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Handbook of Research on

Urban and Humanitarian Logistics



Jesus Gonzalez-Feliu, Marie Chong, Jorge Vargas Florez, and Julio Padilla Solis

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Handbook of Research on Urban and Humanitarian Logistics

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Marie-Laure Baron, University of Le Havre Normandie, France
Ali Khodadad Saryazdi, University of Le Havre Normandie, France

While public-private partnerships remain a valuable instrument to manage new infrastructures, asset specificity and high risk in innovative contexts call for public management. The chapter outlines the importance of public partnerships as a prerequisite to public-private partnerships in developing resilient urban logistics. After reviewing literature related to public partnerships and public-private partnerships, the authors focus their attention on the elaboration of the innovative "La Chapelle" International intermodal urban terminal in Paris. This chapter relies on former research in the fields of public, public-private partnerships, and urban freight logistics. Therefore, from a theoretical point of view, it illustrates the application and consistency of these contributions in the urban freight logistics. From a managerial point of view, the chapter provides insight into cooperation regarding integrated urban freight logistics management in large cities.

Chapter 2
Implications of Activity Classification Aggregation in Urban Freight Trip Generation Linear Models 22
Ivan D. Sanchez-Diaz, Chalmers University of Technology, Sweden
Jesus Gonzalez-Feliu, Ecole des Mines de Saint-Etienne, France

This chapter studies the implication of aggregating establishments by categories with different levels of detail for modeling FTG. To this effect, the chapter conducts an assessment of freight trip generation (FTG) patterns homogeneity inside activity-based grouping. The method implemented is econometric in nature, which allows the assessment of the statistical significance of variables representing commercial activity sectors and sub-sectors. The results show that for some sectors the traditional high-level aggregation includes sub-sectors with homogenous FTG patterns and thus produces appropriate models; in some other cases (e.g., retail, manufacturing), the sub-sectors have different FTG patterns and thus more detailed data is needed to calibrate accurate models. This research can be used to enhance the efficiency of data collection, as it identifies some sub-sectors that need larger efforts for data collection, and some other categories where FTG homogeneity allows for less detailed data collection without hampering the quality of the models.

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Localization Patterns of Urban Food Distribution Centers in Metropolitan Lima 38
Christiam Mendez, Universidad de Lima, Peru
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This chapter is aimed at exploring the patterns that guide the decision of food urban distribution centers in the city of Lima, which is characterized by spontaneous and unplanned growth, and where the inhabitants of the city mainly source of trade traditional with 1,200 food markets and 100,000 neighborhood stores. The rapid food system consultation tool created by FAO was used, which triangulated secondary sources and applied surveys in households, retail traders, and wholesalers. A statistical and spatial description was made of location factors: commercial density, supply habits of the retail and UDC, accessibility, connectivity, land use and access barriers to the land. It was concluded with the identification of four patterns of settlement of UDC: demand, supply, mobility, and land availability.

Chapter 4
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Haiko Eitzen, National University of Asuncion, Germany
Fabio Lopez Pires, Itaipu Technological Park, Paraguay
Fernando Sandoya, ESPOL Polytechnic University, Ecuador & Universidad del Azuay, Ecuador
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Classic formulations of the two-echelon vehicle routing problem (2E-VRP) reflect the perspective of a single provider. The lack of coordination between providers executing their individual schedules and, consequently, the lack of a holistic approach to urban traffic may cause further problems. Various stakeholders may have conflicting objectives. This chapter presents a multi-objective formulation of a multi-provider heterogeneous vehicle 2E-VRP from a city government perspective, demonstrating the potential benefit of this approach to all parties involved, simultaneously considering conflicting objectives. Additionally, the design and development of a multi-objective evolutionary algorithm (MOEA) for the formulated problem is presented. An experimental evaluation considering real data from Ecuadorian cities is presented to validate the proposed MOEA, demonstrating that it is capable to find good quality solutions, is scalable, and its solutions are improved throughout its execution.

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Julio A. Padilla, Universidad de Lima, Peru
Juan E. Coz, Asesores en Gestión de Operaciones S.A., Peru

Companies distributing LPG in cities used to have two kinds of customers: gas stations that sell it to final users and commercial consumers that use the gas in their own operations. They have to manage the inventory of gas and the daily schedule of the vehicles that transport the gas to the customers. The objective is to meet customer demand, but they are producing low average vehicle loads and empty vehicle kilometers. The authors present a short-term horizon tactical planning system that includes forecasting of sales in gas stations, lower and upper limits of the daily requirement in each customer, and a binary goal programming that determines the life cycle of each vehicle. The slack of the limits allows meeting

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a service level in the demands, while working with full loads in the vehicles. The system includes a scheduler for the first day and for each chain. It uses a clustering of customers for each vehicle reducing the GPS time network and a shortest path algorithm to determine the routes to visit each customer. The largest fuel distributor of Peru has implemented the system.

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Elena Valentina Gutiérrez, Universidad de Antioquia, Colombia
Sebastian Cortés Zapata, Universidad de Antioquia, Colombia
Juan Sebastián Jaén, Universidad de Antioquia, Colombia

In home healthcare (HHC) services, patients receive coordinated medical care at home based on previous medical prescriptions. Given geographical dispersion of patients and medical staff within an urban area, the design, provision, and control of HHC service delivery imply a set of complex logistics capabilities that impact service quality. Consequently, the maturity of such capabilities is a key factor to guarantee that patients receive the prescribed medical attention, by the right medical staff, at the right time, and at the right place. Thereby, this chapter presents and assessment of the logistics capabilities maturity of HHC providers certified by the Ministry of Health and Social Protection to provide HHC services in the metropolitan area of the second largest city in Colombia. Results show that an average maturity level of 3.2/5.0 for logistics processes, and 4.0/5.0 for service processes, evidence the need to improve service delivery.

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Erick Castillo, Universidad del Pacífico, Peru
Nestor Martinez, Universidad del Pacífico, Peru
Anatholy Torvisco, Universidad del Pacífico, Peru

The megacity of Lima generates daily around 9,000 t of wastes (organic and non-organic). This waste is collected by a network of municipalities with a customer service level of 43% and average cost of 38 $/t. This research is focused in Comas, a district of Lima. This district generates dairy 450 t of waste. The authors propose a key performance index to increase efficiency (customer service level) and reduce operating costs for waste collection service on Comas district (Lima) by using an on-line demand tool, based on the current population density and the waste generation of a certain area of Comas. They apply a reverse zone distribution (RZD), a term introduced in this study, as a result of an adapted methodology and supported by new technology trends, such as the internet of things. The RZD's value chain has many similarities with a commercial one; however, it differs fundamentally in the attention to the citizen.

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Oscar Rubiano Ovalle, Universidad del Valle, Colombia
Helmer Paz Orozco, Corporación Universitaria Comfacauca, Colombia
Hector Angulo Sinisterra, Fundación Centro Colombiano de Estudios Profesionales, Colombia

The Colombian coffee that grows in the mountainous coffee zone, due to its qualities such as its clean rate, acidity, aroma, softness, and body, continues to have a representative share in the market. In this

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way, the intervention of the state has been necessary so that the sector can have sufficient income both to satisfy its basic survival needs and to guarantee the continuity of production. In this chapter, the impact of the own investment and economic support policies formulated by the Colombian government on the financial flow of the coffee farmers was evaluated through a systems dynamics model. To achieve this objective, the current conditions of the Colombian coffee sector were studied, the supply chain was modeled with systems dynamics, and scenarios were simulated alluding to the policies evaluated.

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Feizar Javier Rueda-Velasco, Universidad Distrital "Francisco José de Caldas", Colombia
Angie Monsalve-Salamanca, Universidad Nacional de Colombia, Colombia
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The food assistance programmes (FAP) has the mission to guarantee minimum nutrition requirements in a vulnerable population. Nevertheless, the small deliveries for a spread population, the social conditions, and the limited technological infrastructure could make it difficult to adequately aid supply. To solve these limitations, this chapter proposes a methodology for the design of traceability systems in FAP which allows increasing supply chain visibility, coordination between deliveries and social conditions, and therefore, possible impacts on public policy implications. A qualitative and quantitative comparison of the conventional frameworks is carried out and contrast with the needs of the programmes studied. Also, new criteria are also added to adapt the design to the technological infrastructure and the socio-demographic conditions of the territory. The methodological proposal is applied to the Bienestarina nutritional programme in Colombia, where the technologies and tools to subsequently design the traceability system are proposed.

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Food insecurity is a recurrent condition in which members of a household do not have enough food to cover their nutritional needs; this condition contributes to increasing social vulnerability of those affected. In Peru, there are more than 9 million people who suffer this condition, which generates malnutrition and anemia, mostly in children. On the other hand, the waste of food is associated with production the large amounts of greenhouse gas emissions that affect global warming. According to reports in Peru, 20% of what is food produced becomes waste. This scenario in terms of food for Peruvians represents 3 billion calories in wasted food that could feed 2 million people. The Peruvian Food Bank manages food donations, ensuring this food can reach people in need through humanitarian aid entities. This applied

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research work uses the tools of operations research to determine a solution to the problem of maximizing the combination of food orders to be distributed based on their total nutritional value to the beneficiaries, seeking maximum coverage and minimum logistic costs.

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Juan Camilo López-Vargas, Universidad Nacional de Colombia, Colombia
Diana María Cárdenas-Aguirre, Universidad Nacional de Colombia, Colombia
Jose D. Meisel, Universidad de Ibagué, Colombia

The incremental trends in the amount of human and material losses, added to a higher frequency of natural disasters, have generated greater interest from different sectors regarding the processes of disaster management. In this sense, it is recognized that the context of disasters is strongly marked by the high diversity and quantity of actors which seek common or conflicting objectives. The aim of this chapter is to present the actors involved in the humanitarian supply chains (HSC) and to highlight the importance of key local actors involved in disaster preparedness and response, the latter from an inter-sectoral perspective towards the importance implied by the coordination of the key actors in terms of the humanitarian purposes. The discussion developed allows for the inference about the critical role of local actors in disaster management and HSC, as well as several topics for the theoretical development of humanitarian logistics, such as the application of decision tools and information technologies, and the use of sustainability approach for disaster management.

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Karol Moreno-Valbuena, Universidad Católica de Colombia, Colombia
Leonardo Gonzalez-Rodriguez, Universidad de la Sabana, Colombia

This chapter proposes a planning methodological framework for humanitarian aid. The proposal combines project management tools and system dynamics to evaluate the effect of different operational strategies on the total system response time. System dynamics allows identifying humanitarian aid sub-systems and the feedback loops between them. The project management approach enables to recognize the response activities in each sub-system, to estimate the response time for each activity and the resources requirements. Also, the system dynamics tools enable the response times simulation under variability conditions. The proposal is tested in a retrospective way on the 1999 "Eje Cafetero" earthquake in Colombia. Additionally, the methodology framework provides a novelty approach to represent humanitarian logistics operations as a project. Finally, the integration of project representation, strategies selection, and system dynamic simulation is not enough studied in the humanitarian logistics field.

Chapter 13
Characterizing Coordination in Humanitarian Supply Chains: A Case Study in Colombia 263
Juan David Suarez, Centro Latinoamericano de Innvoación en Logistíca (CLI), Colombia
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Coordination has been reported as a main issue in humanitarian supply chain. Although it is recognized as a potential driver for efficiency, it is not broadly studied in real cases. This chapter presents a case

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study for humanitarian supply chain. Using Lambert's framework for SCM, humanitarian supply chain is characterized identifying its structure, business processes, and management components. Once humanitarian supply chain is understood, a short review is performed to identify how coordination is being integrated into humanitarian supply chains body of literature, and principles, techniques, and technologies applied for coordination in humanities supply chain are identified. Finally, using content analysis methodology, coordination issues are mapped through humanitarian actors in Colombia by understanding the supply chain strategy of three principal actors for Colombian humanitarian supply chain.

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Edison Puma-Ayasta, Pontificia Universidad Católica del Perú, Peru
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After a major disaster, commercial supply and delivery activities suffer serious problems because transport infrastructures can be damaged, destroyed, inactive, or restricted. During the first months of 2017 in Peru, the phenomenon of the coastal El Niño increased rainfall along the coast, which caused the blockage of numerous roads and bridges that affected one and a half million people. This situation caused many companies to halt their distribution logistics operations. For this reason cabotage was considered to replace traditional transport to merchandise by road. Maritime cabotage consists of the transport of loads and people considering short distances and low-medium loads. This research tackles increasing resilience distribution using cabotage as an option to transport merchandise in post-disaster scenario through a Peruvian processed food company based on empirical evidence. Results show that cabotage service is in process to mature in Peru. The company analyzed showed positive results during the coastal El Niño 2017 phenomenon.

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Miguel Ángel Rodríguez Anticona, Pontificia Universidad Católica del Perú, Peru
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Lima is a city of 10 million inhabitants, and 60% of its population lives in slums settlements. Due to its location in the Circum Pacific Belt of Fire, this is a high-seismic activity area. Despite this fact, there is a serious lack of urban planning and natural disaster planning. El Progreso sector located in Carabayllo, a Lima district in Peru, was selected as the case study because it is one of the slum settlements with the highest potential risk as it is located in a basin surrounded by hills due to the effects of informal constructions (such as ceilings). Filled with rocks and walls, their slopes have suffered much more deterioration than in other hillsides. In addition, this area is prone to debris avalanches, rock fragments, debris flows, among other geologic hazards. The proposal presents a mathematical model based on analyze a risk function through inhabitants' time evacuation, which may replicate in different urban context in real time in order to guide and ensure the most efficient evacuation.

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Rafael A. Alva-Cabrera, Pontificia Universidad Católica, Peru

Natural disasters produce enormous human and material losses. This is amplified if there is poor relief aid humanitarian distribution. Logistics seeks to obtain efficiencies related to response reducing transportation costs; according to humanitarian institutions, they constitute the second largest general expense after labor. Humanitarian distribution challenges are reduce costs, maintaining distribution service, and designing reliable delivery routes in a context where infrastructures may be non-existent, unavailable, or inoperative. This chapter addresses the problem of optimizing the distribution of humanitarian aid by comparing different clustering strategies for the medicines warehouse in charge of the national hospital services entity in Metropolitan Lima and Callao. The chapter is organized as follows. First, a review of the literature on problem of vehicle routing for resilient networks are presented. Then the proposed model will be shown considering those limitations to humanitarian delivery in a post-disaster context; finally, feasible solutions will be compared.

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Eliseo Vilalta-Perdomo, University of Lincoln, UK
Martin Hingley, University of Lincoln, UK
Rosario Michel-Villarreal, University of Lincoln, UK

Microbusiness, MB, importance for the global economy is uncontestable; they have huge participation of the world's production. In Peru, small-and medium-enterprises, SMEs, are 99% of the total of existing companies and contribute approximately 47% of the country's GDP; MBs are grouped within SMEs. They are the greatest generators of employment, although this may be informal and of poor quality. MBs confront difficulties, mainly due to their limited human and financial resources. Theories around how to deal with it have been developed mainly with big enterprises in mind, and this has little connection with what happens inside MBs. Accordingly, this chapter offers "collaboration" as a response strategy in case of a disruptive event to support MB resilience construction. This is contextualized from the experience of the Peruvian Costal El Niño 2017 and illustrated through the actions that a MB case (a beekeeper) took to deal with it.

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Alvaro Talavera, Universidad del Pacífico, Peru
Michelle Rodríguez, Universidad del Pacífico, Peru
Andrés Regal, Universidad del Pacífico, Peru

The rapid growth of cities in the 21st century along with the congestion of road infrastructure and high population density makes urban spaces highly vulnerable to disasters. After a disaster occurs, health services infrastructure is critical to support medical operations for injured patients. This chapter presents a methodology for evaluating the vulnerability of health services infrastructure from a logistics perspective, based on several layers of information such as population density, road congestion, and

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hospital location. The methodology uses computational and business intelligence techniques such as fuzzy inference systems, geographic information systems, graph theory, and visualization. The purpose of this methodology is to generate a unique score of vulnerability that identifies each health services facility, providing decision makers with the analytical framework of a spatial multicriteria analysis to evaluate their options for facing a disaster.

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Manuel Rodriguez-López, Pontificia Universidad Católica del Perú, Peru
Miguel Nunez-del-Prado, Universidad del Pacífico, Peru

Resilience is the capacity of a society or infrastructure to resist, adapt, and recover after being impacted by an extreme event. In this chapter, the authors focus on measuring how much the road infrastructure is able to withstand the appearance of extreme events. An extreme event will be represented by an intentional (e.g., perpetrated attacks) or unintentional (e.g., as result of climate extreme event) damage on the routes or intersections of the road network within a city. To do this, the authors measure the primary characteristics of urban networks in order to understand their morphology (i.e., the way in which they were constructed). Then, they evaluated the resistance capacity of different points of the road networks with three types of attacks: random, directed, and localized. The first results of this study show the fragility of some roads and intersections before the appearance of extreme phenomena. These results can be exploited by those in charge of public management and then converted into policies.

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Irineu de Brito Junior, Universidade Estadual Paulista at São José dos Campos, Brazil
Ernesto Guerrero, Universidad del Pacífico, Peru
Juan Machuca, Universidad del Pacífico, Peru
Mario Chong, Universidad del Pacífico, Peru

This chapter develops a decision support tool with a focus on the humanitarian logistic chain in a crisis environment considering process drivers' constraints such as costs, capacity, and throughput time. For instance, elements to reduce the suffering of the affected families, by using an adequate supply support for the first 72 critical hours. The authors will focus on minimizing the risks of shortages in the first response supplies in a high flood probability zone in Peru. This research presents different scenarios and it analyzes the representative variables (demand, civil defense warehouses, points of distribution, distance and logistics resources), the humanitarian chain value, and the effective distribution of the aid in the affected areas with efficient operations that balance between the economic and operative resources in this recurrent logistical problem. The results present three crisis situations with a distribution plan and a base of a public policy to prevent a crisis.

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Johanna Camargo-Pérez, Universidad de la Sabana, Colombia
Jairo R. Montoya-Torres, Universidad de La Sabana, Colombia

Multiple actors from both private and public sectors are currently involved in the design and operation of urban passenger transport systems seeking at optimizing their own objectives. Multi-criteria decision-making (MCDM) techniques actually aid this process. In this chapter, the authors consider the problem of locating multimodal terminals of an integrated public passenger transport system (IPPTS). A case study for the city of Bogota, Colombia is evaluated. Majority of works in MCDM does not explicitly justify the choice of the applied technique. This chapter applies three different techniques, AHP (analytic hierarchy technique), ELECTRE II (elimination and choice expressing the reality), and CRITIC (criteria importance through intercriteria correlation), to solve problem. A feature of this study is that traditional economic and logistic criteria are evaluated together with environmental and social criteria not previously evaluated in the literature. Numerical results show that each multi-criteria approach may prefer a different alternative, depending on the intrinsic behavior of each technique.

Chapter 22
SMS as a Tool to Improve Information Flow on Humanitarian Logistics: Case Study – Quebrada Quirio in Chosica 408
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Amelia A. Flores Dextre, Universidad del Pacífico, Peru
Andrea Guillen Reina, Universidad del Pacífico, Peru
Brenda Pedreschi Garcia, Universidad del Pacífico, Peru

This chapter assesses the suitability of mobile phone technology, an established technology (humanitarian), to support humanitarian operations, create an inventory of support donations, and track the needs of people throughout humanitarian logistics after the disaster. The main objective is to reduce the exposure to the consequences of disasters by reducing the time of information flow through SMS interaction technology. Quebrada Quirio was used as a prototype. The process consists of using the INDECI rapid assessment visit to collect basic data, including a telephone number, of the people affected by the disaster, and based on this information, multiple initiatives aligned with the optimization of the flow of information were created.

Chapter 23
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Roland Acuña, Universidad del Pacífico, Peru
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Cristian Huicho, Universidad del Pacífico, Peru
Andrea Ochoa, Universidad del Pacífico, Peru
Astrid Salazar, Universidad del Pacífico, Peru
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In the chapter, the optimal budget was assigned to prevention projects in the northern regions, through an analysis that took into account criteria such as the degree of vulnerability, the level of poverty, the

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population, and the level of expenditure execution (capacity management of each regional government) in 2015 and 2016. AHP (multicriteria analysis) was used to estimate the degree of vulnerability of each region, since to determine this it is necessary to take into account several criteria and fuzzy logic in order to obtain the budget for each region. The regions to be analyzed were Ica, Lima, Ancash, La Libertad, Lambayeque, Piura, and Tumbes, the most affected by El Niño Costero in 2017.

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Preface

Humanity has, since thousands of years, organized their societies and civilizations around the development of cities and conurbations (Nissen, 2011). That urban development relies also on resilient logistics systems, which are not new but have been deployed since Antiquity (Gonzalez-Feliu, 2018).

Indeed, in urban areas, various logistics and freight flows can be seen, and are of different nature (Gonzalez-Feliu, 2018):

- Flows to supply the different economic activities of an urban area, known as inter-establishment movements, and representing about 40-45% of the road occupancy issues of urban logistics.
- Flows to supply end consumers, less studied but not less important, since they represent about 45-50% of the total road occupancy issues of urban freight flows.
- Flows related to urban management, which include waste collection, construction and infrastructure maintenance, moving trips, etc., and represent about 8-10% of road occupancies.
- Internal logistics flows, which do not contribute to road occupancy but are crucial to good functioning of cities' activities.

To those flows, we can add humanitarian logistics movements, which were traditionally not considered in urban logistics but start to be also included as being part of cities' operations, mainly in sensible geographies (Taniguchi, 2016). Humanitarian logistics can be of different nature, since crises and humanitarian needs are not always the same (Holguin-Veras et al., 2012). Table 1 outlines the main differences between these four types of humanitarian intervention from the logistic management point of view, based on the main characteristics of logistic systems for each of these four types of crisis: exceptional emergencies (Holguin-Veras et al., 2010); recurrent crisis situations (Vargas Florez, 2017); long-term crises (Van Wassenhove, 2006) and needs for social improvement (Gonzalez-Feliu et al., 2018).

Both urban and humanitarian logistics are popular fields in research and practice, but they are in general addressed by different communities and there are few works dealing with both subjects at the same time (Taniguchi, 2016). However, it seems important that, bringing cities more resilient via their urban logistics systems will enhance the capabilities of humanitarian supply chains, so a synergic development of both fields would increase the efficiency of both urban and humanitarian logistics planning and management.

The present book is the result of a two-year collaboration, and marks the launch of an international network of research and practice on urban and humanitarian logistics. The origin of this collaboration was a scientific event held in Lima in 2017 where all four editors met and exchanged. After that, various projects and collaborations made the need of deploying a more formal research network, which aim is

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Table 1. Comparison of different types of humanitarian logistics systems (authors' elaboration)

Element	Exceptional Emergencies	Recurrent Emergencies	Long-Term Crises	Social Improvement
Frequency	Punctual Exceptional	Punctual recurrent	Permanent	Permanent
Anticipation and prevision	Very difficult, high incertitude	From historical events and time series	Robust characterization	Robust characterization
Priorities of the intervention	Saving lives	Saving lives, assisting population	Give a major change	Give continuous improvement
Horizon of the intervention	Very short term	Short term	Very long term	Long term
Planning needs	Post crisis reconstruction	Post crisis reconstruction, anticipation	Long term change	Continuous improvement
Basic references	Holguin-Veras et al. (2012)	Vargas-Florez (2017) ; Osorio Ramírez (2017)	Van Wassenhove (2006)	Maldonado et Moyá (2013); Gonzalez-Feliu et al. (2018)

to develop knowledge on the subject of planning and management of logistics issues dealing with urban and humanitarian logistics in a joint environment.

The book is organized in three parts. Section 1 (Chapters 1 to 7) deals with recent developments in the field of urban logistics. Section 2 (Chapters 8 to 16) is related with the case of humanitarian logistics in Latin America, with a focus on decision processes and support for the various stakeholders. Section 3 (Chapters 17 to 23) is then dedicated to resilience and efficiency construction for urban logistics systems that can respond to humanitarian needs at different horizons and under various reactivity conditions.

Section 1 (Chapters 1 to 7) includes four chapters dealing with classical urban logistics, B2C distribution issues and three chapters more related to city management issues.

Chapter 1 presents a case study (the innovative "La Chapelle" International intermodal urban terminal in Paris) to introduce and discuss the main collaboration issues between urban logistics stakeholders, with a focus on partnerships. In that chapter, Baron and Saryazdi make a theoretical contribution via the presentation and formalization of various partnerships and their application to intermodal terminals in urban areas, which are still little studied. Moreover, and from a managerial point of view, the chapter provides insight about muilti-stakeholder collaboration in terms of urban goods transport in metropolitan areas.

Chapter 2 addresses the implication of category aggregating and heterogeneity in freight trip generation (FTG) modelling suitability. More precisely, Sanchez-Diaz and Gonzalez-Feliu proposes an assessment of freight trip generation (FTG) patterns homogeneity inside activity-based category classifications, via econometrics methods and error assessment for linear models. Main results confirm that heterogeneity plays an important role in some categories, but the heterogeneity level not being the same for each sector, the impacts are different for each of them. However, the hypotheses and choices made to construct categories seem to be conditioning the heterogeneity of those sectors.

Chapter 3 proposes an exploratory but in-depth analysis of the patterns that condition decisions related to Food Urban Distribution Centers location and development in the city of Lima (Peru). Mendez et al. propose, after making an overview of the needs and issues of urban food consolidation, a methodology to survey and collect data necessary to analyze the potential of food consolidation centers in a metropolitan, multipolar area like Lima. Results propose first a statistical and spatial description of eight

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location factors: commercial density, supply habits of the retail and UDC, accessibility, connectivity, land use and access barriers to the land. Then, a discussion of the main location patterns based on such factors is made. The chapter concludes main patterns are demand, supply, mobility and land availability.

In Chapter 4, Bara et al. address a variant of two-echelon vehicle routing, which is a popular family of combinatorial optimization problems in city logistics and received a particular interest from the operations research community. The chapter aims to introduce the issues of collaboration and multi-stakeholder contexts by applying a multi-objective, multi-commodity version of the problem to a practical case in Quito (Ecuador). The chapter proposes a problem formulation and an evolutionary algorithm, as well as a set of realistic instances which are solved with the proposed algorithm and evaluated via a set of metrics. Results shows that the proposed algorithm finds good quality solutions, and that it can be scalable and applicable to realistic datasets.

Chapter 5 deals with fuel and energy distribution, one of the main components of city management and operations. More precisely, Padilla Solis and Coz Cocks urban logistics issues of LPG distribution. To deal with meeting customer demand and at the same time increase the efficiency of vehicle use and travel distances and times, the chapter proposes a tactical planning modelling system that includes forecasting of sales in gas stations, lower and upper limits of each customer's daily requirement s, and a vehicle life cycle goal. The framework is formulated and discussed, addressing also several practical implications, since the largest LPG distribution company has implemented the framework.

In Chapter 6, Gutierrez et al. deal with Home Health Care (HHC) services, where patients receive coordinated medical care at home based on previous medical prescriptions. The chapter presents an assessment of the logistics capabilities maturity of HHC providers in the metropolitan area of the second largest city in Colombia. It proposes a maturity matrix as well as a set of metrics to assess the logistics capability maturity of such providers. Results show an average maturity level of more than 3/5 for Logistics Processes, and about 4/5 for Service Processes, evidencing the elements that would be improved.

In Chapter 7, Castillo et al. deal with waste collection and management flows, and proposes a methodology and pilot to improve, via smart city and a combinatorial optimization model, the efficiency of waste collection logistics in the city of Comas, a district of Lima's Metropolitan area. The chapter proposes an On-line Demand tool, based on the current population density and a waste generation estimation method, and defines the notion of Reverse Zone Distribution (RZD). A pilot on a given zone of Comas and the application of the prediction model based on online captors data and the proposed methodology, allowed to define precisely the framework and test the capabilities of a dynamic waste collection and container positioning in order to manage waste collection vehicles in function of the demand generation dynamics.

Section 2 (Chapters 8 to 16) deal with the case of humanitarian logistics in Latin America, focusing on two main sub-fields: the first is what can be called social improvement logistics, i.e. the deployment and management of logistics systems aimed to give social value to vulnerable populations and increase their social welfare; the second is post-crisis logistics, i.e. management of humanitarian logistics systems to respond to disasters or important crises.

Chapters 8 to 10 deal with social improvement, and address three different issues, all related to food supply and the creation of social value for sensible populations. Chapter 8 deals with the creation of economic value for small producers of coffee in Colombia. Indeed, small producers are a majority in the Colombia coffee supply chain but their revenues are not always robust, so a State governmental intervention is necessary to make producers having enough income to both satisfy their basic family needs and guarantee the continuity of production. Rubiano Ovalle et al. propose a Systems Dynamics modeling and analysis framework to assess the impact State investment and economic support policies on the

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financial flow of the coffee farmers. First, the chapter proposes an overview on the Colombian coffee production, then the methodological issues are presented: the proposed framework is organized in three parts, i.e. an analysis of the current conditions of the Colombian coffee sector, a supply chain modeling and analysis via Systems Dynamics, and a scenario assessment. Results present the main characteristics of the Colombian coffee supply chain, as well as of their stakeholders and interactions, and propose an assessment of various scenarios of financial investment and value creation for small producers.

In Chapter 9, Rueda-Velasco et al. Propose a methodology to assist the development and monitoring of a traceability system for Food Assistance Programmes (FAP), focusing on the case of Bienestarina in Colombia. Indeed, FAP deal with supplying sensible populations with nutritional complements, leading to an important quantity of small deliveries for a spread population, sometimes in conditions of both social and geographical low accessibilities. Authors combine qualitative and quantitative approaches to compare conventional frameworks and contrast them with the needs of the programmes studied. Additionally, the chapter defines a set of necessary criteria to support the design to the technological infrastructure and the socio-demographic conditions of the territory. The methodological framework is then applied to the Bienestarina nutritional programme in Colombia, where authors address both research and practice issues.

The last chapter of the social improvement subset, i.e. Chapter 10, is related to another important issue: that of food banks. Those structures, already appointed by FAO and Maldonado and Moya (2013) as important nodes to fight malnutrition and contribute to social improvement, manage food donations from private and public organizations, ensuring this food can reach people in need through humanitarian aid entities. In this chapter, Vargas-Florez et al. apply standard tools of operations research to determine a solution to a Food Bank delivery problem that maximizes the variety of macro-nutrients and then improves the nutritional quality of complete meals that can be obtained by families supplying their food needs at food banks. That optimization seeks also maximum coverage and minimum logistic costs. Authors apply the proposed method to the case of Food Banks in Lima, Peru.

Concerning relief logistics facing crises, a subject that became very popular in the last decade, the chapter makes an important contribution to the field, mainly by dealing with recurrent crises (Vargas-Florez, 2017). First, Chapters 11 to 13 present a complementary vision of the involved stakeholders and processes in humanitarian supply chains facing crises in Colombia. In Chapter 11, Lopez-Vargas et al. present the stakeholders involved in the humanitarian supply chain (HSC) to highlighting the importance of key local actors in two crucial phases of the crisis cycle: disaster preparedness and response. The chapter addresses the needs of coordination from an inter-sectoral perspective by identifying the key local actors in terms of agile response and protection of people in highly vulnerable conditions. Then, a discussion about the critical role of local actors in disaster management and HSC and the effects of interference are addressed. Finally, the chapter proposes a set of topics for the theoretical development of humanitarian logistics, such as the application of decision tools and information technologies, and the use of sustainability approach for disaster preparedness and response processes.

However, to address that cooperation, it is important to have a systematic and holistic planning perspective. In that sense, Rueda-Velasco et al. propose in Chapter 12 a methodological framework for humanitarian support planning that combines project management tools and system dynamics to evaluate the impacts of different operational strategies on the total system response time. The proposed framework is illustrated by a retrospective case: that of the 1999 “Eje Cafetero” earthquake in Colombia. Authors identify the main strengths and lacks of the proposed methodology and define the main research and practice implications.

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Chapter 13, the last of this mini-series of chapters dedicated to stakeholders and coordination mechanisms, is related to the characterization of those coordination mechanisms. Suarez et al. propose an analysis framework, based on the well-known supply chain characterization methodology of Lambert, applied to humanitarian logistics in case of crisis, and applies it to a case study in Colombia, at a National level, in a context of preparedness related to meteorological crises which have been recurrent last years. First, authors examine how coordination is being integrated into humanitarian supply chains body of literature, then the Lambert framework is adapted to humanitarian logistics. Then, using content analysis methodology, coordination issues are mapped through humanitarian actors in Colombia by understanding the supply chain strategy of three main for Colombian humanitarian supply chain. The proposed framework completes the two previous chapters giving then (when all three chapters are examined together) a holistic approach to characterize and plan humanitarian supply chains in terms of multi-stakeholder collaboration.

One of the main issues in post-disaster humanitarian logistics is material convergence. Indeed, to the population needs when a disaster occurs, it can be added the fact that commercial supply and delivery activities suffer serious problems because transport infrastructures can be damaged, destroyed, inactive or restricted. Chapter 14 deals with transport design to overcome those interruptions due to the lacks in the transportation systems during crises. During the first months of 2017 in Peru, the phenomenon of the coastal El Niño increased rainfall along the coast, which caused the blockage of numerous roads and bridges that affected one and half million people. This situation caused many companies stopped their distribution logistics operations. For that reason, Puma-Ayala et al. considered cabotage to replace traditional transport to merchandise by road. Empirical results show that cabotage service is in process to mature but with promissory results in humanitarian action, in Peru.

In Chapter 15, Rodríguez-Anticona address a preparation issue that is the organization of evacuation in Slum informal settlements. Indeed, 60% Lima's population lives in slums settlements. Due to its location in the Circum Pacific Belt of Fire, Lima has a high-seismic activity area. Authors focus on El Progreso slum, located in Carabayllo, a Lima district in Peru, because their slopes have suffered much more deterioration than in other hillsides, and its vulnerability is particularly high (it is prone to debris avalanches, rock fragments, debris flows among other geologic hazards). Authors propose a mathematical model based on analyze a risk function through inhabitants' time evacuation, which may replicate in different urban context in real time to guide and ensure the most efficient evacuation.

Humanitarian logistics seeks to obtain efficiencies related to response capacity by reducing transportation costs for intervention, which constitute the second largest general expense after spending by labor. Chapter 16 deals with the problem of optimizing the distribution of humanitarian aid. Vargas-Florez and Alva-Cabrera address that issue by comparing different clustering strategies for the drugs depots in charge of the Peruvian national hospital services entity in Metropolitan Lima and Callao. Results show that the best alternative is obtained with the route solution that follow the heuristic of assigning first, then routing, solving with linear programming.

The third and last section (Chapters 17 to 23) focuses in building resilient urban logistics systems that will be reactive and support responses to crises, so mixing urban logistics notions with humanitarian logistics ones.

Chapter 17 focuses on microbusiness vulnerability to natural disaster. Vargas-Florez et al. proposes a collaborative procedure that may support the increase of resilience in food retailing micro-businesses, in the context of the costal El Niño 2017 in Peru. Authors explore and analyze strategies that build resilience in micro-businesses and their impacts on viability. Hence, alternatives available to define

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and implement such strategies are indicated. Those alternatives need to fit with environment, physical and human-made constraints, and to consider the supply arrangement structure in place. As resilience construction is based on a previous architecture of pre-existing relationships, supply arrangements are configured not just by individual decision also for group interest; this multiplicity of actors makes the situation of a complex nature.

Chapter 18 presents a methodology to evaluate the vulnerability of health-services infrastructure from a logistic perspective, based on several layers of information such as population density and road congestion. Talavera et al. propose a methodology that uses computational and business-intelligence techniques such as fuzzy inference systems, geographic information systems, graph theory, and visualization. The purpose of this methodology is to generate a unique score of vulnerability that identifies each healthcare facility, providing decision makers with the analytical framework of a spatial multicriteria analysis to evaluate their options when facing a disaster.

Chapter 19 analyzes the resilience of transport in urban networks on various interest points. To this purpose, Alatrista Salas et al. propose a network-based, hierarchical analysis of urban road infrastructures. After that, the shape and appearance of each component were studied, and the degree of connectivity, density and intermediate centrality was measured. Three kinds of attacks were performed into the interconnections of these networks to determine how resilient those networks are. Results provide insight into the behaviour of each network component after suffering disruptions around local points of interest.

Chapter 20 develops a decision support tool for humanitarian supply chain management in a crisis environment. De Brito Junior et al. focus on minimizing the risks of shortages in the first response supplies in a high flood probability zone in Peru, considering process drivers' constraints such as costs, capacity and throughput time. Author present the proposed framework, followed by a set of scenarios and the analyses of the representative variables (demand, civil defence warehouses, points of distribution, distance and logistics resources), the humanitarian chain value and the effective distribution of the aid in the affected areas with efficient operations that balance between the economic and operative resources in this recurrent logistical problem. Results show three crisis situations with a distribution plan and a base of a public policy to prevent a crisis.

Chapter 21 deals with a side issue, which is more related to passenger transport but contribute to a city's transport infrastructure resilience: the location of multi-modal public transport platforms and structures. Camargo-Pérez and Montoya-Torres analyze the suitability of Multi-criteria decision-making (MCDM) techniques for the specific issue of locating passenger multimodal terminals of an Integrated Public Passenger Transport System (IPPTS). A case study for the city of Bogota, Colombia is evaluated. Three different MCDM techniques are considerated: AHP (Analytic Hierarchy Technique), ELECTRE II (Elimination and Choice Expressing the Reality), and CRITIC (Criteria Importance Through Intercriteria Correlation). Results show that each multi-criteria approach may prefer a different alternative, depending on the intrinsic behaviour of each technique.

Chapter 22 assesses the suitability of mobile phone technology to support humanitarian operations, and more precisely to create an inventory of support donations and track the needs of people throughout humanitarian logistics after a disaster. Alcantara Panta et al. propose a framework based on SMS interaction in mobile phones, and test it in a practical case, that of Quebrada Quirio in Chosica (Lima, Peru), where a prototype was developed and tested. The process consists on using the INDECI rapid assessment visit to collect basic data of the people affected by the disaster to support post-disaster logistics planning and management. Results show a reduction of response times and a higher reactivity when using the proposed tool.

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Finally, in Chapter 23 Acuña et al propose a framework to assign optimal budget to prevention projects in vulnerable regions, taken into account degree of vulnerability, the level of poverty, the population and the level of expenditure execution (capacity management of each regional government). Authors propose a framework based on multi-criteria analysis, more precisely on AHP and Fuzzy Several Northern regions of Peru where analyzed and assessed. Results show the suitability of the framework and the main implications in planning the prevention phase of a crisis.

The present handbook of research proposes then a coherent and articulated set of chapters, that will guide readers on the main issues and trends of decision support in urban and humanitarian logistics and constitutes one of the first volumes dealing explicitly on capability and resilience building combining the particularities of urban logistics and those of humanitarian logistics.

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Chapter 1
Public and Public-Private Cooperation in Building Resilient Urban Logistics: The Case of "La Chapelle International, Paris"

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ABSTRACT

While public-private partnerships remain a valuable instrument to manage new infrastructures, asset specificity and high risk in innovative contexts call for public management. The chapter outlines the importance of public partnerships as a prerequisite to public-private partnerships in developing resilient urban logistics. After reviewing literature related to public partnerships and public-private partnerships, the authors focus their attention on the elaboration of the innovative "La Chapelle" International intermodal urban terminal in Paris. This chapter relies on former research in the fields of public, public-private partnerships, and urban freight logistics. Therefore, from a theoretical point of view, it illustrates the application and consistency of these contributions in the urban freight logistics. From a managerial point of view, the chapter provides insight into cooperation regarding integrated urban freight logistics management in large cities.

INTRODUCTION

According to 100resilientcities.org, « *resilient cities develop seven qualities that allow them to withstand, respond to and adapt more readily to shocks and stresses: they are reflective, resourceful, robust, redundant, flexible, inclusive and integrated* ». It can thus be inferred that urban logistics contribute to making cities resilient by combining these qualities. In a context where cars and trucks are widely used,

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resourcefulness calls for smarter transport modes, using alternative energy to fossil fuels. *Robustness* suggests that the system should be properly conceived and properly managed to prevent congestion. Offering alternative solutions to traditional road transport also provides *redundancy* and *flexibility* as it gives the possibility to users to better adapt to disruption and changing circumstances. *Inclusiveness* and *integration*, which aim at bringing together city dwellers and various institutions, may be better obtained by using a variety of institutional tools such as cooperation between public players and public-private partnerships. In this chapter, by emphasising the contribution of partnerships to the development of alternative urban freight transport modes, we clarify how resilient cities can emerge.

Various public welfare obligations such as improving transport patterns and reducing pollution, engages public entities into the promotion of cleaner alternatives for freight transport and sponsoring a radical transformation of ongoing behaviours. The development of intermodal urban freight logistics, including inbound and outbound flows, is however particularly complex (Browne *et al*., 2004). Urban freight logistics are normally mainly operated by private actors and involve a wide variety of supply and demand participants including freight and logistics companies, forwarding agents, shippers, loaders, service companies, road and traffic authorities, government, and those living and working in urban areas (Browne *et al.*, 2004). Goods flows are also heterogeneous (Ogden, 1992, Dablanc, 2007) and have become a major issue with the advent of web-based sales that multiply last kilometre small sized deliveries (Morganti *et al*. 2014). The scale of transport operations also necessitates public authorities to work on a larger scale than just the city itself. Inter-local or cross-regional levels would be more relevant. While authorities control and improve traffic flows by setting up delivery times, reducing speed, prohibiting given truck sizes, motorizations or energies within the town, these remain insufficient as attitudes evolve only slowly and fossil fuel energy is still widely used. Moreover, increasing regulation and constraints on existing solutions without providing alternative offers may disorganize economic activities and create legitimate discontent. Promoting resilient urban logistics therefore requires that public authorities provide newly designed infrastructures and engage into innovative projects on a much larger scale than before. Besides being complex in terms of ordinary management, such projects also need to induce effective behavioural change on the part of transport users.

The purpose of this chapter is to outline the cooperative challenges that lie behind the establishment of an intermodal infrastructure designed as an alternative to traditional urban distribution.

Although many authors argue that urban logistics management requires integration at an inter-local level, there is not much work on how and why such inter-local cooperation should be organized. While there are some publications on public-private partnerships in relation to urban logistics (Browne *et al.*, 2004), there are few contributions related to cooperation among public players. In this chapter, we rely on current work in contract theory, cooperation between public entities and public-private partnerships to highlight the importance of cooperation among public actors in urban freight logistics development. Public cooperation is viewed as a prior condition to the creation of new infrastructures and the development of public-private partnerships. It enables us to build a consistent framework to understand how public and private actors articulate resources to develop new intermodal infrastructures. We then confront this framework to our case analysis of the Paris "La Chapelle International" project of intermodal transport. As a result, we conclude how cooperation could provide large cities with resilient urban logistics.

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SETTING-UP INTERMODAL INFRASTRUCTURES TO BUILD RESILIENT CITIES: FROM PUBLIC COOPERATION TO PUBLIC-PRIVATE COOPERATION

The European 2020 policy note on smart choices for cities and sustainable urban freight logistics defines urban logistics as *all movements of goods in to, out from, through or within the urban area made by light or heavy vehicles, including also service transport and demolition traffic as well as waste and reverse logistics* (Civitas Europe, 2020, p.9). This very broad definition focuses attention on the holistic view that needs to be adopted to deal with urban logistics. Urban logistics can be considered at different levels (local, inter-local, inter-regional) and can include various circles of partners. Sjostedt (1996) offers a synthetic presentation of the main resource holders involved in providing urban logistics (Figure 1). Intermodal logistics typically involve a large geographical and institutional area that calls for public cooperation: inter-local cooperation as well as cross-administration cooperation (public transport infrastructure, land management). Such cooperation is useful to design and finance urban infrastructures. Once the infrastructure is decided on and created, cities must make decisions relative to the governance of the infrastructure. Two common alternatives are private markets and integration/unified management. In urban logistics, market mechanisms are often used to leverage private knowledge. The importance of managing urban distribution leads to discussing with different types of stakeholders and various administrations which are scattered over a large territory or beyond the usual city borders. This is particularly true if one wants to establish intermodal terminals. Such a scheme involves providing inbound/outbound transport, building a terminal to deal with incoming/outgoing goods and organizing urban delivery that involve a wide range of public and private resources.

