have been acknowledged responding to the nZEB requirements and, consequently, the development of the corresponding legislation, especially in the field of social housing. In particular it has been identified the following (Ortega et al., 2014; IVE, 2015):

- **Climate Aspects:** Mediterranean countries are characterized by warm climates without extreme temperatures, allowing users to reduce energy consumption. However, thermal comfort is not ensured in cases of energy poverty despite thermal discomfort periods are short, falling to January or February as much. In addition, Mediterranean countries are characterized by the absence of a culture in buildings maintenance, especially in social housing occupied by people with limited economic resources. Regulatory framework of nZEB is very demanding and involves installing highly efficient systems; therefore these strategies may be neglected, especially due to their high maintenance costs. Subsequently, carbon emissions potential is not achieved.
- **Legal and Financial Aspects:** Spain has not yet detailed the key aspects of nZEB. The main obstacle is the lack of capital available to finance nZEB. Owners do not have the necessary budgets or find funding to make the investments. The return of the initial investment is long-term periods which require other different models to those that currently exist. Long-term investment funds, energy service companies and so-called "green funds" are new funding mechanisms that can serve as a great opportunity, however these initiatives depend on regional and national adoption of laws. Therefore, there are some uncertainties in the return of the invested capital as well as in the profitability of the investment since energy savings depend on the future price of energy.
- **Social Aspects:** Difficulties in the implementation of passive and active energy saving strategies in buildings with energy management systems. They result very complex systems to manage and costly to maintain, especially in social housing.

Given the heterogeneity of consumers in the different types of buildings in Spain, it is difficult to identify a common set of profitable energy saving strategies since they mainly depend on the user's consumption habits (Barthelmes et al., 2016).

Finally, the needs and interests of Public Administrations do not always agree with the targets of private entities.

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Table 2. Overview of the energy improvement measures costs for the average household (AENOR, 2008)

Measure	Estimated Cost
Floors	
Floor insulation	10-25 €/m^2
Walls	
Internal wall insulation (5 cm)	20-150 €/m^2
External wall insulation (10 cm – EIFS System)	50-150€/m^2
Roofs	
Remove roof and refit adding a layer of insulation (15 cm)	60-180 €/m^2 of roof area
Add-on a thermal insulation layer (15 cm) over the last slab in contact with unconditioned space (attic)	20-40 €/m^2 of roof area
Windows and doors	
Replacements windows and doors (U value 2.2)	(450) €/m^2 of window area
Replacement windows and doors (U value 1.4)	(525) €/m^2 of window area
Air tightness and ventilation	
Draught – stripping	Up to 100 €
Major air tightness measures	100-1000 €
Air tightness with MVHR	1000-5000 €
Lighting and appliances	
Low energy lights	10-50 €/m^2 of illuminated floor area
Low energy appliances	1000-5000€
Heating	
Condensing boiler	135 €/thermal kW
Indoor thermostatic control system	180 €/per room and m^3/h
Micro CHP gas turbine	2500 €/thermal kW
Ground source heat pump	1650 €/thermal kW
Air to water heat pump	350 €/thermal kW
Wood pellet boiler	1075 €/thermal kW
Renewable energy systems	
Solar thermal for domestic hot water	800 €/m^2 of solar panel
PV installation	3250 €/kWp installed
Micro wind turbine	4000-10000 €/kWp installed

- **Transfer Innovation:** Currently there are innovative solutions for energy efficiency in nZEB design available on the market, however the deployment of these products have not been sufficiently adopted by the construction industry. This fact is enhanced by the uncertainty about their savings, given that there is not a validated experience proving the results over time. Also, the inertia of the construction sector interferes in the implementation of these new alternatives, which is still fairly conservative segment in Spain.

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- **Economic Aspects:** Priori users and professionals refuse to implement solutions or highly efficient systems, especially in social housing, since they consider there are too expensive, both in its installation and maintenance. It is necessary to develop long term studies (30 years), under the criterion of the overall cost, demonstrating the real profitability of various solutions.
- **Information and Communication:** Consumers do not have enough information for correctly analysing different investments in energy saving and efficiency. This fact is exacerbated because users do not have the detailed information on their energy consumption bills. Thus, it is important to monitor energy consumption in buildings by means of automation and control that are friendly for users. Lack of information makes difficult for citizens to understand the relationship cost-benefit, discarding the economic benefits of more energy efficiency devices. In addition, there is a lack of awareness in the technical feasibility of this type of buildings, even among professionals and especially users with low incomes.
- **Education and Training Aspects:** There is a lack of specific training and qualification of professionals in high energy efficiency systems, which ensure the quality of services and allow the development of the sector in all its potential. Labour is not qualified to install more innovative technological devices in the field of energy efficiency and solutions.

GEOGRAPHICAL AND SOCIAL CONTEXT

Spain is located in the West part of Europe with a total area of 504.645 km^2 with most of it concentrated in the Iberian Peninsula but also including two archipelagos: Balearic Islands, in the Mediterranean Sea, and Canary Island, in the Atlantic Ocean near the West African coast. Total Spanish population reaches 46.439.8664 inhabitants (NIS, 2015).

Climate

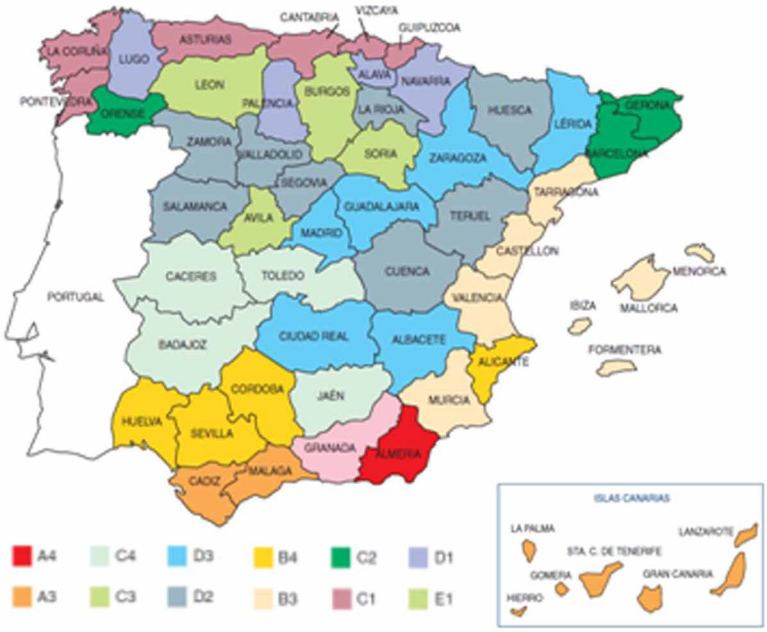
Spain continental area lies between latitudes 36º 00' to 43º 47' N and longitudes 9º 18'W to 3º 19' E and presents 12 different climates zones for energy certification based on limiting energy demand. Winter division is designated by letters (A, B, C, D, E), while summer identification uses numbers (1, 2, 3, 4) (Figure 5).

In general terms, the central part of the country has a continental climate, while the coastal areas have a more moderated climate, warmer in the case of Mediterranean coast. Also, extension and rain fall level varies in these areas as it has been analysed in the period from 1997 to 2007 (Table 3).

The Atlantic area has mild temperatures: between 12º and 15ºC in the winter and 20-25ºC in the summer period and the annual rain fall is above 1000 mm. The Mediterranean area has irregular rainfalls, between 400 and 700 mm per year and concentrated in the spring and fall, in the last period with a torrential behaviour. Winters are short and mild, while summers are long and hot. Average annual temperature is in the range 15º-18ºC. Finally, the continental area has extreme temperatures: between 25º and -13ºC. Winters are long and cold with average minimum temperatures up to -5ºC, while in the summer temperatures exceed the 35ºC, and even 40ºC sometimes. Rainfall in continental zone is low, about 400 mm, in part in the form of storms during July and August (VVAA, 2011).

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Figure 5. Climate areas in Spain



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Table 3. Historic rainfall level

Area	*Climate type*	*Surface fraction*	*Rain fall*
North	Atlantic	10%	High (>1000 mm)
Central	Continental	70%	Low (500 mm)
South and East	Mediterránean	20%	Low but torrential (400mm)

Housing Stock

There are a total of 25.2 million dwellings in Spain, distributed, according to the 2011 census, as follows: 71.5% main dwellings (17,528,518 ones), 14.8% secondary dwellings (3,616,695) and 13.8% as empty and other dwellings (3,374,291) (IDAE, 2011).

In general dwellings are categorized based on usage, with 68.6% of dwellings regarded as multi-family (17,250,759 dwellings) and 31.4% as single-family (7,709,272 dwellings). Moreover, multi-family dwellings have greater weight among main dwellings (71.8% compared to 28.2% of single-family dwellings), while the opposite occurs in the secondary dwelling stock (where single-family dwellings total 46.9% compared to 53.1% of multi-family dwellings). In the case of empty dwellings, the distribution is practically similar to the distribution for the total (68.4% multi-family and 31.6% single-family dwellings).

Out of 18 million Spanish main dwellings, nearly half fall between 61 m^2 and 90 m^2 in size; 29.6% (5,354,920 dwellings) are between 76 m^2 and 90 m^2 and 18.6% (3,360,925) are between 61 m^2 and 75 m^2 (EIA, 2002).

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Registered information of exploited land in 2013 (MD, 2014) makes it possible to differentiate the following dwelling types based on the use of the dwelling: shared (multi-family) in a block or open building, which accounts for 24.1% of the total national dwellings, shared (multi-family) in perimeter blocks, which accounts for 46.3% and, within single-family dwellings, detached and semi-detached homes, accounting for 10% of the total stock. Finally, terraced single-family dwellings or dwellings in a perimeter block (in a traditional urban area or a recent low-density development) reach to 19.6% of the total.

Within a total 25.2 million existing dwellings in Spain, nearly half (47.6%: 11,987,675) are in urban municipalities with over 50.000 inhabitants, with the remaining half distributed as follows: 15.7% in municipalities with 20.001–50.000 inhabitants (3,969,298 dwellings), 20% in municipalities with between 5.001–20.000 inhabitants (5,029,342 dwellings) and another 16.7% in municipalities with fewer than 5.000 inhabitants (4,222,297 dwellings).

According to the data from the 2011 census (NIS, 2014), among main dwellings, over three-quarters (78.9%) are owned, while just 13.5% (2,438,575) are rented and 7.6% are made available free of charge.

Addressing the characterization of the non-residential sector of the building stock, it is considered one last differentiation as key vis-à-vis the dwelling stock: energy use largely depends on the activities accommodated by these buildings, and since the types of activities are so variable, it is impossible to assume that there is a common benchmark pattern as there may be in residential buildings – in spite of the undeniable variety that exists among dwellings. Therefore it is considered decisive to form the segmentation of the non-residential buildings based on a differentiation by types of use.

Non-residential buildings can be also considered to check the relative importance of each group on the search for nearly zero energy buildings. The number of properties by uses and construction decade according to the land categories are shown at the following table. It may be deduced that more than 66% of buildings are residential (Table 4).

Table 4. Categorization of buildings uses and construction decade

	NO OF PROPERTIES BY USES AND DECADE OF CONSTRUCTION												
	Before 1900	1900–1920	1921–1940	1941–1950	1951–1960	1961–1970	1971–1980	1981–1990	1991–2001	2002–2011	Since 2012 (*)	Other (**)	TOTAL
RESIDENTIAL													***23 142 267***
V - Residential	437 912	1 237 387	944 525	661 857	1 278 305	3 123 052	4 185 544	2 938 095	3 728 153	4 419 507	76 738	111 192	23 142 267
NON-RESIDENTIAL													***11 894 635***
TERTIARY, SERVICES AND PUBLIC FACILITIES													***1 967 237***
O - Offices	1 999	5 898	5 981	5 590	10 328	36 178	51 190	36 706	56 613	71 932	593	344	283 352
C - Commercial	13 401	36 134	35 686	25 735	59 062	211 028	280 036	213 446	235 776	181 623	2 356	1 076	1 295 359
K - Sports	177	704	597	823	1 779	5 872	12 874	13 846	11 620	8 777	240	617	57 926
T - Entertainment	147	433	380	303	425	666	904	765	707	380	10	183	5 303
G - Leisure and Hospitality	1 598	4 340	3 019	2 076	4 418	17 556	45 028	64 020	28 005	24 475	172	2 161	196 868
Y - Health and Charitable	424	1 147	1 137	958	1 506	3 993	8 346	7 886	6 483	5 133	117	252	37 382
E - Cultural	1 151	2 853	3 131	2 820	4 965	8 269	9 315	5 843	4 305	4 139	96	695	47 582
R - Religious	11 605	14 788	2 958	2 025	1 848	2 392	2 561	1 464	1 166	974	86	1 598	43 465
INDUSTRIAL													***1 703 522***
I - Industrial	106 613	272 072	120 087	80 468	90 744	152 938	231 222	202 719	207 094	155 928	2 149	81 488	1 703 522
WAREHOUSE - PARKING													***7 984 295***
A - Warehouse - Parking	24 156	74 466	46 550	33 266	61 810	263 439	1 005 188	1 166 184	2 159 091	3 092 778	49 344	8 023	7 984 295
OTHER													***239 581***
M - Urban design and gardening	3 205	9 213	3 349	2 037	2 004	3 878	35 541	6 130	10 975	30 064	922	39 771	147 089
P - Singular building	1 216	2 535	1 642	1 313	1 430	1 775	3 319	2 443	6 978	2 086	46	483	25 266
B - Agricultural warehouse	281	863	593	458	735	949	1 884	1 176	717	969	5	170	8 800
J - Agricultural Industrial	2 273	7 840	4 906	3 939	4 101	5 731	12 753	8 043	5 031	2 316	12	1 481	58 426
Z - Agricultural													
(*) Includes properties whose year of construction is 2012 or 2013.													
(**) Any properties whose year of construction is zero, or after 2013.													