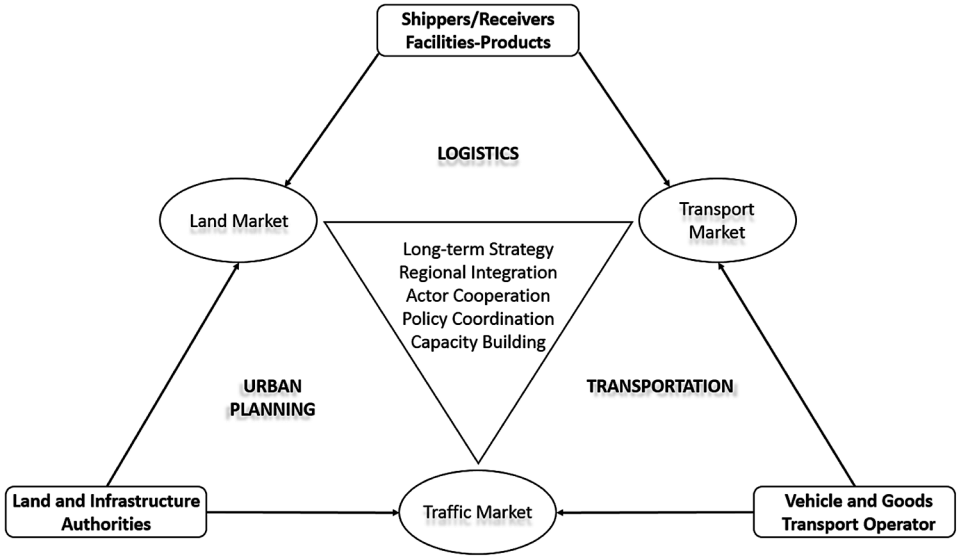
In the following sections, we first present the challenges of cooperating at a cross-administration and inter-local level, then we discuss the interest of going into public-private partnerships and at last we outline the partnerships that are usually used in infrastructure creation and management.

Public Collaboration

In urban freight logistics, in order to build resilient cities various fields of action must be taken into account such as improving traffic fluidity and flow management, offering transportation alternatives, shifting to cleaner sources of energy and operating in ways that promote the inclusion of users as well as participants. Urban logistics are traditionally operated by private actors with so far limited government intervention. Yet, things are gradually changing (Munuzuri *et al*. 2005, Ambrosini & Routhier, 2004, Taniguchi & Thompson, 2015, Gonzales-Feliu, 2018) as logistics activities are increasingly undertaken outside urban areas but have impacts on urban operations (Stantchev & Whiteing, 2006): "*Freight transport and logistics operations in urban areas cannot be viewed and studied in isolation but rather in the context of the entirety of supply chains that typically cross the geographical boundaries of urban areas*" (Browne *et al*., 2004). The need to coordinate public services such as transport organization, urban planning or regional development is thus strongly emphasized. Also, public actors have more authority and are the most legitimate to act in these domains. When urban logistics are incorporated into supply chains that cover relatively long distance inbound as well as outbound flows, cooperation should also involve the integration of public authorities beyond the local area. Therefore, resilient city achievement requires the adoption of a collective strategy (Figure 1) that is sufficiently infused within public services and the existence of a high cooperation from the outset. Transport relates more to long distance and massive transportation flows towards and away from the city, whereas urban logistics refers to final delivery is-

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Figure 1. Framework for sustainable urban freight transport
(Sjostedt, 1996, in Behrends, 2012)
Source: Authors' elaboration



sues. Building resilient urban logistics makes authorities to think about alternative ways of organizing inbound and outbound transportation as well as inner urban logistics with the combination of two or more transport modes in an intermodal perspective. While road transport is increasingly assigned to the short-haul and final deliveries, with cleaner trucks and more efficient planning, long-distance transportation is performed by large-scale transport modes such as rail transport (Behrends, 2012) or river transport.

Scholars as well as public managers have long recognized that urban logistics interdependencies need integrated transport planning between transport policy and land use as well as between local, regional and national government levels (Figure 1).

Though cities have mainly focused on passenger mobility and much less on freight logistics, providing freight infrastructure is not very different in terms of players. Three main different stakeholders are identified: infrastructure providers (most probably public players), infrastructure operators (managers), and landowners. As intermodal terminals link the city to outside locations and involve new processes, urban logistics authorities may need to cooperate with institutions outside their usual perimeter to gather specialized resources.

Intermodal Terminal Investment Characteristics: a Transaction Cost Perspective

Williamson (1981) stressed two main characteristics, asset specificity and performance measurement as key explanations for internalized governance of investments. In the case of intermodal freight logistics, asset specificity arises when an investment, once made, is specific to a transaction with limited or no alternative use. Specific assets induce high risk taking as the parties concerned can behave opportunistically (get out of the transaction) and suffer from technological failure or changes in supply and demand conditions. Moreover, outcomes may be difficult to measure, which creates opportunities for manipulation.

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An intermodal or multimodal terminal is a specific asset built within the city and equipped to deliver a given service. It is difficult and costly to find alternative uses, at least for the infrastructure. In this respect, terminals all have a specific purpose as train and river connexions link a limited number of nodes and are known to be inflexible. For example, they connect point A and B to point C. These connections once settled create high interdependencies between A and C or B and C. Therefore, A, B and C radically depend on the railway or river infrastructure to connect with each other once the investment in infrastructure is made. This pleads for integrated network governance, especially since, rail operators, due to operational costs, tend to concentrate on a small number of nodes and focus on a limited number of high-volume corridors (Behrends, 2012).

Though these investments are made to offer alternatives and change attitudes, there is, however, no guarantee that end users will widely and speedily adopt the new service (Diziain *et al*., 2014). Moreover, because the service relies on a completely new combination of resources, costs of providing the service remain highly uncertain. Therefore, the acceptability of final service price is ambiguous: *Private actors will be reluctant to participate in economic transactions in which expected public benefits exceed private benefits, especially if the latter are not expected to exceed private costs* (Rangan *et al*., 2006 p. 74). Profit-maximizing private actors will find it difficult to recover such costs through the market price mechanism because 1) adoption of new behaviour is slow and expected volumes are relatively low compared to the investment, at least at the beginning, 2) investments are too high for the market price to induce adoption as well as return on investment. In intermodal urban freight logistics therefore, public investment may enable the realization of a transformation in which no private investor alone would rationally engage. Indeed, the upcoming exclusion of diesel trucks from city centres engages authorities towards the design of intermodal freight logistics organization. For the moment, public authorities are expected to provide infrastructure and possibly to compensate non-recoverable private costs.

Selecting Participants to the Public Investment

Though intermodal railway infrastructure is typically supported by public authorities, there must be some support for collaboration among public players. Indeed, the scale of an intermodal infrastructure can require resources from various local governments and different public services or institutions such as, in our case, land managers and railway infrastructure managers.

Motivations for Partnerships Between Public Players

Partnerships are widely recognized as desirable whenever they bring together complementary resources and competencies (Rangan *et al*., 2006, Kivleniece & Quelin, 2012), contribute to interdependency management (Schermerhorn, 1975) and create valuable public goods. Intermodal transport is expected to offer public goods in terms of reduced pollution and congestion, increased flexibility and improved service. Due to widespread European and national policy objectives, all cities and public players set themselves the same goal, i.e. being more sustainable. Cooperation to provide resilient logistics should therefore fall within any public partner's objectives. Though, they may differ in their appreciation of the best way to promote sustainability. Furthermore, a public consortium may lead to smart subsidy leverage as different public players may have access, depending on their area of concern, to different ranges of subsidies. Yet, the harsh reality is that public players face increasing financial constraints and are more and more cautious regarding return on investment.

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Scholars have investigated the field of inter-local cooperation that mostly relates to the cooperation between cities. Part of the theory and results however can be extrapolated to any type of public partnership. Inter-local cooperation occurs when two or more actors anticipate a beneficial result. Incentives to cooperate lie in scale economies by enlarging the consumer base or increasing the utilization of specialized resources (Shrestha & Feiock, 2011), cost savings, economic efficiencies in production through cost savings and complementarities that provide economic efficiencies (Kwon & Feiock, 2010, Feiock, 2013). It also keeps local governments free from national government interference and free of setting up their own strategy (Nelles, 2009), which is at the heart of urban policy definition as proposed in Figure 1. These partnerships are gradually binding as they take the form of informal agreements and networking, joint ventures, and service contracts in mandate or legally binding agreements. Such *mandate* agreements require two or more public authorities or partnerships that often include private and public actors. The participants accept common terms of agreement and obligations for action (Spicer, 2015). Following a transaction cost approach, Shrestha & Feiock (2011) find such inter-local agreements between public services/cities are more likely to develop (compared to market transactions) when there is a high asset specificity or high uncertainty in outcomes. Indeed, cooperation makes it possible for stakeholders to protect the collective investments from potential opportunistic behaviours. However, when asset specificity and measurement difficulty are too considerable (above the average), parties would have less incentive to cooperate with each other. This may result in a non-cooperative behaviour or a reduction in the investment amount.

Reciprocal relationships matter when actors share expenses and incomes. In that case, reciprocity and trust can be considered as the key drivers for inter-local cooperation (Shrestha & Feiock, 2011). Being a small or medium sized actor increases the probability of cooperation with others, because smaller partners can better benefit from scale economies. Major cities seem less encouraged to cooperate. This can be explained by the fact that large cities are more self-sufficient (Spicer, 2013). Large cities also fear their expenses might create growth beyond their borders and weaken their own political position (Spicer, 2013).

Commitment to the Partnership

The intensity of cooperation or commitment to a partnership (Nelles & Alcantara, 2011) is measured by the degree of authority, the amount of resources dedicated to the partnership or the institutionalization of the partnership. Nelles and Alcantara (2011), and Shrestha and Feiock (2011) all consider increased institutionalisation and complex agreements go along with higher risk and higher cooperation. Shrestha and Feiock (2011) propose public partnerships will move from cooperative agreements to joint production and unified management in order to favour effective cooperation and reduce opportunity risk. Since we have described the provision of intermodal transport as a highly specific investment leading to uncertain outcomes, inter-public cooperation should therefore take place within a unified public management structure.

Issues Related to Intermodal Terminal Creation

Many large cities in Europe have grown and fused with surrounding cities and counties to deal with interdependencies and have created institutionalized metropolis or agglomerations. Cooperation within this new perimeter has become a rule. To deal with interdependencies in flows, land management, rights

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of use or building, some cities have specifically dedicated organizations to the provision of resilient urban logistics. These organizations work under unified management within the metropolis or agglomeration. Their size and legitimacy makes them the ideal partners to design and control new intermodal infrastructure for the city, agglomeration or metropolis.

Broadening the customer base and increasing the use of infrastructure are however key challenges for any innovative intermodal terminal as effective use needs developing. Beyond providing financial support, partnerships have to be provided for increased utilization. Given their population, cities tend to induce inbound flows. In the case of intermodal transport, these flows may originate from relatively distant cities. Securing effective infrastructure utilization then requires finding distant cities to connect with and to amortize the infrastructure with a sufficient volume. Generally, the economic performance indicators of a terminal are 1) shippers' distance around the terminal, 2) freight volumes in the area and 3) local costs and productivity i.e., the number of round trips per load unit and loading/unloading times. (Kreutzberger *et al*. 2006, Berentz, 2012). Therefore, typical partners for an intermodal infrastructure should be able to increase its utilization. Such partners have to shelter shippers at a short distance from their own terminal and provide sufficient volume to improve terminal cost performance as well as productive efficiency.

An intermodal infrastructure connects two or more geographical areas. It provides benefits to a number of parties inside and outside the city. It enables locations from which the flows originate to open up, to benefit from transport alternatives and to improve stakeholders' access to the large city. These locations may also benefit from spill-over in terms of employment or economic activity. As such, in the case of large cities, external partners, may find it attractive to partner with cities providing a wide potential market outlet. Several partner locations may eventually compete to benefit from the prime advantage of accessing the large city and serve their own stakeholders. Faced with such competition, cities can select out the most productive origins or duplicate infrastructure and partnerships. The original institution would invest in the terminal and favour infrastructure utilization while the large city would invest in the urban intermodal terminal.

A general cooperation can thus be expected to be developed between institutions holding the initial terminal and the city holding the destination terminal. Considering the asset specificity and the risk of effective exploitation, large cities would be encouraged to cooperate to share stakes and costs as well as securing partner engagement in using the infrastructure.

By engaging into infrastructure creation, assessing risks becomes a major preoccupation. It is no surprise that all the partners want to control the outcomes of operations. This calls for formal contracting or joint production and tight supervision. A high level of risk may however also engage parties into a redefinition of the project. Promoters may be required to redefine the project into identifiable activities so as to reduce risk and improve its efficiency. While risk and cost sharing could be reduced by enlarging consortiums, enlargement is not widespread (Spicer, 2015). According to the latter which has studied Canadian cities, public partnerships involve 2,87 partners as an average and most of them are bilateral.

As mentioned previously however, cities are mostly responsible for passenger mobility and have little control over freight logistics. This outlines the need to find new types of partnerships (Table 1).

Public-Private Partnership

Although public governmental authorities are expected to provide resilient cities, they can partly rely on private players to achieve their goals. Indeed, public-private relationships are widely used across

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Table 1. Characteristics of an investment in intermodal urban infrastructure

Items	Characteristics of the Partnership for Intermodal Transport Provision
Type of investment	Specific asset, uncertain outcomes, hardly controllable costs (new infrastructure, adoption challenges)
Type of partnership for infrastructure building	Public partnership
Incentives to cooperate	For the city: improved utilization of the intermodal service, shared risk and investment For the partners: attraction of the city, exclusive access to markets, asset specificity.
Form of cooperation	Formal agreement, high level of institutionalization, amount invested is representative of commitment.
Complementarity of resources and partners' identity	Municipal institutions in charge of urban logistics development and outer city institutions capable of insuring infrastructure utilization as well as provide knowledge.

Source: Authors' elaboration

the world, particularly in the transport sector (Estache, 2007), and even more so since the advent of New Public Management. They typically involve one or more private parties and public bodies, creating specific benefits in a wide range of public policy concerns and contribute to the emergence of innovative solutions. According to Kivleniece and Quelin (2012), key drivers that explain the recourse to public-private partnerships are those that help solving problems of market failure when new public services emerge (Brinkerhoff & Brinkerhoff 2011). Public-private partnerships (PPPs) indeed benefit from resource and competency complementarities (Rangan *et al*. 2006) as they use private as well as public resources that contribute differently to new service development. PPPs finally benefit from differentials in cost efficiency. This is the case for example when a service is more efficiently operated by a private player than by a public player (Kivleniece & Quelin, 2012). Therefore, the value generated by provisioning public goods while relying together on public and private resources and competencies is superior comparing to the value generated by the same partners separately. Either service quality and service adaptation to evolve technology and needs would be better or the cost for the same service would be lower. As far as the value creation process is concerned, PPPs would therefore be more efficient even though they may induce some governance costs to control the implementation of the service in given conditions (Brinkerhoff & Brinkerhoff, 2011).

Reasons for Forming a PPP in Urban Logistics

The typical scope of a PPP is when public players have expectancies regarding a public policy, but face far higher investment or operating costs than what private costs would be (Rangan, 2006). The provision of the public service then benefits from the inclusion of an effective and efficient private player. In the case of urban freight logistics, it was mentioned previously that public investment is necessary to solve a market failure issue. Joint public-private action enables public actors to offset the private costs incurred in the implementation of a new public policy. While public actors have the ability to bring together various public resources such as land management (Dablanc & Rakotonarivo, 2010), authorizations or financial support to develop a service, private players also provide complementary resources. Private players often have specific knowledge and skills related to the service provided. Such skills include technical knowledge to run equipment and plan operations, pricing and capacity management skills, or

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knowledge related to end-user needs. As a part of sharing costs and responsibilities within a PPP, the service aimed at through the contracting process is thus often operated by the private sector.

Relating to urban freight logistics, private resources can be particularly important due to the complexity that exists in the management of the various professionals involved. The inclusion of key logistics players, capable of coordinating the multiple demands is therefore particularly useful to instil change and provoke adoption targeted by public authorities. As far as transportation is concerned, it is important to adapt the distribution and upstream network to the economic, geographical, organizational and quality constraints (Gonzalez-Feliu, 2012).

The value creation of the new service development therefore stems from the adequate combination of public and private resources and competencies. Adequate combination suggests that part of the service performance relies on the governance of the relationship. A difficult agreement on the nature and extent of the risks, without knowing who should bear them (Estache *et al*., 2007), makes this combination even more difficult to achieve. Perceptions of the profitability and financial feasibility of projects are very important for achieving a PPP and failure often stems from a lack of trust (Koppenjan, 2005).

Depending on the type of contract, PPPs can also reduce the public investment burden by introducing private investment.

PPPs can then induce cost sharing. As most investment is engaged by public bodies, the cost reduction stems from the quality of service developed by the private partner that maintains the infrastructure. In fact, private partner invests in customer service and quality in order to improve benefits. The type of contract qualifies the type of partnership.

Types of Public-Private Partnerships in Transport and Urban Logistics

In a transactions cost perspective, Kivleniece and Quelin (2012) propose that public-private collaboration should be organized in two polar modes, defined by distinct sets of attributes in terms of business models. The degree of operational task sharing and end-user versus tax-based sources of revenue, authority, property rights and incentives are attributes that distinguish both alternative models at the operational, business model and governance levels.

PPPs in fact combine the resources and skills of the public and private sectors in a variety of ways, depending on the combination of resources, objectives, or culture of the country. In France, PPPs are made of contracts or based on mixed enterprises which feature various degrees of autonomy and integration.

Types of Partnerships

In a public service concession, the private sector provides public services on behalf of the public authorities and gets a revenue in relation with the performance of the exploitation. Typical PPPs that fall within this category are the contracting out of services, the concession or leasing contracts. Browne *et al*. (2004) or Gonzales-Feliu *et al*. (2018) describe such partnerships as *narrow* (as opposed to *broad* PPPs*)*. In such partnerships, resources are made available by various private and public stakeholders, but are used by the player carrying the project. Narrow PPPs are mainly related to infrastructure or transport systems development, are established on a long term refunding base, and incorporate financial agreements. Important issues regarding narrow PPPs encompass risk sharing, management and performance measurement. Broad PPPs are less formalized and have thus been less investigated.

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Table 2. A typology of public-private governance forms

Autonomous	← →	**Integrative**
• Operational tasks delegated to private partner • Low need for coordination between public and private counter-parts • Public authority assumes monitoring and supervisory roles	Operational model	• Operational tasks shared with the public partner • High need for coordination between public and private counterparts • Important role of public partner resources and capabilities
• Private actor derives revenue from end users	Revenue model	• Private actor derives revenue from public partner
• Strong private actor authority • Predominantly private property rights • High-powered incentive regime	Governance features	• Weak private actor authority • Shared property rights with public partner • Low-powered incentive regime

Source: Kivleniece and Quelin (2012)

When contracting out services, public authorities remain the ultimate providers of the public service that they subcontract for a relatively short period of time to a private actor. In transport activities, bus or train services are often contracted out. In Europe, a call for tenders is usually needed to select the service provider. Contracting out of services normally does not engage public authorities into much investment, but this type of partnership however requires that they have a good knowledge of the service needed in order to write the call. Private actors however tend to limit risk taking by setting a cost level as a ceiling, beyond which they will leave the project (Estache, 2007). Private players may therefore control their costs.

In a large sense, concessions (often known in Britain as BOT: *Build, Operate, Transfer* or, more recently, DBFO: *Design, Build, Finance, Operate*) refer to any contract that authorises a private player to develop a product or service in the public domain. In French law, concessions can be analysed as rental of land or facilities located in the public domain (Grosdidier de Matons, 2012). The concessions take place between two parties, the grantor of the concession (public party) and the grantee (usually a private party) that has a mandate to operate and expand an infrastructure. The grantee often has to invest in order to provide the service to which they are committed and their investments will be handed back to the grantor at the end of the contract. In exchange for his investments, he is granted the right to charge end-users for the service provided by his activities on public land.

In this context, different types of concessions may however be observed: 1) the grantee makes the investment, 2) the grantee benefits from investments that have been made by the grantor, 3) investments have already been made by a third party when the concession changed ownership (Schevin, 2011). These elements show the diverse arrangements that exist behind the generic term of concession and the way investment costs and revenues are actually shared between public and private players.

Nevertheless, the grantee usually assumes most of the commercial risk associated with the business. Depending on the amount of investment required, in private investment the use of a wide range of financial sources may be required. This can include equity for which institutions may get involved with bank and institutional loans. This type of agreement may enable public players to undertake projects without a major investment and without affecting their debt ratio.

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In many countries, the development and management of transport infrastructure is governed by concessions (Kivleniec & Quelin, 2012, Estache *et al*. 2007). Airports, port terminals or motorways are often conceded to private operators.

In a leasing contract, public authorities delegate the management and operations to a private company for a long period, from 10 to 15 years. The facility ownership remains public and the public authorities are responsible for additional forthcoming investments such as increasing the capacity of infrastructure. The private actor utilizes the infrastructure and is responsible for service billing, staff management, assets renewal and revenues collection.

Financing and Governing the PPP Through a Mixed Enterprise

Financing the investment and governing the PPP can lead public parties to set-up mixed enterprises that feature a high level of public-private integration. Several partners join their forces by transferring capital to an ad-hoc established company. These mixed enterprises are limited liability companies that take advantage of the flexibility of a private company and the majority of their capital is owned by public actors so as to guarantee the pursuit of public interest.

The legal institution defines the ambit, secures and stabilizes the partnership on a long-term basis. It stresses, through capital sharing, the co-responsibility of participants for investments in infrastructure and service delivery. Such institutional arrangements favour the transfer of private knowledge and practices to public enterprises (Hadjar, 2014). They also allow the public owner to gather more information about actual management of the firm and reduce asymmetric information between regulators and regulated firms. This can be obtained by implementing an internal regulation and monitor the private operator more effectively (Marra, 2006). The board of directors can also provide a place for dialogue between the parties.

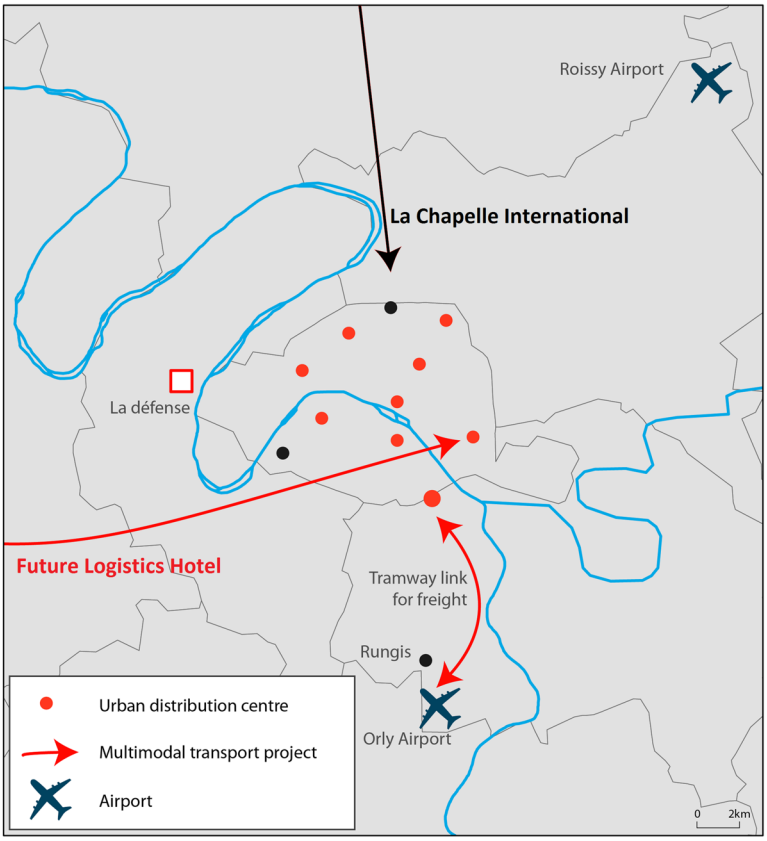
CREATING AND FAVOURING ADOPTION OF CLIMATE-RESILIENT INFRASTRUCTURES: THE PPP IN THE CASE OF LA CHAPELLE INTERNATIONAL IN PARIS

To create resilient cities, European institutions recommend that cities should create special institutions designed to manage interdependencies and contribute to the emergence of coherent freight transport patterns. Paris metropolis (that includes Paris and 3 connected suburban areas) did so by supporting the emergence, under unified management, of a mixed enterprise whose shareholders are however all public to manage urban logistics. This highly integrated and highly endowed institution, Sogaris, materializes the high level of cooperation within the Paris metropolis between the city and surrounding counties.

"Sogaris" is governed by the Paris municipality (49.5%), the three department governments included in the metropolis (Hauts de Seine, 14.7%, Seine Saint Denis 8.6%, Val de Marne 7.2%) and the public investment group "Deposit and Consignment Office" (17,7%). Endowed with €16 million in equity and €200 million consolidated equity as well as considerable real estate holdings (518,000 m^2), the company provides for the future of logistics, the global logistics solutions, space and logistics services. It acquires rights, builds the infrastructures, manages commercial space rental which generates revenue. Sogaris indeed holds a long experience in urban logistics development and Dablanc & Massé (1996) note the company already established urban consolidation centres in the 1960s. As the strategic arm of the Paris

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Figure 2. Plans for intermodal transport, Sogaris, Paris
Source: DEVPORT reproduction from Sogaris strategic plan (2014)



metropolis, "Sogaris" participates in orienting public policy and land management at the scale of the whole territory.

Quite logically, "Sogaris" was put in charge of the development of intermodal freight transport for Paris.

La Chapelle International (Figure 3) is the first and the most advanced case of these projects (Figure 2) that notably aims at dealing with incoming deliveries of web-based sales. The site is a logistics hotel (Boudouin *et al*., 2014) and thus articulates freight flows while blending logistics within the resilient city.

Public Partnerships and Infrastructure Provision

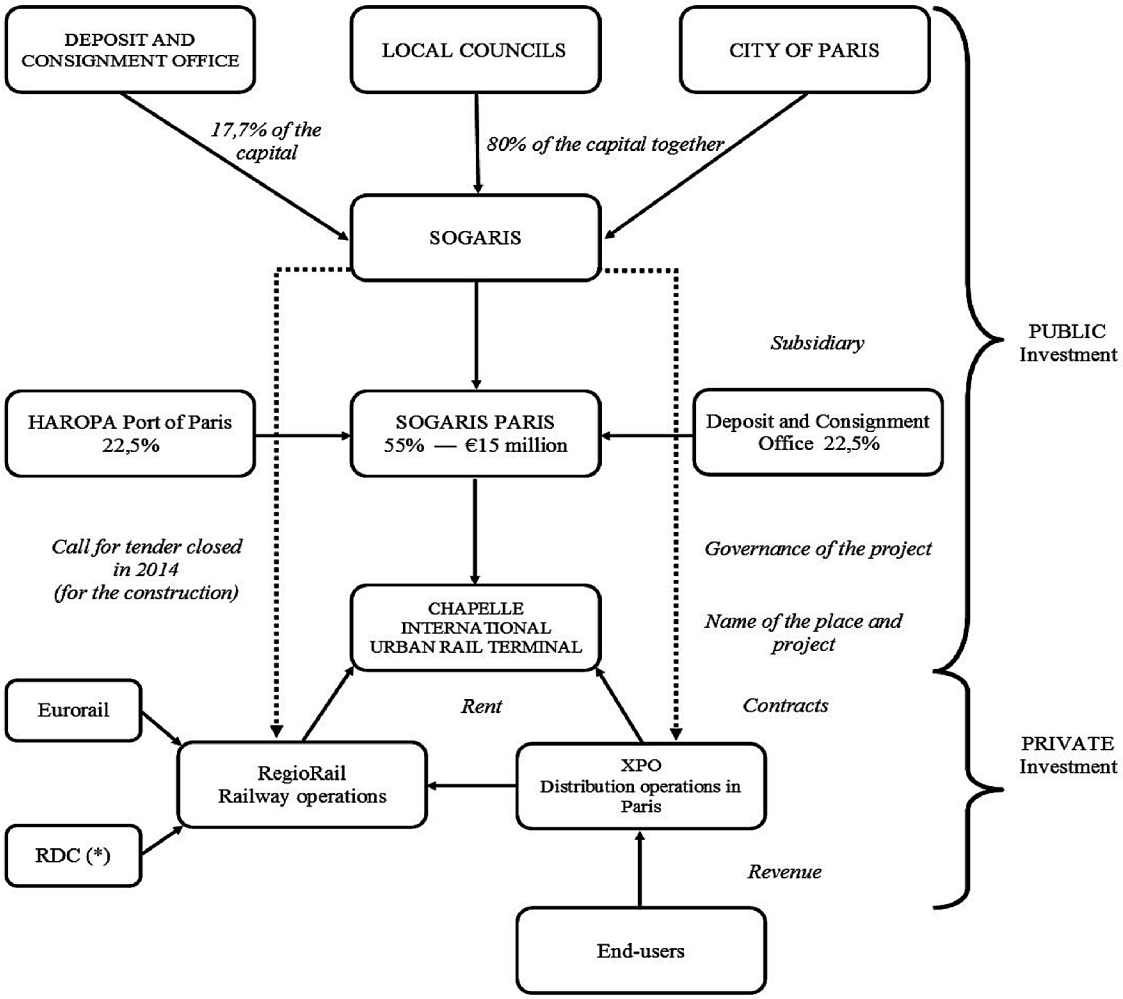
Following our statements on pubic partnerships, we discuss the project on the basis of resource complementarity, institutionalization and cooperation incentives.

Several meetings were organized with logistics and transport companies to understand the operations and organization required for implementing an intermodal transport service similar to La Chappelle. We completed the knowledge acquired by reading press reports, company statutes as well as yearly company reports. This enabled us to fully capture the La Chappelle process of developing the infrastructure to figure out the structure of stakeholder relationships and the prospects of the project.

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Figure 3. Description of the project La Chapelle International in Paris
Source: Authors' elaboration

In Paris, urban freight is constantly on the increase with e-commerce growth. It represents 15% of urban movements and 40% of particles emissions. La Chapelle International provides resilience by setting up an urban freight terminal (15 200 m² and 400 meters long), and converting a brownfield site.



(*) Railroad Development Corporation, an American company.

The project is put forward by Sogaris, the "Deposit and Consignment Office" and "Haropa Port of Paris" and involves direct freight delivery to the heart of Paris by train shuttles originating in Northern France. The merchandise will then be distributed within Paris with electrical, gas or hybrid trucks. The project aims at reducing CO^2 and particulate emissions. Two shuttles are expected to get into Paris every day with ready prepared swap bodies.

Players and relationships in the Chapelle International project

Public Investment: Haropa Port of Paris, Sogaris, and "Deposit and Consignment Office"

Operations handling: Eurorail (railway operations) and XPO (urban distribution with low emissions' vehicles). *XPO Logistics' role is to design, manage and sell the transport solution, as well as providing the road transport* (XPO Company website). *Eurorail will manage the merchandise transport by rail, including reserving train paths with the SNCF network, renting freight cars and managing train driver teams* (SNCF Company website).

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The La Chapelle International project was the winner of a tender in 2010. It then proposed to convert a brownfield site into a mixed urban area combining housing, offices and an urban freight terminal. Located in the 18th district inside Paris, it could reuse an abandoned terminal and connect to the northbound rail network. The logistics hotel was meant to become the interface for the North route to Paris, thus transforming massive merchandise flows into scattered urban streams. Two shuttles are expected to get into Paris every day with ready prepared swap bodies. The project itself started in 2013 and was put forward by Sogaris, the Caisse des Dépôts et Consignations and Haropa Port of Paris that are involved in the infrastructure (public investment). Operations are handled by private players Eurorail (railway operations) and XPO (urban distribution with low emissions' vehicles).

Complementary Resources and Partners' Identity

The creation of new intermodal infrastructures requires the cooperation beyond the usual perimeter in order to guarantee the use of infrastructures by providing high transport volumes and relatively frequent transport trips (Kreutzberger *et al*., 1996). Although private actors could get involved in using the infrastructure, no private player would invest in the infrastructure and assure its sustainable utilization at the same time. Moreover, recurring to private players such as key logistics players or large retailers would probably reduce incentives for competitors to use the equipment. Finally, only a few players have authority on large volume freight flows to guarantee intermodal utilization.

Though cooperation with partners from outside Paris was expected, "Sogaris" chose to join with "Haropa" Port of Paris. This choice confirms the scholar findings that large cities have low tendency to establish a connection with other cities through partnerships. Such an election can be explained by two factors of proximity and trust as, in this case, Paris port will be more willing to adopt a Parisian point of view than other partners would. Also, Sogaris and Port of Paris had already worked together on previous projects dealing with waste treatment, so trust might have developed between the partners. Another advantage of the partnership, given the long-term plan for intermodal freight logistics, would be the long-term cooperation of both parties. This would reduce transaction costs of establishing new partnerships for each new intermodal infrastructure. Ultimately, the port of Paris effectively brings resources and competencies to the partnership as proposed in Table 1. Besides owning extensive real estate, the port of Paris is in charge of fitting out, maintaining and operating port infrastructure for river passengers as well as freight transport in the Paris area (the project should later connect the "La Chapelle" terminal to the River Seine through an inland terminal located in the north of Paris).

As a port, Port of Paris also connects with a variety of other ports that can contribute to feed the intermodal terminal. Ports indeed concentrate high volumes of freight and they gather shippers and freight forwarders. Ports do not govern freight forwarders and logistics players, yet, they are still the most competent public actors to interact with them and to promote an intermodal offer. Since 2012, the port of Paris is involved as a member, with the ports of Le Havre and Rouen, in the HAROPA group. The alliance could thus help Port of Paris access players and improve the utilization of the infrastructure. The port of Paris, may also have connections with other ports such as Dunkerque to cater for intermodal infrastructure use. For their part, ports have a strong incentive to contribute to intermodal urban logistics.

Accessing Paris for French ports, particularly for Dunkerque and Le Havre, is a great business opportunity. French ports have been driven out of the market by the port of Antwerp which has become one of the main ports serving Paris market. They are most willing to recover what they consider should be, with about 12 million inhabitants, the premium region to service. Offering a better access to the Paris

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market, with new transport alternatives, could enable them to attract new customers. Luckily, the 2008 port reform in France also gave French ports the possibility to act as developers. Ports such as Paris, Le Havre, Rouen or Dunkerque are able now, alike their foreign competitors, to invest in any infrastructure outside the port domain they find suitable for their business. All the more so, since port strategists argue that ports are not benchmarked on cost or on the port passage itself, but on the array of services they offer in the hinterland to help customers reach their own clients. In fact, other European ports have invested into dry ports or inland intermodal infrastructure (Rodrigue & Notteboom, 2009, Slack, 2007). Ports are thus potential financial contributors to the creation of an intermodal infrastructure. All the more so, as becoming more sustainable is one of the objectives they must achieve by supporting alternative transport modes to and from the port.

The Port of Paris for itself, and for its possible links with other ports, is therefore a good contributor to the project. The project also involves "Deposit and Consignment Office" which provide the public fund dedicated for supporting innovative infrastructure projects. The group is an expert in fund providing and one of his key objectives is to finance sustainable projects.

The project, therefore, combines complementary resources and competencies that are very consistent with the pursued objectives. Because the project falls within the partners' objectives and interests, there would be a great willingness to cooperate. In addition, the cost of the project is somehow reduced by the possibility of using and converting industrial wasteland and abandoned railroads in Paris.

The inbound/outbound infrastructure and other terminals also already exist. The infrastructure costs were limited to the construction of 400m urban terminal, the electrification of the local network and the equipment supply. Some of the public actors involved, whether "Sogaris" or the port of Paris, are the most appropriate for networking with railway operators in order to acquire rights of use. The public partnership therefore makes it possible to reduce the cost of the operation and to trigger relatively quick response from cross-administrative networks. Together, they form a credible partnership which gives incentives to cooperate.

Institutionalization

The partnership is highly institutionalized as it is materialized in the mixed real estate enterprise "Sogaris Paris" that was initially created in 2011. In July 2015, its capital was increased to €3 842 300 owing to the 25% stakes' involvement of both, the port of Paris and "Deposit and Consignment Office" (Figure 3). As a subsidiary of Sogaris, *Sogaris Paris* is dedicated to providing urban freight logistics. The provision of urban storage premises or urban freight terminals are the objects of the enterprise. It rehabilitates or creates, administrates and manages buildings and networks. The company can also acquire holdings. All partners participate in decision making regarding the creation of new urban infrastructure which reduces individual risk linked to asset specificity. They also benefit from a preference in case of capital increase, which characterizes a stable relationship. It may also be noted that no shares may be transferred without prior notification and other partner's agreement on the new shareholder. Shares may also only be transferred in blocks that limits the possibility of increasing the number of shareholders. If an investor withdraws, they will also transfer all the shares to only one beneficiary. The company statutes naturally allow for dividend sharing when utilization generates revenue and, finally, a follow-up committee, which takes strategic decisions, is created where shareholders name representatives according to their share in the company.

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Most decisions require a 75% majority, some, such as changing the rules to include new associates, require unanimity. The term of collective decision is used several times in the company statutes. Such institutionalization where any infrastructure creation, loan taking or acquisition is submitted to shareholder approval is consistent with asset specificity (Williamson, 1981). Resource and competency complementarity are however the heart of the company meant at developing resilient intermodal logistics. Though Sogaris remains the major investor (which is consistent with the multiple dimensions of the project, as it includes the creation of commercial surfaces) a 25% stake and commitment should urge the port of Paris to provide freight.

Commitment and Contractual Benefits

The public partnership principles are consistent with the fact that intermodal terminals are specific assets that require infrastructure creation with usually a low adoption rate at the beginning of their career. As far as Paris and Sogaris are concerned, the partnership helps to reduce investment costs and provides complementary resources such as access to key shippers. The focus is on infrastructure building which in turn gives rights to share rental revenues. Although revenues will only show up if the infrastructure is utilized, Sogaris and the port of Paris are both interested in kicking off the project. The commitment to the project, measured by the amount of investment and the degree of institutionalization, is important for the port of Paris, which is a newcomer in the urban logistics' business. Therefore, Sogaris and the port of Paris are both interested for kicking off the project. Though the city of Paris owns most decision and property rights on the infrastructure, property and decision rights are shared and closely tied-in, which enables the port of Paris to keep control over the company and future plans. The statutes provide for cooperation in the long term, which suggests the partnership is meant to be long lasting. Although assets remain specific, the institutionalization of the project may rather be linked to the intention of pursuing the partnership and duplicating intermodal terminals.

The partnership established between the Parisian partners (Sogaris, port of Paris) can be rooted in trust and former relationships. In fact, the trust reduces transaction costs related to the contract negotiation. It was however argued previously that on-going competition for growth and development between cities and between regions could hinder cooperation with neighbouring areas. Local players do not wish to connect with the outside players because they do not tend to promote growth beyond their borders. This could be supported by politicians' eagerness to demonstrate citizens how credibly they are involved in developing their area. A characteristic feature of the agreement that was reached for "La Chapelle International" and the design of the project itself, is that it provides little room for strangers. This is consistent with the idea that partnerships are easier to build in presence of the trust (Keser & Winden, 2000; Shrestha & Feiock, 2011).

There are however political issues in the project such as whether the jobs are created in Paris or in other places such as Dourges (the logistics zone close to Dunkerque from which shuttles leave in the north of France). The creation of the "Bruyère sur Oise" terminal inside the Paris region as the fore terminal to the "La Chapelle International" may also be a consequence of inter-local competition. The Paris Region would then seek to appropriate as many benefits as possible such as attracting companies into Paris, developing economic activity and creating jobs. If value added logistics activities were only concentrated around Paris, other cities/ports could be less willing to cooperate.

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Public-Private Partnership

The logistics hotel created in "La Chapelle" next to the main terminal, includes some storage areas ready to be rented as well as offices and commercial premises which can all contribute to process the goods. Though the public partnership was a prerequisite to develop and exploit the new infrastructure, the real estate company's object does not authorize effective operational exploitation. The provided space will therefore be rented to business operators. Moreover, none of the public players involved have any specific knowledge about managing a train terminal, running train shuttles or delivering the goods to Paris.

From a private standpoint, running an urban intermodal terminal is a new and uncertain business in terms of revenue for any private profit maximizer. Leveraging private resources in the first stages of a new business is particularly difficult. Finding a risk taker who accepts a concession contract in which all the risks should be supported by the private player, would not be easy. However, thanks to the public partnership in the mixed enterprise and the project design in which public actors take some risks, the contributions of private actors can now be clearly specified. The public-private partnership can be settled where the infrastructure maintenance and daily operations are run by private specialists.

Once the infrastructure runs, there is in fact little need for public-private complex coordination. Private players acquire the necessary equipment for their business (trucks, wagons) and plan daily operations depending on incoming orders. When a strong incentive scheme is pushed forward, the outsourcing of services, to benefit from additional resources and improve infrastructure efficiency, is therefore sufficient to meet the reciprocal obligations of private / public partners. Private actors in this perspective are very autonomous in running their business and derive revenue from the service they render to end-users. They hold property rights because they have a monopoly access to the infrastructure for the given service, depending on the duration of the contract. In exchange, they pay a rent to the property holder, "Sogaris Paris". Regular contract renewal is a market mechanism which is supposed to enhance the performance. Sogaris Paris will have to find the first customers, because they ultimately bear the commercial risk, and may reduce operating costs by fixing low rental rates when the business starts. However, the service providers also have incentives to contribute to the business development to recover their own investments, make a profit and acquire knowledge they can reuse elsewhere.

To provide complementary resources, a protocol was signed in September 2015 between Sogaris, Regiorail and XPO (Figure 3), far before the buildings were completed. It thus allowed the operators to participate in the final definition and technical tests to be carried out before effective commercialization. *XPO*, the large logistics company, is a full-service forwarder for food, home and personal equipment merchandise and manages pre-and post-feeding train operations from the north of Paris into the city centre. The company organizes final delivery with clean gas propelled trucks. XPO bills final users for the full service and subcontracts the rail service to Regiorail. This latter company bills XPO for the rail service and pays the slot access to the railways, provides the train connection, rents or acquires wagons as well as electric locomotives and exploit the train terminal. Their main challenge remains to benefit from sufficient volume in order to recover fixed or variable operating costs and make a profit.

The use of market mechanisms to manage operations suggests that each new intermodal project can lead to a new call for tenders. It also suggests that several railway operators as well as several logistics players could exploit different terminals in Paris. In doing so, public authorities would act much like leading private players that use competition and market mechanisms as key performance inducers. Later, once the business knowledge is acquired and become stable, concessions contracts could be concluded as to engage the private players to bring additional investments for a better business start-up.

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CONCLUSION

The "La Chapelle International, Paris" case is presented in this chapter as a cooperation benchmark in building resilient cities. The case features a high level of public cooperation before the public actors call on public-private cooperation to bring about innovative logistics processes. While public-private partnerships remain a valuable instrument to manage new intermodal infrastructure, when projects are innovative, public partnerships are a new prerequisite to their development. Close public cooperation in infrastructure and building design enables public players to define, settle and govern a clear private contribution and public-private relationship. The public partnership provides for high asset specificity, risk sharing in the context of novelty. Beyond providing financial resources, the partnership with Port of Paris, potentially supplies improved utilization and useful relationships with major businesses.

From a theoretical standpoint, it has been shown, in the case of La Chapelle International, that the requirements in terms of cooperation for urban freight logistics and intermodal terminal development, fit well into existing literature: cooperation builds on complementary resources, reduces costs, improves efficiency and improves infrastructure utilization. Asset specificity and risk seem to induce a strong institutionalization of the public partnership and a high level of commitment. However, institutionalization might also be linked to the fact that the public actors seem to engage in a long-term relationship, for several projects. Strong institutionalization could therefore rather reveal, in the La Chapelle International case, the intention of public players to cooperate on a long-term basis.

Contrary to what was expected, there is no inter-regional or inter-local direct cooperation and, though there is resource complementarity, partners committed to the project are closely linked to the large city. The large city thus keeps close control over urban logistics and relies on partnerships embedded in trust and easy potential reciprocity. This suggests that there is an important urban commitment in intermodal logistics. Based on the trust between closely linked public partners, public-private partnerships are born on a very autonomous basis where private actors manage the operations and assume the commercial risk. Indeed, when introducing innovation, public legitimate institutions are the key players.

From a managerial point of view, the chapter presents a quite detailed perspective of the partnership and contract management aimed at providing intermodal logistics and build resilient cities. As a benchmark, the case shows high consistency between urban strategy, selected partners, contractual arrangements and expected benefits. The transformation is however recent and at the time this chapter is written, there is no evidence of the success of the project. As stated previously, more projects are in progress, which will allow the readers to delve into some of the proposals presented in this chapter.

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Chapter 2
Implications of Activity Classification Aggregation in Urban Freight Trip Generation Linear Models

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ABSTRACT

This chapter studies the implication of aggregating establishments by categories with different levels of detail for modeling FTG. To this effect, the chapter conducts an assessment of freight trip generation (FTG) patterns homogeneity inside activity-based grouping. The method implemented is econometric in nature, which allows the assessment of the statistical significance of variables representing commercial activity sectors and sub-sectors. The results show that for some sectors the traditional high-level aggregation includes sub-sectors with homogenous FTG patterns and thus produces appropriate models; in some other cases (e.g., retail, manufacturing), the sub-sectors have different FTG patterns and thus more detailed data is needed to calibrate accurate models. This research can be used to enhance the efficiency of data collection, as it identifies some sub-sectors that need larger efforts for data collection, and some other categories where FTG homogeneity allows for less detailed data collection without hampering the quality of the models.

INTRODUCTION

Urban freight demand models are an important tool for urban planners and transportation authorities to assess local needs, design appropriate infrastructure, and define policy interventions. The increasing relevance of this subject in an urbanized world has attracted the interest from both researchers and practitioners with various frameworks and applications. In general, these models start with a demand

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generation stage which include freight generation (FG) and freight trip generation (FTG). FG models measure the freight flows (e.g., tons, volume) that result from the commercial interaction between a shipper and a receiver, and provide an excellent insight to understand economic interactions and the demand for goods movement. FTG models measure the amount of freight-related trips that result from the demand for goods and the logistics decisions of shippers and receivers. FTG includes both freight trip attraction (FTA) mainly resulting from the reception of deliveries by an establishment, and freight trip production (FTP) mainly resulting from shipments sent-out by an establishment (Holguín-Veras et al. 2012). This paper focuses on FTG models because enhancing these models will produce more immediate benefits for well-informed decision making and for more accurate local needs assessment and infrastructure planning.

As urban freight traffic is a direct consequence of commercial activities taking place at the establishment level, it is important to collect primary data at this level and estimate statistical models to capture establishments' freight traffic patterns. FTG models can estimate current freight traffic patterns as well as forecast future freight traffic based on planned commercial activity. One salient characteristic of FTG models is, thus, their reliance on commercial activity categorization.

There are a number of publications in the literature focusing on FTG models (Iding, Meester et al. 2002, Beagan et al. 2007, Holguín-Veras et al. 2011, 2012, 2013, Lawson et al. 2012, Alho and de Abreu e Silva 2014, González-Feliu, Cedillo-Campo et al. 2014, Ducret and Gonzalez-Feliu 2015, Aditjandra, Galatioto et al. 2016, Gonzalez-Feliu, et al., 2016; Sánchez-Díaz et al. 2016a,b; de Oliveira et al., 2017; Gonzalez-Feliu, 2018), most of them use either land-use or industry classifications to group establishment that perform similar commercial activities and estimate either constant rates per employee (Iding et al. 2002, Beagan et al. 2007, Holguín-Veras et al. 2011, 2013) or econometric models for each group (Holguín-Veras, Jaller et al. 2011, González-Feliu, Cedillo-Campo et al. 2014, Ducret and Gonzalez-Feliu 2015, Sánchez-Díaz, Holguín-Veras et al. 2016). In general, the classification systems are borrowed from the ones used by National offices to produce economics statistics. These classification systems use a digit-based nomenclature—where a larger number of digits in the code denotes a more disaggregated category with a more specific activity—that provides the framework for collecting and presenting extensive statistical data according to the economic activity used in other fields of economic statistics (e.g., production, employment) (Eurostat 2016). Similarly, when used for modeling purposes these classifications have different levels of detail and entail different modeling implications. Models estimated with more aggregated categories have less detail, high risk of heterogeneity within the modeling group, but require less data; while models estimated with more disaggregated categories have a higher level of detail but require a substantial amount of data (Holguín-Veras, Jaller et al. 2011).

The criteria used to group establishments under a certain aggregation level are often based on the premise that businesses with similar commercial activity have similar FTG patterns, and on practical reasons, such as, the convenience to use secondary data sources available at higher aggregation levels. Recent works address the impacts of aggregation level on model's quality, either for linear (Gonzalez-Feliu et al., 2016) and nonlinear (Sanchez-Diaz et al., 2016a) models. Those works state on the importance to further analyzing heterogeneity and a first exploratory analysis is provided in Sanchez-Diaz et al. (2016).

This chapter proposes an econometric approach to assess the implications of using different aggregation levels within each industry for FTG modeling. Since linear models are the most common and easy to understand, as well as to decompose in sub-models, we focus here only on linear models. The results from this study will be instrumental to design more efficient data collection frameworks, because the results will allow to identify industry sub-sectors that require higher level of detail and thus more data,

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and other industry groups with higher homogeneity that require less data. Another contribution from this research will be to enhance the quality of the models' estimation by identifying sub-sectors that have a FTG pattern that differ from the rest of the sector and thus require a separate model.

This paper extends the results of (Gonzalez-Feliu, Sánchez-Díaz et al. 2016a) by proposing a methodology to carry out a heterogeneity analysis with the aim of exploring needs and opportunities of different aggregation levels in FTG modeling. More specifically, the paper aims to assess if and when aggregated categories have a prediction accuracy that represents well the FTG phenomena without the need of disaggregating data and in which cases a higher disaggregation is necessary. First, the authors propose the methodological framework to carry out the analysis, the data used and the main hypothesis of the research work. Then, the main results of the analysis are presented and discussed. Finally, as a conclusion, practical implications as well as future developments are proposed.

METHODOLOGY

This section introduces the methodology proposed to investigate the implications of aggregating data by commercial activity for FTG. This section includes a summary of the data used in this paper, the hypotheses underlying the analysis and a formal description of the methodology used for the formal assessment.

Data Description

The first step in the analysis is to define and present the data, as well as the classification system. The authors chose to deploy this analysis framework on the French Urban Goods Surveys of 1995-1998, for a detailed description of the survey, the reader is referred to Ambrosini et al. (2013). This survey consists of three main parts: the first one describes the establishments' attributes, the second one studies pickup and delivery operations and the third one presents the truck driver's patterns, vehicle rounds and paths. For FTG, the authors use the first two parts of the survey. The data were collected from three cities with different characteristics (Bordeaux, Dijon and Marseille) and includes 2,970 establishments and 11,588 freight delivery operations (including both FTA and FTP).

Although this dataset is outdated, it provides a unique opportunity to assess the modeling implications of different aggregations of classification systems, because of the number of observations within each sector: 2,970 establishments with at least one operation of any type (i.e., FTA or FTP), 2,613 establishments with at least one FTA, and 1,500 establishments with at least one FTP. Although the survey presents detailed information on both FTA and FTP, this study focuses on FTG, by adding up both FTA and FTP, for the following two reasons: (i) estimating FTG without a distinction by nature of the operation can be useful for planning purposes (identification of truck types and mileages for congestion estimation, definition and dimensioning of parking and delivery bay facilities, etc.) and (ii) making no distinction between the type of operations provides a larger dataset, i.e., about 300 establishments more than only FTA and more than 1400 only FTP, which enhances the statistical significance of the results. It is also noteworthy that this study focuses only on the influence of the aggregation level of the industry groups (i.e., the typology of establishments) on FTG, and not on other variables such as type of distribution, vehicle class, or differences across cities.

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Aggregation Levels and Hypotheses

Although the quality of FTG models is, in the literature, often related to the explanatory variables and functional forms, the data aggregation through classification systems is an understudied factor that plays a key role in determining the functional form and quality of the models. Since considering many variables can affect the identification of direct impacts of data aggregation on the model's accuracy and robustness, this paper uses employment as the only explanatory variable and focuses only on the data aggregation by commercial activity of establishments. For the proposed analyses, the authors adapted the classification proposed in the French urban goods surveys analyses [13]. This classification is based on the type of activity of the firm, eventually coupled with the main function of the establishment (depending on the level of detail 8, 28 or 44 activities are distinguished).

The authors explain below the rationality underlying the classification systems as well as the technique to obtain the different aggregation levels. The first aggregation level (the most aggregated classification) distinguishes 8 categories of establishments (ST8), which has been set in correspondence with the most aggregated classification of French NAF codes (the French declination of European NACE classification). Then, each ST8 group is divided into one or more sub-sectors with more detail on the type of activity taking place in the establishment, resulting in the 28 different categories (ST28). This classification corresponds to a second level of disaggregation in the sampling phase of the surveys. The third aggregation level, ST44, consists on repeating the ST28 codes and adding a sub-index designing a sub-sector within the ST28 classes. In all three classifications, the only discrimination criterion is the economic activity of the establishment. Table 1 presents these different levels of aggregation.

Table 1. Synthesis of the three first level of aggregation (ST8-ST28-ST44)

ST8 Code	Description	ST28 Code	Description	ST43 Code	Description
1	Agriculture	1	Agriculture	1	Agriculture
2	Craftsmen/ services	2	Craftsmen	2-2	Repair activities
				2-3	Manufacturing or installation
				2-4	Light repair
		26	Services	26Ha	Tertiary services: high flows
				26Mi	Tertiary services: mixed flows
				26Mo	Tertiary services: average flows
3	Manufacturing/ Repair	3	Chemical	3	Chemical industry
		34	Construction	34-2	Repair industry
				34-3	Construction – Manufacturing or installation
		4	Production and intermediate	4-2	Production and intermediate – unprocessed basic bulk
				4-6	Production and intermediate – small objects
				4-7	Production and intermediate – bulk
		5	Consumption goods	5-2	Fragile foodstuffs
				5-4	Non-fragile foodstuffs
				5-5	Non-fragile consumer goods, non-food

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Table 1. Continued

ST8 Code	Description	ST28 Code	Description	ST43 Code	Description
4	Wholesalers	7	Intermediary products	7-2	Fragile intermediate products
				7-3	Oher intermediate products
		8	Non food	8-2	Non-food fragile consumer goods
				8-3	Non-food non fragile consumer goods
		9	Food products	9-2	Fragile food consumer goods
				9-3	Other food consumer goods
5	Department stores	10	Department stores	10	Hypermarkets and big department stores
				11	Supermarkets
				12	Specialized department stores
6	Retailers	13	Minimarkets	13	Minimarkets
		14	Clothes, shoes	14	Clothes, shoes, leather shops
		15	Butcher's shops	15	Butcher's shops
		16	Small groceries	16	Grocer's shops
		17	Bakery retailers	17	Bakeries – Cake shops
		18	Ho.,Re.,Ca.	18	Hotels, Restaurants, Cafés
		19	Pharmacies	19	Pharmacies
		20	Hardware stores	20	Hardware stores
		21	Furniture shops	21	Furniture shops
		22	Bookshops	22	Bookshops
		23	Other	23	Other retail shops
		29	Street trading	29	Street trading (outdoor trading centers, marketplaces)
7	Tertiary/ offices	6	Pure transport	6	Transport (except storage)
		25	Pure tertiary	25	Pure tertiary sector (offices)
		24	Other tertiary	24Fa	Other tertiary activities with low flows
		27	Offices – not pure tertiary	27-2	Not tertiary offices (agriculture, wholesales)
				27-3	Not tertiary offices (retail, industry, transport, admin.)
8	Warehouses/ transport	28	Warehouses	28-2	Warehouses (bulk)
				28-3	Warehouses (of which transport)

The Methodology Proposed

The methodology proposed aims to assess the heterogeneity within aggregated categories, i.e., assess the degree at which an aggregated category is able to capture the FTG patterns of its sub-categories. The methodology is articulated on the following 4 steps:

1. Data processing and model construction preparation. This includes the choice of the data (the combination of the three surveys' data samples) and justification (table with data variability among cities).

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2. Assessment of a model for each category of the three aggregation levels (ST8, ST28, and ST44), obtained by linear regression on each category. The methodology used assesses the specification of the FTG models using an econometric approach. Following the methodology described in Sanchez-Diaz et al. (2017), the models can take three different forms: (i) a constant number of trips per establishment (does not depend on employment), (ii) a model where the number of trips is directly proportional to the number of employees working in the establishment, and (iii) a combined model where there is a constant number of trips per establishment and a term that shows the increase of the number of trips depending on the number of employees. The criteria used to select the model are the conceptual validity, the statistical significance of the constant and the employment variable, and the Root-Mean-Square-Error (RMSE). In this paper, these models will be referred to as *FTG sector or sub-sector models*. A summary of the models is shown in Table 2 (for an extensive analysis of the models and other details, see Gonzalez-Feliu et al., 2016; Sanchez-Diaz et al., 2016).

Table 2a. Summary of FTG model by sector and sub-sector

ST8	ST25	ST44	Description	Obs.	Model		RMSE	R2
					const.	empl.		
1	1	1	Agriculture	41	2.80	0.21	3.95	0.17
2	All	All	Craftsmen and services	375	5.47	-	12.99	n.a.
	2	All	Craftsmen	188	3.19	1.01	9.66	0.11
		2-2	Repair activities	52	9.30	-	12.33	n.a.
		2-3	Manufacturing/ installation	135	-	1.27	8.18	0.38
	26	All	Tertiary services	187	4.71		15.24	n.a.
		26Mi	Tertiary services: high flows	140	3.64	-	9.08	n.a.
		26Mo	Tertiary services: mixed flows	15	1.06	0.38	1.74	0.67
		26Ha	Tertiary services: average flows	32	9.95	-	31.43	n.a.
3	All	All	Industry	623	8.61	0.22	20.95	0.41
	3	3	Chemical industry	46	23.88	0.15	30.32	0.41
	34	All	Construction industry	125	6.57	0.21	20.50	0.15
		34-2	Construction repairs	28	-	1.11	34.52	0.44
		34-3	Construction manufacturing/ install	97	-	0.24	10.02	0.53
	4	All	Primary and intermediate products	256	6.52	0.25	15.09	0.66
		4-2	Basic bulk	144	9.35	-	9.28	n.a.
		4-6	Small objects	92	8.11	0.31	12.93	0.28
		4-7	Bulk	112	3.92	0.25	18.32	0.74
	5	All	Food, non-fragile consumer goods	196	8.68	0.23	23.68	0.25
		5-2	Consumer goods (fragile foodstuffs)	8	24.69	-	38.53	n.a.
		5-4	Non-consumer goods (fragile	105	-	1.72	19.06	0.62
		5-5	Non-fragile consumer goods (house)	82	5.96	0.21	15.95	0.57
4	All	All	Wholesale	414	18.74	0.68	88.28	0.04
	7	All	Intermediary products	200	-	1.90	119.26	0.06
		7-2	Fragile intermediate products	80	-	2.25	185.24	0.06
		7-3	Other intermediate products	120	6.88	0.92	29.99	0.07
	8	All	Non food consumer goods	118	10.80	0.70	30.82	0.07
		8-2	Non-food fragile consumer goods	92	13.11	0.66	34.41	0.06
		8-3	Non-food non fragile consumer goods	33	-	1.01	9.57	0.46
	9	All	Food	96	21.82	0.62	55.08	0.27
		9-2	Fragile food consumer goods	32	33.25	0.95	83.23	0.18
		9-3	Other food consumer goods	64	14.19	0.61	31.69	0.60
5	10	All	Department stores	47	-	0.54	44.47	0.81
		10	Hypermarkets and department stores	13	-	0.54	75.82	0.77
		11	Supermarkets	20	11.49	0.60	15.57	0.32
		12	Specialized department stores	14	-	3.92	14.18	0.58

Source: Sanchez-Diaz et al. (2016)

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Table 2b. Summary of FTG model by sector and sub-sector

ST8	ST25	ST44	Description	Obs.	Model		RMSE	R2
					const.	empl.		
6	All	All	Retailers	1080	6.93	0.24	10.33	0.11
	14	14	Clothing, shoes, leather	109	2.01	0.17	2.19	0.24
	15	15	Butcher's shops	70	3.55	1.18	5.85	0.40
	16	16	Small groceries	97	4.34	1.02	8.03	0.40
	17	17	Bakery retailers	112	6.48	0.18	7.29	0.03
	18	18	Hotels, restaurants, cafés	145	2.63	0.61	7.14	0.53
	19	19	Pharmacies	61	15.94	1.94	14.71	0.24
	20	20	Hardware stores	43	-	1.45	3.85	0.55
	21	21	Furnishing shops	49	6.11	0.10	8.51	0.15
	22	22	Bookshops	90	10.25	-	7.03	n.a.
	23	All	Other retail shops	274	6.81	0.21	10.76	0.16
		13	Minimarkets	13	-	3.92	14.18	0.58
		23	Other retail shops	261	6.38	0.21	10.42	0.18
	29	29	Street trading (marketplaces)	30	5.77	-	7.52	n.a.
7	All	All	Tertiary/ offices	322	4.26	0.02	13.93	0.03
	6	6	Transport except storage	34	10.76	-	35.55	n.a.
	24	26Fa	Other tertiary activities with low flows	32	4.13	-	11.01	n.a.
	25	All	Offices	256	3.57	0.02	7.80	0.13
		25	Pure tertiary sector (offices)	178	2.77	0.02	5.92	0.10
		27-2	Non-tertiary offices (agriculture,	48	5.89	-	6.19	n.a.
		27-3	Non-tertiary offices: retail, industry…	30	7.82	-	17.19	n.a.
8	28	All	Warehouses/ transport	68	114.92	-	269.60	n.a.
		28-2	Warehouses (bulk)	21	170.91	2.94	431.03	0.05
		28-3	Warehouses (with transport)	68	60.86	-	122.87	n.a.

Source: Sanchez-Diaz et al. (2016)

Estimation of a model for each ST8 category that assesses statistically whether each sub-sector within the ST8 category has a different FTG pattern, i.e., if the ST8 category groups establishment with homogeneous FTG patterns. To this effect, the authors create a binary variables for each sub-sector (identified in ST24 and ST48); and estimate a least squares model for each sector in the classification ST8 where the parameters are obtained using robust variance estimates, or sandwich estimators, that are robust to specification errors and outliers (Freedman 2006). In this model, FTG is the dependent variable, while number of employees, the binary variables and the interaction terms between binary variables and number of employees are the independent variables. To identify which sectors have heterogeneous FTG patterns (i.e., one or more sub-sectors have different FTG patterns) only the variables that are conceptually valid and significant at the 5% level are conserved in the model. The resulting models are described using a set of equation where the t-stat is presented under each parameter and the RMSE is computed. In this paper, these models will be referred to as the *FTG heterogeneity models*.

Finally, to compare all those models, the models estimated in Steps 2 and 3 are applied to the entire calibration dataset. Then the data are grouped by the most aggregated category (ST8) and the RMSE is computed at this aggregation level for each model. The RMSE provides a good indication of the match between the model's prediction and the observed data. Therefore, the lower the RMSE the better the absolute fit of the model (Greene 2014). The results of each RMSE assessment are compared and the suitability of each model is discussed.

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ASSESSMENT OF THE HOMOGENEITY WITHIN CATEGORIES

FTG Heterogeneity Models

This section presents the results from the homogeneity assessment within categories using an econometric approach, as explained in Step 3 of the methodology. For the categories corresponding to agriculture (ST8-1), department stores (ST8-5) and warehouses including transport (ST8-8), no binary variable or interaction is found significant, meaning that the FTG patterns of establishments within these categories are homogeneous or that there are no sub-categories to assess. In the case of craftsmen/services, the final heterogeneity model is as follows:

$$FTG_{C} = \underset{(4.75)}{4.64} - \underset{(-2.47)}{3.24}ST44_{2-3} + \underset{(3.24)}{1.12}E - \underset{(-2.92)}{1.03}E_ST44_{26Mo} - \underset{(-3.24)}{1.12}E_ST44_{26Mi} \quad (1)$$

Observations: 375; RMSE: 12.69; R2 adjusted: 0.06

Where, ST442-3 corresponds to the binary variable for establishments in the manufacturing or installation sub-sector; E represents the number of employees at the establishment; E_ST4426Mo represents the number of employees for establishments in the tertiary sub-sector with average flows; E_ST4426Mi represents the tertiary sub-sector with mixed flows.

As shown, a typical establishment in the craftsmen/services sector has in general 4.64 deliveries per week, plus 1.12 more deliveries per employee. However, this pattern is not homogeneous within the sector, as a typical establishment within the manufacturing or installation sub-sector has 1.4 weekly deliveries (i.e., 3.24 less than other establishments in the sector) plus the same 1.12 per employee. In the case of establishments in the tertiary sub-sectors, the difference is that a typical establishment in that sector tends to produce 4.64 weekly trips, independent from the number of employees. It should also be noticed that there is a small decrease in the RMSE from 12.97 to 12.69, when heterogeneity within the sector is taken into account. Equation (2) shows the heterogeneity model for manufacturing and repair (ST8-3).

$$\begin{aligned} FTG_{I} = {} & \underset{(6.71)}{23.04} - \underset{(-5.20)}{21.10}ST44_{34-3} - \underset{(-5.20)}{21.06}ST28_{5} - \underset{(-4.02)}{14.60}ST28_{4} - \underset{(-3.12)}{4.59}ST44_{4-7} + \underset{(3.00)}{1.65}E \\ & - \underset{(-2.71)}{1.49}E_ST28_{3} - \underset{(-2.62)}{1.43}E_ST44_{5-5} - \underset{(-2.50)}{1.40}E_ST28_{34} - \underset{(-2.71)}{1.40}E_ST28_{4} \end{aligned} \quad (2)$$

Observations: 623; RMSE: 18.57; R2 adjusted: 0.54

Where, ST4434-3 corresponds to the binary variable for establishments in the construction and manufacturing installation sub-sector; ST285 corresponds to the binary variable for industry establishments in the consumption goods sub-sector; ST284 corresponds to the binary variable for industry establishments in the primary and intermediate products sub-sector; ST444-7 corresponds to the binary variable for industry establishments in the primary and intermediate bulk goods sub-sector; E_ST283 represents the number of employees for establishments in the chemical sub-sector; E_ST445-5 represents the number

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of employees for establishments in the non-fragile consumer goods sub-sector; E_ST2834 represents the number of employees for establishments in the construction industry sub-sector; and E_ST284 represents the bulk products sub-sector. In terms of the RMSE, there is a decrease from 20.95 to 18.57 when using the heterogeneity model as compared to the sector model.

For the wholesale sector, the final heterogeneity model is shown in equation 3:

$$FTG_{W} = \underset{(4.41)}{19.82} - \underset{(-3.23)}{15.65} ST44_{8-3} + \underset{(6.52)}{0.68} E \tag{3}$$

Observations: 414; RMSE: 88.30; R2 adjusted: 0.05

Where, ST448-3 corresponds to the binary variable for wholesale establishments in the non-food non-fragile sub-sector. In this case the model shows that only the non-food non-fragile goods sub-sector has a different pattern, which attracts about 4 trips less per week than other establishments in the sector, has a significantly different FTG pattern. Other establishments within this sector have homogeneous FTG patterns.

For the retail sector, the final model is shown in equation 4:

$$\begin{aligned} FTG_{R} = {} & \underset{(6.51)}{2.72} + \underset{(2.67)}{3.38} ST28_{21} + \underset{(-4.82)}{3.76} ST28_{17} + \underset{(5.30)}{3.93} ST28_{23} + \underset{(8.06)}{7.45} ST28_{22} + \underset{(8.75)}{17.08} ST28_{19} \\ & + \underset{(6.03)}{1.29} E - \underset{(-2.95)}{0.68} E_ST28_{18} - \underset{(-4.94)}{1.08} E_ST44_{23} - \underset{(-4.82)}{1.11} E_ST28_{17} - \underset{(-5.70)}{1.16} E_ST28_{14} \\ & - \underset{(-5.47)}{1.18} E_ST28_{21} - \underset{(-5.77)}{1.27} E_ST28_{22} \end{aligned} \tag{4}$$

Observations: 1080; RMSE: 8.47; R2 adjusted: 0.41

Where, ST2821 corresponds to the binary variable for retailers in the furniture sub-sector; ST2817 corresponds to the binary variable for retailers in the bakery sub-sector; ST2823 corresponds to the binary variable for the other retailers sub-sector; ST2822 corresponds to the binary variable for retailers in the books sub-sector; ST2819 corresponds to the binary variable for the pharmacies sub-sector; E_ST2818 represents the number of employees for retailers establishments in the hotel, restaurants, and cafés sub-sector; E_ST4423 represents the number of employees for the other retailers sub-sector; E_ST2817 represents the number of employees for retailers in the bakery sub-sector; E_ST2814 represents the number of employees for retailers in the clothing, shoes and leather products sub-sector; E_ST2821 represents the number of employees for retailers in the furniture sub-sector; and E_ST2822 represents the books sub-sector. In essence, there exists a high heterogeneity within this sector. In terms of the RMSE, there is a decrease from 10.33 to 8.47 when using the heterogeneity model compared to the sector model.

In the case of the tertiary and offices sector, equation (5) represents the FTG:

$$FTG_{T/O} = \underset{(3.76)}{6.11} - \underset{(-1.96)}{3.35} ST44_{25} + \underset{(2.46)}{0.02}\mathrm{E} \tag{5}$$

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Observations: 322; RMSE: 13.85; R2 adjusted: 0.05

Where, ST4425 corresponds to the binary variable for the pure tertiary sub-sector. In this case the model is homogeneous, except for the pure tertiary sub-sector that attracts about 3 trips less per week than other establishments in the sector.

In essence, these results show that for about half of the cases the model used for the higher aggregation level can also be used for more detailed sub-sectors as their FTG patterns do not differ significantly. However, the substantial different FTG pattern from some sub-sectors within the industrial and retail sectors (e.g., manufacturing of construction goods, manufacturing of consumption goods, pharmacy retail) suggests the need to collect more detailed data for those sub-sectors to obtain more appropriate models. A summary of the findings is illustrated in Table 3, where sub-sectors (at the ST28 and ST44 level) showing a significant different FTG pattern are highlighted.

To analyze the implications of implementing heterogeneity models on estimation performance, RMSE are computed and compared for the models estimated in Step 2 of the methodology and the heterogeneity models from Step 3. Table 4 summarizes the results.

The first salient result is the different magnitudes of RMSE across sectors. While agriculture, retailers, craftsmen/services and tertiary/offices models lead to RMSE of 4.50, 8.42, 12.59 and 13.79 respectively; wholesale and warehouses/transport models lead to RMSE of 87.98 and 269.60. These differences can be the result of both lower performance and higher magnitude (and thus larger deviations) of FTG for some sectors, so instead of comparing RMSE across sectors the analysis focuses on comparing RMSE across models for the same sector. In general, the more disaggregated the categories are, the better the model. However, the results show that for craftsmen/services, wholesale, department stores, and tertiary offices the higher disaggregation does not lead to a considerable improvement in the RMSE (always less than 3%) revealing a homogeneity of FTG patterns within each of these sectors, confirming the findings from the heterogeneity models.

In the cases of manufacturing/repair activities and retail the heterogeneity model produces considerably lower RMSE than the sector models for aggregation ST8. For manufacturing the heterogeneity model's RMSE is also lower than the one for the ST28 sub-sector models, but higher than ST44. For retail, the heterogeneity model's is similar to the ST28 sub-sector model. For these sectors, collecting more data at the ST28 level to produce models that consider heterogeneity can enhance the quality of the models. However, this is not the case for other sectors, such as wholesale, department stores and warehouses, where the FTG patterns seem to be homogenous across sub-sectors, and thus more detailed data on each sub-sector does not improve the quality of the models. These results are not surprising given the similarity in logistics practices within those sectors.

CONCLUSION

This paper studies the implications of using classification systems with different aggregation levels to model Freight Trip Generation (FTG). The methodology is econometric in nature and seeks to identify which sectors have heterogeneous FTG patterns as a way to enhance data sampling efficiency and the quality of FTG estimates. The results show that establishments classified as department stores, craftsmen/services, wholesale and tertiary/offices tend to have homogeneous FTG patterns, and estimating models using more disaggregated classifications (i.e., sub-sector specific models) do not lead to an improvement

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Table 3. Commercial activity sectors with heterogeneous FTG patterns

ST8 code	Description	ST28 code	Description	ST44 code	Description
1	Agriculture	1	Agriculture	1	Agriculture
2	Craftsmen/ services	2	Craftsmen	2-2	Repair activities
				2-3	Manufacturing or installation
				2-4	Light repair
		26	Services	26Ha	Tertiary services: high flows
				26Mi	Tertiary services: mixed flows
				26M	Tertiary services: average flows
3	Manufacturing/ Repair	3	Chemical	3	Chemical industry
		34	Construction industry	34-2	Repair industry
				34-3	Construction – Manufacturing or installation
		4	Production and intermediate	4-2	Production and intermediate – basic bulk
				4-6	Production and intermediate – small objects
				4-7	Production and intermediate – bulk
		5	Consumption goods	5-2	Fragile foodstuffs
				5-4	Non-fragile foodstuffs
				5-5	Non-fragile consumer goods, non-food
4	Wholesalers	7	Intermediary products	7-2	Fragile intermediate products
				7-3	Oher intermediate products
		8	Non food	8-2	Non-food fragile consumer goods
				8-3	Non-food non fragile consumer goods
		9	Food products	9-2	Fragile food consumer goods
				9-3	Other food consumer goods
5	Department stores	10	Department stores	10	Hypermarkets and big department stores
				11	Supermarkets
				12	Specialized department stores
6	Retailers	13	Minimarkets	13	Minimarkets
		14	Clothes, shoes, leather	14	Retail trades, clothes, shoes, leather
		15	Butchers shops	15	Butchers shops
		16	Small groceries	16	Groceries shops
		17	Bakery retailers	17	Bakeries – Cake shops
		18	Ho.,Re.,Ca.	18	Ho.,Re.,Ca.: Hotels, Restaurants, Cafés
		19	Pharmacies	19	Pharmacies
		20	Hardware stores	20	Hardware stores
		21	Furnishing	21	Furnishing shops
		22	Bookshops	22	Bookshops
		23	Other retail	23	Other retail shops
		29	Street trading	29	Street trading (outdoor trade and
7	Tertiary/ offices	6	Pure transport	6	Transport (no storage)
		25	Pure tertiary (offices)	25	Pure tertiary sector (offices)
		24	Other tertiary	24Fa	Other tertiary activities with low flows
		27	Offices – not pure tertiary	27-2	Not tertiary offices (agriculture, wholesales)
				27-3	Not tertiary offices (retail, industry, transport, administration)
8	Warehouses/ transport	28	Warehouses	28-2	Warehouses (bulk)
				28-3	Warehouses (include transport)

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Table 4. Root Mean Square Error (RMSE) comparison among models with different aggregations and the heterogeneity model

Category	Aggregation ST8	Aggregation ST28	Aggregation ST44	Heterogeneity
1-Agriculture	4.50	4.50	4.50	n.a.
2-Craftsmen/services	12.97	12.71	12.52	12.59
3-Manufacturing/repair activities	33.11	20.39	18.30	19.64
4-Wholesale	89.36	88.27	87.86	87.98
5-Department stores	44.47	44.47	41.87	n.a.
6-Retailers	14.73	8.43	8.38	8.42
7-Tertiary/ offices	13.89	13.76	13.79	13.79
8-Warehouses/ transport	269.60	177.17	177.17	n.a.

in the accuracy of the estimates. In contrast, establishments in the manufacturing/repair and the retail sectors have significant heterogeneity, so that estimating sub-sector (ST28 or ST44) models or a heterogeneity model that assesses each sub-sector's significance can enhance the quality of the estimates as illustrated by lower RMSE. The heterogeneity in those sectors has been highlighted in precedent works about the data surveyed, using a qualitative approach (Ambrosini et al., 2010).

According to the models, in the case of the manufacturing and repair sector a typical establishment generates a base of 23 trips per week plus 1.65 weekly trips per employee. However, if the establishments focus on manufacturing of construction and installation or on consumption goods, it only generates a base of 2 trips per week plus 1.65 weekly trips per employee for consumption goods, or 0.20 weekly trips per employee for construction goods. Similarly, a typical establishment focusing on primary and intermediate products generates a base of 9 trips per week plus 0.25 weekly trips per employee; however, if this establishment focuses on bulk goods it generates a base of only 4 trips per week plus the same 0.25 weekly trip per employee. In the case of manufacturing establishments focusing on chemical products and non-fragile consumer goods, a typical establishment generates a base of 23 weekly trips, plus about 0.2 trips per employee. These results reveal that designing samples with strictly enough observations to estimate a single model for all manufacturing establishments can lead to large estimation errors; instead it is necessary to sample enough observation in the sub-sectors identified in this paper as having particularly different FTG patterns. In terms of infrastructure planning implications, these results show that traffic forecasts do not depend exclusively on the size of the facility to be built, but also on the type of activity that will take place in the premises.

Similar results are observed for the retail sector, where a typical establishment generates a base of 2.72 trips per week plus 1.29 weekly trips per employee. However, if the establishment focuses on furniture, bakery, books, or pharmacy the base increase to 6.1, 6.48, 10.17, respectively; and the amount of weekly trips per employee decreases to 0.11, 0.18, and 0.02, respectively. In the case of hotels, restaurants and cafés a typical establishment generates a base of 2.72 trips per week plus only 0.21 weekly trips per employee. A typical retailer of clothing, shoes and leather products generates a base of 2.72 trips per week plus only 0.13 weekly trips per employee. These results show that FTG patterns are very different for establishments in different retail sub-sectors, which is not surprising giving the diversity of logistics decisions and needs across these sub-sectors. In terms of planning implications, it is necessary to plan parking infrastructure according to the type of commercial activity that takes place in the zone of analysis.

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In essence, this paper identifies sectors with homogeneous FTG patterns, sectors having sub-sectors with slightly different patterns and sectors with very heterogeneous patterns. Understanding the different sectors FTG patterns is fundamental for planning considerations. In addition to provide an idea of the different FTG patterns present in urban establishments, the results from this research provide useful insight for an efficient sampling design in which the strata and the number of observations per stratum are designed based on the sector's FTG homogeneity. The main limitations from this analysis is the use of an outdated dataset, and restricting to linear models of employment (which explains the high RMSE found). Further research could focus on improving these two aspects. Although the quantitative analysis does not allow to conclude that these findings are transferable to other cities and countries, and across time, the conceptual validity of the results lead to think that the same patterns will be found for different cities and will remain in the medium term. However, this needs to be confirmed in further research endeavors.

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KEY TERMS AND DEFINITIONS

French Urban Goods Transport Surveys: A set of generic surveys deployed in France between 1995 and 1999 to quantify the main trends in the generation and spatial distribution of urban goods transport flows. They combine an establishment survey, a transport carrier survey and a driver diary follow-up. They were deployed in three cities (Bordeaux, Dijon, Marseille).

Generation (Transport Modelling): The process of estimating the transport demand at origin (Production) and/or destination (Attraction). It is usually assumed that demand generation models include both production and attraction flows. That stage corresponds to the first of four-step models. In freight

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transport, generation can be made for number of trips (or deliveries, or shipments), in that case we call this process freight trip generation, or for commodity quantities, in that case we will qualify those models with the term "freight generation."

Heterogeneity (in Category Classification): When associated to a category classification, the quality or state of a category's individuals to be diverse in their characteristics. If we consider multi-level category classifications, disaggregated categorizations (i.e. considering the sub-category or sub-sub-category levels) will lead to mode homogeneous categories (since their number increases) whereas very aggregated categories will not account, when defining them by average values, the heterogeneity of their population.

RMSE: Root mean square error; a common measure of error used to assess the accuracy of models and estimators. It represents the square root of the second sample moment of the differences between predicted and observed values or the quadratic mean of these differences.

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Chapter 3
Localization Patterns of Urban Food Distribution Centers in Metropolitan Lima

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ABSTRACT

This chapter is aimed at exploring the patterns that guide the decision of food urban distribution centers in the city of Lima, which is characterized by spontaneous and unplanned growth, and where the inhabitants of the city mainly source of trade traditional with 1,200 food markets and 100,000 neighborhood stores. The rapid food system consultation tool created by FAO was used, which triangulated secondary sources and applied surveys in households, retail traders, and wholesalers. A statistical and spatial description was made of location factors: commercial density, supply habits of the retail and UDC, accessibility, connectivity, land use and access barriers to the land. It was concluded with the identification of four patterns of settlement of UDC: demand, supply, mobility, and land availability.

INTRODUCTION

In the coming years, cities will contain around 70% of the world's population, which will demand multiple services and products. This demand will generate greater traffic congestion, food shortages, and environmental pollution, among other problems for cities.

Urban Distribution Centers (UDCs) are proposed as a solution to logistical problems faced by developed cities. Thus, research has been conducted to seek alternatives that optimize localization to reduce transportation costs, generate less congestion and pollution, and reduce food losses (Janjevic et al., 2016).

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This chapter aims to identify and to evaluate the localization factors of public and private UDCs created in cities from emerging countries with poor planning, using the Lima metropolitan area in Peru as an example. The complex social context and the levels of informality allow public and private decision-makers to localize these food UDCs in the city, without clearly established criteria.

Here, we propose exploring food UDC localization patterns in polycentric cities, such as the Lima metropolitan area. First, the background and existing literature on the field are reviewed and presented. Second, the methodological issues addressed in this chapter are proposed. Third, the results of the analysis of the localization patterns are proposed. Finally, a conclusion on the contributions of that analysis and further works is made.

BACKGROUND AND CONTEXT

Urban Distribution Centers and Food Logistics

The urban distribution of goods is an important activity to maintain commercial and productive activity and to supply the population (BESTUFS, 2007). Efficient transportation and distribution systems are important to improve a city's competitiveness, due to the revenue it generates, such as job creation (Sanz et al., 2013). One of the most popular research and application issues is that of the development and analysis of urban logistics platforms (Boudouin, 2006; Gonzalez-Feliu et al., 2014; Taniguchi, 2015; Waller, 2016).

From the various types of urban logistics platforms (Boudouin et al., 2014), urban distribution centers (UDC) remain the most studied category. Also called urban consolidation centers (UCCs) and city distribution centers (CDC), the various works refer to slightly different notions having all in common the following elements: UDC are platforms that allow the consolidation and distribution of goods directed to urban zones (of different extension), in an aim of sustainability improvement of urban goods transport. UDCs bring diverse types of products together and have become a solution to reducing the logistical impact of food in cities (Russo et al., 2013). There are monocentric and polycentric cities (Anas et al., 1998) that determine the location, the number of centers, and the combination of products. Moreover, UDC can be mono-user and multi-user (Ville et al., 2013), have a city or zonal influence area (Gonzalez-Feliu et al., 2014), deal with general or specific transport (BESTUFS, 2007) or present different degrees of collaboration (Janjevic et al., 2016), among others.Moreover, and with the increase of interest for food logistics in urban areas, the notion of food hub (considered as a collaborative structure among producers and logistics stakeholders related to food value chain) are starting to be developed (Palacios-Argüello et al., 2017). Morganti and Gonzalez-Feliu (2015) show the interactions between Food Hubs and urban logistics platforms, identifying the UDC as one of the most suitable common points. Therefore, the deployment of food-based UDC became a popular subject (Morganti and Gonzalez-Feliu, 2015), mainly in Latin America (Palacios-Argüello and Gonzalez-Feliu, 2016; Palacios Argüello et al., 2017). Most food-based UDC are nowadays related to wholesale produce market and marketplace distribution. However, they deal with either small cities (Morganti, 2011) or to zones of big cities (Alcaldía Mayor de Bogotá, 2006).

Localizing the facilities—the UDCs—is the process of choosing a geographical location among several to conduct operations. The fields of location theory and modeling have their roots in the works

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developed by Weber, Hotelling, Christaller, and Losch, which remains an active field of knowledge (Sanabria et al., 2016). In a Metropolis like Lima, where food distribution needs to be addressed in a systemic way, it is important then to analyze the localization patterns of potential UDCs and link them to the food distribution chains. But to do this, it is necessary to first know the city context. Therefore we present below the main background and context issues for the city of Lima and the urban food systems related to urban supply.

Urban Structure of the Lima Metropolitan Area

Lima is a megacity and one of the 20 largest cities in the world, which is home to 30% of the country's population. It contributes slightly more than 50% of the Peru's GDP and almost 80% of the country's tax revenue. Lima is the capital and headquarters of all of Peru's administrative functioning and concentrates the country's economic and political power. This has materialized in the divergent growth between Lima and the rest of the country, with a commercial and technological disjointing from the rest of the regions, as well as from the regional cities with their rural environment (Lazarte, 2015).

Since it was founded, its spatial organization was based on a single center. For centuries, it fulfilled multiple functions, from the seat of government to the administrative, financial, and cultural center, among other roles. Since the demographic explosion of 1940, a radial metropolitan structure brought together by the Historical Center of Lima has been formed, surrounded by two rings or "urban crowns." The first arises from the first expansion and responds to a regular urbanization process, and the second responds to a process of informal occupation of land, the product of internal migrants who come to occupy deserted sandy areas lacking basic services and public amenities. As these peripheral areas became established, they acquired urban functions.

According to Cacho and Conto (2018), new economic centers have been developed in recent years in the Lima metropolitan area. However, the most representative are located in the central area, as mentioned by Gonzales (2011), as commercial spaces called "Mercado Central" and "Mesa Redonda." Both are from the metropolitan hierarchy, as described by Fernandez and Vilela, so these commercial spaces act as an attraction for shopping trips, a result of these commercial activities. On the other hand, its concentric radial structure is a problem, since many roads go to the center and, as they approach the Historical Center, narrow significantly, causing traffic congestion.

For Ríofrío (1991), the growth of the Lima metropolitan area gives the sensation of an oil stain from the center of the city and has a "tentacle-like" structure. The old urban area has spread with urban branches that traverse progressively up to the inner valleys of the Andean foothills. On the other hand, Ortiz de Zevallos (1992) states that Lima, seen from the air, offers the appearance of an "explosion" with a center and branches saturated with activity, which gives rise to an extensive and centralist urban structure that has determined the patterns of displacement of all citizens, especially those who reside in the "poor city" (Avellaneda, 2008).

In recent years, one of the most relevant changes to the urban structure of Lima and Callao has been the transformation of a monocentric city into a polycentric one. According to Gonzales de Olarte and del Pozo Segura (2012), the city's polycentrism is a process that has accelerated in the last 20 years as a product of unplanned growth. These new centers arose because of several converging factors: an accelerated process of capital accumulation in the area, institutional changes promoted by structural adjustment, access to financial resources, and demographic changes such as migration, the aging of the

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population, and educational improvements. Likewise, the emergence of new economies of agglomeration in different parts of the city has benefited workers and entrepreneurs through the positive externalities generated by a polycentric city (Gonzales de Olarte and Del Pozo, 2012).

The distribution of urban functions in the city, together with the population density, translates into the distribution of economic activities related to industry and commerce, of education and health facilities (Avellaneda, 2008), and of UDC localization, as we will demonstrate in this study.