Source: (MD, 2014)

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Final energy consumption in Spain for residential and non-residential buildings in year 2011 shows the penetration of renewable sources in this sector, together with the gas (Table 5).

Residential homes are responsible for almost 18% of the total final energy consumption. Using IEA data (IEA, 2017) it is possible to follow up the evolution of the energy consumption of the residential sector. It has not decreased during the last years of economic crisis (Figure 6).

In the case of residential homes, the types of use for the same year 2011 enables to consider energy consumption for heating as the key for establishing energy consumption in climate control, since energy consumption for cooling is marginal (accounts for less than 2% of energy consumption for climate control) (Table 6).

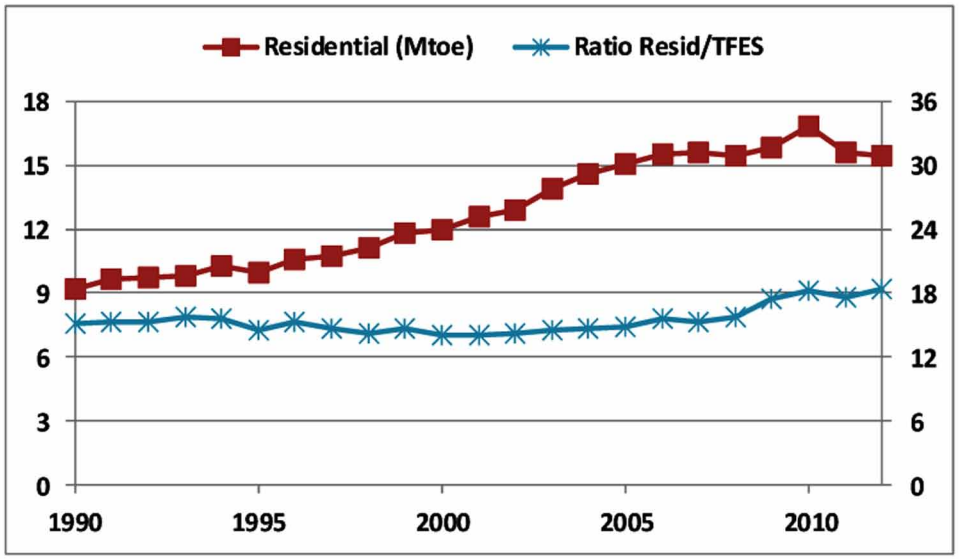
The distribution of consumption according to final energy fuel in heating for the different climatic zones and dwelling type (single family/multi-family) (Table 7).

Table 5. Final energy consumption in Spain according to sectors (2011)

FINAL ENERGY CONSUMPTION (ktoe)	COAL	PETROLEUM PRODUCTS	GAS	RENEWABLE ENERGY SOURCES	ELECTRIC POWER	TOTAL
INDUSTRY	1 717	4 356	7 697	1 256	6 317	21 344
TRANSPORT	0	33 696	83	1 721	388	35 889
MIXED USE	198	5 779	6 220	2 838	14 237	29 272
Agriculture	0	1 518	466	70	349	2 404
Fishing activities	0	0	0	0	0	0
Business, Services and Public	0	1 355	1 755	104	6 992	10 206
Residential	122	2 906	3 411	2 647	6 545	15 631
Other unspecified	76	0	587	17	351	1 031
FINAL ENERGY CONSUMPTION	1 915	43 832	14 001	5 815	20 942	86 505

Source: (IDAE, 2011)

Figure 6. Energy consumption in residential sector



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Table 6. Final energy consumption in the residential sector in Spain according to types of use (2011)

Type of Use	Coal	Petroleum Products			Gas	Renewables				Electric Power	TOTAL
		LPG	Liquid Fuels	TOTAL		Biomass	Solar	Geothermal	TOTAL		
	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe
Heating	12	388	2 033	2 421	1 695	2 368	10	6	2 384	380	6 892
DHW	1	459	183	642	1 566	50	129	3	182	385	2 776
Cooking	2	185	-	185	399	26	-	-	26	479	1 091
Lighting	-	-	-	-	-	-	-	-	-	606	606
Air conditioning	-	-	-	-	-	-	-	3	3	120	123
Electrical household	-	-	-	-	-	-	-	-	-	3 188	3 188
TOTAL	15	1 032	2 216	3 248	3 660	2 444	139	12	2 595	5 158	14 676

Source: IDAE.

Source: (IDAE, 2011)

Table 7. Distribution of consumption according to final energy fuels in heating by SEC-SPAHOUSEC climatic zones and dwelling type (single family/multi-family)

DISTRIBUTION ACCORDING TO FINAL ENERGY FUEL IN HEATING	Dwelling type	
	Single family	Multi-family
NORTH ATLANTIC ZONE	MWh	MWh
TOTAL PETROLEUM PRODUCT HEATING	2 145 662	862 921
TOTAL GAS HEATING	291 781	1 595 117
TOTAL RENEWABLES HEATING	2 526 742	2 835
TOTAL ELECTRICITY HEATING	137 152	539 250
TOTAL	5 101 336	3 000 123
CONTINENTAL ZONE		
TOTAL PETROLEUM PRODUCT HEATING	8 145 127	8 950 298
TOTAL GAS HEATING	2 601 256	7 221 319
TOTAL RENEWABLES HEATING	10 806 596	4 427
TOTAL ELECTRICITY HEATING	480 435	1 181 465
TOTAL	22 033 413	17 357 508
MEDITERRANEAN ZONE		
TOTAL PETROLEUM PRODUCT HEATING	5 977 658	1 480 953
TOTAL GAS HEATING	2 099 425	5 491 210
TOTAL RENEWABLES HEATING	13 627 833	1 847
TOTAL ELECTRICITY HEATING	594 419	1 392 030
TOTAL	22 299 335	8 366 040
TOTAL	49 434 085	28 723 671

Source: (IDAE, 2011).