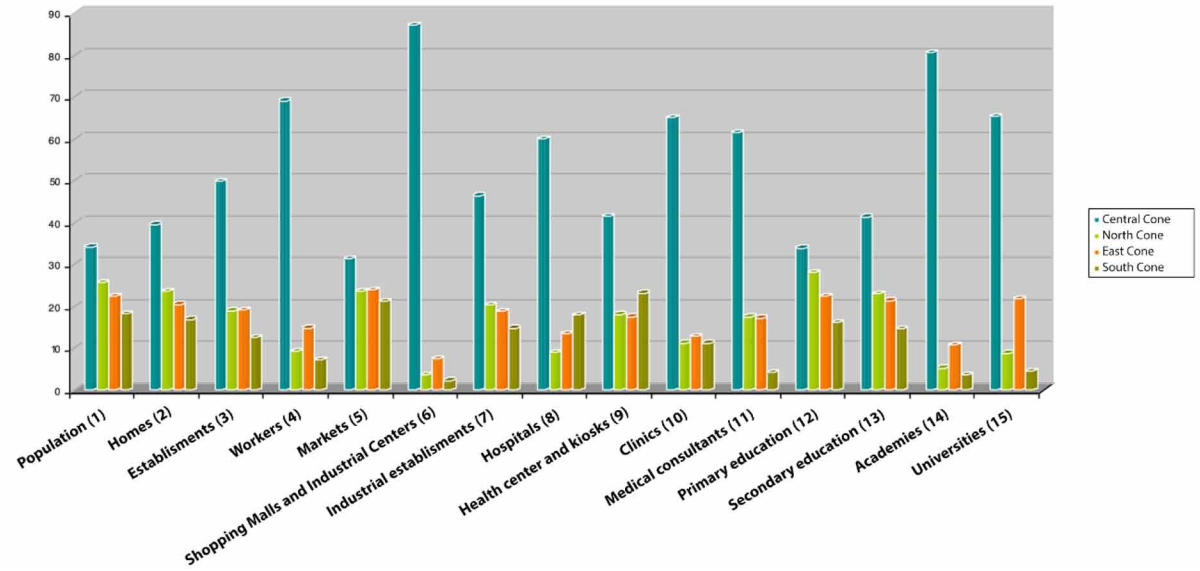
In the 80s model, Lima was structured in four concentric zones, crossed by radial axes in the center-periphery direction, and by linear sectors that expanded radially like wedges from the center to the periphery. All these areas are "spattered" without distinction of central components, which as sub-centers or residential neighborhoods (small, medium and large), belonging to the low, medium, and high sectors, have been placed following the guidance of the city's socio-spatial segregation logic (Ludeña, 2016).

However, referencing the diverse nature that includes all types of economic, industrial, and productive activities, it is possible to sectorize the Lima metropolitan area into North Lima, South Lima, East Lima, Central Lima, and Modern Lima, sectioning that has been used for this study.

The denomination of "cones," used previously, was replaced by "Lima" to refer to the territories that project toward the North, South, and East of the city from the group formed by the Historical Center, the old urban center and the first working-class neighborhoods (Rímac, La Victoria). Presently, Lima is much more complex and diverse, so the idea of "cone" as a projection from "a center" has lost relevance as an image to represent a city that has many centralities (Cabrera, 2011).

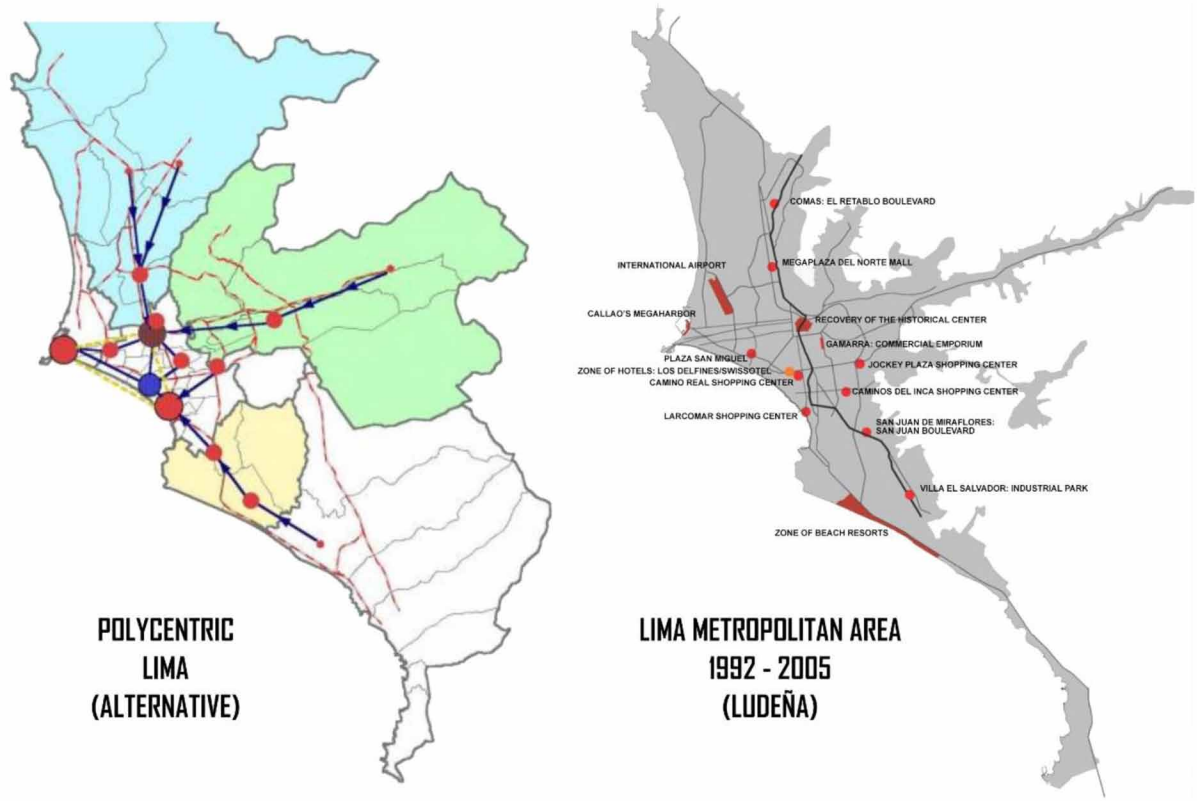
Moving from "cones" to "Limas" has been a process of recognizing the economic and social diversity that was lost with the generic denomination of "cone," which, in everyday speech, was equivalent to "poor districts," "of young communities." Moreover, the denomination "Lima" (South, North, East)

Figure 1. Lima metropolitan area. Distribution of urban functions (by Cone).
Source: http://repositorio.pucp.edu.pe/index/bitstream/handle/123456789/28695/Cuadernos_10.pdf?sequence=1



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Figure 2. Maps of Lima according to the development of sectioning
Source: https://limalalima.wordpress.com/2011/08/04/las-limas-y-los-conos/



makes the territories part of the identity of the city and clears up that sensation of beyond the wall that the denomination "cone" implies: what is outside of/far from/apart from (true) Lima[1].

Commercial Structure of Food

In the Lima metropolitan area, the main food retailers for households are traditional shops, consisting of wholesale markets and grocery stores (small neighborhood stores). These two types total around 238,510 points of sale, 118,198 points of sale in wholesale markets, and 113,312 grocery stores, distributed in five areas of Lima, with a greater presence in the periphery of the city (see Figures 7 and 8).

This commercial dispersion and density has generated the emergence of food UDCs, both informal and formal, to meet a demand that is not being adequately covered and has grown despite the increase in high operating and transportation costs.

The Lima metropolitan area has around 9,148,966 inhabitants (INEI: census projection for 2017). The development of economic dynamics, mainly those with food, and the merchandise's mobility deficiencies leads us to the emergence of food UDCs in a disorganized, informal manner.

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METHODOLOGY

This research study begins with a scope of the city of Lima, with the purpose of understanding the logistics system of fresh foods such as tubers, vegetables, and fruits, which are key in-demand food items in the city (Janjevic et al., 2016).

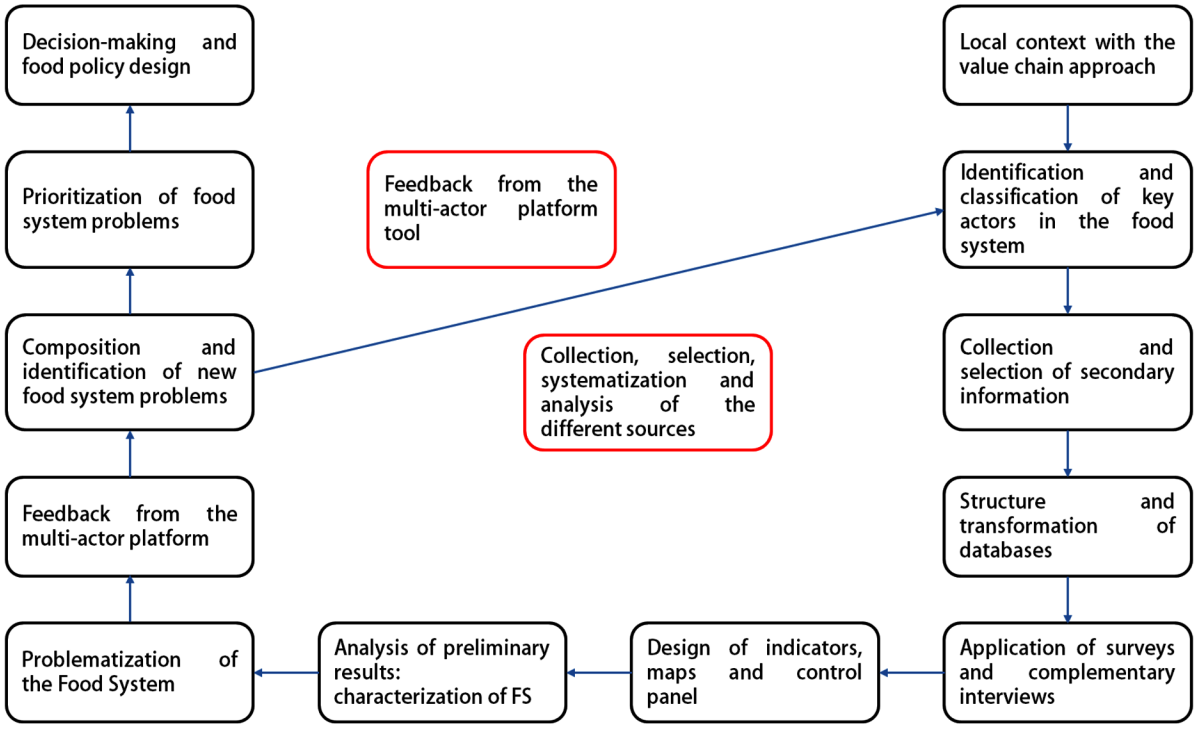
Data Collection

The RUFSAT integrated various secondary sources, institutionally recognized by the members of the multi-actor platform (composed of public institutions, academia, cooperation, and consumer representatives). In the selection process, some sources were discarded due to facts at issue or a bias perceived by the actors, since they could create doubt in RUFSAT users.

Through Internet searches, personal interviews with officials, and meetings with the multi-actor platform, various sources of secondary information were consolidated and subsequently processed and analyzed in an interactive data management tool (QlikView, specialized software).

The secondary sources were previously processed in two stages, approximately three months each. In the first phase, actors were classified into three types: information generators, compilers, and users. Some of the actors identified as information generators included the Great Wholesale Market of Lima, the National Institute of Statistics, the Ministry of Agriculture, and some NGOs. The information com-

Figure 3. Data collection process
Source: Created by the authors.



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pilers were the Ministries of Agriculture and Health. The users were the ministries themselves—the Metropolitan Planning Institute, universities, and some NGOs—but without a food system approach.

The sources of information obtained took different forms and were, in most cases, free to access and available on official websites. However, formal information requirements were made simultaneously to the various generating and compiling institutions.

Following the metadata of the available information sources, we were able to reprocess the information by integrating it into an interactive system structured according to the value chain. This integration of secondary and primary information allowed for the following benefits:

- Integrating various sources of public information on the food system.
- Providing access to information to the key food system agents for decision-making.
- Facilitating information so that universities and other institutions can further their research.
- Structuring the information with a descriptive model of the food value chain, providing a broad view of the problem.
- Contributing to disseminating the importance of sustainable food systems in the city.
- Recognizing the importance of having more detailed information about the problems, the accuracy of the data obtained, and the identification of problems not easily visible by public policy decision-makers.
- Inviting stakeholders to evaluate the possibility of incorporating representative and validated methods in their information surveys.

Analysis Descriptive

A descriptive analysis was done by triangulating secondary sources obtained from the Rapid Urban Food System Appraisal Tool (RUFSAT) for the city of Lima, prepared by the FAO's NADHALI project[2].

The search criteria were based on the food value chain approach and guided the collection and selection of data, seeking to obtain the greatest amount of information in each of the value chain links, which helped to guide the technical team's efforts.

Additionally, primary information collection was proposed to complement the secondary information obtained, for which surveys and interviews were conducted in homes, retailers, and wholesalers in the city of Lima.

At the conclusion of the exploratory stage of collecting, systematizing, and analyzing secondary and primary sources, a characterization of Lima's food value chain was developed from the research in each of the stages (city suppliers, urban wholesale distribution centers, retailers, and households). This characterization made it possible to consider some problems in the food chain.

Then, the first approach to the problems related to Lima's food value chain that were identified was completed, to then have feedback from the multi-actor platform and international specialists from FAO to make some adjustments or identify some problems with the city's food system.

With the aim of making adjustments and identifying new problems in the food system, we returned to the first steps of searching for, selecting, systematizing, and analyzing secondary information to finally prioritize the most relevant problems from the perspective of the multi-actor platform.

All the surveys were conducted in person, but with different sampling techniques. The household survey applied probabilistic sampling to obtain information that could be extrapolated to households in Lima, while non-probabilistic sampling was applied for the survey of retailers and wholesalers.

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Figure 4. Triangulation of secondary sources
Source: RUFSAT, FAO, 2017.

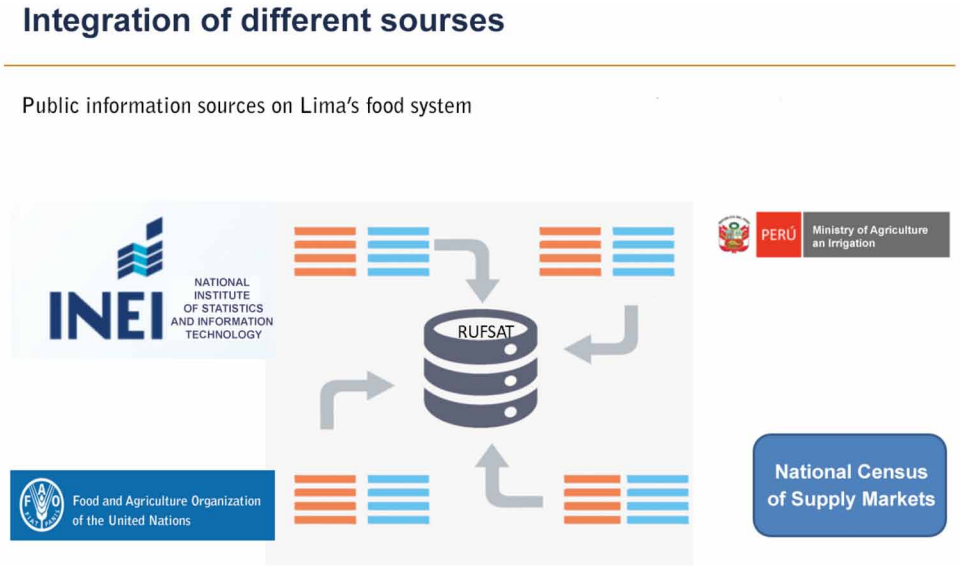
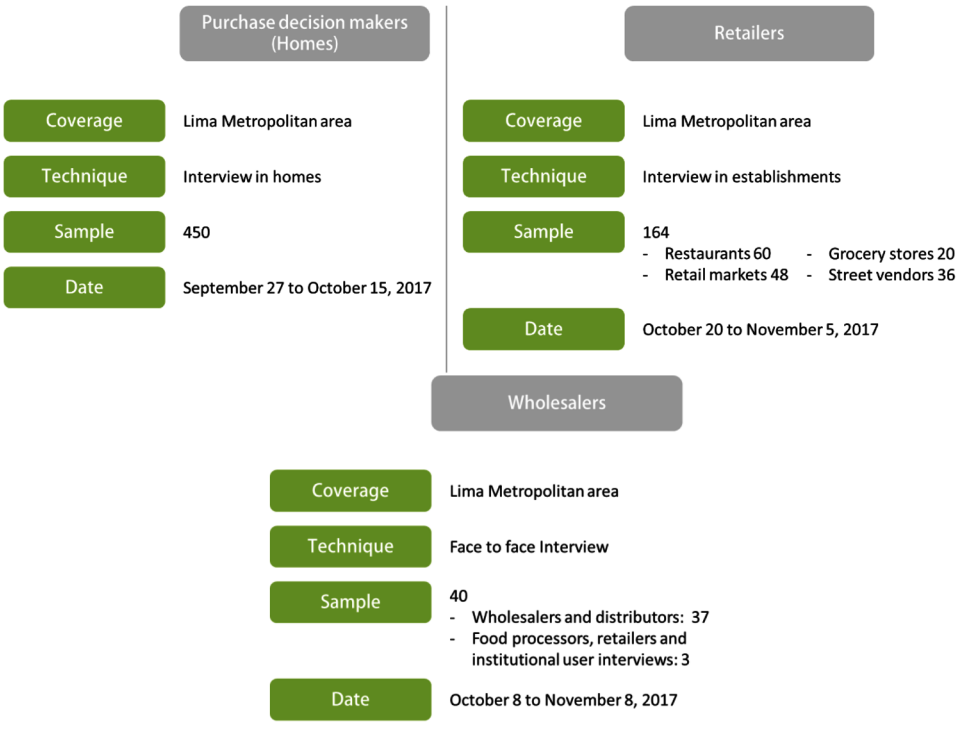


Figure 5. Data sheet of the sample from households, retailers, and wholesalers
Source: RUFSAT-FAO survey, 2017



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For households, multi-stage sampling was applied, based on a study of sample clusters from the city of Lima in 2000. Then, population clusters were randomly selected by socioeconomic level stratification: A, B, C, D, and E, following the classification technique from the Peruvian Association of Market Research Companies, and by Lima's zones: North, South, East, Central, and Modern (referencing IPSOS Peru's classification). After randomly selecting the conglomerate, a starting point and a random routing system for the interviewer was proposed, surveying the homemakers of the 450 households selected. The margin of statistical error is 4.62%, with a confidence level of 95%.

Retailers and restaurants had a different protocol, considering that the sampling had no extrapolation purposes, but it was relevant to try to characterize the complexity of the city with more than 118,198 grocery stores and about 1,122 food markets (traditional trade). We proposed identifying the scattered sample through the different zones of Lima and business types, since there is a wide heterogeneity in this realm, and a sample of only 164 cases was used.

For wholesalers, 37 surveys were applied to specialized UDC traders identified in the Great Wholesale Market of Lima, as well as to officials.

Moreover, 50 in-depth interviews were conducted with operations managers of large food processing and distribution companies, which were later transcribed.

RESULTS

In Lima, there are two types of UDCs for agricultural food products: specialized and mixed.

The specialized UDCs in Lima are, for example, urban distribution centers for tubers and vegetables and urban fruit distribution centers, which consolidate the largest volume entering the city.

These specialized UDCs consolidate the largest volume of tubers, vegetables, and fruits that enter the city. In addition, by consolidating a wide variety of products, they supply markets, wholesalers, and retailers in other cities, around 25% of the food goes to other locations and has a regular clientele of retailers located in the city.

Mixed UDCs are characterized by being located in the periphery of the city, selling varied products, wholesale and retail, and emerging informally.

We identified eight factors that are related to food UDC localization in Lima: commercial density, retailer supply habits, retailer storage capacity, UDC supply habits, accessibility, connectivity, land use, and land access barriers.

It is important to note that in Central Lima, there are two UDCs specialized in fruit, and in East Lima, the UDC is specialized in tubers and vegetables. These three UDCs are the only ones authorized to market these products. The distance traveled from MAs and the most remote grocery stores to these UDCs is around 50–60 km.

MAs and street vendors located in the conglomerates of North, South, and East Lima have a high demand for goods, which means that many of these MAs and street vendors migrate to the wholesale market, converting into UDCs that sell products at wholesale and retail-mixed prices.

As shown in Figures 8, the markets located in North, South, and East Lima are quite far from the specialized UDCs, while the mixed UDCs located in these commercial conglomerates are very close to retail stores (grocery stores and market stalls). Thus, they generate high opportunities for grocery stores

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Table 1. Decision factors in localization patterns matrix

Construct	Construct Definition	Construct Application	Effect on UDC Localization
Commercial Density	The concentration of retailers in a given territory and its relation to the number of inhabitants.	Number of market stalls, grocery stores, and supermarkets per inhabitant.	UDCs are located in areas of greater commercial density.
		Commercial area per inhabitant.	
Retailer Supply Habits	Retailer's preference and frequency of purchase by UDCs.	Retailer's preference and frequency of purchase by UDC type.	UDCs are located in areas where there is more trade among retailers (business opportunity).
Retailer Storage Capacity	Retailer's availability of cold storage facilities and warehouses.	Retailer's area available to properly store products.	UDCs are located closer to retailers with less storage capacity.
UDC Supply Habits	UDC's preference and frequency of purchase according to the provider's place of origin.	UDC's preference and frequency of purchase according to provider.	UDCs are located in places near their most preferred providers.
Accessibility	UDC location on a high traffic route.	One location on a high traffic route.	UDCs are located on high traffic routes.
Connectivity	Time devoted to moving the merchandise.	UDC travel time to the retailer.	UDCs are located in areas with less traffic congestion or that generate fewer travel hours for retailers.
		Vehicle volume per hour on access roads to the UDC.	
Land use	The urban zoning assigned in the urban management instrument for wholesale trade activity.	Areas assigned by the urban management instrument for commercial use.	UDCs are located in areas assigned by the approved or current urban management instrument for wholesale commercial activity.
Land access barriers	Availability for sale, area, and price suitable for commercial activity.	Areas greater than 1,000 m^2 and value of industrial land per m^2.	UDCs are located in areas with greater availability of land; mixed UDCs do not have a standard.

Source: Created by the authors.

and market stalls to be supplied by mixed UDCs, due to the concentration of commercial premises, a wide variety of wholesale and retail products, and the presence of producers offering their merchandise in trucks (direct sales).

For MCs, there is a high concentration of supermarkets in Modern Lima (47.2%), with one supermarket for every 21,736 inhabitants, while in Central Lima, there are not as many supermarkets, since there

Table 2. Number of supermarkets in the five areas of Lima

Limas	No. of Supermarkets	%	Indicator (Inhabitant/ Supermarket)
Central Lima	17	13.8%	40,420
East Lima	18	14.6%	136,805
Modern Lima	58	47.2%	21,736
North Lima	16	13.0%	155,436
South Lima	14	11.4%	160,831
Total	**123**	**100.0%**	**74,382**

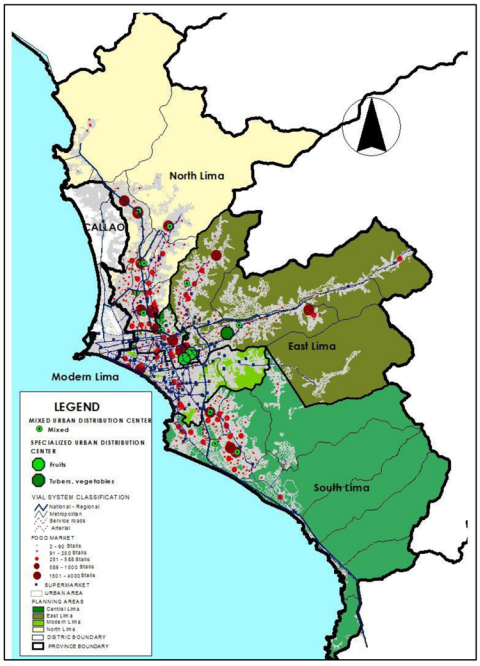
Source: Lima metropolitan area, trends in population growth, estimates, and projections by province and district through 2035. IMP Study Created by the author, 2018.

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is one supermarket for every 40,420 inhabitants. It should be noted that in Central Lima, a significant number of people are in transit, which influences the decision for a commercial establishment's location.

In the Lima metropolitan area, the forms with the highest purchase preference are food markets (93%), followed by grocery stores (69%). See Figure 7.

Figure 6. Map of markets and number of supermarkets and stalls in the 5 areas of Lima
Source: RUFSAT, FAO, 2017.



AREAS OF LIMA	DISTRIT	SUPERMARKETS	MARKERTS
CENTRAL LIMA	LIMA	7	54
	BREÑA	3	22
	LA VICTORIA	3	34
	RIMAC	3	27
	SAN LUIS	1	15
EAST LIMA	ATE	5	69
	CHACLACAYO	1	7
	CIENEGUILLA	0	4
	EL AGUSTINO	1	21
	LURIGANCHO	1	19
	SAN JUAN DE LURIGANCHO	8	123
	SANTA ANITA	2	31
MODERN LIMA	BARRANCO	3	5
	JESUS MARIA	5	2
	LA MOLINA	8	8
	LINCE	1	11
	MAGDALENA DEL MAR	3	8
	MIRAFLORES	8	3
	PUEBLO LIBRE	2	11
	SAN BORJA	5	9
	SAN ISIDRO	7	1
	SAN MIGUEL	3	22
	SANTIAGO DE SURCO	12	34
	SURQUILLO	1	14
NORTH LIMA	ANCON	0	8
	CARABAYLLO	0	25
	COMAS	4	47
	INDEPENDENCIA	6	20
	LOS OLIVOS	3	56
	PUENTE PIEDRA	1	30
	SAN MARTIN DE PORRES	2	118
	SANTA ROSA	0	2
SOUTH LIMA	CHORRILLOS	5	54
	LURIN	2	14
	PACHACAMAC	0	15
	PUCUSANA	0	3
	PUNTA HERMOSA	0	1
	PUNTA NEGRA	0	1
	SAN BARTOLO	0	1
	SAN JUAN DE MIRAFLORES	4	64
	SANTA MARIA DEL MAR	0	0
	VILLA EL SALVADOR	2	51
	VILLA MARIA DEL TRIUNFO	1	58
	TOTAL	123	1,122

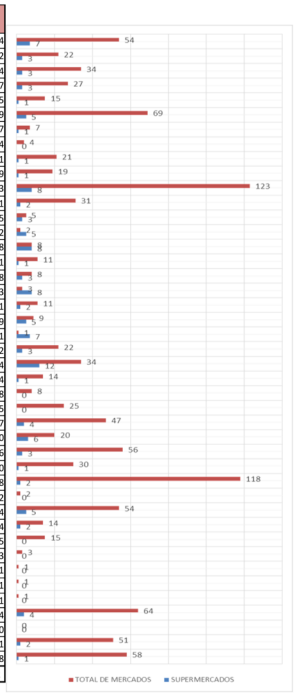


Figure 7. Final consumer purchase preference places in Lima
Source: RUFSAT-FAO surveys, 2017.



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This behavior is maintained in the five areas of Lima3, except for Modern Lima, where consumers have the option of purchasing at supermarkets (86%), followed by grocery stores with a lower percentage (50%).

The frequency at which the food is purchased can be attributed to the proximity of the multiple markets dispersed in the city of Lima, 49% go every day and 39% go two to three times a week. See Figure 8.

Table 3. Final consumer purchase preference places in the five areas of Lima

	Central	East	Modern	North	South
Food Markets	78%	100%	91%	98%	98%
Grocery Stores	40%	88%	50%	75%	93%
Supermarkets	27%	41%	86%	29%	41%
Retail stores	15%	24%	25%	28%	33%
Others	54%	11%	13%	24%	17%

Source: RUFSAT-FAO surveys, 2017.

Figure 8. Final consumer purchase frequency in food markets
Source: RUFSAT-FAO survey, 2017

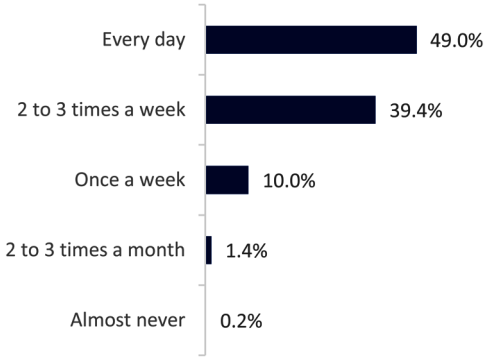
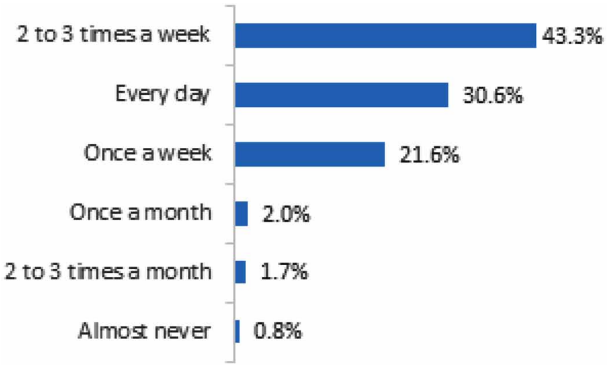


Figure 9. Final consumer purchase frequency in grocery stores
Source: RUFSAT-FAO survey, 2017



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In grocery stores, final consumers' purchase frequency is primarily from two to three times a week (43%), followed by every day (30.6%), and once a week (22%). On the other hand, supermarkets and hypermarkets have more varied shopping frequencies: once a week (35%), once a month (31%), and 2–3 times a month (19%). See Figure 10.

The daily and every few days' frequency of both the traditional formats—markets and grocery stores—validate the proximity to their clientele and explain their relationship with high density.

The main reason for preferring markets is their low prices (59%) and the variety of products (34%), as well as the fresh products (24%) and proximity (25%). Meanwhile, for grocery stores, proximity reaches 100% and the variety of products only 38% (See Figure 11 and 13).

The primary reason for preferring supermarkets and hypermarkets is the sales and promotions that they have (41%). Other important preferences are proximity (24%) and the variety of products (23%), considering that the sales of this modern form are updated weekly.

Grocery stores are located closer to the final consumer (100 meters) than markets, whose average distance is 300 meters. In South Lima, this distance is between 300 and 400 meters and in East Lima, 400 and 500 meters.

Figure 10. Final consumer purchase frequency in supermarkets and hypermarkets
Source: RUFSAT-FAO survey, 2017

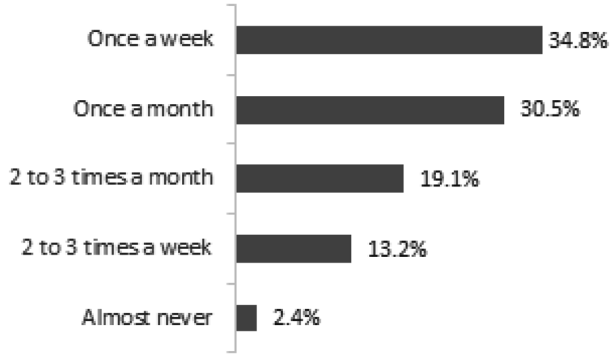
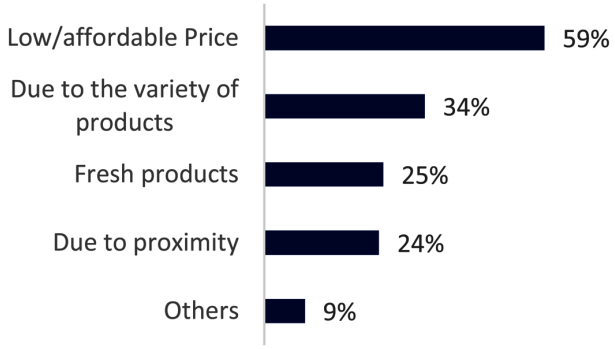


Figure 11. Final consumer preferences by food markets
Source: RUFSAT-FAO survey, 2017



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Figure 12. Final consumer preferences at supermarkets and hypermarkets
Source: RUFSAT-FAO survey, 2017

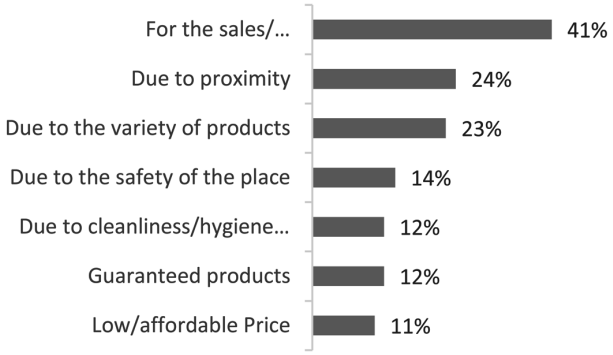


Figure 13. Preference for grocery stores
Source: RUFSAT-FAO survey, 2017

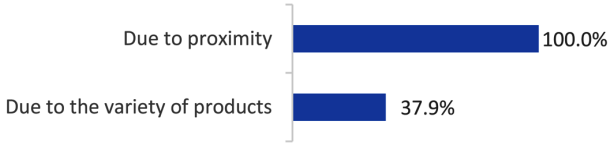
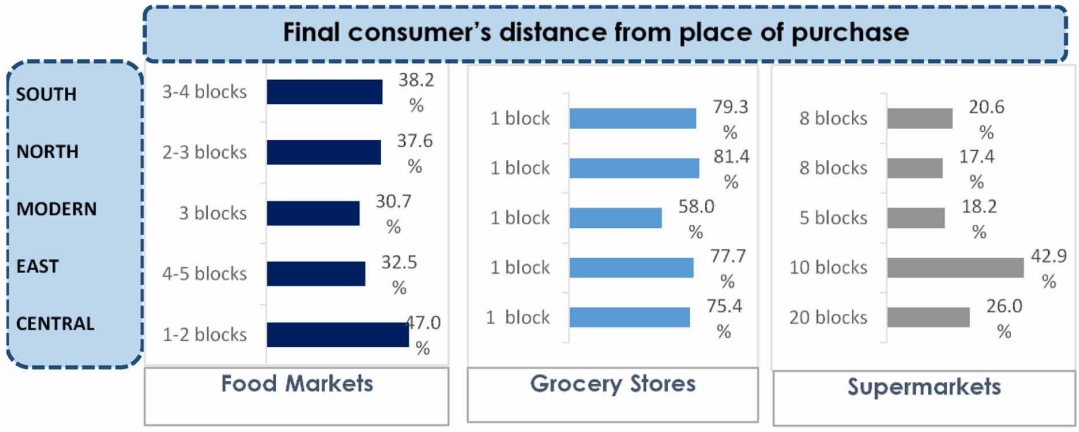


Figure 14. Final consumer's distance from markets, grocery stores, and supermarkets
Source: RUFSAT-FAO survey, 2017



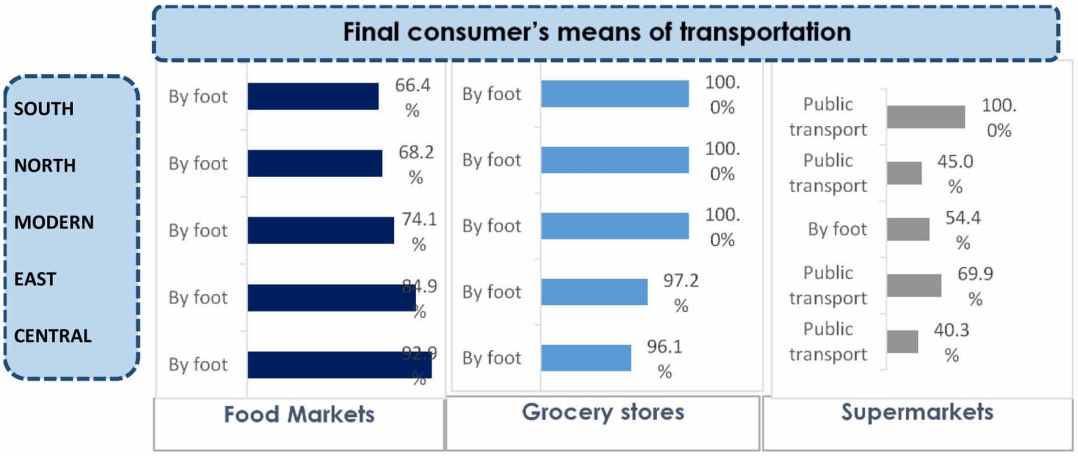
Final consumers walked to markets and grocery stores, while they used public transit to go to supermarkets.

Retailer Supply Habits

Retail supply habits are from daily to every few days, except for basic foods, which is once a week (33%). This is linked to the products' shelf life, since these items are composed of tubers, roots, and grains.

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Figure 15. Means of transportation used by the final consumer to go to markets, grocery stores, and supermarkets.
Source: RUFSAT-FAO survey, 2017

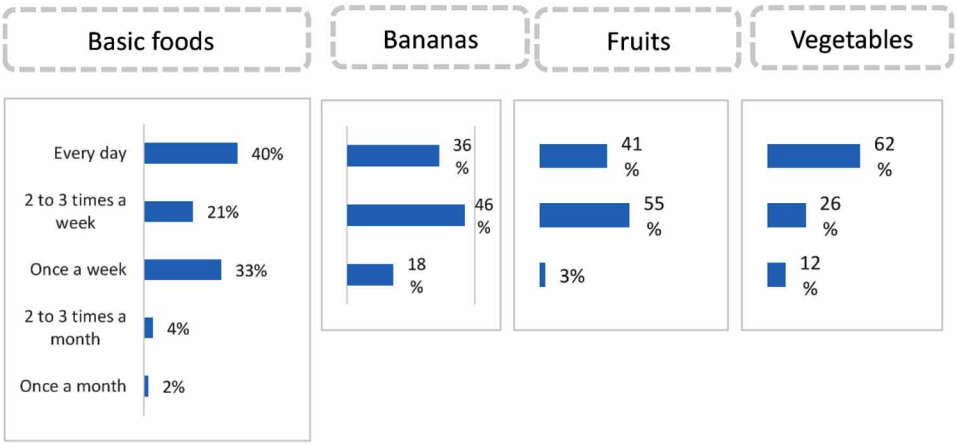


We can verify that the supply channel of the products is mainly through wholesalers. However, there is evidence that 1% of the supply—basic food—is directly from farmers' groups like other retailer supplies. See Figure 16 and 17.

Food market retailers mostly buy from UDCs, as do street vendors, while grocery stores buy mostly from other retailers. See Table 4.

Conducting an analysis of UDC type per product, retailer fruit supplies are mostly purchased from specialized UDCs, while other products (vegetables and basic foods) are supplied by mixed distribution centers (wholesale and retail) and specialized UDCs, but grocery stores are primarily supplied by mixed distribution centers. See Table 5. This may be due to the low sales volume.

Figure 16. Retailer supply frequency
Source: RUFSAT-FAO survey, 2017



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Figure 17. Retailer supply place
Source: RUFSAT-FAO survey, 2017

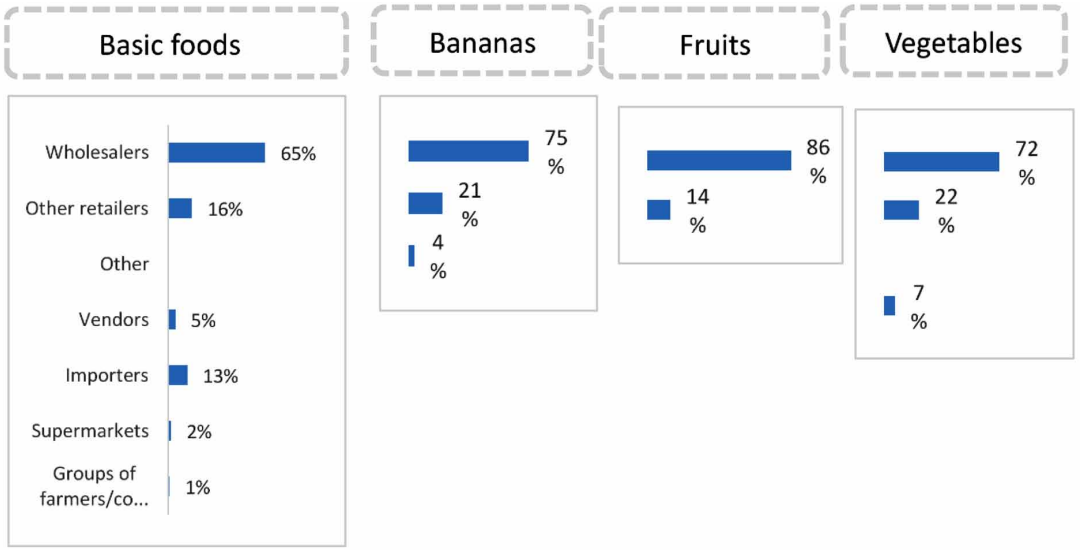


Table 4. Traditional retailer (food markets, grocery stores and street vendors) supply by product according to UDC and retailer

Products	Markets		Grocery Stores		Street Vendors	
	UDCs	Retailers	UDCs	Retailers	UDCs	Retailers
Fruits	100%	-	50%	50%	94.7%	5.3%
Vegetables	87.5%	12.5%	66.7%	33.3%	71.4%	30.3%
Basic foods	70%	10%	61.1	11.1%	62.5%	25%

Source: RUFSAT-FAO survey, 2017

Table 5. Traditional retailer (food markets, grocery stores and street vendors) supply by product according to UDC type (specialized and mixed)

Products	Markets		Grocery Stores		Street Vendors	
	Specialized DCs	Mixed DCs	Specialized DCs	Mixed DCs	Specialized DCs	Mixed DCs
Fruits	100%	-		100%	83.3%	16.7%
Vegetables	57.1%	42.9%	50%	50%	20%	80%
Basic foods	57.1%	42.9%	9.1	90.9%	60%	40%

Source: RUFSAT-FAO survey, 2017

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For the supply frequency of basic foods according to UDC, it is 50% daily, while fruits are 43% daily and vegetables are 25%. The only item that is supplied once a week is the banana (50%).

UDC Supply Habits

UDC vendors primarily source from farmers, especially fruits and vegetables. In the basic foods category, farmers supply 50% and retailers 16.7%, followed by other wholesalers (16.7%) and others (16.7%).

Agricultural products are mostly transported without having been subjected to primary processes (classification, cleaning, and proper packaging). Only fruit is classified and packaged, while classification and packaging of tubers and vegetables is conducted informally at UDCs.

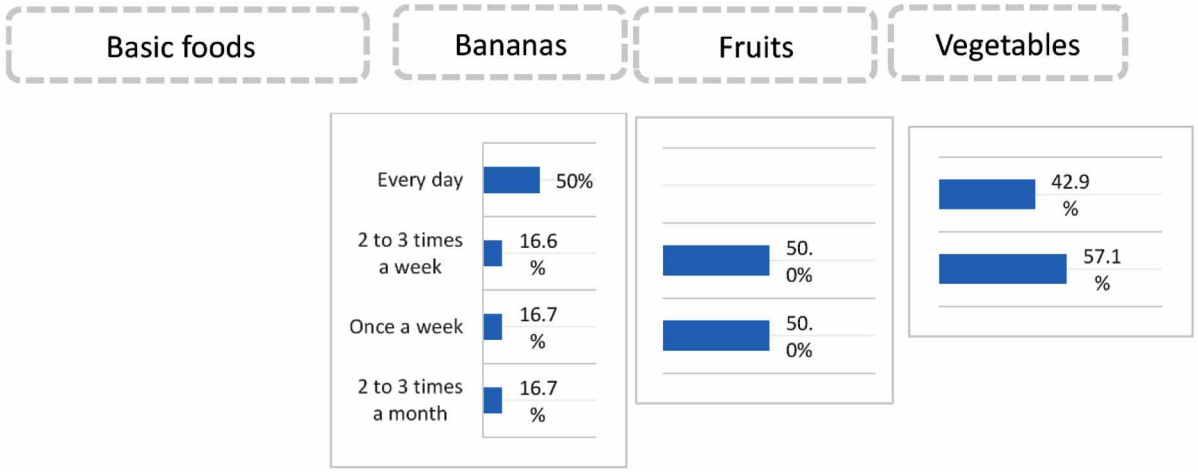
UDC supply frequency is mostly daily (50%) and for two to three times a week for the other 50%, with bananas and packaged products as the exception. This UDC purchase frequency is linked to the shelf life of the products, as in the case of the most sensitive products (lettuce, basil, and spinach, among others) and whose origin are from the areas closest to Lima, due to the absence of the refrigeration chain during transportation and at the UDCs (see Figure 18).

Specialized UDC entry trends of agricultural food is maintained throughout the year and the highest volumes are found in basic products (50%), including tubers, followed by fruits (33%) and vegetables (17%).

Accessibility

Specialized urban distribution centers, such as fruit UDCs, are located in Central Lima, on major roads (arterial). UDCs specialized in tubers and vegetables are located in East Lima, very close to the Central Highway, classified as an arterial route, but very far from the businesses located in the periphery of North and South Lima (see Figure 21: Urban distribution center location and classification of roadway system roads.)

Figure 18. Wholesaler supply frequency
Source: RUFSAT-FAO survey, 2017



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Figure 19. Wholesaler supply places
Source: RUFSAT-FAO survey, 2017



This situation has an impact on purchases made by grocery stores to stock up, since this form has a greater purchase preference than retail stores and is more willing to buy from mixed UDCs because they are located closer to them (see Table 5).

The origin of agricultural products and their accessibility to distribution centers in the city are important, considering the merchandise's entry flow. Annually, around 3 million tons of agricultural products enter the city. In 2016, 2,973,401 entered from different regions of the country, that is to say, 8,146 tons enter daily and are transported in 400–500 trucks per day.

Agricultural products enter, almost entirely, by land; the products that arrive at UDCs are primarily from the north of the country (52.1%), while 34% (Central Highway) and 0.5% (Canta) are from the east, while the smallest volume comes from the south (12.1%). Their final destinations are primarily specialized UDCs, as they have greater purchasing capacity unlike the mixed UDCs (see Figure 20: Location of primary national roads that enter the Lima metropolitan area and percentage of product volume that enters each way)

Mixed UDCs are located along the border of North, South, and East Lima, very close to their customers, on higher traffic roads, just as the specialized UDCs are at the most important intersections to benefit from greater accessibility for arriving customers.

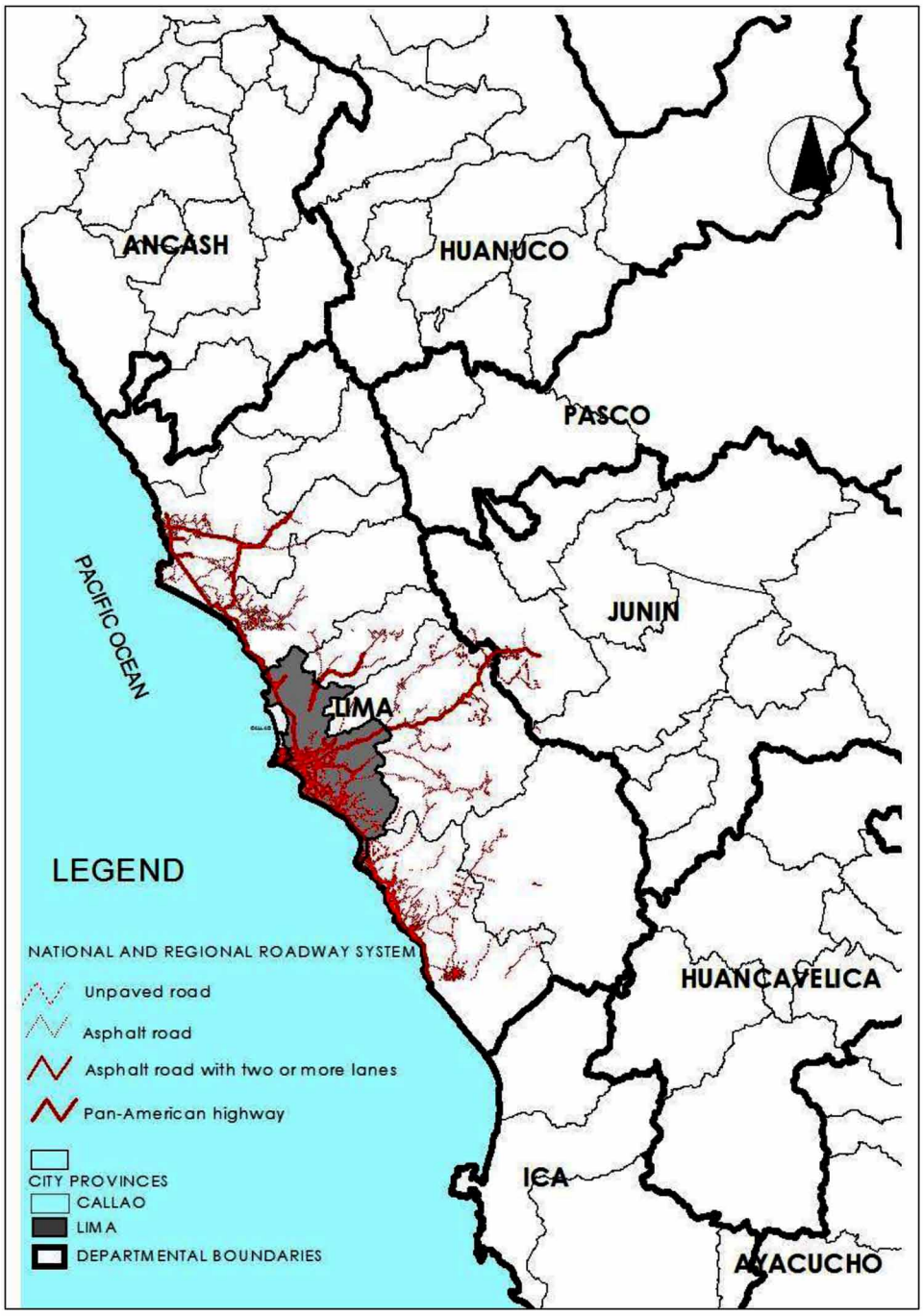
The largest number of mixed UDCs is in North Lima, followed by East and South Lima, which have a higher purchase frequency of every few days and a greater number of retailers (see Figure 16: Retailer supply frequency and 17).

Connectivity

Lima has serious mobility problems. Traffic routes with the greatest volume of vehicular flow are the main roads that lead to the center of the city, giving rise to a radial effect.

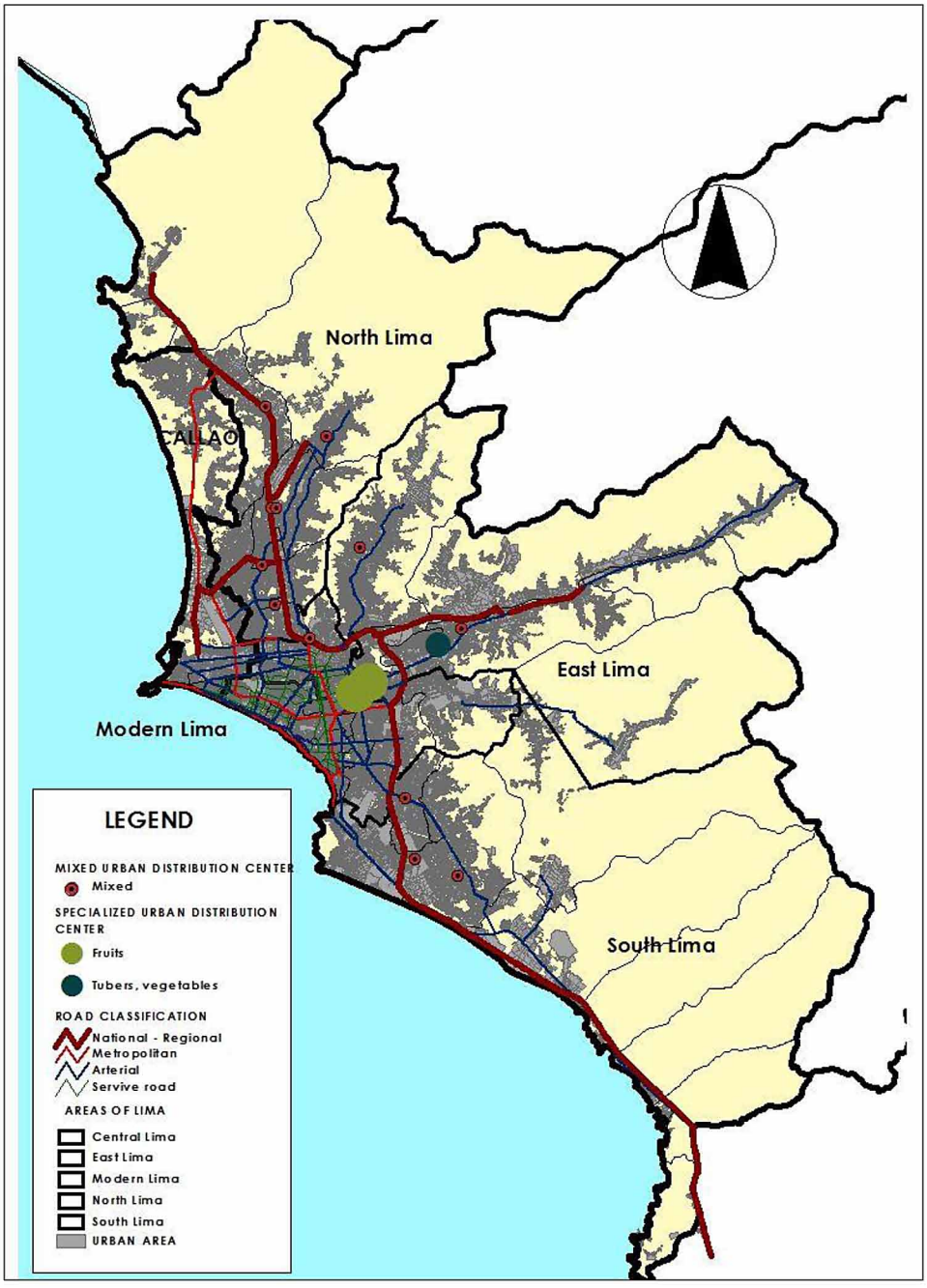
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Figure 20. Location of primary national roads that enter the Lima metropolitan area and percentage of product volume that enters each way
Source: RUFSAT-FAO, 2017, MINAGRI 2017, created by the authors.



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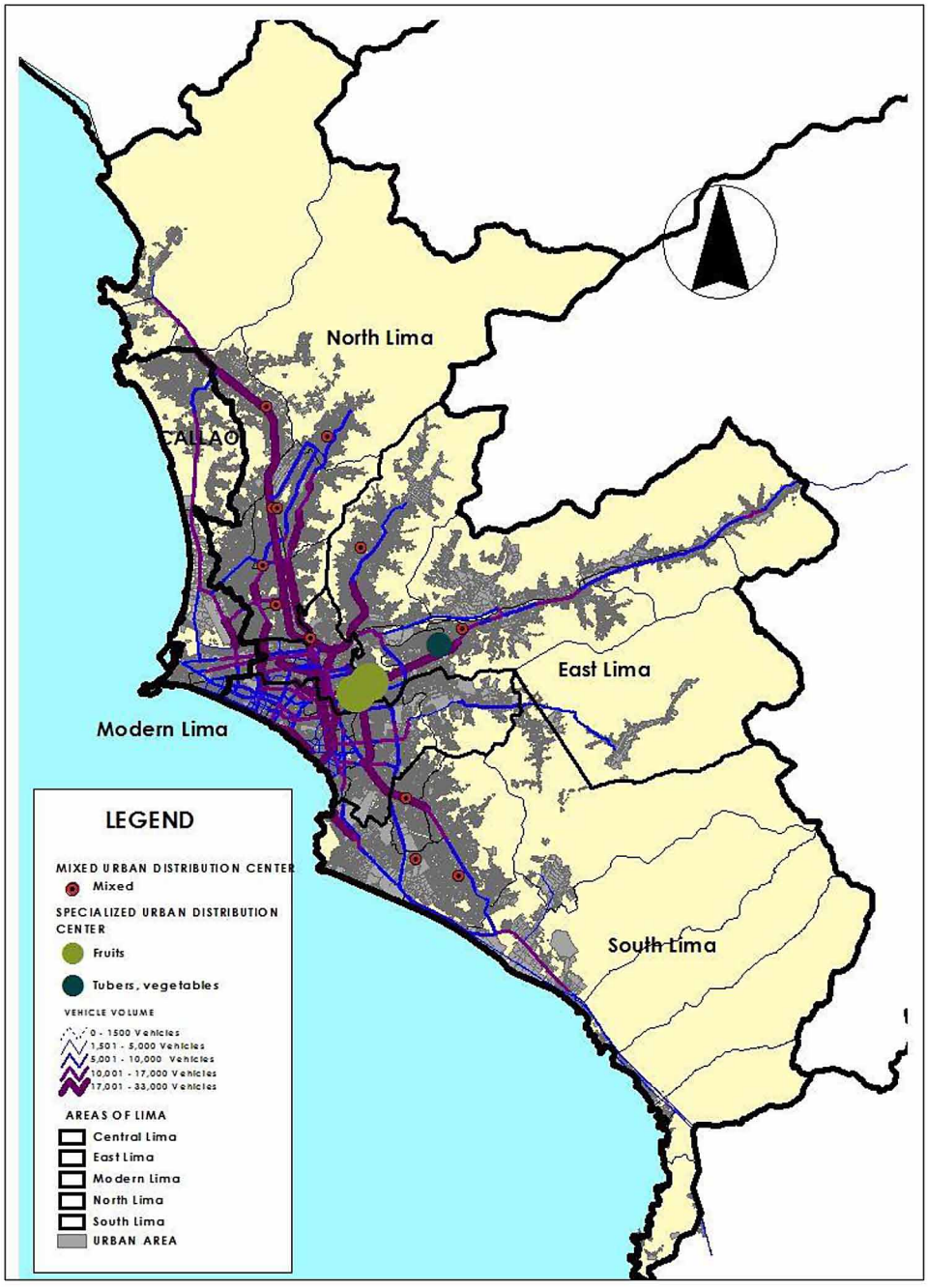
Figure 21. Urban distribution center location and classification of roadway system roads



Specialized UDCs, those with the highest volume of product merchandise, are located in the center of the city and in East Lima, on roads with the highest volume of vehicles per hour. These generate slow trips and longer travel time for customers, who are mostly located in North, South, and East Lima, and must travel long routes to stock up. These specialized UDCs offer more variety than mixed UDCs (see Figure 22: Urban distribution center location and roadway volume.)

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Figure 22. Urban distribution center location and roadway volume



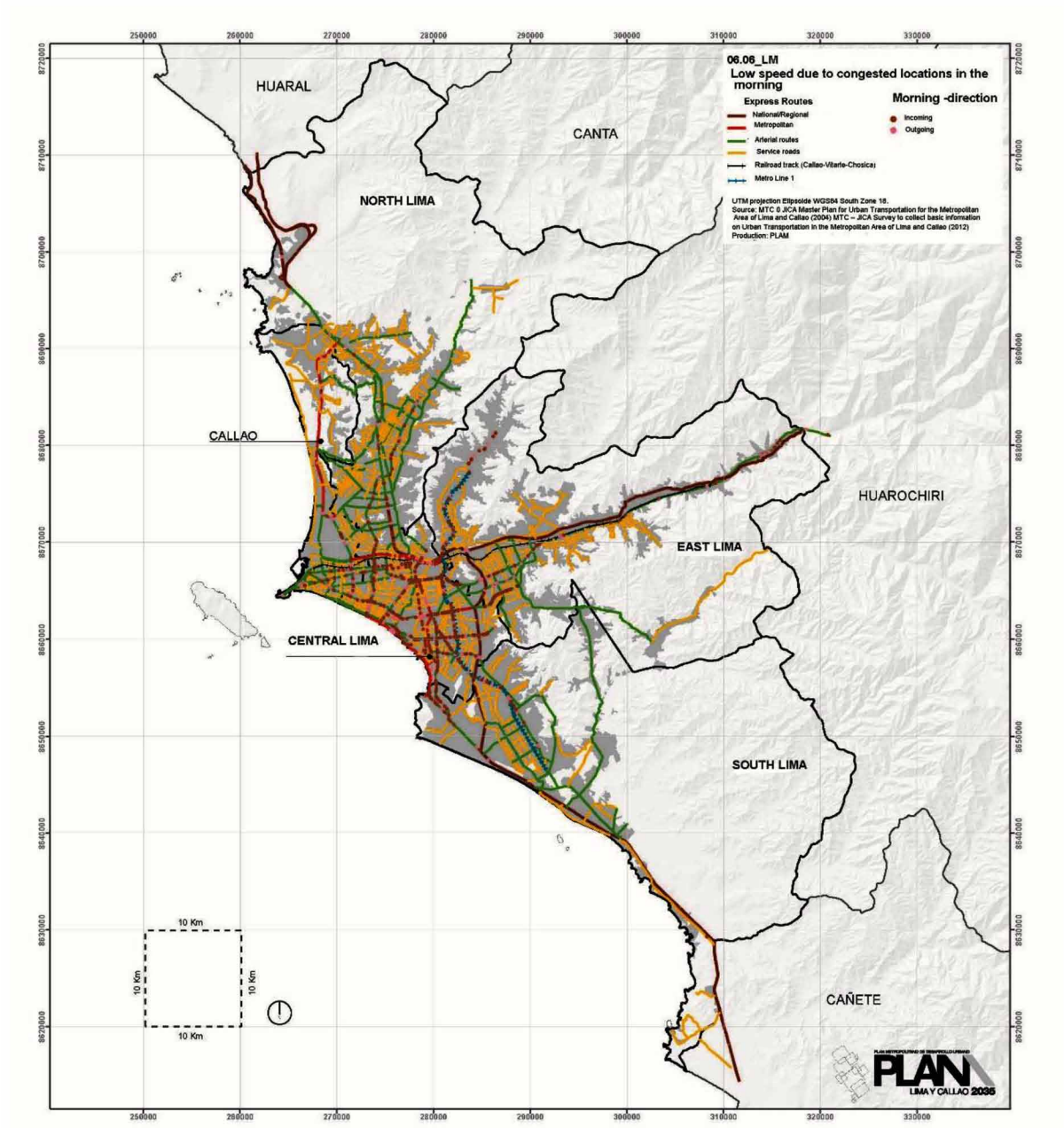
Travel time for market retailers located in North, South, and East Lima to specialized UDCs is a significant factor. Each merchant takes between 1 and 4 hours per trip, back and forth, three times per week. That is, each trip back and forth with their merchandise takes retailers between 3 and 12 hours per week in travel time to a specialized UDC. These retailers make other trips to other specialized UDCs to achieve the necessary variety of products, such as fruits and vegetables.

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In Figure 23, we can see that the greatest traffic congestion in the morning hours is at the entry points to Central Lima, from North, South, and East Lima, with congestion being greater on the main roads and close to Central Lima. This affects the exit routes in North, South, and East Lima.

A retailer who takes a trip to specialized UDCs located in Central and East Lima faces greater travel time and becomes an access barrier for markets and grocery stores located in North Lima and South Lima.

Figure 23. Low speed due to congested locations in the morning
Source: PLAM 35, IMP, 2015



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Land Use

The urban regulatory instruments required to authorize UDC localization are urban zoning and roadway impact approval.

Zoning, as a concept, responds to a set of urban regulations that regulate land use. They consider the population's physical, economic, and social demands. In turn, this allows them to plan a compatible, balanced, and harmonious localization of different urban activities, whether they are for housing, production, commerce, industry, equipment, services, recreation, tourism, culture, environmental protection, civil defense, or other uses.

Likewise, in addition to zoning, there is another important instrument: the use index for the location of urban activities. This regulatory instrument, in addition to zoning plans, allows for defining the urban activities that are carried out in different zones and areas of the metropolitan area, in accordance with the International Standard Industrial Classification (ISIC), which responds to the analysis of the potentialities and limitations offered by a territory to manage each of the activities, as well as considering the compatibility between the adjacent activities.

In the city of Lima, four regulatory treatment areas (RTAs) were defined in terms of urban zoning. They require different urban regulations, such as urban planning parameters, building parameters, and land use indexes, due to urban characteristics.

In RTA I, there are the areas with the lowest level of urban consolidation and the greatest diversity of land use, localizing the districts of North, South, and East Lima. Meanwhile, in RTA II, there is greater urban densification and it is located in the districts of Central Lima and Modern Lima.

In RTA III, the areas with greater urban development are grouped and have a higher building quality. The districts of Modern Lima are shown here. On the other hand, RTA IV comprises the areas that have special zoning, such as natural areas or historical zones, located in the districts of Modern and Central Lima.

The districts located in RTA I and II have a compatibility index for the location of urban activities that allows for UDC localization, on land that makes use of Basic and Complementary Industry (I1), Light Industry (I2) or Metropolitan Commerce (CM), while in the other cases, RTA III and RTA IV, UDCs are not allowed.

Another instrument for UDC authorization is the Traffic Impact Study (TIS). Localizing UDCs in Central Lima and Modern Lima would be restricted since they are the areas where the greatest problems with congestion persist (see Figure 25).

Land Access Barriers

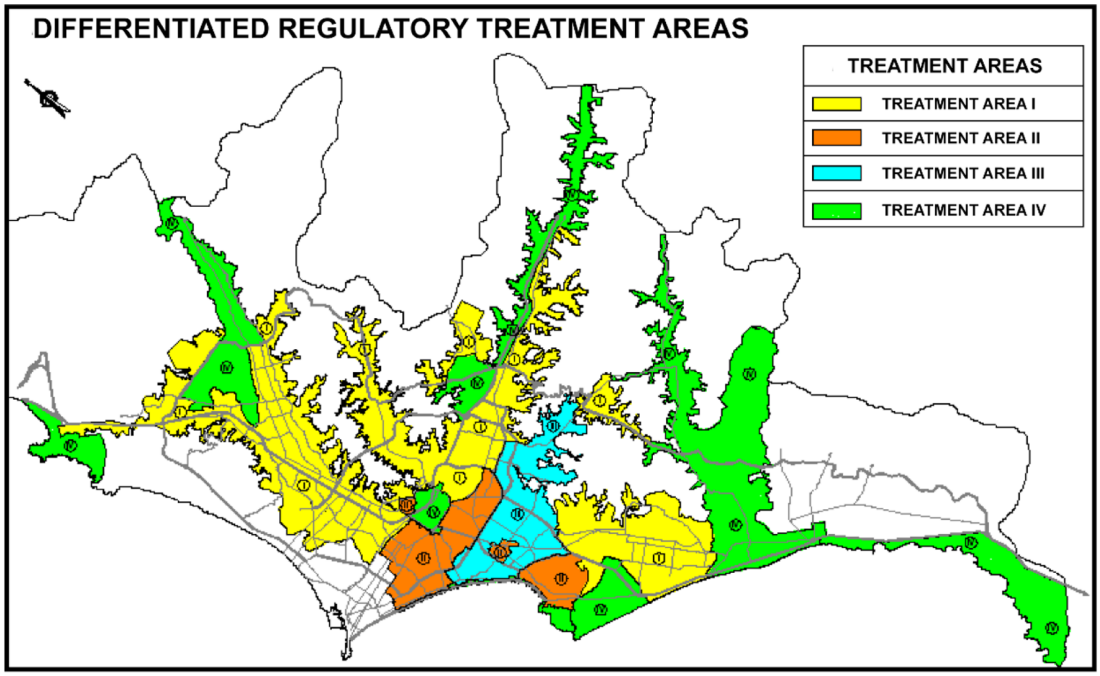
UDCs require large areas of land for proper operation, that is, they require land with space for vehicles to enter so they can load and unload products and for storage areas and cold storage facilities, among other requirements.

According to calculations by Tracey, FAO in Wholesale Markets—Planning and Design Manual, a UDC in metropolitan cities may need between 20ha and 100ha. Mixed UDCs in the Lima metropolitan area are small and do not have the minimum environments characteristics to perform these functions (loading and unloading areas, classification yards and parking for heavy vehicles, and warehouses and cold storage facilities), according to secondary sources obtained from the RUFSAT for the city of Lima, created by FAO's NADHALI project.

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Figure 24. Regulatory treatment areas applicable to the Lima metropolitan area
Source: http://www.munipachacamac.gob.pe/licenciasdefuncionamiento/Areas%20de%20Tratamiento.pdf

Differentiated Regulatory Treatment Areas applicable to the Lima Metropolitan area

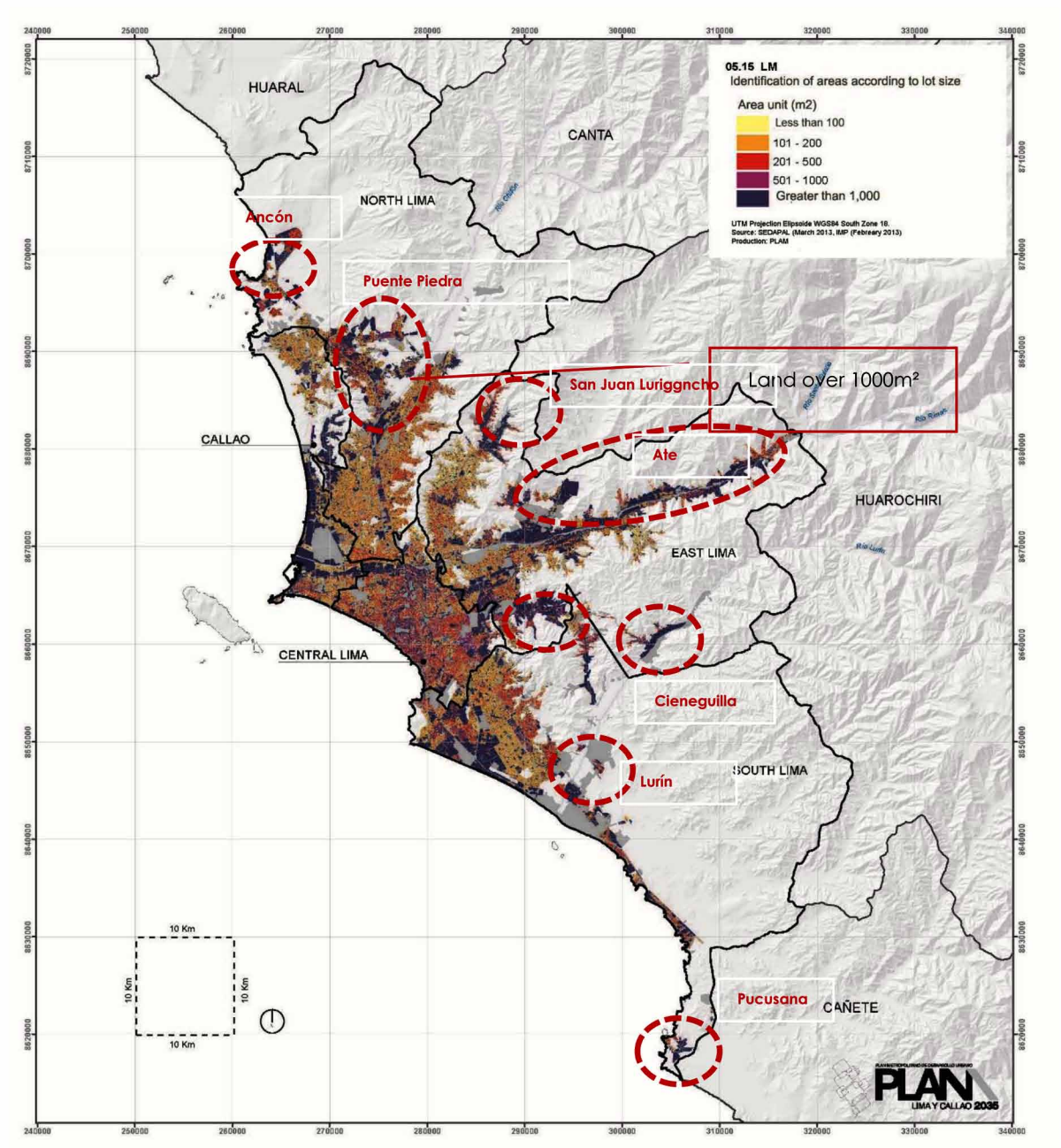


Area I	**- Regulated densification - Greater compatibility with other activities**	**Districts:** Carabayllo, Puente Piedra, Comas, Los Olivos, Independencia, San Martin de Porres, Rímac (P), Cercado de Lima (P), El Agustino, San Juan de Lurigancho, Ate (P), Santa Anita, San Juan de Miraflores, Villa Maria del Triunfo, Villa El Salvador.	**Scope of application of Ordinance No. 620**
Area II	**- Greater densification - Regulated compatibility with other activities**	**Districts:** San Miguel, Pueblo Libre, Magdalena (P), Breña, Lince, Jesús María, La Victoria, San Luis, Cercado (P), Barranco, Chorrillos (P), Surquillo (P), Rímac (P), San Borja (P), Santiago de Surco (P).	
Area III	**- Regulated densification - Restricted compatibility with other activities**	**Districts:** La Molina, Santiago de Surco (P), San Borja (P), San Isidro, Miraflores, Magdalena (P), Surquillo (P).	
Area IV	**Special regulation: - Historical Center - Large Zones - Valley Areas - Ecological Areas - Seaside Resort Areas**	**Districts:** Cercado (P), Rímac (P), Chorrillos (P), Carabayllo, Puente Piedra, Lurigancho (P), Chaclacayo (P), Lurín (P), Punta Hermosa, Punta Negra, San Bartolo, Santa María, Pucusana, Pachacamac, Cieneguilla, Ancón (P), Santa Rosa (P).	**Scope of application of specific rules**
(P) Partial			

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To establish a UDC, lots with more than 1000m2 are primarily located in North, South, and East Lima, in areas far from the Central Lima. They represent 3% of the number of lots in the city. Larger areas are located outside the city, in zones that are not classified as urban and considered rural areas (see Figure 25: Lot availability by size).

Figure 25. Lot availability by size
Source: PLAM 35, IMP, 2015

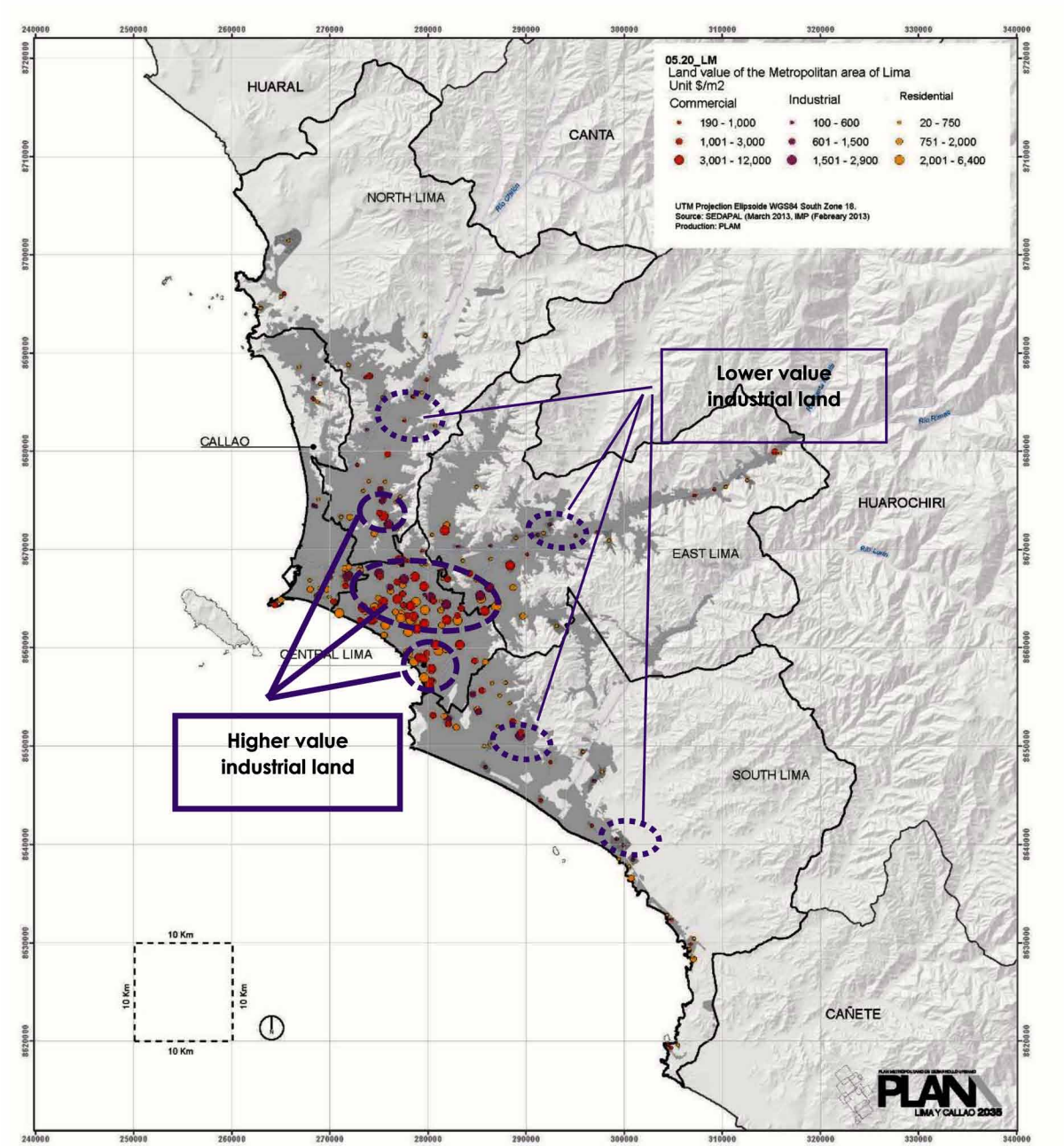


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In East Lima, 31% of the land is composed of 1000m2 lots, known as industrial lots. In the most remote areas of East Lima, there are large expanses, but they do not have authorization and lack basic services.

In Central Lima, there are some areas with large expanses, but they are recreational infrastructures or used for other purposes and are occupied by golf courses, stadiums, racecourses, or military areas.

Figure 26. Land value of the Lima metropolitan area
Source: PLAM 35, IMP, 2015



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In the same way, in South Lima and North Lima, there are large expanses, but in some cases, they are not yet authorized, and in others, they are industrial zones.

Land value varies according to its location, accessibility, access to basic services, and assigned urban zoning. Land whose urban zoning is not compatible for localizing a UDC, according to urban regulations, must be classified for industrial use.

In this way, we show that the industrial land with the highest values is found in East and North Lima, but they increase as they get closer to Central Lima.

Industrial land located in the districts of Central Lima, specifically in the districts of La Victoria, El Cercado, and San Luis with higher values, range between 1,500 and 2,900 dollars/m2, with the highest land values located in the district of La Victoria, while in the districts located in South Lima and East Lima, the values are much lower.

In the districts of Ate (East Lima) and Villa El Salvador (South Lima), there is more land with areas over 1000m2 (see Figure 25: Lot availability by size). However, in North Lima, due to urban development trends, the industrial land located closest to Central Lima has increased in value, and those further away (Puente Piedra and Ancón) have a lower value (see Figure 26: Land value of the Lima metropolitan area).

CONCLUSION AND DISCUSSION

The factors that seem to determine UDC location patterns in Lima are related to the supply and demand of their suppliers, in accordance with that proposed by Maya.

Figure 27. Constructs by settlement pattern
Source: Created by the authors.

SETTLEMENT PATTERN	CONSTRUCT
SETTLEMENT PATTERN BY DEMAND	**Commercial density**
	Retailer supply habits
	Retailer supply capacity
SETTLEMENT PATTERN BY SUPPLY	**UDC supply habits**
SETTLEMENT PATTERN BY MOBILITY	**Accessibility**
	Connectivity
SETTLEMENT PATTERN BY LAND	**Land use**
	Land access barriers

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"According to the traditional approach, there are two ways to determine the location of facilities, namely, a supply-oriented approach and a market-oriented approach. When determining UDC location, however, there is a return" (Bertha Maya Sopha, 2016).

Settlement patterns change according to UDC. Specialized UDCs have been determined by a settlement pattern based on land availability and mobility, since they have been determined by more restrictive factors. Meanwhile, mixed UDCs, which have had a more flexible and informal behavior, have been guided by a settlement pattern based on demand.

The localization models of various optimization objectives have not considered the supply habits of retailers and UDCs. Moreover, the frequency of supply is due to capacity, as well as having storage infrastructure in adequate conditions. This need for ongoing supply requires proximity to traditional retail stores to avoid high costs and travel time. The implementation of new localization proposals must consider routines acquired by key actors in the food supply chain.

Suppliers do not seem to affect the localization decision with the same notoriety as the demand within the city. This generates long trips in the last mile that congest the city's transit.

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ENDNOTES

1 In Cabrera, T. Las limas and los conos, 2011, in: https://limamalalima.wordpress.com/2011/08/04/las-limas-y-los-conos/

2 Disclaimer: The document has not been edited by FAO and is available as it was submitted by the authors; consequently, the opinions expressed therein belong to the authors.

3 It should be noted that the surveys conducted were defined based on the five areas of the city: North Lima, South Lima, East Lima, Modern Lima, and Central Lima.

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Chapter 4
Modelling City Logistics Scenarios in Ecuadorian Big Cities Based on Multi-Objective Two-Echelon Vehicle Routing Problems

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ABSTRACT

Classic formulations of the two-echelon vehicle routing problem (2E-VRP) reflect the perspective of a single provider. The lack of coordination between providers executing their individual schedules and, consequently, the lack of a holistic approach to urban traffic may cause further problems. Various stakeholders may have conflicting objectives. This chapter presents a multi-objective formulation of a multi-provider heterogeneous vehicle 2E-VRP from a city government perspective, demonstrating the potential benefit of this approach to all parties involved, simultaneously considering conflicting objectives. Additionally, the design and development of a multi-objective evolutionary algorithm (MOEA) for the formulated problem is presented. An experimental evaluation considering real data from Ecuadorian cities is presented to validate the proposed MOEA, demonstrating that it is capable to find good quality solutions, is scalable, and its solutions are improved throughout its execution.

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INTRODUCTION

Current trends of urbanization and growing economies bring with them rising levels of traffic congestion in cities, especially if the potential development of urban infrastructure is limited, due to costs, popular resistance to large-scale construction projects, or natural accidents such as mountains, estuaries, or rivers (e.g. Guayaquil). If the infrastructure cannot be adequately expanded to absorb the rise in traffic, national and city governments need new strategies that optimize vehicle routing to deal with such problems (Cattaruzza et al., 2017). One possible strategy, already employed by individual businesses and transportation companies, is multi-level distribution of urban goods. This chapter presents a framework using the Two-Echelon Vehicle Routing Problem (2E-VRP) in order to design a multi-level distribution strategy from a holistic perspective, useful for city governments Eitzen et al., 2017; Lopez-Pires et al., 2018).

The classic Vehicle Routing Problem (VRP) consists in serving a number of customers located at distinct geographic points, and to do so, a central depot and a fleet of vehicles are provided. To solve this problem, routes must be assigned, meaning ordered sets of clients, to the vehicles in the most optimal way possible, usually striving for the minimal cost to cover the demand, which is in most cases resumed to a total travel distance minimization (Toth and Vigo, 2014). However, distance minimization is not the most suitable approach in city logistics, where travel times, but also cost and pollution issues are more important criteria for both public and private stakeholders (Gonzalez-Feliu, 2018a, 2019).

Under certain circumstances there may be reasons to use multi-stage distribution systems, i.e. to not to serve the clients directly from the central depot but to use intermediary platforms (in the form of city distribution centers (CDCs), proximity delivery areas or other forms of urban logistics spaces). This can happen for example if there are large trucks that leave the central depot but should not (or are even forbidden to) enter a certain zone, such as the inner city, and CDCs are set up outside or on the edges of these restricted areas where the large trucks unload their freight and smaller vehicles deliver the freight to the customers within the restricted areas (Crainic et al., 2004). In this case, it can be said that there are two layers or echelons of vehicles and locations, giving rise to the 2E-VRP.

The most studied approach for the 2E-VRP considers a multi-level distribution scenario for products of a single provider (Gonzalez-Feliu, 2011, 2013; Cuda et al., 2015). However, each provider in a city solving its own routing problem separately and independently of the others could result in suboptimal solutions for the city as a whole. Furthermore, a city government may have the goal of reducing traffic congestion and pollution, requiring a holistic perspective of Urban Goods Transport (Cattaruzza et al., 2015), considering all stakeholders contributing to city traffic (Gonzalez-Feliu, 2018a,b).

For this reason, one can consider the 2E-VRP as a multi-level distribution scenario with multiple providers and products, also known as multi-commodity (Hernandez-Perez and Salazar-Gonzalez, 2014). This holistic approach that reflects the diverse nature of urban traffic is better adapted to tackle the global problem of urban traffic congestion. In this way, instead of solving several parallel 2E-VRP instances that are not aware of each other, one for each provider or product, a city government can unify these instances by having all (or several) providers share all (or several) CDCs, from where (possibly independent) smaller, greener second-echelon vehicles carry diverse freight to serve the demand of clients in restricted areas.

Additional challenges arise when adapting the 2E-VRP to the con-text of Urban goods movement (UGM), given the existence and participation of multiple stake-holders, e.g. the city government and companies. The objectives of the different stakeholders will most likely be distinct and they may be in conflict, such as companies seeking to minimize cost, distance, and time of travel and delivery, while

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the city government seeking to minimize the number of freight vehicles in simultaneous transit during a given period in the considered area, or the pollution those vehicles produce. A viable solution may require reasonable trade-offs. This situation motivates the consideration of a multi-objective formulation that attempts to simultaneously optimize several objective functions, presenting a Pareto set approximation to the decision makers (Coello Coello et al., 2007).

When considering traffic problems in major cities, such as Guayaquil (which has more than 3 million people), it may seem impossible or at least unfeasible to model the whole traffic of the entire urban land-scape and apply the aforementioned strategy to the whole city in an attempt to reduce traffic congestion. However, inspired by the classic divide-and-conquer method used so often to solve large problem in-stances, the goal can be to reduce traffic congestion in just a relatively small area, such as part of the city downtown with heavy commercial activity. This area can be a restricted area or the second echelon, while trips from providers to the CDCs set up on the edges of this area would be the first echelon.

The 2E-VRP is a generalization of the VRP which is known to be NP-hard (Lenstra and Kan, 1981) and it is therefore very difficult to find the optimal solution at least, in polynomial time. The difficulty is further raised considering the multiple objectives to be optimized, the multi-dimensional nature of the demand in a multi-commodity scenario, the potentially large size of input data given large numbers of depots, customers, and vehicles, and the high cost of routing computation. For this reason, an Evolutionary Algorithm (EA) is proposed to solve the problem.

In this chapter, a novel approach to multi-commodity multi-echelon distribution is presented, with a problem formulation that considers several providers, heterogeneous vehicle fleets and multiple objectives to model the problem and an EA to solve instances of said problem. Section 2 outlines the related work considered and studied in order to confirm the novelty of this research and define its scope, as well as the motivation for this work. Section 3 presents the mathematical model and problem formulation, including the problem and solution representation, constraints, and the proposed objective functions. Section 4 describes solution strategies and introduces the algorithm designed and developed to solve the formulated problem, as well as several assumptions and limitations adopted for this first iteration. Section 5 presents the experimentation framework and experimental results and analysis thereof. Finally, conclusions and future directions are proposed in Section 6.

RELATED WORK AND MOTIVATION

Research on the 2E-VRP is relatively limited, even more if considering said problem in the context of City Logistics and Urban Goods Movement. Related research is presented in this section, followed by the motivation for this work.

To the best of the author's knowledge, the first formal definition of a two-echelon routing optimization problem is made by Jacobsen and Madsen (1980) but the first theoretical analysis of formulations and problem issues of the 2E-VRP is found in Gonzalez-Feliu (2008), specifically considering the Two-Echelon Capacitated Vehicle Routing Problem (2E-CVRP). Gonzalez-Feliu et al. (2007) introduce the family of multi-echelon VRPs and present the 2E-CVRP. Other examples of contributions by Gonzalez-Feliu to the growing body of literature on the 2E-VRP and closely related topics include (Gonzalez-Feliu, 2011), where the main concepts of two-echelon distribution are presented via a systematic review, and Gonzalez-Feliu (2012) on the main concepts of multi-echelon distribution with cross-docks and a unified notation for the N-echelon location routing problem.