Energy use corresponding to residential sector in Spain accounted for 15.5 Mtoe in 2012 (IEA, 2017). This represents 18% of the total final energy use of the country. Taking into account the number of households, the average annual energy use for each household is approximately 10,604 kWh, and assuming that average Spain household size is 90 m^2, the numerical indicator for the typical energy use of the average Spanish household is 117,8 kWh/ m^2 per year.

LEGISLATIVE FRAMEWORK

Along this section it is described current policies related to nZEB as well as building standards defined for energy efficiency.

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Current Policies

In order to comply with the target in Article 7 of Directive 27/2012/EU and in accordance with the provisions of paragraph 1 of this Article, Spain is adopting the Energy Saving and Efficiency Action Plan 2011-2020 (IEA, 2017) based on the standardised energy certification system.

Regarding to renewable projects, it is defined a special regime (i) Royal Decree 661/2007, regulating electrical energy production under the special regime, (ii) Royal Decree 1578/2008, on the compensation of electrical energy production using photovoltaic solar technology, and (iii) Article 4 and Section 2 of the Fifth Transitory Disposition of Royal Decree Law 6/2009, for the adoption of certain measures in the energy sector and the approval of the social bond ("RDL 6/2009"). Nevertheless, due to the crisis, some provisions have repealed, in special the pre-assignment mechanism. This mechanism was currently in suspension pursuant to provisions of Article 1.b) of Royal Decree Law 1/2012, which had suspended the compensation pre-assignment procedures and suppressed the economic incentives for new renewable, cogeneration, and waste-to-energy plants. This unfavourable economic framework lead to other design approaches in nZEB (Forlani, 2015; Giordano, 2016).

Actual policies on nZEB are basically based on the abovementioned Royal Decree 235/2013 and the Royal Decree 238/2013, both published the same day, amending certain articles and technical instructions in the Regulations on Building Heating Installations (RITE) of 20 July 2007 to set out stricter requirements concerning the energy performance of heating and cooling equipment, as well as equipment used to move and transport fluids. This amendment arises from the need to transpose Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings into the Spanish legal system and the requirement set out in the Second Final Provision of the abovementioned Royal Decree 1027/2007 to carry out a periodic review at intervals not exceeding five years to keep it in line with the progress of technology and Community legislation.

The second decree regulates the energy efficiency and safety requirements that must be met by heating installations in buildings in order to address the requirements of personal well-being and hygiene. This law sets out requirements related to general energy efficiency, correct installation and sizing, appropriate control and adjustment of the installations that are present in existing buildings. Moreover, it establishes the inspections that must be carried out periodically on the accessible parts of climate control installations throughout their useful lives, in order to verify compliance with the energy efficiency requirement.

Energy Efficiency Building Standards

The Spanish report on Energy Efficiency and Savings Policy Measures (ESE, 2013) breaks down final energy consumption in three sectors (industry, transport and residential, services and other). It uses ktoe units to measure and compare energy savings in 2010, 2011 and 2012, and contrasting their average with the savings targets set on final energy. Total savings target for the period 2014–2020 for Spain – excluding the transport sector– reaches the 21.305 ktoe and for the residential, services and other sector is 12.432 ktoe. In accordance with the possibility set out in Article 7(2) and (3) of the Directive, the cumulative savings target is reduced from 21.305 ktoe to 15 979 ktoe for the entire period between 1 January 2014 to 31 December 2020. Three different final energy consumption savings scenarios have been established for residential buildings (MD, 2014):

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- **Scenario 1 – High Residential:** Savings on the cumulative final energy consumption for thermal uses (heating, cooling and DHW) for the period 2014–2020 equal to 32% of the average total final energy consumption for the years 2010–2012.
- **Scenario 2 – Average Residential:** Savings on the cumulative final energy consumption for thermal uses (heating, cooling and DHW) for the period 2014–2020 equal to 26% of the average total final energy consumption for the years 2010–2012.
- **Scenario 3 – Basic Residential:** Savings on the cumulative final energy consumption for thermal uses (heating, cooling and DHW) for the period 2014–2020 equal to 7% of the average total final energy consumption for the years 2010–2012.

This last scenario for the residential sector would arise from extending, between 2014 and 2020, approximately, the direct subsidies already committed for improving energy efficiency in the building sector in the various plans and programmes already in force. In addition, it considers the application of an estimated percentage of new European funds 2014–2020 for subsidies for energy efficiency in the building sector (Table 8).

However, in order to work with the reduction targets in the way to nZEB, it is necessary to recognize the functional logic in the factors that determine climate control energy consumption in buildings. The factors that determine climate control consumption in a building are:

- The use and management of the building and of its elements and systems;
- The energy demand, considering the energy losses due to transmission and the energy losses due to ventilation separately, if desired;
- The efficiency of the climate installations that satisfy the comfort demand;
- The source of the energy that is supplied to the building.

The rational order of intervention in case of separate actions over time is precisely the order in which they have been presented in the list. Normalized codes for these applications are not yet approved in Spain.

Actual Instruments to Promote nZEB

Currently in Spain there are no schemes promoting nZEB. Nevertheless, there are various schemes regarding the retrofit of domestic buildings towards energy efficiency.

Table 8. Energy efficiency scenarios for residential buildings

Residential buildings	Final energy CONSUMPTION (ktoe)				Cumulative Savings 2014–2020	
	2010	2011	2012	AVERAGE	ktoe	%
Scenario 1. HIGH RESIDENTIAL	16 924	15 648	15 512	16 028	5 077	32
Scenario 2. AVERAGE RESIDENTIAL					4 088	26
Scenario 3. BASIC RESIDENTIAL					1 044	7

Source: (SMD, 2014).

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- ICO (Official Credit Institute) Line for the '*Renovation of dwellings and buildings*' (WEB 1). The line provides funding aimed at the self-employed, businesses and public and private entities, both Spanish and foreign, that make productive investments within Spain. The portion associated with renovation is aimed at addressing the funding requirements of individuals and homeowners associations, in order to undertake renovation or refurbishment projects on their homes and buildings, common elements and homes. The transactions are processed directly through the credit institutions.
- Institute for Energy Diversification and Saving (IDAE) PAREER Programme (WEB 2). The IDAE's PAREER Programme came about in order to encourage the implementation of integral energy efficiency saving and improvement actions, as well as the use of renewable energy sources, such as the renovation of windows, façades, roofs, boilers, air conditioning equipment, the incorporation of equipment to individually measure heating and domestic hot water consumption, replacing conventional energy with biomass or geothermal energy, etc. (WEB 3).

TRAINING MARKET

Given there is still no specific legislation in Spain referring to nZEB, no procedure is defined for the definition and accreditation of nZEB experts. However, several indicatives are in progress at the European level: MEnS (WEB 4) and PROF/TRACT EU (WEB 5) projects, which are developing Open Training Platforms and Qualification framework for professionals dealing with nearly zero energy buildings.

In addition, national strategies have been defined offering particular opportunities for growth and generation of employment in the construction sector. These strategies include a series of measures that need to be undertaken in the short term aimed to:

- Raise awareness and create a pro-renovation culture to create a positive impression of the energy renovation of the building stock. Any basic scenario could noticeably improve if the public were aware of renovation's potential in the improvement of their homes and dwellings, their quality of life, the energy bills they pay and in the revaluation of properties for their owners. At present, the current lines of public aid are not providing the right response, largely due to this lack of awareness and culture, which does already exist in other European countries.
- Develop business strategies with particular focus on the needs of homeowners associations. This would mean facilitating the restructuring of development/construction companies with a view to a new role as integral managers of renovation processes and changing the model of energy suppliers by influencing new emerging values.
- Define administrative measures logically associated with improving coordination between the three levels of public administration: State, regional and municipal. They are all involved in these policies and in the processes to implement the same, in different ways, but the objectives are shared. The coordination must prevent, as far as possible, any duplications or contradictions that could arise.
- The renewable energy sector is a very attractive investment opportunity for green entrepreneurs (Ndubisi et al., 2009), entrepreneurs capable of discovering opportunities in extant economic structures in order to introduce competitiveness in sustainable behaviours (Pacheco et al., 2010).

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In the energy sector, any green initiative needs to be thoroughly analysed, considering general energy planning. Entrepreneurs need to understand the big picture of energy sources in a country, how and why these sources are used, and the possible future demand scenarios, before taking any strategic decision for renewable energy investment (Peñalvo et al, 2017; Cárcel et al, 2018).

CONCLUSION

The necessary convergence of energy certification with the core document of energy saving (DB-I) of the technical building code (CTE) and the regulation of facilities heating of buildings (RITE), both updated in the year 2013, forced to the revision of the procedure used for rating the energy efficiency of the building.

Spanish housing stock represents an opportunity to increase energy savings and equivalent CO_2 emissions in the residential sector based on their large savings potential. Despite national legislation has included directives regarding minimum energy demand and integration of renewable energy sources in buildings, it is necessary to go a step further. Nearly Zero Energy Buildings (nZEB) concept should be implemented in new public building by 2018, while in the rest of building constructions will be mandatory by 2020. Nevertheless, specific targets and requirements for nZEB are still to be concreted. It is necessary to define a national nZEB roadmap to identify the final goal and intermediate steps in order to achieve a massive implementation of nZEB in Spain, especially in social housing.

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About the Contributors

Vicente González-Prida Díaz is PhD in Industrial Engineering by the University of Seville, and Executive MBA by the Chamber of Commerce. He currently works as Business Development Manager in the company General Dynamics - European Land Systems. He shares his professional performance with the development of research projects in the Department of Industrial Organization and Management at the University of Seville and the Department of History, Logic and Philosophy of Science at UNED in Madrid, Spain. He has written multitude of articles for conferences and publications, national and international-wide. His main interest is related to industrial asset management, specifically the reliability (design specification, data analysis), maintenance (outsourcing, e-maintenance) and sales management (cost analysis, logistics, organization). Recently, he has published a book in Spanish language about the ISO 55000, and also the book "After–sales Service of Engineering Industrial Assets" by the editorial Springer-Verlag.

Jesús Zamora Bonilla graduted in Philosophy (1986) and in Economics (1995) at Universidad Autónoma de Madrid, where he also attained a PhD in each of both areas (1993 and 2001). He taught Economic Methodology at Universidad Carlos III (1994-2002) before becoming professor of Philosophy of Science at UNED (Universidad Nacional de Educación a Distancia), where he currently is the dean of the Faculty of Philosophy. His research has focussed around scientific realism and truthlikeness, the rationality of science, philosophy of social sciences, and the application of economic models to social epistemology. He has published papers in most of the top journals in philosophy of science and philosophy of economics and the social sciences (*Synthese, Philosophy of Science, Erkenntnis, Theoria, Episteme, Journal for General Philosophy of Science, Journal of Economic Methodology, Philosophy of the Social Sciences, Economics & Philosophy*, etc.) and is also co-editor, with Ian Jarvie, of *The SAGE Handbook of Philosophy of Social Science* (2011), besides having also published numerous papers and monographs in Spanish. He has been member of the Executive Board of INEM (2006-2012), is founding member of the steering committee of the European Network for the Philosophy of the Social Sciences, was treasurer of the Spanish Society of Logic, Methodology and Philosophy of Science (1999-2007), is full member of the Académie Internationale de Philosophie des Sciences, and has served as associate editor of the European Journal of Philosophy of Science (2009-2017).

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Ignacio Aranís is an industrial civil engineer who graduated from the technical University Federico Santa María in 2017. He is currently working as an engineering and development leader in Unidad Coronaria Movil (UCM), a company that provides emergency rescue services to individuals, as well as clinics.