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Cattaruzza et al. (2017) briefly explore the well-known VRP in the context of multi-level distribution, defining CDCs and explaining the 2E-VRP as well as the Two-Echelon Location Routing Problem (2E-LRP). They identify the 2E-VRP as the most studied problem in multi-level distribution and lay out several common assumptions, such as a unique central depot. They also identify a number of articles that concern multi-level distribution. They refer to two articles in particular for complete surveys on two-level distribution systems (Gonzalez-Feliu, 2013a; Cuda et al., 2015).

Gonzalez-Feliu (2013) attempts to unify the concepts of multi-echelon distribution with cross-docks and the notation standards for cost optimization in order to provide a guide to researchers and practitioners. He first lists the main problems and methods found in the literature and subsequently presents the main concepts and standards of multi-echelon based vehicle routing optimization problems by applying a hybrid systematic analysis method combining a lexical and a meta-narrative analysis. A theoretical model and a classification of solution methods are also presented.

Cuda et al. (2015) survey two-echelon routing problems providing an overview of two-echelon distribution systems. They consider three classes of problems: the 2E-LRP, the 2E-VRP, and the Truck and Trailer Routing Problem (TTRP). Regarding specifically 2E-VRP, the problem class is described in general and the 2E-CVRP, being the most studied problem of the class, is emphasized, followed by a review of the foremost papers tackling the problems of this class. The papers listed and summarized in that work were mainly selected for the literature overview in this work, resulting in most relevant articles related to the 2E-VRP algorithms, both exact and heuristic. We however completed with other relevant works that were not taken into account in Cuda et al. (2015).

Crainic et al. (2010, 2011, 2013) present three separate but related papers on solving the 2E-VRP with (meta) heuristics based on separating the first and second level routing problems and solving iteratively the two resulting routing sub-problems, while adjusting the satellite workloads linking them. Their objective is to minimize the total cost of the traffic on the overall transportation network while the demand is delivered on time. In Crainic et al. (2010) they present several meta-heuristics, the two main ones using a clustering and a multi-depot VRP-based approach, respectively; in Crainic et al. (2011) they present a family of Multi-Start heuristics; and in Crainic et al. (2013) they propose a meta-heuristic based on GRASP (Greedy Randomized Adaptive Search Procedure) combined with Path Relinking to address the problem.

Separately, Crainic et al. (2009) focus on the integrated short-term scheduling of operations and management of resources, for the general case involving a two-tier distribution structure, this being a City Logistics planning issue. Fundamentally a modelling paper, they aim to present a comprehensive view of the problem, identify issues and challenges, and propose and analyze modelling approaches, also identifying promising solution avenues, but without detailed algorithmic developments. Crainc et al. (2009) explore the reality of freight distribution in an urban context in further depth than other papers on the 2E-VRP. The goal of their formulation is to minimize the number of vehicles in the city while satisfying demand requirements.

Perboli et al. (2010) present valid inequalities based on the Traveling Salesman Problem (TSP) and the Capacitated Vehicle Routing Problem (CVRP), the network flow formulation, and the connectivity of the transport system graph. An extension of this paper re-proposes the model of Gonzalez-Feliu et al. (2007) alongside with an extension of Perboli et al.'s (2010) inequalities into a Branch-and-Cut and two math-heuristics based on said model.

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Hemmelmayr et al. (2012) propose an adaptive large neighborhood search heuristic for the 2E-VRP and the Location Routing Problem (LRP). They consider the LRP to be a special case of the 2E-VRP in which vehicle routing is performed only at the second level. Additionally, they identify City Logistics as a potential application of the 2E-VRP. They assert that in most cities, space is limited, especially in the city center, and has to be shared among passenger transports, both public and private, as well as parking facilities. Furthermore, freight transportation produces congestion, polluting emissions and noise, and the presence of large, heavy vehicles is a discomforting factor for citizens. Moreover, they point out that large vehicles frequently have low average loads. They suggest that the key idea is to develop an integrated logistic system encompassing all components by consolidating freight that comes from different shippers and coordinating the freight transportation in the city. To the best of our knowledge, the most performing heuristic for the 2E-CVRP is that of Hemmelmayr et al. (2012) and, as shown in Gonzalez-Feliu (2019) few works on such heuristics are proposed since, most new works on 2E-VRP dealing with proposing new variants than on trying to solve the basic version of the problem. From those variants, we highlight three papers (Gonzalez-Feliu and Salanova, 2012; Eitzen et al., 2017) dealing with urban and regional distribution, which implies various depots, various stakeholders/providers, and sometimes time constraints. The two first works deal still with a mono-objective formulation and the second with a multi-objective one.

Regarding exact methods, Jepsen et al. (2013) present an exact method to solve the symmetric 2E-CVRP. The presented method is based on an edge flow formulation of the CVRP introduced by Laporte and Nobert (1983) and the Split-Delivery CVRP (SDCVRP) formulation proposed by Belenguer et al. (2000). The mathematical model is a relaxation for the 2E-CVRP and provides a lower bound for the problem, but it does not necessarily provide feasible solutions. A specialized branching scheme is employed to obtain feasible solutions, solving the problem to optimality. The objective is to minimize vehicle travel costs and the handling costs at the satellites. Baldacci et al. (2013) describe a formulation of the 2E-CVRP used to derive valid lower bounds and an exact method that decomposes the problem into a limited set of multi-depot CVRPs with side constraints. Santos et al. (2012) try a Branch-and-Prize based on Column Generation, but as announced in Gonzalez-Feliu (2008) and confirmed in Gonzalez-Feliu (2019), the proposed set covering formulations have difficulties to converge. Table 1 compares the above-mentioned papers. We compete it with the three papers dealing with urban and regional distribution problems (Gonzalez-Feliu and Salanova, 2012; Eitzen et al., 2017).

One can see in Table 1, as Cuda et al. also point out, that only Crainic et al. (2010) consider the 2E-VRP with additional characteristics, these being a multi-depot, multi-provider formulation with heterogeneous fleets of vehicles at each level and time windows. However, the authors of Crainic et al. (2010) provide only a formulation of the problem and some solution methods, but no algorithm is presented, and to the best of the author's knowledge, such algorithm has not yet been implemented and no computational experiments have been reported. Their formulation is also not multi-objective. Therefore, the multi-objective 2E-VRP with multiple depots and providers, as well as other characteristics appropriate for the context of City Logistics and Urban Goods Transport, is identified in this work as yet unsolved.

The ultimate goal and motivation of this research is to aid city governments in the development and implementation of a multi-stage freight distribution software based on the 2E-VRP within a UGM context, and for this to be seriously considered, a formulation that goes beyond the simple single-depot single-provider model must be developed. This model is considered to be multi-objective as there are multiple stakeholders with potentially conflicting objectives.

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Table 1. Summary of related works

Reference	Type of Algorithm	Multi-Depot	Multi-Commodity	Fleet	TW	Objective
Crainic et al. (2010)	Heuristic	No	No	Homogeneous	No	Minimize travel distance
Crainic et al. (2011)						
Crainic et al. (2013)						
Hemmelmayr et al. (2012)						
Perboli et al. (2010)	Exact					
Perboli et al. (2011)						
Santos et al. (2013)						
Jepsen et al. (2013)						
Baldacci et al. (2013)						
Mancini (2014)	Exact	Yes	No	Heterogeneous	Yes	Cost
Gonzalez-Feliu and Salanova (2012)	Heuristic	Yes			No	Travel time
Eitzen et al.(2017)			Yes			Cost, vehicle use, CO_2 emissions

As a proof of concept of the proposed solution framework, an algorithm that solves theoretical instances of said model must be designed and developed. In the following chapters, a first-time model and algorithm are presented and explored as a first step towards a real-world functioning holistic framework for multi-objective, multi-commodity, and multi-echelon distribution of goods in urban centers, these being the main contribution of this research.

PROPOSED MATHEMATICAL MODEL

According to the survey discussed in the previous section Crainic et. al (2004) and to the best of the author's knowledge, no mathematical model and framework exists for the Multi-Objective Two-Echelon Vehicle Routing Problem from a city government perspective. In this section, a model that considers multiple objectives, multiple providers (depots and products), and multiple vehicle types (or heterogeneous fleets) is presented, followed by two motivational examples to showcase the multi-provider approach to multi-echelon distribution and the calculation of the objective functions presented in the model.

Additionally, a proposal for formulating and mathematically modelling the Multi-Objective Multi-Commodity 2E-VRP (tentatively identified as M2-2E-VRP) with heterogeneous fleets is presented. This formulation considers the following stakeholders:

- Providers;
- independent contractors for distribution or city companies (clients);
- city government and residents (taken together as their objectives may be considered to be the same).

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Given these stakeholders, the four objective functions to be optimized in this formulation are the following:

- $f_1(s)$: transportation cost in the first echelon, related to the costs of providers (see Equation (20));
- $f_2(s)$: transportation cost in the second echelon, of concern to independent contractors or clients, depending on who bears the brunt of the distribution costs in this level (see Equation (21));
- $f_3(s)$: number of vehicles used, related to traffic contribution, of concern to the city government and residents (see Equation (22)); and
- $f_4(s)$: carbon emissions, of concern to the city government and residents (see Equation (23)).

Problem Representation

The proposed formulation of the M2-2E-VRP assumes as known the sets of depots, satellites, customers and vehicles separated into their respective echelons. These sets, defined by extending the work of Eitzen et al. (2017) on the basis of the basic 2E-CVRP vehicle flow formulation of Gonzalez-Feliu (2008, 2019), are represented in this work as follows:

- a set D of n_D depots;
- a set S of n_S satellites;
- a set C of n_C customers;
- a set L_1 of m_1 first-echelon vehicles; and
- a set L_2 of m_2 second-echelon vehicles.

Each depot i is associated with a unique product p; consequently, there are n_D products. Regarding the depots, satellites, and customers, the following data is required as well:

d_{ij}: distance from i to j (length of arc)

where i and j may be any depot, satellite, or customer where an edge, or arc, exists. For simplicity and considering the parameters used further ahead, the unit of measurement of distance will be kilometers.

As this formulation considers heterogeneous fleets with differing characteristics in each vehicle, parameters referring to the capacity and carbon emissions of the vehicles do not describe whole sets of vehicles but are associated with individual vehicles. In this work, k is used for capacity, c for cost per kilometer and g (garbage) for carbon emissions. Cost per kilometer is a single parameter for each vehicle that summarizes the inherent costs of operation, such as fuel consumption and maintenance. These parameters are represented as follows:

- k_q^1: capacity of L1 vehicle q, in weight (kg);
- k_r^2: capacity of L2 vehicle r, in weight (kg);
- NPs_i: number of product types managed by satellite i;
- NPc_i: number of product types managed by customer i;
- c_q^1: unitary cost per kilometer of L1 vehicle q;
- c_r^2: unitary cost per kilometer of L2 vehicle r;

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- g_q^1: greenhouse gas emissions of L1 vehicle q (in g CO_2 per km);
- g_r^2: greenhouse gas emissions of L2 vehicle r (in g CO_2 per km).

In the classic VRP and subsequent formulations, a non-negative weight or demand may be attached to each customer, who must be satisfied (Laporte, 1992). This demand is usually one-dimensional for each customer, or one-commodity as it is also known (Hernandez-Perez and Salazar-Gonzalez, 2004)). In this formulation however, multiple products are considered, known as multi-commodity, and the representation of the demand must reflect this multi-dimensionality. Therefore, this formulation considers a variable demand (represented by r as in requires) associated with both a customer and a specific product, resulting in practice in an array of demands by each customer:

dem_i^p: demand of product *p* by customer *i*

Solution Representation

The resulting solutions are sets of routes taken by the vehicles and the combination of freight carried and delivered by each vehicle to each point on its associated route. We will define the problem using a vehicle flow model (Toth and Vigo, 2014) as an extension of the basic version of the problem (i.e., mono-commodity and mono-objective) proposed in Gonzalez-Feliu (2008, 2019). This information may be constructed with the following variables:

- x_{ij}^q and y_{ij}^r: binary variables that represent the usage of arc (i; j) by a vehicle in each echelon (x_{ij}^q for the first echelon and y_{ij}^r for the second echelon). Those variables take a value of 1 if the considered vehicle travels the considered arc and 0 otherwise.
- z_{ij}^{pq}: real variable that represents the quantity (in weight) of product *p* carried by vehicle q on each edge (*i; j*) it travels

Moreover, a vehicle usage variable is derived from x and y:

- u_q^1: binary variable that takes the value of 1 if 1st-echelon vehicle *q* is used and 0 otherwise.
- u_r^2: binary variable that takes the value of 1 if 2nd-echelon vehicle *r* is used and 0 otherwise.

Constraints

In order for a solution to be valid, it must satisfy all customers' demands while complying with vehicle movement and capacity restrictions. A valid solution is restricted by the following constraints.

Constraints (1, 2, 3) ensure the consistency of product demand volume. Constraint (1) ensures that the total volume of products leaving a depot is equal to the total demand for that product.

$$\sum_{i\in D}\sum_{j\in S}\sum_{Q\in L_1} z_{ij}^{pq} = \sum_{k\in C} dem_k^p \forall p = \left\{.1,2,\ldots,n_D\right\} \quad (1)$$

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Constraint (2) ensures that the total quantity of a certain product carried to any satellite must either satisfy or exceed (because it could also be intended for a subsequent satellite) the combined volume of products that leave that satellite.

$$\sum_{i\in D\cup S}\sum_{Q\in L_1} z_{ij}^{pq} \geq \sum_{k\in C}\sum_{Q\in L_1} z_{jk}^{pr} \forall j \in S; \forall p = \left\{1,2,\ldots,n_D\right\} \tag{2}$$

Constraint (3) ensures that the total quantity of a certain product carried to any customer must either satisfy or exceed (because it could also be intended for a subsequent customer) the customer's stated demand.

$$\sum_{i\in D\cup S}\sum_{q\in L_2} z_{ij}^{pq} \geq dem_k^p \forall j \in C; \forall p = \left\{1,2,\ldots,n_D\right\} \tag{3}$$

Constraints (4) through (11) ensure the consistency of the freight quantity carried along routes. Constraints (4) and (5) ensure that the freight quantity loaded onto an L1 vehicle at a depot, or L2 vehicle at a satellite, respectively, does not exceed the vehicle capacity. Moreover, they ensure that vehicles travel visit only nodes to deliver freight.

$$\sum_{P=1}^{n_D} z_{ij}^{pq} \leq k_q^1 \cdot x_{ij}^q \forall q \in L_1; \forall i \in D; \forall j \in S \tag{4}$$

$$\sum_{P=1}^{n_D} z_{ij}^{pr} \leq k_r^2 \cdot y_{ij}^r \forall r \in L_1; \forall i \in S; \forall j \in C \tag{5}$$

Constraints (6) and (7) ensure that the products of the same type are only carried by a vehicle q on arcs said vehicle effectively travels.

$$\sum_{i\in S} x_{ij}^q \leq NPs_j \forall q \in L_1 \tag{6}$$

$$\sum_{i\in C} y_{ij}^r \leq NPc_j \forall r \in L_2 \tag{7}$$

Constraints (8) and (9) ensure that the volume of products carried is equal or reduced at each step of a route, and that the considered customer at that step is delivered by the right quantity of freight (i.e. its demand).

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$$\sum_{i\in D\cup S} z_{ij}^{pq} \leq \sum_{j\in D\cup S} z_{jk}^{pq} \forall p \in \left\{1;2;\ldots;n_{D}\right\}; \forall q \in L_{1}; \forall j \in S \tag{8}$$

$$\sum_{i\in S\cup C} z_{ij}^{pr} \leq \sum_{j\in S\cup C} z_{jk}^{pr} \forall p \in \left\{1;2;\ldots;n_{D}\right\}; \forall r \in L_{21}; \forall j \in C \tag{9}$$

Constraints (10) and (11) ensure that all vehicles return empty to their starting depot or satellite.

$$\sum_{i\in S}\sum_{j\in D}\sum_{p=1}^{n_{D}}\sum_{q\in L_{1}} z_{ij}^{pq} = 0 \tag{10}$$

$$\sum_{i\in C}\sum_{j\in S}\sum_{p=1}^{n_{D}}\sum_{r\in L_{2}} z_{ij}^{pr} = 0 \tag{11}$$

Constraints (12) through (19) ensure the consistency of routes. Constraints (12) and (13) ensure that each L1 vehicle begins and ends its trip at only one depot, and that each L2 vehicle begins and ends its trip at only one satellite.

$$\sum_{i\in D}\sum_{j\in S} x_{ij}^{q} = \sum_{i\in S}\sum_{j\in D} x_{ij}^{q} \leq 1 \forall q \in L_{1} \tag{12}$$

$$\sum_{i\in S}\sum_{j\in C} y_{ij}^{r} = \sum_{i\in C}\sum_{j\in S} y_{ij}^{r} \leq 1 \forall r \in L_{2} \tag{13}$$

Constraints (14) and (15) ensure that the depot or satellite from which a vehicle departs is also the same to which it returns.

$$\sum_{j\in S} x_{ij}^{q} = \sum_{j\in S} x_{ji}^{q} \leq 1 \forall q \in L_{1}; \forall i \in D \tag{14}$$

$$\sum_{j\in C} y_{ij}^{r} = \sum_{j\in C} y_{ji}^{r} \leq 1 \forall r \in L_{2}; \forall i \in S \tag{15}$$

Constraints (16) and (17) ensure that trips are contiguous and no vehicle visits the same location more than once.

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$$\sum_{i \in D \cup S} x_{ij}^{q} = \sum_{k \in D \cup S} x_{jk}^{q} \leq 1 \forall q \in L_1; \forall j \in D \cup S \tag{16}$$

$$\sum_{i \in S \cup C} y_{ij}^{r} = \sum_{k \in S \cup C} y_{jk}^{r} \leq 1 \forall r \in L_2; \forall j \in D \cup S \tag{17}$$

The definitions of x and y already prevent L1 vehicles from traveling to customers and L2 vehicles from traveling to depots. Constraints (18) and (19) additionally prevent L1 vehicles from traveling between depots and L2 vehicles from traveling between satellites.

$$\sum_{i \in D} \sum_{j \in D} \sum_{q \in L_1} x_{ij}^{q} = 0 \tag{18}$$

$$\sum_{i \in S} \sum_{j \in S} \sum_{r \in L_2} y_{ij}^{r} = 0 \tag{19}$$

Objective Functions

Although in general some objective functions can be minimized while maximizing other objective functions, in this work each of the considered objective functions is formulated in a single optimization context (i.e. only minimization). In this work, optimizing the following four objective functions is proposed in order to obtain optimal solutions:

- first echelon transportation cost minimization;
- second echelon transportation cost minimization;
- number of vehicles minimization; and
- carbon emissions minimization.

Transportation Cost Minimization

Typically, as seen in Table 1, most works dealing with 2E-VRP consider some form of traffic or transportation or shipping cost minimization as the only objective to optimize. This is included in this work as transportation cost. However, it is divided into two separate objective functions, one for the first echelon and one for the second, given that they may affect different stakeholders as previously mentioned (providers and contractors or clients). This considers that two different solutions may have the same or similar cost of transportation, but one with more routing (and therefore cost) in the first echelon, and the other in the second one. Furthermore, although previous works [24] use only a single cost parameter for each arc to calculate the transportation cost, in this work two are used (i.e. c and d). This is due to previous works' use of homogeneous fleets, where the cost of operation of all vehicles would be the same and therefore the total cost would be directly proportional to the total accumulated distance covered by

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all vehicles. For this reason, there was no need to consider cost of operation separately from distance. However, in this present work, the fleets are heterogeneous and the cost of operation will in all likelihood differ among vehicles (e.g. fuel consumption of a diesel vehicle compared to a petrol vehicle of same or similar capacity).

The objective functions regarding transportation cost are formulated below.

Transportation cost in the first echelon:

$$f_1(s) = \sum_{q \in L_1} \sum_{i \in D \cup S} \sum_{j \in S \cup C} c_q^1 . d_{ij} . x_{ij}^q \tag{20}$$

Transportation cost in the second echelon

$$f_2(s) = \sum_{r \in L_2} \sum_{i \in S \cup C} \sum_{j \in S \cup C} c_r^2 . d_{ij} . y_{ij}^q \tag{21}$$

Minimization of the Total Number of Vehicles

A situation may arise in which the solution with the lowest transportation cost utilizes all available vehicles. However, it may be desirable to keep the vehicles traveling at a low number in order to avoid saturating the transportation network. Therefore, minimizing the quantity of vehicles used is considered as an objective function, formulated as follows:

$$f_3(s) = \sum_{q \in L_1} u_q^1 + \sum_{r \in L_2} u_r^2 \tag{22}$$

Carbon Emissions Minimization

Few papers concerning 2E-VRP, if any, and none to the knowledge of the author, explicitly consider environmental impact minimization as an objective function to be optimized. Environmental impact is however a more studied subject within the framework of City Logistics and Urban Goods Transport, specifically within the field of city logistics sustainability (Russo and Comi, 2012). Urban mobility accounts for 40% of all CO_2 emissions of road transport and up to 70% of other pollutants from transport, and traffic emissions in general are responsible for 70% of cancerous and other dangerous substances (Silva and Ribeiro, 2009). As this work concerns 2E-VRP from a UGM perspective within a City Logistics framework, environmental impact minimization is considered as a necessary goal. This objective function is formulated as follows:

$$f_4(s) = \sum_{q \in L_1} \sum_{i \in D \cup S} \sum_{j \in S \cup C} g_q^1 \cdot d_{ij} \cdot x_{ij}^q + \sum_{r \in L_2} \sum_{i \in S \cup C} \sum_{j \in S \cup C} g_r^2 \cdot d_{ij} \cdot y_{ij}^q \tag{23}$$

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Objective function (23) potentially conflicts with the first two relating to transportation cost, as vehicles with a lower rate of emissions (e.g. electric or hybrid) may currently have higher operation costs, depending on how these are calculated, due to the higher cost of acquisition, maintenance, and fuel, or limited supply thereof (Van Vliet et al., 2011).

It should be noted that other pollutants, such as carbon monoxide or nitrogen oxides, can also be considered and appended as additional objective functions within this novel formulation. It is only a matter of adding the required information to the vehicles and formulating the objective function based on (23).

Problem Complexity and Solving Issues

Once the problem defined, it is important to address its complexity and propose suitable methods to solve it. According to Gonzalez-Feliu (2019), in solving vehicle routing problems but more generally in city logistics modelling and optimization issues, it is important to verify the suitability of the modelling issues and also the representability of the realty the modeler deals with.

In our context, the real problem to be modelled is a city logistics multi-stage delivery problem that needs to be addressed in a multi-objective way. Concerning the two-echelon vehicle routing problem, the proposed formulation takes into account both the consolidation-distribution nature of city logistics and urban freight transport systems and the presence of various transporters and commodity flows (Gonzalez-Feliu, 2013b). Moreover, and taken into account the plethora of stakeholders in urban transport (Gonzalez-Feliu et al., 2018), needs to take into account multiple criteria. In that context, addressing multi-criteria analysis as a sum of weights, or even defining weights seems to us not a suitable and representative way to deal with it, since summing weights implies giving more importance to one criterion and then conditioning, if for this criterion there is one option outstanding the rest, the decision to only that criterion because of both weight and solution dominances. On another hand, since the aim of the optimization is to provide a tool to feed consensus and analyze the potential of trade-offs, a non-weighed tool seems more suitable. Finally, since the different criteria cannot be expressed on a comparable basis, i.e. using the same units (since they are heterogeneous), a multi-objective optimization appears as a really suitable option. For that reason, the proposed model fits with the reality that we aim to analyze.

Regarding the problem's complexity, and as stated above, the problem is issued from combining two single-stage VRP's (Gonzalez-Feliu, 2008) with a resource allocation problem (or location-allocation problem if we consider satellites to be not all open, and then the choice of opening them is related to a location problem, Jacobsen and Madsen). Since the VRP is an extension of the Travelling Salesman Problem (TSP), which is known to be NP-Hard, as well as 2E-CVRP and all two-echelon vehicle routing (and location routing) variants (Gonzalez-Feliu, 2012). In that context, the proposed formulation is difficult to be solved, for real size instances, with a linear programming solver. Indeed, linear programming allows to solve the mono-commodity, mono-depot version of the problem for instances up to 2 satellites and 32 customers, and exact methods up to 10 satellites and 200 customers (Gonzalez-Feliu, 2019). Adding the complexity of a multi-objective optimization may make more difficult to solve the problem (as well as adding the multi-commodity component, Contardo et al., 2017). For those reasons, the model proposed here is given a title of illustration of the problem's complexity but is not solved with a linear programming tool or an exact algorithm.

Indeed, we propose a heuristic algorithm to solve the problem. Since multi-objective optimization needs an in-depth exploration of solution spaces, we propose an evolutionary algorithm, which combines genetic algorithms and local search meta-heuristics that improve the aforementioned genetic algorithm.

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Evolutionary Algorithms (EAs) are population-based algorithms for optimization problems that use meta-heuristics to iteratively evolve towards better solutions.

Genetic Algorithms (GAs), the most common EA, emulate the process of biological evolution, representing solutions as chromosomes and using mechanisms inspired by evolutionary biology, such as reproduction and mutation (Davis, 1991). EAs have been found to be especially suited to multi-objective optimization problems with high complexity (Zitzler and Thiele, 1999). Considering the large amount of input parameters and the multi-objective nature of the formulation presented in this work, a deterministic algorithm would prove unfeasible, and a Multi-Objective Evolutionary Algorithm (MOEA) is proposed and presented in this section. The proposed algorithm is based on the Non-dominated Sorting Genetic Algorithm II (NSGA-II) proposed by Deb et al. (2000) which, according to the specialized literature, is currently a reference algorithm even used for comparison with new multi-objective methods (Coello Coello et al., 2007). We describe the proposed EA algorithm below.

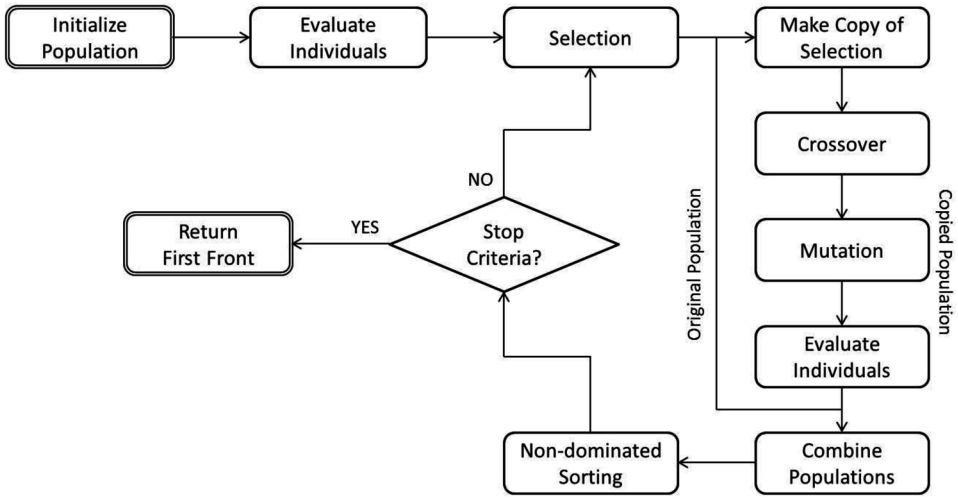
PROPOSED EVOLUTIONARY ALGORITHM

In this section we present the proposed EA algorithm. Therefore, an outline of the NSGA-II is described, followed by a detailed description of the first algorithm developed to solve the M^2-2E-VRP, including the design of the chromosome representation, generation of initial population, crossover and mutation mechanisms and a solution repair method, as well as a few assumptions and limitations considered for the correct functioning of this algorithm.

Non-Dominated Sorting Genetic Algorithm II

The NSGA-II is an enhancement of the original Non-dominated Sorting Genetic Algorithm (NSGA) presented by Srinivas and Deb

Figure 1. Non-dominated Sorting Algorithm II



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It resembles a simple GA, albeit with a significant variation in the selection operator, leaving the crossover and mutation operators unmodified. Before any selection is performed, the population is ranked according to the non-domination of the individuals. In this manner, the population is separated into fronts, the first being composed entirely of non-dominated individuals, the second being composed of individuals dominated only by those in the first front, and so forth.

Within a front, individuals are sorted according to a crowd comparison factor, in order to guide the selection process towards a uniformly spread out Pareto-optimal front. The population is then reproduced according to this ranking, the first N individuals being selected, N being the chosen population size. This process is known as Non-dominated Sorting. At each generation, a copy of the selected population is modified with crossover and mutation operators, and then combined with the original selected population, resulting in a population of size 2N, which is, once again, sorted by Non-dominated Sorting and the first N individuals selected for the next generation. A flowchart of the described process can be seen in Figure 1.

Assumptions and Limitations

Although an algorithm that can work with any vehicle type and demand volume is desirable, the development of such an algorithm is considered as future work. Certain assumptions were made about in-put data as well as limitations imposed on the algorithm search space.

The vehicle fleet in the first echelon is assumed to be homogeneous, and each vehicle is assigned to a single provider, reflecting a scenario where all providers use their own trucks. Furthermore, it is assumed that each provider has only one vehicle and the combined demand volume for any single product is not greater than the capacity of the designated first-echelon vehicle, essentially signifying that, in the first echelon the entire volume of demand for a certain product is served by a single vehicle to the satellites that require it. These assumptions allow for the first-echelon routing to be solved as n_D (number of depots or providers) parallel TSP instances (Miller et al., 1960; Gavish and Graves, 1978), instead of being part of the chromosome and consequently enlarging the search space.

An exact algorithm is used to solve the arising TSP instances. Not only is this algorithm used to deterministically solve first-echelon routing, it is also used to route the second-echelon vehicles once clients have been assigned to them, as well as the products they must deliver to them. Said algorithm solves TSP instances to optimality in relatively low time given the instance isn't too large. Therefore, it is assumed that no vehicle serves more than 12 clients or satellites, for a maximum total of 13 points in a TSP instance. This limit, chosen empirically after tests that showed the time consumed by the algorithm to produce optimal results for sets of more than 13 points rose exponentially, is implied in the first echelon, as the problem instances are designed with no more than 5 satellites, and is imposed on the second echelon, where the largest instance contains 50 clients. See Section 4.4.1 for more de-tails on vehicle routing in both echelons, and Section 5 for more details on the instances designed for this work.

Additionally, assumptions are made about the demand volume and the vehicle capacity available in the second echelon. It is assumed that the combined second-echelon vehicle capacity is greater than the demand volume, allowing for solutions with variable number of vehicles used. It is also assumed that the demand by a single customer for a single product is not greater than the total capacity of the smallest second-echelon vehicle. Considering that the smallest vehicle in the instances presented in this work has a payload capacity of 700 kg, and that the distribution scheme is designed for daily or semi-daily

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demand, clients that demand more than 700 kg of a single product may be considered an exception and scenarios with this exception can be reasonably ignored by this first algorithm.

MOEA for M²-2E-VRP

The Multi-Objective Evolutionary Algorithm proposed in this work and developed for M2-2E-VRP uses the NSGA-II previously presented as foundation. A two-part chromosome was designed to represent the assignment of clients and distribution centers to vehicles, as well as sub-algorithms used for optimal vehicle routing on both echelons, executed for each modified individual at each generation. Specialized crossover and mutation operators that take into account the unique structure of the chromosome were designed, as well as a solution repair mechanism.

The pseudocode for the NSGA-II-based MOEA for M²-2E-VRP is outlined in Algorithm 1. It receives as input the following data:

- the number of depots n_D, number of satellites n_S and number of clients n_C (see Notation in Section 3.1);
- a first-echelon distance matrix of size $(n_D + n_S)^2$, containing the distances between depots and satellites, represented by $D^1=\{d_{ij}\}$;
- a second-echelon distance matrix of size $(n_S + n_C)^2$, containing the distances between satellites and customers, represented by $D^2=\{d_{ij}\}$;
- the demand matrix of size $(n_C n_D)$, containing the demand for each product by each customer, represented by $R = \{ d_i^p \}$
- the lists of vehicles, of sizes m_1 and m_2, containing each vehicle's characteristics (payload capacity k, cost per kilometer c, greenhouse gas emissions per kilometer *g*) represented by the first and the second echelon, respectively;
- the size *N* of the initial population; and
- the maximum number of generations *maxgen*.

As a result, the algorithm returns a Pareto set approximation, containing all non-dominated solutions found.

Chromosome Representation

When considering evolutionary algorithms, the representation of any solution (or individual) is known as the chromosome. For the problem presented in this work, a chromosome with two parts has been designed. The first part is an array of length m_2 (number of vehicles in L_2, see Notation in Section 3.1) and for increased clarity it is known as Starting Points. The second part is a matrix of n_C (number of clients in the second echelon) rows and n_D (number of depots, equal to the number of products as each depot is assigned exactly one product) columns, known henceforth as Product Delivery.

The Starting Points of the chromosome represent the satellites at which the vehicles in L_2 begin and end their routes. Each cell represents the starting and ending satellite for one second-echelon vehicle and it can have any integer value in $[0, n_S]$ (number of satellites). A value of 0 indicates that the vehicle is not being used.

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The Product Delivery portion of the chromosome represents which vehicles deliver which products to which customers. Each cell represents the delivery of the demand of a single product to a single customer, and can have any integer value in [1, m_2], unless the demand by said customer for that product is 0, in which case the value of the affected cell will be 0 in all individuals.

In a scenario with 6 vehicles in L_2, 3 depots and products, 3 satellites, 5 customers, and no demand by customers 2 and 4 for products 1 and 2 respectively, a chromosome could look like the following example.

$$Starting\ Points = \begin{bmatrix} 1 & 3 & 0 & 2 & 2 & 3 \end{bmatrix}$$

$$Product\ delivery = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 4 & 4 \\ 2 & 5 & 6 \\ 2 & 0 & 4 \\ 6 & 5 & 5 \end{bmatrix}$$

In the solution represented by (24), 5 of the 6 second-echelon vehicles are used; vehicle 3 is not, as indicated by the value 0 in cell 3 of Starting Points. Accordingly, the value 3 does not appear in Product Delivery as it would be inconsistent with Starting Points. Furthermore, the values 0 in positions (2,1) and (4,2) in Product Delivery reflect the lack of demand for products 1 and 2 by clients 2 and 4, respectively.

From the information encoded in this chromosome, one can deduce the clients served by each second-echelon vehicle, the points each vehicle needs to traverse (the clients and the assigned satellite), as well as which products will be distributed at each satellite, allowing the de-termination of the satellites to be served by each first-echelon vehicle. For example, the vehicles that start and end their routes at satellite 2 (vehicles 4 and 5) only deliver products 2 and 3. Therefore, the first-echelon vehicle assigned to depot 1 need not serve satellite 2.

Vehicle Routing in Both Echelons

The vehicle routing in the first and second echelon is not part of the chromosome and is not improved upon in every generation as part of the evolutionary process. Instead, the routing for each vehicle is deter-mined to optimality using a sub-algorithm. The routing problem for every vehicle, once given the list of locations to traverse (assigned depot and satellites for first-echelon vehicles, and starting satellite and clients for second-echelon vehicles), can be considered as an independent instance of the Travelling Salesman Problem, which can be optimally solved using a Branch-and-Bound (BB) algorithm (Balas and Toth, 1983).

When the quantity of locations that a vehicle must traverse is no greater than 3, the order is irrelevant as the distance between points is symmetric and the route must be circular (returning to the point of origin), and therefore the distance covered will always be the same. In these cases, the clients or satellites to be served will simply be sorted according to numerical order. Only if the first-echelon vehicle must serve more than 2 satellites, or a second-echelon vehicle must serve more than 2 clients, is the branch-and-bound algorithm used to optimally solve the routing problem.

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In the case of the solution represented by (24), the following information required for the routing sub-process can be deduced:

- L1 vehicle 1 starts at Depot 1 and serves Satellites 1 and 3. No BB algorithm required.
- L1 vehicle 2 starts at Depot 2 and serves Satellites 1 and 2. No BB algorithm required.
- L1 vehicle 3 starts at Depot 3 and serves Satellites 1, 2 and 3. BB algorithm required.
- L2 vehicle 1 starts at Satellite 1 and serves Client 1. No BB algorithm required.
- L2 vehicle 2 starts at Satellite 3 and serves Clients 3 and 4. No BB algorithm required.
- L2 vehicle 3 is not used.
- L2 vehicle 4 starts at Satellite 2 and serves Clients 2 and 4. No BB algorithm required.
- L2 vehicle 5 starts at Satellite 2 and serves Clients 3 and 5. No BB algorithm required.
- L2 vehicle 6 starts at Satellite 3 and serves Clients 3 and 5. No BB algorithm required.

Initial Generation

The first generation of individuals in an evolutionary algorithm is often generated according to a designed strategy. For the algorithm in this work, two individual generation strategies or methods were designed: an ordered generation method and a random generation method. The first combines a greedy strategy with randomness, while the second is more exploratory and uses just randomness. The initial population is composed of 30% solutions generated by the order strategy and 70% randomly-generated solutions.

Ordered Generation

The original focus of this work was the solution of traffic problems in the second echelon. It is therefore desirable that each client receives as few vehicle visits as possible, in order to disrupt business as little as possible. The ordered generation method seeks to do that by attempting to schedule the second-echelon vehicles in such a manner that each customer receives the visit of only one vehicle wherever possible. Essentially, the algorithm for ordered generation computes the Product Delivery component of the chromosome in two phases: a first one where the total demand of clients is attempted to be satisfied by single visits, and a second one where the demand of the remaining clients is satisfied by randomly choosing multiple vehicles with sufficient capacity, meaning that these clients receive multiple visits.

Additionally, the satellites are chosen in such a manner to minimize the travel of second-echelon vehicles, by computing and comparing the routing cost for each vehicle considering its assigned clients and each satellite as starting point. The number of clients each vehicle may serve is limited to 12 (see Section 4.2). The pseudocode for ordered generation is presented in Algorithm 2.

Random Generation

A second generation method was developed applying the more traditional approach of simple randomness. In this method, each cell in Starting Points and Product Delivery is randomly assigned, with the rule that only vehicles where the corresponding cell in Starting Points is greater than 0 can be assigned in Product Delivery, and no vehicle may serve more than 12 clients (see Section 4.2). In most cases, this may result in unfeasible solutions, so the solution repair method is applied after the generation. The pseudocode for random generation is presented in Algorithm 3.

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Crossover

When considering evolutionary algorithms, the crossover operator emulates the mating or \crossing over" of two individuals (parents) to form new individuals (children). For this algorithm, a specialized crossover operator that takes into account the specialized structure of the chromosome was developed. From two parent individuals, two child solutions are produced. Each child maintains the Starting Points of one of the parents while random rows of Product Delivery are swapped between them, as it can be seen in Figure 2. In most cases, this may result in unfeasible solutions, so the solution repair method is applied after the crossover. The parents are then replaced in the population by their children. Crossovers are performed with a 50% probability at each generation, that is, probabilistically on half of the copied population.

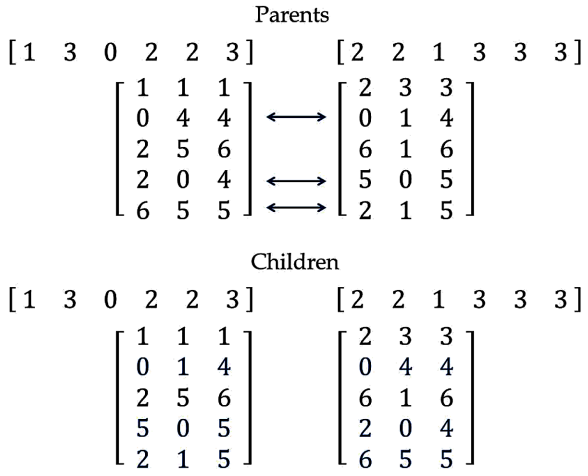
Mutation

The mutation operator emulates the mutations that occur naturally in the process of biological evolution, allowing the exploration of previously unknown and possibly beneficial characteristics for individuals. For this algorithm, a variety of mutation methods were developed, and then combined into a single mutation operator where some or all are applied in random order to a given individual.

The mutation operator is applied to all individuals in the copied population at each generation. In most cases, this may result in un-feasible solutions, so a solution repair method is applied after the mutation.

The starting satellites and clients served are swapped between two randomly selected second-echelon vehicles. Although the total distance covered will not change, provided both vehicles have sufficient capacity to serve the assigned demand, there may be a change in transportation cost and carbon emissions as each vehicle may have different characteristics in these aspects.

Figure 2. Crossover example



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Satellite Swap

Only the starting satellites are swapped between two randomly selected second-echelon vehicles. If both vehicles have the same starting satellite, new points of origin are randomly selected for each vehicle. This may lead to new routes not only in the second echelon, but also in the first as the alteration of services from a satellite may require changes in the service of first-echelon vehicles to the satellite.

Delivery Switch

A customer and product (where the demand for the product by the client is non-zero) are randomly selected, and a new vehicle is randomly selected to serve the selected product to the selected customer.

Customer Swap

Two second-echelon vehicles are randomly selected, followed by a random selection of two customers served by them. The products delivered by the selected vehicles to the selected clients are then reassigned to be delivered by the other selected vehicle.

Consolidate Service

A client and vehicle are randomly selected. The entire row in Product Delivery corresponding to the selected client is assigned to the selected vehicle.

Solution Repair

Taken into account the nature and quantity of the M^2-2E-VRP constraints, an unchecked generation, crossover, and mutation of individuals (i.e. when the respect of constraints is not verified at the generation phase) may lead to a large number of unfeasible solutions. Therefore, a solution repair method was developed, which is invoked at every generation of the algorithm. By design of the chromosome, problems such as multiple vehicles delivering the same product to the same client will not come up. The repair method verifies the client and capacity limit of each vehicle and corrects if any vehicle exceeds these limits. It also verifies that all vehicles that serve clients have a starting satellite and that no non-used vehicle has a non-zero starting point. The routing of vehicles is performed after solutions are repaired. The procedure of the repair method is outlined in Algorithm 4.

EXPERIMENTAL RESULTS

In order to validate the evolutionary approach presented in Section 4 to the M2-2E-VRP model proposed in Section 3, several experiments were performed. These experiments concerned the quality of the solutions provided, the scalability of the algorithm, and the improvement of the solutions at each generation according to the hypervolume metric, the unary metric preferred by the research community according to Riquelme et al. (2015). In this section, the experimental framework and the design of the experiments is laid out, as well as the results of the performed experiments.

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The NSGA-II-based algorithm presented in the previous section was implemented in Python 2.7 and it is publicly available online[1]. The chromosome, crossover and mutation operators, solution repair, and evaluation methods were written and implemented by the authors, while for the NSGA-II framework, including the non-dominated sorting of the populations and procurement of the Pareto set approximation, the DEAP[2] implementation was used (Fortin et al., 2012).

Ten different instances of the M[2]-2E-VRP were designed for the experiments, denoted as I_1 to I_{10} (see Table 3). These instances consider real data from the city of Guayaquil including five CDCs or satellites, ten depots and 856 clients, and are publicly available at the same site as the algorithm code[2]. Each of these instances is a data le that contains: the number of depots (n_D), satellites (n_S), and customers (n_C); two distance matrices (D^1, D^2), one for each echelon; a demand matrix (R), with n_C rows and n_D columns; the characteristics of the L_1 vehicle type, and the characteristics and quantity available of each L_2 vehicle type. The depots, satellites, clients, and vehicle types are identified with real-world names, however these are only of use to the reader and are not used by the algorithm, which only returns the numerical identifiers in its solutions.

The accurate locations and coordinates were obtained with Google Earth[3], and the distance matrices, with distances in kilometers, using the Geographic Distance Matrix Generator version 1.2.3[4]. The distances correspond to geometric or Euclidean distances and are symmetric. The vehicle types used, seen in Table 2, correspond to existing vehicles, such as the Renault Kangoo used in Section 3.5. However, although the characteristics of these vehicles are not random and in-tend to portray actual vehicles with relative realism, they were set arbitrarily, based on available data from diverse online sources, and do not necessarily reflect accurately the specifications of their real-world counterparts.