Niccolò Becattini holds a Master Degree in Mechanical Engineering with honors (University of Florence, Italy) and a PhD in Mechanical Engineering (Politecnico di Milano, Italy). He has been working at the Department of Mechanical Engineering of Politecnico di Milano since 2009, first as a research fellow and now as Assistant Professor. He teaches and co-teaches courses of "Technical Drawing" (undergraduate major in mechanical, energy and aerospace engineering), "CAD laboratory" (undergraduate major in mechanical and biomedical engineering) and "Methods and tools for systematic innovation - Problem Solving and Inventive design module" (graduate major in mechanical engineering). In December 2016 he got the qualification as Associate Professor by the Italian Ministry of Education, Universities and Research (MIUR). He also delivers vocational courses for companies on systematic innovation themes and trains professionals on the application of inventive design tools in real industrial case studies. He is author of more than 40 peer reviewed publications that have been published in international journals and in conference proceedings. His research interests covers the domain of design methods and tools, with a specific focus on cognition and techniques to enhance design creativity and idea generation. He has been involved with an active role in international projects funded by the European Union (OPEN-IT - ERA-SME project n. 72659; FORMAT - Marie Curie IAPP - PIAP-GA-2011-286305). Since January 2016 he has been also working as Assistant Project Coordinator for the EU's Horizon2020 project SPARK (Spatial Augmented Reality as a Key for Co-creation - (H2020-ICT-19-2015- 688417).

Jan Braaksma is an assistant professor in the chair of Maintenance Engineering at the University of Twente and is the director of the WCM Summer School part of World Class Maintenance. He has worked for the University of Groningen (RuG) and the Dutch Defense Academy (NLDA). He holds a Master's degree in Business and ICT and a PhD degree in Economics and Business. Jan's research focuses on Asset Management with a special attention for Asset Life Cycle Planning, Maintenance Engineering and Design for Maintenance. A significant part of his research is in cooperation with companies such as Liander, Strukton Rail, Netherlands Railways (NS), Heineken, AkzoNobel, Sitech, Huntsman, Sabic and TataSteel. Jan is responsible for the Master Class on Maintenance Engineering & Management provided by the University of Twente.

F. Javier Cárcel-Carrasco is an Industrial Engineer with a PhD in Industrial Engineering from the Universitat Politècnica de València (UPV), Spain. He holds a PhD in Economic and Business Sciences from UNED, Spain. He is currently Professor in teaching and research in the Department of Building Construction in the UPV. He is a member of the Institute of Energy Engineering of the UPV. His main research areas are renewable energy sources, energy efficiency and industrial maintenance engineering.

María Carmen Carnero has a Doctorate in Industrial Engineering from the University of Castilla-La Mancha (2001) and is a lecturer at the Higher Technical School of Industrial Engineering at the University of Castilla-La Mancha. She has published two books, four chapters in science books, and has published research articles in Omega, Decision Support System, European Journal of Operational Research, Reliability Engineering and System Safety, European Journal of Industrial Engineering, Journal of Manufacturing Systems, The International Journal of Advanced Manufacturing Technology, Mechanical Systems and

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Signal Processing, Production Planning and Control, etc. She has 70 contributions to conferences and congresses. She was the lead researcher in three projects financed by the regional government, and has been a part of 16 other European, national, regional and local projects, and of 10 contracts.

Simone Centuori is the current Head of the Mission Analysis & Navigation Division at DEIMOS Space. He has more than 10 years of experience in the mission analysis domain both for Earth observation and interplanetary missions. He has led the mission analysis of several ESA missions, among them FLEX, BIOMASS, SAT-AIS, Phobos Sample Return, Mars Sample Return and Proba-3. In 2017 he obtained the degree in philosophy at UNED with a final thesis on "Techno-science epistemology - The study case of asteroids investigation".

Constanza Céspedes is a Product Design Engineer, currently student of M.Sc Industrial Engineering at Technical University Federico Santa María. Her latest developed works were executed in work teams mainly in management and organization areas. Also, hers researching has been related with Management, Design and Product Development Process.

K. B. Chuah received degree in mechanical engineering from Loughborough University, U.K. He received the Ph.D. degree for his work on a U.S. Navy-funded project on roughness and hydrodynamic drag. He was a Senior Research Coordinator managing a multidisciplinary computer integrated manufacturing research team at the University of Teesside, Middlesbrough, U.K. before starting his lecturing career. He is currently an Associate Professor of the Department of Systems Engineering and Engineering Management, City University of Hong Kong, Hong Kong, China. Apart from being a core faculty member of various undergraduate and postgraduate programs, he teaches project/ engineering management, teamwork & communication supervises many MPhil, PhD, and EngD candidates in research areas that spans from project/ engineering management, production/ industrial process analysis to organizational learning/ development.

Ana Cuevas-Badallo is associated professor at the Philosophy department, and Researcher at the Institute for Science and Technology Studies (Ecyt) at the University of Salamanca (Spain). She received her PhD in Philosophy at the University of the Basque Country and has been the academic director of the Ecyt, the Postgraduate program at the Institute, and the General Secretary of the University of Salamanca. Cuevas-Badallo has published on technological sciences epistemology, technological bio-artefacts and public participation in science and technology. She coordinated several research projects on Public Understanding of Science focusing on biotechnology and public participation in scientific and technological controversies. She has been visiting researcher at the University of Helsinki (Finland), the University of Delaware (USA), the University of Delft (The Netherlands) and the University of Valparaiso (Chile).

Javier Echeverría Ezponda is a Research Professor at Ikerbasque (Basque Foundation on Science) associated to the Department of Sociology 2 (University of the Basque Country), research group Innolab. He has leaded research projects in Spain and in the Basque Country on Hidden Innovations, Social Innovation and Innovation in the Creative Economy.

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J. Roberto Reyes García holds a Bachelor degree in Mechatronics and a Master degree in Industrial Engineering, both by the Instituto Politécnico Nacional (IPN) in Mexico; and a Professional Doctorate in Engineering (PDEng) by the University of Twente. He has industrial experience in the fields of Industry 4.0, Maintenance Engineering & Management, and the (Industrial) Internet of Things. Currently, he works as a Junior Researcher at the University of Twente within the Multidisciplinary Systems Design group. His research focuses on the application of IoT in electric mobility systems, data-driven models for the promotion of electric mobility in Europe, and data-driven architectures and business models for the development of an electric Mobility as a Service (eMaaS) solution.

S. C. Ho received the Bachelor's Degree in Logistics and Supply Chain Management from University of Northumbria at Newcastle, Master's Degree in Global Supply Chain Management and Master's Degree in Integrated Engineering from The Hong Kong Polytechnic University. Before he started his Engineering Doctorate Degree studies, he was a Manager, Program & Projects Operations at Hong Kong R&D Centre for Logistics and Supply Chain Management Enabling Technologies (LSCM). His current research interests include innovation systems management, R&D technology commercialization, process and system re-engineering. He is a committee member in Education and Training Committee & Logistics Policy Committee and chartered member of The Chartered Institute of Logistics and Transport in Hong Kong (CILTHK).