The demand matrix for each instance was generated randomly, by allocating demands between 0 and 700 kilograms (the payload capacity of the smallest vehicle, see Section 4.2) to each client-product intersection, in such a manner that the total demand for a single product does not exceed the available capacity of the first-echelon vehicle type, and that the combined demand of all products is less than the combined available capacity of second-echelon vehicles, in order to allow solutions with variable number of vehicles used (see Section 3.4.2). The number of vehicles available at each instance was set arbitrarily, increasing according to the number of clients.

A summary of the characteristics of each instance designed can be seen in Table 3, including the number of depots, satellites, and clients considered, the total demand for all products by the clients, the combined capacity of all second-echelon vehicles, and the number of vehicles available.

Three experiments were designed and performed on the instances in order to evaluate the following aspects:

Table 2. Vehicle types used in experiment instances

Vehicle Type	Echelon	Capacity (kg)	Cost (Gs./km)	Emissions (gCO_2/km)
Fuso Canter 7C15	1	5500	673.53	408
Renault Master SWB	2	1600	443.82	204
Renault Master LWB		1400	415.37	189
Renault Kangoo		800	400.00	180
Fiat Fiorino Van		700	392.61	161

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Table 3. Summary of instances used in experiments

Instance	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9	I_{10}
Depots (n_D)	10	10	10	10	10	10	10	10	10	10
Satellites (n_S)	5	5	5	5	5	5	5	5	5	5
Clients (n_C)	10	20	30	40	50	60	70	80	90	100

- Quality of Solutions: a comparison of the optimal Pareto front obtained by an exhaustive search algorithm and the Pareto set approximation obtained by the proposed evolutionary algorithm.
- Algorithm Scalability: a demonstration of the capacity of the proposed algorithm to execute workloads of different sizes in reasonable time, including workloads for which it would be unfeasible to obtain optimal solutions.
- Hypervolume Improvement: an analysis of the change in the hypervolume metric over the course of the execution of the pro-posed algorithm.

The experiments were performed on a Dell server, with following characteristics: Intel(R) Xeon(R) CPU E5-2640 v4 Processor @ 2.40GHz with 128 GB DDR3 RAM running Linux. The version of Python used was 2.7.9.

Experiment 1: Quality of Solutions

For this first experiment, an exhaustive search algorithm was developed in Python and executed on an instance in order to obtain the optimal Pareto set for that instance, and subsequently compared with the combined Pareto set approximation of 10 runs of the proposed evolutionary algorithm on the same instance. The exhaustive search algorithm, available online at the same site as the code for the MOEA[5], essentially iterates through all possible Product Delivery combinations and, if a certain combination is valid, tests all valid Starting Points combinations for the Product Delivery matrix, each combination being an individual unique solution. The size of the decision space in each instance is $n_S{}^m 2\ m_2{}^n C^n D$ (see Notation in Section 3.1). Due to the Decision Space size and computational time needed by the exhaustive search algorithm, this experiment was only performed on the first in-stance (I_1). The runs of the evolutionary algorithm in each case were performed with a population size of 100 (N = 100) over 100 generations (maxgen = 100). The evaluation of the results can be seen compared in Table 5 which contains the following columns:

- Hypervolume: hypervolume value (n-dimensional space that is contained by a solution set, if solutions are considered as points in the objective space, Bradstrfleet, 2011) for the Pareto sets obtained by exhaustive search and the proposed evolutionary algorithm, respectively. Simon Wessing's Python implementation[6] is used for its computation in this work. The hypervolume metric computation requires reference points, and the reference points used for each objective function for each instance, including for this and for the following experiments, are listed in Table 4.
- NofSol: number of solutions found by each algorithm. The number of solutions that are finally non-dominated is also specified for the evolutionary algorithm; this it is calculated by counting

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Table 4. Objective function reference points for hypervolume metric

Instance	Reference Points			
	f_1	f_2	f_3	f_4
I_1	246.000	4.000	38	151.000
I_2	245.000	6.000	44	151.000
I_3	249.000	9.000	44	153.000
I_4	246.000	9.000	50	153.000
I_5	249.000	42.000	50	168.000
I_6	249.000	12.000	50	154.000
I_7	249.000	16.000	64	157.000
I_8	249.000	49.000	64	172.000
I_9	249.000	21.000	64	159.000
I_{10}	249.000	43.000	64	170.000

how many solutions are among the solutions found by the exhaustive search and how many are not.

- PercHypDif: the percentage of hypervolume difference between the obtained Pareto sets is shown in this column, and is calculated using the exhaustive search hypervolume (HV_{ES}) and the evolutionary algorithm hypervolume (HV_{MOEA}) as follows:

After combining all 10 Pareto set approximations produced by the evolutionary algorithm into a single set of non-dominated solutions, it can be seen that the optimal Pareto front is obtained. In this manner, it is demonstrated that the proposed evolutionary algorithm can procure good quality solutions as compared to an optimal solution set.

Experiment 2: Algorithm Scalability

The purpose of this experiment is to demonstrate the capability of the proposed evolutionary algorithm to provide solutions for instances of varying sizes, with increasing workloads. One run with a population size of 100 (N = 100) over 100 generations (maxgen = 100) was performed on each of the five previously described instances. Experimental results can be seen in Table 6, with the same columns as in Table 5 except for PercHypDif, in addition to a column indicating the instance and the elapsed time in the following time format: H:MM:SS.

With this experiment it can be verified that the proposed algorithm is scalable, being capable of dealing with instances of various sizes in reasonable time (considering small server computational resources).

Experiment 3: Hypervolume Improvement

Finally, in order to demonstrate the improvement of the set of solutions throughout the course of the algorithm execution, the third experiment analyses the hypervolume of the Pareto set approximations provided at discrete intervals. The values of the Pareto set approximation were stored after each 20 gen-

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Table 5. Comparison of exhaustive search algorithm and MOEA on I_1 instance

Exhaustive Search		Evolutionary Algorithm		PercHypDif
Hypervolume	**NofSol**	**Hypervolume**	**NofSol**	
115,048,754,180	22	115,048,754,180	22.22 non-dominated	0%

erations on the runs of the algorithm for the previous experiment, and the hypervolume at each of these points was computed using Simon Wessing's Python implementation[6].

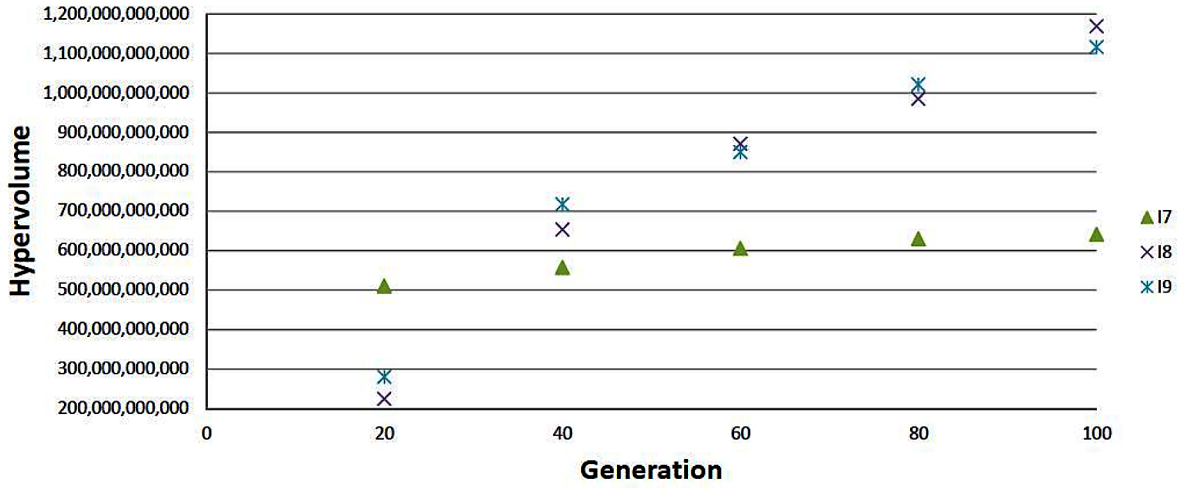
The hypervolume metric computation requires reference points, and the reference points used for each objective function for each instance are listed in Table 6.

Example results (for instances I_7, I_8 and I_9) of these computations can be visualized in Figure 11, corresponding to the progress of the hypervolume of the Pareto set approximation during the execution of

Table 6. Performance of proposed MOEA on all instances

Instance	Hypervolume	NofSol	Time
I_1	115,048,754,180	22	0:00:41
I_2	31,054,505,566	23	0:02:01
I_3	120,332,472,404	36	0:13:14
I_4	23,449,240,268	9	2:41:15
I_5	2,882,517,813,872	99	1:52:24
I_6	598,219,753,796	55	4:18:40
I_7	641,126,941,080	40	1:25:14
I_8	1,168,228,358,334	59	1:51:33
I_9	1,115,520,901,788	76	1:35:31
I_{10}	1,308,816,075,351	94	0:54:45

Figure 3. MOEA hypervolume progress



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the MOEA. As the hypervolume is a metric of the objective space covered, an increasing hypervolume implies an improving set of non-dominated solutions. In all charts it can be seen that the hypervolume effectively increases as the MOEA progresses through generations. Thus the progressive improvement of the solution set of the proposed evolutionary algorithm is demonstrated, indicating that executing a larger number of generations generally result in better quality solutions.

CONCLUSION AND FUTURE WORK

This chapter presented the case for using a holistic multi-objective multi-level distribution strategy concerning all significant stakeholders, both businesses and city authorities, as means to reduce traffic congestion and its resulting pollution in an urban context while minimizing financial cost. The proposed strategy is based on organizing the commercial traffic related to the movement and delivery of goods in an urban area, from the viewpoint of a city government seeking a holistic solution method, within the framework of a two-tiered distribution scheme known as the Two-Echelon Vehicle Routing Problem (2E-VRP). Said strategy adapts the 2E-VRP to the context of City Logistics and Urban Goods Movement by considering multiple providers, products, depots, stakeholders and objectives, as well as heterogeneous vehicle fleets, thus receiving the name of Multi-Objective Multi-Commodity Two-Echelon Vehicle Routing Problem (M^2-2E-VRP). This problem was subsequently mathematically modelled and formulated, including problem and solution representations, constraints, and objective function calculations.

Several stakeholders were considered, namely providers, independent contractors for distribution, clients, residents and the city government. Based on the objectives of these stakeholders, four objective functions were considered and formulated for multi-objective optimization:

1. first-echelon transportation cost minimization (objective of providers);
2. second-echelon transportation cost minimization (objective of clients or independent contractors);
3. number of vehicles minimization (objective of city government and residents); and
4. carbon emissions minimization (objective of city government and residents).

Solutions to the afore mentioned problem considering these objectives would provide routing schedules that simultaneously minimize traffic and its related costs as well as pollution due to CO2 emissions. The model however is flexible and not limited or bound to these objectives, and can be easily modified to consider more or different objectives, such as minimizing other types of emissions, maximizing the usage of electric vehicles, or minimizing the number of satellites.

In order to solve the formulated problem, a multi-objective algorithm was developed. To the best of the authors knowledge, such an algorithm for the 2E-VRP had not yet been published and the authors proposed to do so with a Multi-Objective Evolutionary Algorithm (MOEA), based on the Non-dominated Sorting Genetic Algorithm II (NSGA-II), given that said algorithms generate sets of solutions allowing for a relatively straightforward approximation of the Pareto front in subsequent iterations. An NSGA-II-based algorithm was designed and developed for the formulated M2-2E-VRP.

Several assumptions and limitations were made and imposed on this first iteration of the algorithm and instances. Subsequently, several in-stances were designed, proving the studied problem can be effectively instantiated, and experiments were performed in order to validate the algorithm. Experimentation demonstrated the capability of the pro-posed algorithm to find good quality solutions, to scale with

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increasing instance sizes, and to progressively improve its set of non-dominated solutions throughout execution. However, there is still effort to do in order to propose applied decision support systems for urban logistics planning and development based on M^2-2EVRPS. Further developments include:

- Analyzing and formulating more objectives and data concerning the vehicles and products, such as additional vehicle emissions rates, constraints on which products can be loaded together considering their compatibility, or minimizing travel time as an additional objective. These steps may help evolve the present formulation towards a more realistic and integral one that better reflects the complexity of commercial urban traffic.
- Design and development of more comprehensive algorithms, that do away with some of the assumptions and limitations imposed on the algorithm presented in this work, including multiple vehicles per provider, heterogeneity among first-echelon vehicles, and no limits on the number of clients or satellites per vehicle. Such algorithms could furthermore consider including vehicle routing as part of the chromosome representation and subject to the evolutionary process. This would exponentially enlarge the search space, however it would eliminate the need for the costly vehicle routing computation.
- Analyzing the applications of this research for the reduction of traffic congestion in cities of Ecuador within the framework of the DEMOSDUM project, as well as cities in Paraguay, and finally a generalization to South American cities.

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ENDNOTES

1 https://github.com/HaikoEitzen/ea m2-2e-vrp
2 https://github.com/DEAP/deap
3 https://www.google.com/earth/
4 http://biodiversityinformatics.amnh.org/opensource/gdmg/

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[5] https://ls11-www.cs.tu-dortmund.de/media/rudolph/hypervolume/hvpython.zip
[6] https://ls11-www.cs.tu-dortmund.de/media/rudolph/hypervolume/hvpython.zip
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Chapter 5
Efficacy in Liquefied Petroleum Gas (LPG) Distribution in Urban Environments

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ABSTRACT

Companies distributing LPG in cities used to have two kinds of customers: gas stations that sell it to final users and commercial consumers that use the gas in their own operations. They have to manage the inventory of gas and the daily schedule of the vehicles that transport the gas to the customers. The objective is to meet customer demand, but they are producing low average vehicle loads and empty vehicle kilometers. The authors present a short-term horizon tactical planning system that includes forecasting of sales in gas stations, lower and upper limits of the daily requirement in each customer, and a binary goal programming that determines the life cycle of each vehicle. The slack of the limits allows meeting a service level in the demands, while working with full loads in the vehicles. The system includes a scheduler for the first day and for each chain. It uses a clustering of customers for each vehicle reducing the GPS time network and a shortest path algorithm to determine the routes to visit each customer. The largest fuel distributor of Peru has implemented the system.

INTRODUCTION

Liquefied petroleum gas (LPG) is a fuel derived from petroleum that is used in a gaseous state, but it is stored and transported in a liquid state, since it is cheaper: its volume is 250 times smaller. These functions are performed by placing the gas in containers with adequate pressure. The main uses of LPG are heating, cooking, transport vehicles, power generation and industries in general. The use of LPG has

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many advantages over other fossil fuels such as gasoline or petroleum, especially as regards environmental pollution and, as a result, its consumption in the transport and industrial sectors has increased exponentially in recent years. The need for clean energy in cities is highlighted by many organizations (Nations, 2017) and the use of LPG in replacement of gasoline and diesel is one solution. This demand increment requires an adequate infrastructure to supply customers, mainly located in cities. Service stations and special vehicles of great dimension, supplying them, are typical of this business. The LPG marketing format for these sectors is bulk: consumers have storage tanks that are replenished according to their needs by a distributor.

The take-off of the market has attracted various organizations that venture into the distribution of LPG in bulk, generating a scenario with its own characteristics, but the efficiency of its supply has not received sufficient attention.

This document deals with this scenario, identifies the problems of its distribution and presents a practical solution for them, based on principles of supply chain management. We present a complete solution, fulfilling the corresponding demands, seeks the greatest possible efficiency for the movement of the supplying vehicles within the objectives of urban logistics. The proposal includes strategic, tactical and operational planning of the distribution system, supported by mathematical models. These proposal proceeds from a solution developed for a real situation: one of the main distribution companies in Peru has implemented it.

BACKGROUND

The references of the literature review address three topics: those concerning urban logistics, those referring to gas transportation and those that exhibit vehicle planning and routing models. The proposal presented in this research is a mixture of these areas of knowledge as explained in the following comments.

Excellent compilations of everything that existed about Urban Logistics until that moment, are presented in (Teodor Gabriel Crainic, 2014) and (Gonzalez-Feliu J., 2018). It is emphasized that traffic and parking regulations, although necessary, are not sufficient and new organizational models are required for urban freight transport activities. Based on the fact that cargo transports within urban areas generate large numbers of vehicle movements with a low average load per vehicle and that many vehicles travel empty, it concludes that the only way to obtain significant improvements in these aspects is through a rationalization of the distribution activities that results in fewer vehicles circulating in the cities. The work discusses a two-layer model for an integrated logistic system presented in (Teodor Gabriel Crainic, Nicoletta Ricciardi, Giovanni Storchi, 2009), which proposes that, as in business systems, transport systems in urban logistics require planning at the strategic, tactical and operational levels. At the strategic level, it concerns the design of the system and the evaluation of the probable behavior and performance of the system under different scenarios. At the tactical level, a transportation plan is constructed to provide an efficient operation and an adequate use of the resources, satisfying the demand of the clients within the quality criteria. Finally, the operational level complements the above with the scheduling of terminals and vehicles with their respective drivers and personnel. Tactical level models can also be used to evaluate the project and the system planning mode. It is also highlighted that the important point in urban logistics is the volume of vehicles present in the city and not the assignment work of these vehicles. In the same direction, with the aim of reducing and controlling the number and dimensions of freight vehicles operating within the city, (Teodor Gabriel Crainic, Nicoletta Ricciardi, Giovanni Storchi, 2009) propose

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a series of models for an integrated logistics system that improves efficiency of cargo movements and reduces the number of kilometers traveled by empty vehicles. They emphasize that the optimization component and the methodologies based on operations research do not exist or are not well developed in urban logistics. They concentrate in a two-layered structure with the major terminals located in the peripheries of the city and cross-docking facilities located near or within the city centers, although they recognize the existence of single layer logistics systems in which the loads are sent directly from the terminals to the end customers. The proposal consists of a set of generic models, not being the objective to present detailed algorithms that would allow the implementation of their ideas in specific cases. Other works which overview optimization problems in city logistics are (Cattaruzza, D., Absi, N., Feillet, D. & Gonzalez-Feliu, J., 2017) and (Gonzalez-Feliu J. (., 2019).

The previous proposals have given rise to many works related to the structure of urban logistics. A work in which the problem of locating the urban distribution centers is integrated with the corresponding vehicle routing, is presented in (Andres Muñoz-Villamizar, Jairo Montoya-Torres, Angel Juan, Jose Caceres-Cruz, 2013). They use a hybrid algorithm with induction of skewed randomness using Monte Carlo technique in various stages of the optimization procedure. The aim is to solve the problems of location, sizing and operation of urban distribution centers with a two-stage strategy. First, the location is solved and then the allocation and routing of vehicles is solved integrally. The proposal was tested with data from a French city, but limited to small scenarios; real case applications are not commented. The recommended existence of urban consolidation centers brings with it a dispatch problem that is directly addressed by (W.J.A. van Heeswijk, M.R.K.M., J.M.J. Schutten, 2017). These centers receive orders according to a stochastic arrival process and then dispatch them in batches for the distribution of the last mile. The corresponding operator decides both the timing and the composition of the batches of orders to be dispatched. An approximate dynamic programming algorithm is proposed, which is a method based on simulation to solve instances of problems represented by a Markov decision model. The computational behavior in small theoretical cases yields an error of less than 3%. For larger cases a complete linear program is formulated to be used within the dynamic algorithm with particularly good results when there is sufficient flexibility in the dispatch times since it works with time windows. A controversial point is that these windows are considered at the time of dispatch at the center and not at the time of delivery at the client. They focus on the dispatch decision and leave the routing decision arguing that there are known applications. The fleet considered can be owned or rented considering a fixed amount, but the use of a secondary one with higher costs is allowed.

An alternative to optimization models and the discussed heuristics is simulation. In (Sarra Jlassi, Simón Tamayo, Arthur Gaudron, 2017) a review of the various techniques and simulation tools that have been proposed to analyze urban logistics systems is presented. The importance of these studies for suppliers and transporters is highlighted, since the logistics of the last mile are generally complex and expensive to manage. Despite this, the number of articles that end with a real simulation application is limited. The most studied problems in simulation of urban logistics are infrastructure and vehicle routing. The most used software is Arena, a discrete and continuous simulation language. The simulation based on agents and the discrete by events are the most used techniques, being of special importance the models that combine both techniques. A gap detected in simulation is the lack of micro-simulation of traffic. In that same year, an excellent article on this topic was published in (Linsen Chong, Carolina Osorio, 2017), which partly covers that lack and gives light for future applications. In it, the behavior of individual travelers (people and vehicles) in a city is emulated making decisions about the time of departure, the mode of travel, the route to follow and the behavior during the trip. To test the proposed

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algorithm, the performance of a signal plan for the city of Lausanne is compared. The results of the test are positive with respect to the current plan and those proposed by the commercial software most used in the subject. Also working with simulation, (Bruno Durand, Jesus Gonzalez-Feliu, 2012) present an analysis of the different forms that food retailers distribution can take and how they affect the flow of goods in urban centers. The connection between the development of electronic commerce and the periodic purchases of groceries in urban areas is studied. The two logistics components of web-based retailers are highlighted: the inventory strategy and the transportation schemes. Deliveries at home are still a small percentage of grocery purchases but with a clear trend of growth. Simulation techniques were used to evaluate the alternatives, using metrics like kilometer traveled and roads occupancy rates.

Gas transportation has been a topic widely addressed through the years with many works based on real cases. A good practical work was presented by (Walter Bell, Louis Dalbert, Arnold Greenfield, Pradeep Kedia, Robert Mack, Paul Prutzman, 1983). It describes a complete gas distribution system used in a specialized company. Customers receive gas in storage tanks through contracts with the company, which monitors inventory in each tank and makes deliveries as needed. With the computational difficulties of those years, the application has a lot of merit because it was successfully implemented. In another somewhat old publication, (Ronen, 1995) presents a series of models of set coverage for the distribution of liquid petroleum products. In those years the dispatching complexity required a predominant use of heuristics. Considering that the trucks can be owned or leased, a minimization of costs is presented as an objective. The characteristic of these transports is that the trucks have compartments, which have to be assigned for the delivery of each client and therefore, the quantities can be adjusted within specified limits. Attention is drawn to the fact that the dispatch is an operational function and therefore, every distribution system must provide a fast and reliable solution even with data problems. The system must be designed to support the programmer and not to replace it; it should allow manual interventions, but always giving visibility to the costs associated with any change.

Having as objective another issue of gas transportation, (Cary Swoveland, Jack Cawdery, 1989) studied the problem of safety in the process. Although decreasing the routes carried out by the transport trucks will expose the risks to a lesser extent, work must be done on projects that directly make them safer. This work identifies, through a model, which are the most promising projects expressing the objective in economic indicators: a project is justified if the present value of the net benefit it originates is positive. A company has implemented this approach achieving encouraging results. In an indirectly related study, (Guoming Lai, Mulan X. Wang, Sunder Kekre, Alan Scheller-Wolf, Nicola Secomandi, 2011) analyze the other part of the gas supply chain: from the source to the terminals. They work on the valuation of the real option to store liquefied natural gas in terminals. By means of a complex and approximate method, they achieve results very close to the optimum. The possibility that the method can be extended to other commodities such as petroleum products and agricultural products, is highlighted.

The problem of locating fuel stations is analyzed in (S. A. MirHassani, R. Ebrazi, 2013). It stands out the urgent need to replace liquid fuels, which place transportation as the second largest sector generating CO2 with a global 22%, by alternatives such as gas and electricity. One of the problems for this change is the lack of network infrastructure of service stations. For this, a mixed integer linear programming model is proposed to determine the quantity and optimal location of the stations. Using randomly generated networks, they demonstrate that the new model substantially reduces the solution times of the known algorithms. It also has the mathematical flexibility to change between the concepts of set coverage and maximum coverage. Literature counts with other papers concerning plant location for fuels for specific applications as (Duarte, A.E., Sarache, W.A., & Costa, Y.J., 2014).

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As it has been explained, any study of urban logistics necessarily has to include vehicle routing algorithms. In (Laporte, 2009) there's a compilation of vehicle routing techniques that have been presented in the literature of the specialty. From the branch and bound algorithms, the dynamic programming, the sets coverage until the classic heuristics, is analyzed. It receives special attention a two-phase algorithm under a procedure that is often applied by the programmers of the distribution companies. In the first phase, clusters are formed that minimize the sum of distances from a point to the clients, and in the second phase a route is determined for each cluster. It concludes that both, the exact algorithms and the heuristics, have significantly progressed finding a practical use in the commercial world. In this same trend, (S.P. Anbuudayasankar, K. Mohandas, 2008) present a mixed integer linear models to solve two sub-problems similar to the two previous phases: the nodes are grouped into clusters and then the best tour for each cluster is found. The cluster is the total number of deliveries that will be made by a vehicle and the tour is its sequence. (Wuttinan Nunkaew, Busaba Phruksaphanrat, 2010) present an extension to the problem in which several terminals are considered instead of just one. The proposed practical solution is also two-stage: first, all customers are assigned to the terminals by means of an allocation algorithm, and then, it finds the routing of the clients that are served from each terminal. In the first stage, a transportation model is used considering only the relationships between terminals and customers. In the second stage, the objective is to minimize any interrelation between clients, such as the distance between them. They identify their model as one of programming by fuzzy objectives. Another variation of the routing problem when several vehicles can serve the demand of a customer is presented in (Moshe Dror, Gilbert Laporte, Pierre Trudeau, 1994). Their ideas were not prove in rea cases because computational difficulties of those years showing only theoretical results. Looking to facilitate applications for real life scenarios, a development environment of decision support systems with a set of tools for transportation planning, a microscopic traffic simulator and traffic data analysis tools is presented in (Jaime Barceló, Hanna Grzybowska, Sara Pardo, 2007). Some important aspects for routing in cities are highlighted: the traditional assumption of symmetry in the distances between two routes is not met in the urban context, requiring more realistic approaches such as geographic algorithms of shorter route or the use of information generated by a microscopic simulator. By linking the results of the simulator with vehicle routing applications, they achieve results closer to real scenarios, showing applications in small cities.

An excellent work for vehicles with several compartments transporting more than one product is presented in (Ulrich Derigs, Jens Gottlieb, Jochen Kalkoff, Michael Piesche, Franz Rothlauf, Ulrich Vogel, 2011). This is the case of liquid fuels distribution, such as gasoline and diesel. A binary mixed linear model is proposed that assigns orders to vehicles and orders to compartments satisfying the capacities of vehicles and compartments. The objective is to minimize the total cost of all tours. The base model considers all vehicles with the same capacity, but suggests the extension for vehicles with different capacities. The results of his model are compared with heuristic and meta-heuristic solutions already presented in the literature, and others proposed by the same authors. The scenarios were specially designed to represent the distributions of oil and food products. They conclude that there is opportunity for further research on the problem of vehicle routing with compartments. In (Matthias Winkenbach, Paul KleindorferDeceased, Stefan Spinler, 2016) a mixed linear whole model is presented that solves the problem of location and routing with restricted capacity by one and two steps in the context of urban logistics services, specifically a postal service. The final solution consists of a formula to estimate routing costs and a heuristic that reduces the number and size of vehicles required. Special care is given to the design of the right fleet for different characteristics of the city. They declare that the proposed model

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can solve large-scale applications. In (Marlin W. Ulmer, Justin C. Goodson, Dirk C. Mattfeld, Marco Hennig, 2018) another interesting solution is presented for the services in which the day begins with some known requirements, but during the remainder of the day they have to go adjusting the routes of the vehicles due to new requirements entered. The method integrates predictive tools with prescriptive optimizations to anticipate and respond dynamically to the requirements. They make use of dynamic programming procedures that have to be solved by approximate heuristics due to computational difficulties. The tests are done only in simulated theoretical environments. Other interesting approaches for distribution systems can be found in (Gzara, 2013) and (Crevier, B., Cordeau, J.F. & Laporte, G., 2007).

THE BULK DISTRIBUTION OF LPG

A distributor meets LPG requirements in bulk for customers by means of special pressurized vehicles, whose grouping is called a fleet, that have been previously provided in one of the terminals of the suppliers. The main bulk LPG transportation is usually concentrated in a few organizations that are principally engaged in the sale of fuels to final customers in the transport sector, through their own networks and associated service stations, deployed in a wide geographical area. Its incorporation into the distribution scenario has occurred, in general, as a backward integration of its main activity, to take some perceived advantages: independence from external distributors, search for lower costs, etc. An important consideration is that most of these organizations, before the appearance of the LPG as an alternative in their sector, already commercialized other fuels -gasoline and diesel-, which represent an important volume of their transactions, and in which they were already backward integrated in the distribution process but with very different characteristics. In practice, as expected, each LPG bulk distribution process is unique. However, it is possible to describe them in their common characteristics and identify in them the most complex scenario for their management. The main characteristics are territorial scope, demand, supply and fleet.

The territorial scope of the distribution process is, in general, extensive and covers many cities, being able to cover the territory of a country. The scenario is more complex as the cities and the distances to be served increase.

Regarding demand, two types of customers can be served with very different distribution schemes and requirements: internal and external customers. For internal customers (their own network of service stations and associated), served in a scheme of ‘distribution to stock’ (DTS), the decision of the replenishment is in the distributor. The objective is to avoid breaking of stocks in the stations. For external customers, in a scheme of ‘distribution to order’ (DTO), the customer places a requirement, in a quantity and for a specific date, which the distributor must satisfy. Orders are received daily and their attention is a priority. In the most complex scenario of reference for this proposal, the distribution must accomplish with the two schemes simultaneously. Unifying the attention in the DTS scheme is recommended, but this depends on the relationship established with the external clients.

The supply is made in wholesale distributors, who get the LPG in local or foreign producers. Due to economies of scale, to the necessary investment and the restrictions of their own supply, the dispatch facilities or terminals are few and can be dispersed or concentrated in the geographic region they serve. They are generally not forward integrated in the distribution process. It is possible that the supply could be interrupted repeatedly and in the short term: supply and dispatch plants stop because weather conditions do not allow their replenishment. In this situation, suppliers restrict delivery amounts while stocks

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last in their tanks, then close, generating a temporary shortage. In addition, the facilities that continue in operation, suffer an overload of demand that causes an increase in the time of attention, which may be days. In the most complex scenario, the distributor, which has no control over these events or power over the supplier, has not taken protection for the continuity of its process.

Regarding the fleet, it is necessary to differentiate two aspects: the configuration of the fleet and the execution of transport.

- The configuration of the fleet can consist of own vehicles, rented or a mix of both schemes. The size of the fleet is usually known (do not go out to look for carriers). There are two aspects to consider for its management: the characteristics or conditions of the vehicles and the loading and delivering points. Many times, they are not compatible and require special vehicles for some situations, which leads to inefficient decisions. The capabilities of the vehicles do not fit easily to the demand. There are characteristics of the process design that cannot be changed through management, but must be incorporated.
- Transport execution can be integrated, outsourced or a mix of both schemes. In the worst scenario, transportation supply and execution decisions are not coordinated.

The Management of the Bulk LPG Distribution Process

Just as each LPG bulk distribution process is unique, its management is also unique. However, it is possible to identify a set of management problems that, while not necessarily common to all the scenarios, allows a flexible solution especially for those scenarios identified as complex.

The main problems that can be identified are:

- Little or no visibility of future supply and demand needs. The decisions are reactive to the known situation of the scenario: they are taken after knowing the demand, the supply and the available vehicles, in a cycle "fill-transport-download" with a daily horizon.
- Supply decisions focused on meeting the demand from external customers, accommodating the internal customers' requirements to that decision, without seeking the overall efficiency of the process.
- Minimum management of the fleet (transport execution). There is no coordination between supply decisions and transport execution: the distribution manager must consult the transportation executor on a daily basis about the vehicles available to meet the demand and suggest a volume to be shipped, not the specific schedule since it does not control it.
- No protection for a supply with variable availability in the short term.
- No protection for an unforeseen demand at a time shorter than the time required for supply.

This managing system leads to inefficient decisions of 'transport' and 'dispatch'. Vehicles travel greater distances than necessary and, therefore, remain longer on the scene. They take longer to meet their objective because they are waiting to get demand. It ends up by requiring vehicles in quantities greater than needed when dispatching them with a content less than their capacities.

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PROPOSED ORGANIZATIONAL FRAMEWORK

In the area of urban logistics, the main objective has been to minimize the amount of kilometers traveled by vehicles on the scenario. The bulk distribution of LPG, a growing sector that makes intensive use of vehicles that must circulate in cities to serve users, is a relevant process to propose solutions in this regard. This paper proposes a practical solution to guide the management of multiple real scenarios towards that objective.

The solutions proposed in the urban logistics literature are mainly focused on two approaches (related to each other). Organizing the logistics of the city in a two-tier scheme where the necessary products are accumulated in peripheral locations and then, an efficient distribution from them to the city; and structuring distribution management in a supply chain management approach through integrated planning at the strategic, tactical and operational levels. When dealing with organizational issues, and more precisely with multi-stage transport systems mainly with two-tier forms, two main elements seem to be dominant. However, two-tier systems, to be economically viable, need to mobilize a threshold demand (which can be high in some cases, like more than 30-40% of total catchable demand, (Gonzalez-Feliu J., 2018) and group freight with low time and handling constraints.

The solution presented in this paper considers a single-level logistics. The two-tier approach is not applicable in bulk LPG distribution scenarios for two reasons. The restrictions of the storage and transport process itself make prohibitive the implementation of intermediate warehouses and the use of two fleets to maintain supply from the terminals to the customers. The territorial scope is greater than one city, covers many cities, and it could include the territory of a country. From there, the proposal develops a practical application for a single level approach to allow its application in multiple real scenarios, applying principles of supply chain management. It presents a flexible solution for the application of strategic, tactical and operational planning with the following general characteristics:

- Strategic planning (Definition of LPG distribution scenario as a supply chain). The objective is to structure real scenarios as supply chains, where the restrictions and relations between the participants are accurately identified. Unlike the theoretical approaches, the proposal does not seek an ideal definition of the scenario chain. It presents the required characteristics that the chains must have in order to apply the other components of the proposed solution.
- Tactical planning (Coordination of processes on the horizon for the defined supply chain). A management process is presented whose objective is to propose effective decisions of supply and dispatch for the forecasted demand, so that the planner can take the most appropriate decisions for loading, transport and unloading actions. It is a flexible solution, supported by calculations and models, which can be applied in multiple scenarios.
- Operational planning (Coordination of the tactical plan with execution). The objective is to transform the tactical plan into an efficient action plan for execution, avoiding independent decisions of the operators. A process is presented, supported by models, applicable to multiple scenarios.

The design of the planning processes of any process requires alignment with the management model; therefore, this work proposes one that corrects the problems identified and guides the decisions towards the objective sought to minimize the number of kilometers traveled by vehicles in the system. This aspect is very important, since the solution developed for the three planning levels, seeks to support the characteristics of this management model, which has three main characteristics:

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- Manage inventories between supply and dispatch using vehicles as warehouses. This means making both processes independent: on the one hand, all empty vehicles are filled, regardless of whether there is demand; on the other, all full vehicles are quite emptied, to meet the needs of internal and external customers. This definition allows, and it is important, to manage vehicles with an inventory approach and not as a capacity. They must be understood as warehouses with inventories available to meet the demand of the chain (in a lead-time), with the condition to close empty each time they are used, and that they are replenished (within a lead-time), with the condition to fill up immediately.
- Coordinate through the tactical planning process and for each vehicle (warehouse), the cycle "transport - download - return - fill" (instead of the reactive "fill - transport - download") that allows a balance of the inventory of the chain to fulfill effectively with the demand. If there are imbalances at a time, it is not due to lack of transport capacity -more vehicles do not solve the problem-, but because the inventories do not reach or are not adequate to comply with the supply cycle. On the other hand, the independence between both processes, with different logistical characteristics and objectives, but that use successively the same resources (warehouses), allows a more flexible configuration of the scenario and more efficient decisions when coordinating them.
- Manage the use of vehicles in their cycle. The objective is to control the life cycle of the inventory and decide on its coordination, integrating the distribution management with the execution of the transport.

Strategic Plan

The objective of this level is to structure the scenario as one or more customer supply chains. A customers chain consists of a set of delivery points (demand), which share a fleet - set of vehicles (warehouses with inventories) - associated with a set of load points or terminals (supply) where the supply and demand are approximately balanced. The objective in the definition of each chain is to relate the vehicles that can meet their demand with the suppliers that can supply them, to coordinate the life cycle of their inventories.

The customer chains must comply with the following characteristics in order to apply the proposed solution:

1. Each chain must function regularly and its supply, dispatch and demand must be balanced in its service cycle.
2. All the delivery points of a chain are served only with the fleet assigned to it. A fleet can be assigned to several chains.
3. Each fleet is supplied only at the load points or terminals assigned to it.
4. A vehicle belongs to a single fleet and must be able to be supplied at any of its loading points.
5. The arrival time of each fleet, from a specific location in the geographical region of the scenario to any loading point, should be similar: the loading points are not scattered.
6. The charging time in each terminal can be different and variable in time.
7. Any vehicle in the fleet assigned to a chain must be able to download at any of its delivery points.
8. The transportation time of any vehicle in the fleet to the delivery points in its chain should be similar: the vehicle departs from locations that are not dispersed and does not carry out downloads during transport.

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9. The download time must be similar for any combination of delivery points in the chain: the set of delivery points in the chain must belong to the same geographical area (city) in terms of service.

Tactical Plan

The following is a description of all the relevant aspects of the design of the tactical planning process, as well as the calculations and the mathematical model that supports it.

Horizon. The time of future visibility, that is required to coordinate the "transport-download-return-fill" cycle of each vehicle. It is one of the characteristics that this planning incorporates. It must be greater than the sum of the transportation times (round trip), the unloading time and the load time, expressed in periods; the horizon is expressed in periods.

Period. The minimum horizon in which the aforementioned cycle is coordinated. It is another feature that incorporates this planning. The definition is a compromise between two times: the periodicity in which it is possible to define supply requirements (the demand) and the cycle time of the vehicle. In the first one, the normal is a daily periodicity; in the second one, the ideal is to use the same definition, however, there are chains in which, by the proximity between the loading and delivery points, the cycle is half of a day and it works in shifts. In those cases it is recommended to use this unit of time as period (one day is two periods).

Planning cycle. The periodicity of execution of the planning process. It is restricted by the periodicity of definition of demand requirements, which is daily. It must be taken into account that if the chosen period is half of a day, the planning will coordinate the horizon with that condition, but its short-term suggestions will include the execution actions of two periods.

Demand. There are two types of demand according to the distribution scheme, which are identified as:

- Internal customers: the delivery points that are served in the DTS scheme. The demand for these must be forecasted; the tactical planning will use the forecast data to define the maximum and minimum limits that restrict the attention of each chain. The forecast is not of continuous generation, it can be done in spaced periods to verify whether the conditions are maintained. It is mandatory to do it when the characteristics of the chains change significantly and permanently. This is one of the features that the tactical planning incorporates.
- External customers: the delivery points that are served in the DTO scheme. If its incorporation to the previous scheme is not possible, the demands of these clients are identified by the orders that the clients make. Therefore, it is advisable to establish the mandatory condition of a delivery time (anticipation in the placing of the order) to serve them. The delivery time must be longer than the transport time in, at least (two periods), to allow efficient decisions.

Configuration of the supply chains. This aspect was already structured in the strategic planning and all the defined chains must be incorporated. It is advisable to recognize all the cargo points and vehicles of the fleet assigned to each chain even if they are not used. Then, those of current availability will be activated. This allows incorporating new resources simply by activating them when exceptional situations appear.

Supply availability. There are two definitions about the default behavior of each load point, valid on the horizon.

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- Availability: volume available by default in the horizon periods.
- Attention periods: Identification of periods in which it can be charged; useful to set up attentions in day and night shifts.

Vehicle cycle times. There are three definitions concerning this topic:

- Load time: load time by default, expressed in periods. It will only be applied during the attention periods of the loading point.
- Transportation time: travel time of a full vehicle to its delivery points and of an empty one to the terminal that will supply it, expressed in periods.
- Download time: by condition of the chain, it is one period.

Other loading and unloading restrictions. If it is desired to incorporate another restrictions to those considered for supply, transport or distribution, the tactical planner must be adapted to these additional conditions. Some possible restrictions are the following: preference for the price of the product at the loading point to decide where a transportation unit will be filled; fleet utilization quotas for external suppliers; number of desired turns of each vehicle; minimum dispatching quotas; etc.

Flexibility of use. The definitions mentioned above allow us to configure a great variety of distribution scenarios and the mathematical model that will be presented, adapts to all of them. Additionally, the availability of supply can be varied for the short term (to consider specific events).

Integration of all the chains of the scenario. The tactical planning operates centrally: all the chains are planned at the same time, this is necessary because several of them can share resources (terminals or fleets) and the model determines the most effective allocation of all of them. However, if there are one or more independent chains (they do not share resources), it is possible to plan them independently.

Determination of the cycle of the vehicles. For each vehicle, it is determined:

1. If it is empty (its download has finished), where to supply (loading point) and when (period) it will be full (available) again.
2. If it is full (its load has finished), when (period) and where (chain) it should dispatched, according to the supply rules, and when (period) it will finish its download (it is empty again).

Then, according to the defined loading and downloading times, it is determined when (period) the replenishment or delivery should begin. In this way, the supply and distribution processes become independent, there are decoupling inventories and the total management of the fleet is achieved on the horizon. The tactical planning incorporates these characteristics.

Attention to the demand. For each internal customer, the upper and lower limits for the deliveries that can be made in each period are calculated. The objective is that compliance with the lower limit allows satisfying the demand with a certain service level. For the upper limit the objective is that the planned discharge for a period can be delivered totally depending on the capacity of the tank and with a certain probability, which has been called replacement level. The calculation procedure is presented below.

Determination of the lower and upper limits for deliveries of LPG in internal customers (service stations).

Indexes:

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k, k1 = period (of set K)

Data:

capacity = capacity of the LPG storage tank in the internal client
content = LPG content in the tank at the start of the day 1
level of service (ns) = probability that the service station will be able to satisfy the LPG demand that it receives
replacement level (nr) = probability that the internal customer's tank will be able to fully receive the LPG dispatched volume,
forecast (k) = estimate of the demand of period k that the service station will receive
standard deviation (k) = the standard deviation of the demand estimate of the period k

Calculations:

maximum demand (k) = forecast (k) + z (ns) * standard deviation (k)

minimum demand (k) = forecast (k) -z (nr) * standard deviation (k)

$$maximum\,cumulative\,demand\left(k\right)=\sum_{k1\le k} maximum\,demand\left(k1\right).$$

$$limsup\left(1\right)=capacity-content\ .$$

$$limsup\left(k\right)=limsup\left(k-1\right)+minimum\,demand\left(k-1\right);\ \forall\,k\ge 2\,y\,k\le 4\,.$$

$$limsup\left(k\right)=limsup\left(k-1\right)+forecast\left(k\right);\ \forall\,k\ge 5\ .$$

$$liminf\left(k\right)=\min\left(\max\left(maximum\,cumulative\,demand\left(k\right)-content,0\right),limsup\left(k\right)\right).$$

For each chain of customers, the upper and lower limits are also determined, incorporating all internal and external customers (based on orders) that belong to them. The calculation procedure is presented below.

Determination of the lower and upper limits for LPG deliveries of customer chains made up of internal and external customers.