Juan Jauregui-Becker works as an assistant professor at the University of Twente, Department of Design, Production, and Management and as a consultant at Symbol bv. Juan has a PhD on Product Development and a MSc in Mechanical Automation, both obtained at the University of Twente. Juan got his bachelor degree in mechanical engineering at the University of Los Andes, in Venezuela. As an assistant professor, Juan Manuel researches the application of Industry 4.0 tools and techniques to improve operational excellence in product development and manufacturing processes. Juan is a strong believer in the power of product design and product development for social change. As a Lean Six Sigma and Industry 4.0 consultant, Juan Manuel provides trainings, audits, workshops and strategy sessions to high-level management teams of manufacturing companies interested in starting their Industry 4.0 transformations as well as to production engineers performing operational excellence improvement projects.

Daniel Labrador-Montero has a PhD fellowship funded by Junta de Castilla y León and Social European Fund. He holds a BA in Philosophy from the University of Salamanca. He holds a MA in Social Studies of Science and Technology from the University of Salamanca. He researches mainly in Philosophy of Science, specifically in Philosophy of Biology and Philosophy of Social Sciences.

Stefan Lie is an academic design practitioner whose work in design began in the field of Industrial Design and has evolved, through project experience as a consultant, postgraduate study, and academic research, to focus on interactive product design. Lie's specific research interest is in developing new ways in which people can be guided into interacting with physical artefacts. Lie is the director of Product Design at the University of Technology Sydney.

Daniel Toscano López is a Researcher and academic at Observatory of Bioethics and Law, Faculty of Medicine, UDD, Chile. He is a full-time researcher of biopolitical and bioethics. He received the PhD in 2014. His research work has been published in several journals.

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Alberto Martinetti is assistant professor in the chair of Maintenance Engineering in the Faculty of Engineering Technology at the University of Twente. He is the coordinator of the Maintenance Engineering and Operations (MEO) Specialization in Mechanical Engineering and chairman of the Maintenance Research Day in the Netherlands and Belgium. He has worked for the Polytechnic of Turin and for the University of Turin. He holds a Master's degree in Geo-resources and Geo-technologies Engineering and a PhD degree in Safety and Health at the Polytechnic of Turin (2013) on Prevention through Design approach for mining activities. His expertise and research interests are Occupational Safety & Health, Risk Analysis, Maintenance engineering and the application and utilization of new technologies to Maintenance and Safety domains.

Rodrigo Mena (BS and MSc in Mechanical Engineering, Universidad de Chile, 2008, PhD in Industrial Engineering, CentraleSupélec, 2015) Full time faculty member at the Department of Industrial Engineering, specifically in Operations Management Study Area, at Universidad Técnica Federico Santa María. Since 2010, He has worked on the design and implementation of computational frameworks for modelling, simulation and optimization of complex engineered systems, for both the industrial and academic sectors. His research interests include systems modelling, advanced simulation methods, forecasting and prognostics, optimization, uncertainty modelling and risk analysis, with focus on the development of tools to provide comprehensible spectrums of information for well-supported decision making regarding the planning and operation of complex systems. The field of application of his research concerns the capacity expansion planning and operations of electric power systems, including uncertainty and risk analyses for the integration of renewable generation.

Jan-Jaap Moerman is a PhD candidate in the chair of Maintenance Engineering within the department of Design, Production and Management. He is both a practitioner as well as a researcher. He holds a Master's degree in Business Administration and in Information Management. His current research is on reliable introductions of new rolling stock.

Sabrina Nino graduated in 2017 of Design Engineering from the Universidad Técnica Federico Santan Maria. Actual user interface development, focusing the work in the user experience.

Yuliia Parfenenko started her academic career Nov, 2008 at the Sumy State University, Ukraine. She received the PhD Degree of Computer Science in 2016. The topic of her PhD thesis is "Models and Information Technology of Decision Support in the Management of Heat Supply of Social and Public Sector Objects". She works on the position of Seniour Lecturer at the Department of Computer Science of the Sumy State University from July 2016 till now. Her research interest are application information technology for energy efficiency, decision support systems development, and intelligent data analysis.

Elisa Peñalvo-López holds a doctorate in industrial engineering. She is a member of the Institute of Energy Engineering of the UPV. Her main research areas are renewable energy sources, energy efficiency.

Jan Roodt has over 25 years of experience in modeling and simulation of complex systems. His current focus in this area is on the validation and verification of qualitative models. He established and managed the laboratory for simulation-based acquisition at the CSIR in South Africa and introduced the use of Morphological Analysis for policy development and capability scoping while being responsible

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for a large portfolio of military technology projects from 1999 – 2010. His current focus at the Waikato Institute of Technology in New Zealand is understanding the diversification of energy sources and operations to make them more sustainable and to lessen the impact on the environment. In addition, he leads a postgraduate workplace based degree at the Master level in applied innovation. Henk holds a PhD in Engineering Science from the University of Stellenbosch as well as a Master's degree in Physics from the University of the Free State in South Africa.

Jesús Parra Sáez holds a Degree in philosophy and a Master's Degree in contemporary philosophy from the University of Murcia (Spain). Currently, he is a PhD student in applied ethics research line at the same university. His research is focused on the ethical-political problems of biotechnological human enhancement. He is doing a pre-doctoral research stay at the Centre for Research Ethics and Bioethics (Uppsala University, Sweden), which he is investigating the consequences of radical extension of human physical and cognitive abilities.

Sergii Shendryk started his academic career Oct, 2016 at the Sumy State University, Ukraine. Now he is a PhD student at Sumy State University. The topic of his PhD thesis is "Models and Information Technology Decision Support in Management of the Hybrid Energy Grid". He has 20 scientific publications. He works part-time as an Assistant Lecturer at the Computer Science Department of the Sumy State University. His research interests are applied Information Technologies for alternative energy, Decision Support Systems development, and Information Security.

Vira Shendryk started her academic career in Sept. 2002 at the Sumy State University, Ukraine. She was a visiting scholar at McMaster University, Canada in 2012, visiting professor at Malmo University, Sweden in 2013 and Riga Technical University, Latvia in 2014. Her research interest is focused on the field of Information Systems and Decision Science particularly in decision making under uncertainty. She has written over 200 journal articles and conference paper and presentations. She has also been a Member of the Editorial Board of the International Journal of Green Computing (IJGC) and a Member of Programme Committees the International scientific conferences on Information and Software Technologies (Lithuania) and Advanced Information Systems and Technologies (Ukraine).

Olha Shulyma is a researcher of computer science at the Sumy State University, Sumy, Ukraine. She received the M.Sc. degree and the Ph.D. degree in computer science both from Sumy State University in 2012 and 2017 respectively. Her research interests center on using IT in a power system based on RES. From November 2012 till September 2016 she was a Ph.D. student at the Sumy State University. In 2014, she was enrolled in a Ph.D. Sandwich in Computer Science in Malmö University, Sweden.

Sarbjeet Singh is Associate Professor and Head at Mechanical Engineering Department, Government College of Engineering & Technology (University of Jammu), India. He completed his PhD in 2011 in Mechanical Engineering from the National Institute of Technology, Hamirpur, India. Further in 2012-2104, he receives his Post-Doctoral fellowship from Division of Operation and Maintenance, Lulea University of Technology, Sweden. Presently, he is working as Sr. Researcher in the Division of Operation and Maintenance, Lulea University of Technology, Sweden. His expertise and research interests are human factors and Maintenance Engineering, Human Reliability, Human Factors and the application and utilization of new technologies to Maintenance and Safety topics.

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Raúl Stegmaier is a full time professor at the Department of Industrial Engineering USM, Valparaíso, Chile. Industrial Engineer at the Universidad Técnica Federico Santa María (USM) and Master of Science in Industrial Engineering at the Universidad de Chile. His teaching is in the field of Operation Management with emphasis in the Physical Asset Management and Maintenance and Reliability Engineering in undergraduate and graduate programs. His research work has been published in several journals and books. Additionally, he has directed various industrial and consulting projects in System Reliability Analysis, Reliability Engineering deployment and in the implementation of Lean Manufacturing Principles from the mining to the services industries and was a member of the TC 251 - ISO 55000 series, Chilean chapter. In the area of university management he has held diverse positions at the USM such as Director of Academic Affairs, Director of Planning and Development and Head of the Department of Industrial Engineering. He is currently director of the Master in Asset Management and Maintenance and is a member of the board of directors of the Universidad Técnica Federico Santa María.

Raúl Tabarés Gutiérrez comprises an area of expertise that combines Digital Skills, Social Media and Social Studies of Science & Technology. He is senior researcher at Fundación TECNALIA RESEARCH & INNOVATION and holds a PhD in Science, Technology and Society Studies. Raúl has published several journal articles, conference papers and book chapters and has been a speaker in different seminars, workshops and events. He has contributed to developing several strategies to foster the embracement of Web 2.0 technologies and skills across TECNALIA. He has taken part in several RTD projects in these topics, mainly at European level (especially H2020). Nowadays, his research is tightly related with the maker movement, DIY culture and user innovation.

Sergii Tymchuk graduated from the Kharkiv National Polytechnic University in 1978. He holds a Ph.D since 1987 at the Kharkiv Aerospace University. Since 1994 he has been working at the Kharkiv Petro Vasilenko National Technical University of Agriculture. He is a Professor in the Department of Automation and Computer-Integrated Technologies. Sergii is a Doctor of Technical Sciences since 2015 at Kharkiv National Polytechnic University. His scientific interests include information technologies in power engineering.

Manuel Valcuende-Paya is a doctor architect from the Universitat Politècnica de València (UPV), Spain. He is currently Professor in the Department of Building Construction in the UPV. His research area is in the area of construction, environment and sustainability. He has published numerous articles in research journals, as well as research books.

Leo A. M. van Dongen (1954) has worked for the Netherlands Railways (NS, 100% state owned) for over 30 years. He is Chief Technology Officer (CTO), responsible for the Asset Management of the rolling stock fleet, workshops and maintenance equipment. Since 2010, he has been a part-time professor in Maintenance Engineering at the faculty of Engineering Technology, in the department of Design, Production and Management of the University of Twente. After his studies in mechanical engineering, he completed his doctoral research at Eindhoven University of Technology on energy efficiency of drive trains for electric vehicles. At DAF Trucks he was active in the development of diesel engines. His career within NS has concentrated mainly on technological functions. These include project manager of electric locomotives, secretary to the executive board, fleet manager at NS Reizigers, and, within Ned Train, he was responsible for technical fleet management, maintenance systems, spare parts purchase,

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maintenance management and construction of new capital goods. In addition to his work at NS he promotes the academic development of the profession and encourages further research into maintenance processes: from design methodologies for capital goods to the development of associated maintenance concepts, not only for the initial investment, but also for the management during the entire life-cycle! "It is a challenge to collaborate between organization and people in order to unite technology, knowledge and sustainable operational management. I intend to enable the new generation of engineers make even more progress in this respect."

Pablo Viveros Gunckel is a Researcher and Academic at Technical University Federico Santa María, Chile. He has been active in national and international research, both for important journals and conferences. Also he has developed projects in the Chilean industry. Consultant specialist in the area of Reliability, Asset Management, System Modeling and Evaluation of Engineering Projects. He is Industrial Engineer and Master in Asset Management and Maintenance.

Roderick Walden undertakes research into the contemporary methods and practice of professional industrial design. His principal areas of research interest lie in professional practice, practice-based design research, design expertise and academic design. He has previously worked as a product designer and production engineer for a range of local and international manufacturers in the commercial office furniture industry including Herman Miller U.S., and Wilkhahn and König + Neurath Germany. His design consultancy, Walden Design Pty Ltd, formed in 2003, designed a range of products for Australian companies, working particularly closely with manufacturing SMEs. In his academic role, he has co-developed, through research, prototypes including a mountain bike (MTB) multi-tool (2008), leather-moulded office accessories (2008) and a fire-fighters cooling vest (2009), all with long-time colleague and friend Stefan Lie. He has conducted research into additive manufacturing technologies with the design of a DMLS MTB Crank Arm (2010) as part of the CCDP-sponsored Digifacture project, which was co-curated with Berto Pandolfo. His masters (by research) degree studied self-initiated product design and modelled connections between knowledge and practice that he is currently advancing as part of his PhD. He has co-authored research on topics including university-industry collaboration (UIC), design in business, design education and academic design practice. Roderick is passionate about his role as a teacher, the technical work of design and the meaning behind the connections designers make with other areas of knowledge to solve problems, innovate and learn.

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