Indexes:

i = internal client belonging to the chain *j* of clients (from set *I*)
j = customer chain (from set *J*)
k, k1 = period (of set *K*)

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Data:

limsup (i, k) = upper limit for delivery to the internal client *i* in the period *k*
liminf (i, k) = lower limit for the delivery in the internal client *i* in the period *k*
order (j, k) = orders from external clients located in the chain *j* for the period *k*

Calculations:

lsr (j, k): upper limit for the delivery of LPG in the chain *j* in the period *k*
lir (j, k): lower limit for the delivery of LPG in the chain *j* in the period *k*

$$lsr\left(j,k\right) = pedido\left(j,k\right) + \sum_{i \in I} limsup\left(i,k\right).$$

$$lir\left(j,k\right) = \min\left(\sum_{k1 \leq k} pedido\left(j,k1\right) + \sum_{i \in I} liminf\left(i,k\right), lsr\left(j,k\right)\right).$$

Identification of exceptions to demand fulfillment. The model identifies where (chain) and when (period) there would be supply problems for demand accomplishment (lower limit) or lack of reception (upper limit) with respect to the capacity of a vehicle. This allows the planner to focus on decisions that try to correct the situation. There are three situations identified:

1. High demand: the inventory balance predicted for the planned supply is not enough to meet the expected demand for a period. The appropriate decision, according to the horizon, would be to decide which demand will not be satisfied and to communicate it in advance, or incorporate an additional vehicle to the chain that corrects the imbalance.
2. Short supply: the inventory balance foreseen for the supply is not met due to delays in the supply cycle. The appropriate decision, according to the horizon, would be to try to incorporate another loading point or coordinate with the current ones to accelerate the loading process of the vehicles.
3. Low demand: the demand to satisfy in a period is not enough to start a supply. The appropriate decision would be to decide which demand will not be satisfied and to communicate it in advance or generate an inefficient dispatch, leaving a vehicle without having compromised its total capacity.
4. Excess inventory: the model reports, for each fleet, the full vehicles that are not used, on the horizon, for the dispatch of the chains to which they are assigned. The planner can deactivate other vehicles, from the same fleet, that are empty (cut its supply cycle) and use the available inventory of the full ones until achieving equilibrium. It must be taken into consideration if the full vehicles are not being used due to a low demand situation.

Current situation of the vehicles. The execution is not necessarily done as planned (even more if there are two periods between each planning process); therefore, it is necessary to know the current situation of the vehicles in their cycle. The planner must verify three data before proceeding to tactical planning:

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1. The full vehicles available (inventories on hand not assigned to any delivery).
2. The period in which the vehicles that are downloading will be empty.
3. The period in which the vehicles that are being loaded will be full.

This information is always available: it is with the carrier (loads) and with the programmer that tracks the requirements accomplishments (downloads).

Coordination with the operation. Suggestions for immediate execution actions (within the periods of the planning cycle) are:

1. Load plan. Vehicles that must complete their filling in the following two periods to fulfill the supply cycle.
2. Transportation plan. Vehicles that must exit to a chain in the next two periods to fulfill the supply cycle.
3. Download plan. Vehicles that must meet customer delivery points in the following two periods to fulfill the supply cycle. These vehicles require a determination of which delivery points to visit and in what sequence. This objective is solved in the operational plan described below.

Binary linear model for the tactical planning of LPG distribution. The tactical planning is supported by the following binary linear model, which is formulated through a goal programming.

Indexes:

i = available vehicle (from set I)
j = customer chain (from set J)
t = terminal (of set T)
$k, k1$ = period (of set K)

Data:

capac (i) = vehicle capacity i
tc (t) = charging time in terminal t
quota (t) = weekly quota to comply with terminal t
dispter (t, k) = availability of LPG at terminal t in period k
lsr (j, k) = upper limit for the delivery of LPG in the chain j in the period k
lir (j, k) = lower limit for the delivery of LPG in the chain j in the period k
lt (t, j) = travel time between terminal t and chain j
carpro (i, t, k) = 1, if vehicle i is programmed to be loaded at terminal t during period k; 0, if not
dispro (i, j, k) = 1, if vehicle i is programmed to make deliveries in chain j during period k; 0, if not
asigct (i, t) = 1, if the vehicle i can receive load in terminal t; 0, if not
asigcr (i, j) = 1, if vehicle i is assigned to the chain j; 0, if not
xin (i) = 1, if vehicle i is initially loaded; 0, if it is initially empty

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Decision variables:

x (i, k) = 1, if vehicle *i* will be loaded at the close of period *k*; 0, if it will be empty at the close of the period *k*
y (i, t, k) = 1, if vehicle *i* was finished loading in terminal *t* at the close of period *k*; 0, if not
w (i, j, k) = 1, if vehicle *i* will make deliveries in chain *j* during period *k*; 0, if not

Deviation variables:

elir (j, k) = excess compliance over the lower limit in the chain *j* in the period *k*
dlir (j, k) = breach of the lower limit in the chain *j* in the period *k*
elsr (j, k) = excess compliance on the upper limit in the chain *j* in the period *k*
dlsr (j, k) = breach of the upper limit in the chain *j* in the period *k*

Objective Function:

$$\textit{Minimize} \sum_{\substack{i\in I\\ k\in K}} 100 * \left(1 - x\left(i,k\right)\right) + \sum_{\substack{j\in J\\ k\in K}} \left(10000 - 10 * k\right) * dlir\left(j,k\right) + \left(10 - 0.1 * k\right) * dlsr\left(j,k\right) + 100 * elsr\left(j,k\right).$$

Restrictions:

1. Vehicles can be loaded at any assigned terminal that has availability

$$\sum_{i|asigct\left(i\right)=1} capac\left(i\right) * \left(y(i,t,k) + carpro\left(i,t,k\right)\right) = dispter\left(t,k\right) - ddispter\left(t,k\right); \forall j \in J, k \in K\,.$$

2. The accomplishment of a chain demand in a period must be between its corresponding lower and upper limits

$$\sum_{\substack{k1|k1\le k\\ i\in I}} \left(capac\left(i\right) * \left(w\left(i,j,k1\right) + despro\left(i,j,k1\right)\right)\right) - elsr\left(j,k1\right) = lir\left(j,k\right) + elir\left(j,k\right) - dlir\left(j,k\right); \forall j \in J, k \in K$$

$$\sum_{\substack{k1|k1\le k\\ i\in I}} \left(capac\left(i\right) * \left(w\left(i,j,k1\right) + despro\left(i,j,k1\right)\right)\right) = lsr\left(j,k\right) + elsr\left(j,k\right) - dlsr\left(j,k\right); \forall j \in J, k \in K$$

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3. A vehicle can make deliveries in only one assigned chain in a period

$$\sum_{\substack{j\in J| \\ asigcr(i,j)=1}} w\left(i,j,k\right)+despro\left(i,j,k\right)\leq 1;\forall i\in I,k\in K\,.$$

4. A vehicle can be loaded only in a terminal assigned, at the close of a period

$$\sum_{\substack{t\in T| \\ asigct(i,t)=1}} y\left(i,t,k\right)+carpro\left(i,t,k\right)\leq 1;\forall i\in I,k\in K\,.$$

5. Unassigned vehicles have binary variables equal to zero

$$y\left(i,t,k\right)=0;\forall i\in I,t\in T,k\in K\mid asigct\left(i,t\right)\neq 1\,.$$

$$w\left(i,j,k\right)=0;\forall i\in I,j\in J,k\in K\mid asigcr\left(i,j\right)\neq 1\,.$$

6. State balance for each vehicle and in each period

$$x\left(i,k-1\right)+\sum_{t\in T}y\left(i,t,k\right)+carpro\left(i,t,k\right)=x\left(i,k\right)+\sum_{j\in J}w\left(i,j,k\right)+despro\left(i,j,k\right);\forall i\in I,k>1\,.$$

$$xin\left(i\right)+\sum_{t\in T}y\left(i,t,k\right)+carpro\left(i,t,k\right)=x\left(i,k\right)+\sum_{j\in J}w\left(i,j,k\right)+despro\left(i,j,k\right);\forall i\in I,k=1\,.$$

7. Comply with the loading times of each terminal

$$\sum_{\substack{k\in K| \\ k\leq tc\left(t\right)}} y\left(i,t,k\right)=0;\forall i\in I,t\in T\mid xin\left(i\right)=0yasigct(i,t)=1\,.$$

$$\sum_{\substack{k1\geq k-lt\left(t,j\right) \\ k1\leq k+tc\left(t\right)-1}} y\left(i,t,k1\right)+carpro\left(i,t,k1\right)+w\left(i,j,k1\right)+despro\left(i,j,k1\right)\leq 1+x\left(i,k\right);$$
$$\forall i\in I,t\in T,j\in J,k\in K\left|asigct\left(i,t\right)=1yasigcr\left(i,j\right)=1yk\right\rangle lt\left(t,j\right)y\left(lt\left(t,j\right)>0otc\left(t\right)>0\right)$$

8. Comply with travel times between terminals and chains

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$$\sum_{\substack{k1 \geq k-lt(t,j) \\ k1 \leq k}} y(i,t,k1) + carpro(i,t,k) + w(i,j,k1) + despro(i,j,k1) \leq 1;$$

$$\forall i \in I, t \in T, j \in J, k \in K \mid asigct(i,t) = 1 y asigcr(i,j) = 1 y (lt(t,r) > 0 otc(t) > 0$$

9. Comply with weekly quotas of each terminal (this condition is not activated in the objective function)

$$\sum_{\substack{i \in I \\ k \in K}} capac(i) * y(i,t,k) + carpro(i,t,k) = cuota(t) + ecuota(t) - dcuota(t).$$

Operational Plan

The tactical plan indicates which vehicles unload in each chain (city) for each period. The demand for these chains is made up with the sum of the requirements of each of their delivery points. To move on to the execution of the tactical plan, the scheduler has to decide for each vehicle which delivery points it will visit, in what order and what volume it will download. The objective of the operational plan is to support these decisions. The proposal is to do it in two stages with the support of binary linear models. The first one will determine which delivery points are assigned to each vehicle and will be solved by means of a clustering model. The objective of the model is to minimize the total potential travel times of the vehicles, ensuring that they are shipped at full load. The flexibility to find a feasible solution is given by the lower and upper limits within which the volume to be download is determined at each delivery point. The formulation is as follows.

Binary linear model to determine the clusters of delivery points of a chain of customers that will be served by each vehicle. The following binary mixed linear model formulated as one of goal programming, supports the first stage of operational planning.

Indexes:

k = planned vehicle (of the K set)
i, j = delivery point (from set I)
t = terminal (of set T)

Data:

capac (k) = vehicle k capacity
terini (k) = terminal from which the vehicle will start k
terfin (k) = terminal to which the vehicle k is routed when it finishes its deliveries
liminf (i) = the lower limit to download at the delivery point i so that it does not break stock
limsup (i) = the upper limit to discharge at the delivery point i according to the capacity of its storage tank
tiempo (i, j) = the travel time from the delivery point i to the delivery point j
tpoterpun (t, i) = the travel time from terminal t to the delivery point i

(All the travel times should be obtained with a Global Positioning System)

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Decision variables:

x (k, i) = 1, if the delivery point *i* will be included in the cluster of vehicle *k*; 0, if it will not be
vol (k, i) = the delivery volume that the vehicle *k* will download at the delivery point *i*
asig (k, i, j) = 1, if the route from the delivery point *i* to the delivery point *j* is part of the potential route for the vehicle *k*; 0, if it is not

Deviation variables:

dcapac (k) = the difference between the sum of the deliveries a vehicle will make and its capacity

Objective Function:

$$\text{Minimize} \quad \sum_{\substack{k\in K \\ i\in I \\ j\in I \\ i\neq j}} asig\left(k,i,j\right) * tiempo\left(i,j\right) + \sum_{\substack{k\in K \\ i\in I}} \left(tpoterpun\left(terini\left(k\right),i\right) + tpoterpun\left(terfin\left(k\right),i\right)\right) * x\left(k,i\right) + \sum_{k\in K} 100000 * dcapac\left(k\right) .$$

Restrictions:

1. Determine the potential routes of each cluster

$$asig\left(k,i,j\right) \geq x\left(k,i\right) + x\left(k,j\right) - 1; \forall k \in K, i \in I, j \in I \mid i \neq j .$$

$$asig\left(k,i,j\right) = 0; \forall k \in K, i \in I, j \in I \mid i = j .$$

2. Each delivery point must be visited by only one vehicle

$$\sum_{k\in K} x\left(k,i\right) = 1; \forall i \in I .$$

3. The total volume transported by each vehicle must not exceed its capacity

$$\sum_{i\in I} vol\left(k,i\right) = capac\left(k\right) - dcapac\left(k\right); \forall k \in K .$$

4. The volume transported to each delivery point must be between the lower and upper limits to be unloaded at the delivery point

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$$vol\left(k,i\right) \leq limsup\left(i\right) * x\left(k,i\right); \forall k \in K, i \in I\ .$$

$$vol\left(k,i\right) \geq liminf\left(i\right) * x\left(k,i\right); \forall k \in K, i \in I\ .$$

Once the set of delivery points that each vehicle will visit has been determined, the route that it will follow must be found. The proposal is to support this decision through another binary linear model. The objective is to minimize the sum of the arrival times to each delivery point plus the travel times of each vehicle. No time windows were incorporated into the model since the tactical planning divided into day and night shifts and it may be sufficient. If necessary, the model presents all the facilities for this, because it has variables specifying the arrival times at each delivery point and they could have limits easily.

Model to determine the route that each vehicle will follow when visiting all the delivery points of the assigned cluster. The binary mixed linear model presented below supports the second stage of operational planning.

Indexes:

k = planned vehicle (of the K set)
i, j = delivery point (from set I)
t = terminal (of set T)

Data:

terini (k) = terminal from which the vehicle k will start
terfin (k) = terminal to which the vehicle k is routed when it finishes its deliveries
tpodesc (i) = download time at the delivery point i
tiempo (i, j) = the travel time from the delivery point i to the delivery point j
tpoterpun (t, j) = the travel time from terminal t to delivery point j
x (k, j) = 1, if the delivery point j is included in the cluster of vehicle k; 0, if it is not

Decision variables:

y (i) = arrival time at the delivery point i
tpotot (k) = total time of the vehicle k route
asig (k, i, j) = 1, if vehicle k uses the route from delivery point i to delivery point j; 0, if not
zini (k, t, i) = 1, if vehicle k uses the route from terminal t to delivery point i; 0, if not
zfin (k, i, t) = 1, if the vehicle k uses the route from the delivery point i to the terminal t; 0, if not

Objective Function:

Minimize $\sum_{i \in I} y\left(i\right) + \sum_{k \in K} tpotot\left(k\right)$.

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Restrictions:

1. Avoid closed loops in the routes of each vehicle

$$asig\left(k,j,i\right)+asig\left(k,j,i\right)\leq 1;\forall k\in K,i\in I,j\in I\mid x\left(k,i\right)=1yx\left(k,j\right)=1\,.$$

$$asig\left(k,j,i\right)=0;\forall k\in K,i\in I,j\in I\mid i=jox\left(k,i\right)=0ox\left(k,j\right)=0\,.$$

$$z\left(k,terini\left(k\right),j\right)+\sum_{\substack{i\in I\mid\\ x\left(k,i\right)=1}}asig\left(k,i,j\right)+\sum_{\substack{i\in I\mid\\ x\left(k,i\right)=1}}asig\left(k,j,i\right)\leq 2;\forall k\in K,j\in I\mid x\left(k,j\right)=1\,.$$

2. Each route must start and end at the assigned terminals

$$\sum_{\substack{j\in I\mid\\ x\left(k,j\right)=1}}zini\left(k,terini\left(k\right),j\right)=1;\forall k\in K\,.$$

$$\sum_{\substack{j\in I\\ t\in T\mid\\ x\left(k,j\right)\neq 1\,o\\ t\neq terini\left(k\right)}}zini\left(k,t,j\right)=0;\forall k\in K\,.$$

$$\sum_{\substack{j\in I\mid\\ x\left(k,j\right)=1}}zfin\left(k,j,terfin\left(k\right)\right)=1;\forall k\in K\,.$$

$$\sum_{\substack{j\in I\\ t\in T\mid\\ x\left(k,j\right)\neq 1\,o\\ t\neq terfin\left(k\right)}}zfin\left(k,j,t\right)=0;\forall k\in K\,.$$

3. Each delivery point must be visited only once

$$zini\left(k,terini\left(k\right),j\right)+\sum_{\substack{i\in I\mid\\ x\left(k,i\right)=1}}asig\left(k,i,j\right)=1;\forall k\in K,j\in I\mid x\left(k,j\right)=1\,.$$

4. There must be only one exit from each delivery point

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$$zfin\left(k,i,terfin\left(k\right)\right)+\sum_{\substack{i\in I|\\ x\left(k,j\right)=1}} asig\left(k,i,j\right)=1;\forall k\in K,i\in I\mid x\left(k,i\right)=1\,.$$

5. Calculation of the total route time for each vehicle

$$tpotot\left(k\right)=\sum_{i\in I} tpoterpun\left(terini\left(k\right),i\right)*zini\left(k,terini\left(k\right),i\right)+\sum_{\substack{i\in I\\ j\in I}}\left(tiempo\left(i,j\right)+tpodesc\left(i\right)\right)$$
$$*asig\left(k,i,j\right)+\sum_{j\in I}\left(tpoterpun\left(terfin\left(k\right),j\right)+tpodesc\left(j\right)\right)*zfin\left(k,j,terfin\left(k\right)\right);\forall k\in K$$

6. Calculation of arrival times for each delivery point

$$y\left(i\right)\geq\sum_{\substack{k\in K|\\ x\left(k,i\right)=1}} tpoterpun\left(terini\left(k\right),i\right)*zini\left(k,terini\left(k\right),i\right);\forall i\in I\,.$$

$$y\left(j\right)\geq y\left(i\right)+\left(tiempo\left(i,j\right)+tpodesc\left(i\right)\right)*asig\left(k,i,j\right)-99999*\left(1-asig\left(k,i,j\right)\right);$$
$$\forall k\in K,i\in I,j\in I\left|\,j\right\rangle iyx\left(k,i\right)=1yx\left(k,j\right)=1$$

$$y\left(i\right)\geq y\left(j\right)+\left(tiempo\left(j,i\right)+tpodesc\left(j\right)\right)*asig\left(k,j,i\right)-99999*\left(1-asig\left(k,j,i\right)\right);$$
$$\forall k\in K,i\in I,j\in I\left|\,j\right\rangle iyx\left(k,i\right)=1yx\left(k,j\right)=1$$

CONCLUSION

The replacement of liquid fuels such as gasoline and diesel by the LPG, is of great benefit both for the lower pollution that it produces and for the economy that is achieved. This situation has been happening with great advances in the energy, transport, industrial and commercial sectors. For these users, the LPG has to be transported and stored in bulk. The distributors in charge of the supply, in their objective to satisfy the demand, have committed many inefficiencies in the movement management of the special (pressurized) vehicles required for this product. The apparent impossibility of creating decoupling inventories between producers and customers exacerbated this difficulty. The work proposed in this case study, solves this difficulty by using the vehicles themselves as warehouses for the product. It also defines for all the internal customers (those served by a continuous replenishment), lower and upper limits that allow flexibility in volumes and time for the gas amount that can be dispatched in compliance with the demand at a certain service level. With such flexibility, the movements of vehicles can be planned and scheduled so that they always use their full capacity and that their routes are the most efficient possible.

The LPG distribution has been planned at its strategic, tactical and operational levels. For the last two plans, mathematical support models are used that allow a rapid application of the proposed process.

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The main Peruvian fuel distribution company has implemented the proposed solution. This implementation implied a deep cultural change in the company. They realized that a discipline to attend the customers and the use of technical management tools give many benefits not only in economic aspects, but also in demand meeting with improved service levels which delivers a smooth administration with satisfied customers.

All the ideas developed in this work can be extended for the distribution of any product that is transported in bulk and in a single presentation. Logically, each case will have particularities that should be incorporated to the models presented. One of the main characteristics of the solution, the planning of the life cycle of the inventory through the cycle of movement of the vehicles, is directly applicable to any reality.

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Chapter 6
Assessment of Logistics Capabilities Maturity of Home Healthcare Providers:
Case of Study for a Metropolitan Area in Colombia

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ABSTRACT

In home healthcare (HHC) services, patients receive coordinated medical care at home based on previous medical prescriptions. Given geographical dispersion of patients and medical staff within an urban area, the design, provision, and control of HHC service delivery imply a set of complex logistics capabilities that impact service quality. Consequently, the maturity of such capabilities is a key factor to guarantee that patients receive the prescribed medical attention, by the right medical staff, at the right time, and at the right place. Thereby, this chapter presents and assessment of the logistics capabilities maturity of HHC providers certified by the Ministry of Health and Social Protection to provide HHC services in the metropolitan area of the second largest city in Colombia. Results show that an average maturity level of 3.2/5.0 for logistics processes, and 4.0/5.0 for service processes, evidence the need to improve service delivery.

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INTRODUCTION

Home Health Care (HHC) services are growing worldwide, due to the use of safer and effective medical interventions and technologies, in and out hospital settings, and to a growing population with increasing demand, especially in urban areas. HHC services appeared around 1950 (Cotta et al., 2001), as an alternative to improve the performance of health care providers and the utilization of scarce resources, at lower general costs for the health system (Borsani, Matta, Beschi, & Sommaruga, 2006). Increases in HHC services are reported in the U.S., where more than 4.7 million patients receive HHC in 2011 (Harris-Kojetin, Sengupta, Park-Lee, & Valverde, 2013), in Europe, where between 1% and 5% of the total public health budget is spent in HHC (Fikar & Hirsch, 2017; Genet, Boerma, Kroneman, Hutchinson, & Saltman, 2012), and in Colombia, where HHC providers increased from 482 as of December 2013, to 1,644 as of April 2018 (Colombia, 2018).

A HHC system can be viewed as a health service network which operates in urban settings, that includes the patient and his/her family, the interested party or institution who seek/provide home care, the people involved in logistics and financial aspects of home care, and the home care team (Bricon-Souf, Anceaux, Bennani, Dufresne, & Watbled, 2005). Coordination of this health service delivery network is a complex task, particularly given the geographical dispersion of patients and medical staff within an urban area. Furthermore, health managers face several logistics decisions when designing, planning and operating the system. According to the framework proposed by Gutiérrez & Vidal, (2013a), HHC managers face a set of logistics decisions, defined by each of the logistics functions in a service network. Moreover, the framework identifies service processes as the set of steps performed when the HHC service is delivered to a patient, which also have to be coordinated by HHC managers.

Despite the increase of HHC services, measured in the number of patients that receive such care, in the number of health services offered in such scheme, and in the number of HHC providers, only few studies have addressed the assessment of logistics capabilities of HHC providers. Based on the model proposed by Paulk, Curtis, Chrissis, & Weber (1993), logistics capabilities in HHC can be defined as the capacity of HHC providers' logistics and service processes to deliver coordinated medical care at home patients. Moreover, only few works assess maturity levels of logistics capabilities, creating a gap between the existent literature and the real operations of HHC providers. The literature evidences a significant growth on models and methods to support management decisions in health services, but most of them have small application in real systems and focus on operative decisions, in general health services (Brailsford & Vissers, 2011; Turner, Mehrotra, & Daskin, 2010), and in particular for HHC services (Gutiérrez & Vidal, 2013b). Additionally, most works in the literature study HHC systems in developed countries, and in Colombia, to the best of our knowledge, only one work refers to these services from the medical perspective (Echeverri, Manzano, Gomez, Quintero, & Cobo, 1972), and two study the maturity levels of logistics capabilities (Gutiérrez et al., 2014; Gutiérrez, Cortés, & Jaén, 2018).

Consequently, the aim of this chapter is to assess the logistics capabilities maturity of HHC providers, through the application of a logistics capability maturity model, with focus on the metropolitan area of the second largest city in Colombia. The model proposed by Gutiérrez et al. (2018) is implemented with health care institutions certified by the Ministry of Health and Social Protection (MHSP) to provide HHC services in the metropolitan area of *Valle de Aburrá*, Colombia. The chapter is organized as

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follows. The first section presents the background and a literature review that supports the work. The second section describes the methods followed to assess logistics capabilities in HHC. The third section presents and analyzes the results obtained. Finally, the last section presents conclusions and future research opportunities.

BACKGROUND AND LITERATURE REVIEW

The assessment of logistics capabilities maturity requires a definition of the logistics capabilities in HHC, as well as a description of the model implemented to identify maturity levels for each of the processes. Thereby, this section provides the definitions used for each of the capabilities based on the characterization presented by Gutiérrez & Vidal (2013a). The section also presents a description of the Capability Maturity Model (CMM) used to assess maturity levels, based on the model proposed by Gutiérrez et al. (2018). For each section, a brief literature review is also provided to identify the theoretical background that support the assessment.

Home Health Care Logistics Capabilities

According to the framework presented by Gutiérrez & Vidal (2013a), HHC logistics management comprises a set of processes that correspond to each of the logistics functions, as well as the set of service processes defined as the set of steps performed when the HHC service is delivered to a patient. Logistics functions include four main sets of processes: (i) Network Design, (ii) Transportation Management, (iii) Staff Management, and (iv) Inventory Management. Each of these processes also include a set of decisions that must be made at strategic, tactic, and operative levels. Service processes include: (i) Patient Remission, (ii) Admission, (iii) Appointment Scheduling, (iv) Visiting Patients, (v) Billing, and (vi) Payment Collection. Table 1 presents a brief description for each of the processes.

To the best of our knowledge, two works have completed literature reviews including all logistics functions in HHC (Emiliano, Telhada, & Carvalho, 2017; Gutiérrez & Vidal, 2013b). Most reviews in HHC have focused on studying routing and scheduling problems (Cissé et al., 2017; Di Mascolo et al., 2017; Fikar & Hirsch, 2017; Paraskevopoulos, Laporte, Repoussis, & Tarantilis, 2017). Works dedicated to Network Design process study the location of facilities in HHC (Ahmadi-Javid, Seyedi, & Syam, 2017), and districting configurations in urban areas to provide HHC services (Bennett, 2010; Benzarti, Sahin, & Dallery, 2013; Blais, Lapierre, & Laporte, 2003; Cortés, Gutiérrez, Palacio, & Villegas, 2018; Gutiérrez & Vidal, 2015). Most of the available literature to support logistics decisions in HHC services, focuses on scheduling and routing problems within the Transportation Management process, at the operative level. A review in 2013 showed 15 published works that study such problems (Gutiérrez & Vidal, 2013b), and one of the most recent reviews in 2017 showed at least 41 of such works (Fikar & Hirsch, 2017). This chapter does not include each of the 41 works in this section, but the reader is referred to the referenced reviews. Works studying decisions in the Staff Management process include tactical decisions for patients admission and staff assignment (De Angelis, 1998; Hertz & Lahrichi, 2009; Kommer, 2002; van Campen & Woittiez, 2003), while only one work refers to the inventory control of medicines for HHC services (Chahed, Marcon, Sahin, Feillet, & Dallery, 2009).

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Logistics Capability Maturity Model for HHC

The logistics capability maturity model for HHC proposed by Gutiérrez et al. (2018), is based on the Capability Maturity Model (CMM) designed by Paulk et al. (1993). The authors presented the CMM as a conceptual framework which aims to improve processes management within an organization, in a consistent and disciplined scheme. The CMM was first created in 1986 by the Software Engineering Institute upon request of the Department of Defense of the United States, to evaluate software providers and help organizations to improve their processes. In 1993 the framework evolved into the CMM, which establishes a set of key processes that are grouped into key process areas. The term *maturity* refers to the degree of formality and process optimization, which goes from *ad hoc* practices, to formally defined steps, to managed result metrics, and finally active process optimization. Based on a standard maturity scale, and according to the level of maturity each process is evaluated, and goals are established to improve processes.

A brief literature review of the most cited papers of the CMM, reveals that the majority of works are dedicated to study and implement the model in software development and engineering (Bamford & Deibler, 1993; Conwell, Enright, & Stutzman, 2000; Díaz-Ley, García, & Piattini, 2010; Jokela, Siponen, Hirasawa, & Earthy, 2006; Manzoni & Price, 2003; McGuire, 1996; M. C. Paulk, 1994; M. Paulk et al., 1993; Purvis, Santiago, & Sambamurthy, 1998; Saiedian & Kuzara, 1995; Serrano, De Oca, & Cedillo, 2003; von Wangenheim et al., 2010). Only one application is in the area of telemedicine (von Wangenheim, von Wangenheim, McCaffery, Hauck, & Buglione, 2013), and one work in HHC services (Gutiérrez et al., 2014). Other applications include education, human resources, sustainable supply chains, and the service sector.

The adaptation of the CMM for HHC services proposed by Gutiérrez et al. (2018) is completed in two steps. First, logistics capabilities are defined in terms of the variables that determine the maturity of such capabilities (see Appendix). Second, a structured survey is designed with the objective to identify, for each evaluated variable its maturity level, according to the maturity scale proposed. Table 2 illustrates the scale proposed, based on Paulk et al. (1993). The survey comprises ten sections that includes all variables indicated in the Appendix, for Logistics and Service Processes. The first four sections correspond to the Logistics Processes, and they include standardized questions related to decision criteria, methods to support decisions, documentation and follow up of records, support team, estimation of logistics costs, and improvement opportunities. The last six sections correspond to the Service Processes include inquiries related to the number and type of HHC services offered by the provider, the methods to measure capacity, the record and documentation of processes, the deployment of processes, the definition of promises of service, the evolution of patients, and the process evaluation performance (see Tables 3-4 in Appendix).

METHODS

In order to assess logistics capability maturity for HHC providers in *Valle de Aburrá*, a three stages method was followed. First, the model proposed by Gutiérrez et al. (2018) was adapted and implemented. Second, the population of HHC providers in *Valle de Aburrá* was identified and contacted. Third, the

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Table 1. Definition of HHC logistics capabilities

Processes		Definition and Decisions/Description
Logistics	Network Design	Strategical and tactical decisions that define in the long term the geographical covering of the HHC services. Includes: • Location of HHC central facilities • Districting of the covering area
	Transportation Management	Strategical, tactical and operative decisions that define the transportation function so medical staff travel to visit patients. Includes: • Fleet selection and sizing • Fleet assignment • Staff routing
	Staff Management	Strategical, tactical and operative decisions that define the capacity of the system in terms of medical staff, as well as the design of shifts and the allocation and assignment of staff. Includes: • Staffing • Shift scheduling • Staff allocation • Staff assignment
	Inventory Management	Strategical, tactical and operative decisions that define inventory policies related with suppliers, levels of inventory, and inventory control. Includes: • Suppliers selection • Inventory policies • Inventory control
Service	Patient Remission	Refers to the medical prescription that indicates the patient can receive medical care at home. The prescription is based on the medical diagnosis, and it must define: • List of medical procedures • Frequency and duration of each procedure
	Patient Admission	Defines the set of procedures and criteria to admit a patient into a HHC service. Includes: • Review of the insurance coverage policy • Review of the patient location versus de districting configuration • Review of the list of medicines, supplies and devices require • Approval of medical procedures with frequencies and duration
	Appointment Scheduling	Defines, for each medical procedure of each patient, the assignment of the medical staff that will provide the service. Considers: • Patient and medical staff location • Average medical procedure duration • Medical qualification required to provide the service • Shift assignment of medical staff
	Visiting Patients	Actual performance of the medical procedures at the patient location, which must be executed according to the established medical protocols. Must fulfill: • Medical prescription • Medical qualification • Scheduled day and hour
	Billing	Implies the administrative tracing and review of actual visits, and the generation of bills to insurance companies.
	Payment Collection	Implies the administrative follow up with insurance companies to collect payments generated by the services registered in the billing process.

Source: Elaborated by the authors based on Gutiérrez & Vidal (2013a)

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Table 2. Adapted maturity scale to assess logistics capabilities

Maturity Level		Description
0	Non-existent	Non-existent process in the evaluated institution
1	Initial	Existence of the process is recognized and its execution is *ad hoc*. The process is considered appropriate, but occasionally is chaotic because at this level providers do not have a stable environment for the development and maintenance of the process. Lack of planning is evident, failures, delays and cost overruns can occur.
2	Repeatable	The process is known, accepted and repeated, but not standardized nor documented. There is basic project management practice. There are basic metrics such as tracking costs and deadlines in order to repeat successes that have been previously achieved. Responsibility for the execution of the process rests with one person.
3	Defined	The process is defined as a standard through the formalization of existing practices. The documentation and standardization activities are carried out and the processes are integrated into the standard of the organization.
4	Managed	It is characterized by having a set of metrics and indicators of quality and productivity, which are used in a systematic way for decision making. In addition, detailed measures of the process are collected to generate high-quality products. The use of information technology tools is limited.
5	Optimized	The process is continuously and systematically improved. It makes intensive use of metrics coupled with a quantitative feedback of the process and manages the innovation process. Information technology tools are used to maintain competitive advantages.

Source: Elaborated by the authors based on Gutiérrez et al. (2018)

structured survey defined in the model of Gutiérrez et al. (2018) was applied, and the obtained responses were processed to identify logistics capability maturity of HHC providers. This section provides a description of each stage.

Stage 1: Implementation of the Capability Maturity Model

With the aim to identify logistics capability maturities for Logistics and Service Processes in HHC the model proposed by Gutiérrez et al. (2018) was implemented through the adaptation of the ten sections structured survey. Thus, to implement the survey, an initial characterization of HHC providers of *Valle de Aburrá* was completed. The characterization included a general description of the provider, its age, business model, type of business group to which it belongs, coverage service, patient classification system, and strategic planning methods. Although such aspects were not included in the estimation of the maturity metric, they allow placing the institution under analysis in the sector.

To define the standard maturity scale, the adaptation illustrated in Table 2 was implemented. In this scale, unlike the general model of the CMM, the model establishes a scale of six maturity levels compared with the five levels proposed by Paulk et al. (1993). The additional level corresponds to a process with a zero degree of maturity, defined as a non-existent level because some providers do not have or have not defined some of the variables or processes evaluated through the maturity model proposed. The assignment of maturity levels for each of the evaluated variables are completed in three schemes. In the first one, questions in which the maturity level is evaluated directly, and the six maturity levels described in Table 2 are provided, the maturity value corresponds to the value selected in the level description of the corresponding process. In the second scheme, the maturity level is assigned linearly to the alternatives of the question, i.e., questions that have six alternatives in ascending order is assigned to each alternative, respectively, each maturity level. In the third scheme, a uniform allocation of maturity level according

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to the number of alternatives available is assigned. As indicated in the example provided by Gutiérrez et al. (2018), if seven alternatives were available for the type of HHC services offered, and a particular provider offered five of them, the proportional maturity value in this variable will be 5/7 (71.43%) in relation to the maturity scale. With these schemes, having maturity levels assigned for each variable, the maturity level for each Logistic and Service process was calculated trough a simple average of the values obtained for each of the variables of a given process.

Stage 2: HHC Providers Identification and Contact in *Valle de Aburrá*

The population of HHC providers in *Valle de Aburrá* was identified through a query to the special registers of health care providers from the *Dirección de Prestación de Servicios y Atención Primaria* from the MHSP (Colombia, 2018). As of November 2016, 34 providers were certified by the MHSP to offer HHC services in *Valle de Aburrá*, and 29 of them were located in the state capital, Medellín, two of them in the municipality of Envigado, and one respectively in the municipalities of Itagüí, Bello, and Copacabana. According to the MHSP records, these 34 institutions provide HHC services to patients classified as acute, chronic with mechanical ventilation and chronic without mechanical ventilation. Furthermore, registers evidenced that seven of the 34 institutions have the three classes of patients, and the other 27 take care of only one type or at most two types of patients.

Once the population of HHC providers was identified, all 34 providers in *Valle de Aburrá* were contacted and invited to participate in the study. For one month, HHC providers were invited to participate in the study by three means: an invitation letter from the Municipal Secretary of Health (MSH), a cycle of contacts by telephone calls and e-mails, and a visit to the facilities of the providers which we perform to invite them personally to be part of the study. During this process, one of the objectives was to identify the leaders, coordinators and people in charge of the HHC service, who knew the operation of service at a strategic, tactical and operational level. This was done in order to have more accurate and complete answers for each of the questions of the structured survey, and to guarantee that each variable of the model was evaluated based on a complete knowledge and understanding of its meaning and effect on the service provision.

Stage 3: Application of the CMM in HHC and Results Processing

In this stage, an application of the adapted structured survey proposed in the model by Gutiérrez et al. (2018) was completed with the institutions that accepted to participate in the study. Such institutions delegated to the managers or coordinators of the HHC services to respond the structured survey. In some cases, several service coordinators were consulted in each institution to confirm and record the data. The survey was applied during two work meetings and random visits to selected HHC providers' facilities.

During the work meetings and the random visits, we first provided a detailed description of the research project and presented the theoretical background that support the structured survey. Moreover, HHC managers were assured of the confidentiality of the provided data. Subsequently, the research team conducted survey going through each of the ten sections of the survey. In this process, the research team assisted HHC managers to understand and respond each of the questions, validated the responses obtained with each manager. When surveys were applied directly and within the HHC providers' facilities, the research team was able to validate personally, each of the maturity levels reported by managers.

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Once the application and validation of the survey was completed, the research team registered and processed data obtained, using the Microsoft Excel application provided by Gutiérrez et al. (2018). First, general information of each provider was processed and characterized. This comprised an analysis of general characteristics of each HHC provider, which included features such as: years in operation, business model, type of business group, coverage municipalities, patient classification system, and strategic planning methods. Subsequently, the research team consolidated answers for each of the ten sections of the survey, for all participant providers. For each section, descriptive statistics such as centering and dispersion metrics were calculated. Responses of attributes for each variable of each process were codified based on the maturity scale presented in Table 2. Moreover, the research team processed maturity levels for each of the Logistics and Service Processes using descriptive and graphic analysis, identifying work and improvement opportunities.

RESULTS AND ANALYSIS

Results of the assessment of the logistics capabilities maturity reflect the complexity of providing HHC services within an urban area such as *Valle de Aburrá*. This valley is the natural basing of the Medellín river and one of the most urbanized and rapid growing areas in the Andina region. Nearly five million inhabitants share the valley which is politically divided into ten municipalities. The city of Medellín is the largest city in the valley followed by the municipality of Bello. The valley is 60 kilometers long, in its widest part is nine kilometers, and in its narrowest part is just three kilometers. The valley is surrounded by mountains where 90% of the poorest population reside. Similarly, about 90% of the rich people also reside in the slops of the valley. In this case, the geography, plus its interaction with the socio-economic profile of its inhabitants, configure a large conurbation of mostly poor, isolated and sometimes violent settlements. Their interconnection is only possible by narrow, step and sinuous streets where any kind of logistics operations is subjected to be slow, costly and unsafe. The structured survey of the assessment captures the diversity of providers and their strategies for adapting to serve demand and the competition among them.

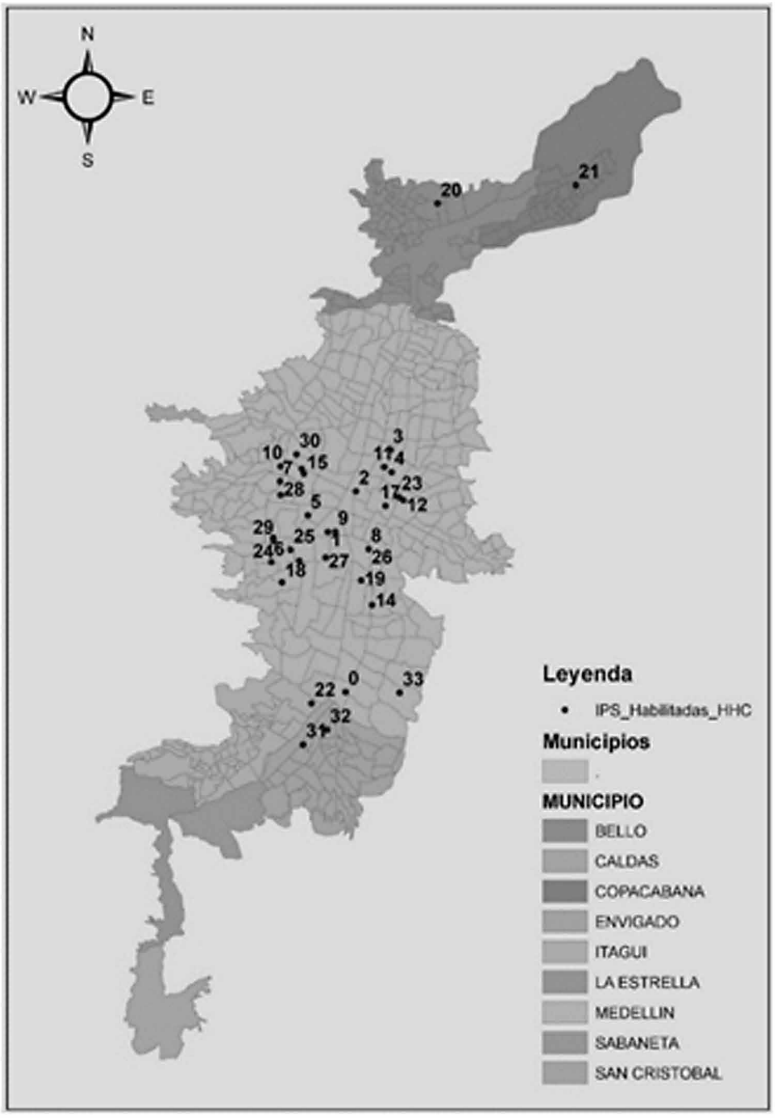
From the 34 HHC providers located in *Valle de Aburrá*, only 28 were effectively providing HHC services. Out of these, 16 providers (57%) responded to the structured survey, despite efforts to enlist most of them. However, those responding to the study allowed drawing critical clues about the logistics capability maturity of HHC in *Valle de Aburrá*. This section provides a description of the results of the application of the logistics capability model found with the sample of HHC providers. First, a characterization of HHC providers in the urban area is provided. Then, results of the maturity levels are described for each Logistics Process. Third, a general description of the results for Service Process is presented. For each set of results, we provide a brief results analysis and a comparison with other results found in the literature.

HHC Providers in *Valle de Aburrá*

From the 16 providers studied, 85% are located in the city of Medellín, 9% in the south of the valley where they serve the municipalities of Envigado (two providers) and Itagüí (one provider). The remainder 6% of the certified HHC providers is located in the north of the valley, operating in the municipalities of Bello and Copacabana. Figure 1 illustrates the exact locations of these providers. Average age of

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Figure 1. Location of the 34 authorized HHC providers in Valle de Aburrá
Source: Elaborated by the authors based on (Colombia, 2018)

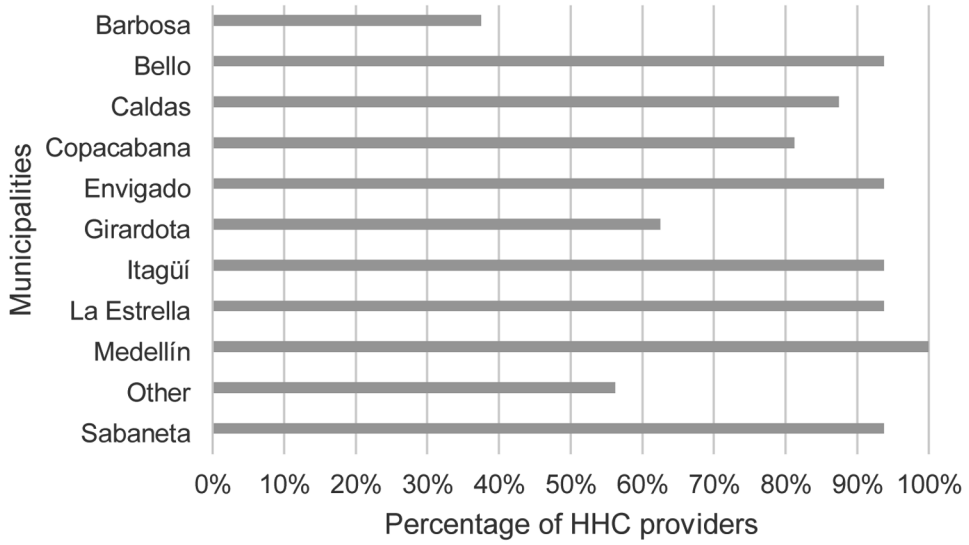


operations from HHC providers is 12 years. All providers attend patients in Medellín meaning that this municipality has the highest coverage. The municipality with less coverage is Barbosa where only 38% of the providers operate. On the contrary, municipalities such as Bello, Envigado, Itagüí, Sabaneta and La Estrella, are covered by 15 of the 16 providers that answered our survey (Figure 2).

The assessment allowed identifying that municipalities such as Sonsón, Yondó, Marinilla and Rionegro, outside of *Valle de Aburrá*, receive also HHC attention by some of the surveyed providers. Most of the providers (15 of 16) are registered as IPS (in Spanish services provider institution), and two of them outsource their services to other institutions. A 69% of these HHC providers has a system to classify their patients based on, either their degree of complexity, or their degree of affiliation (subsidized

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Figure 2. Percentage of HHC providers in Valle de Aburrá by municipality
Source: Elaborated by the authors based on results of the survey



or not) in the national health care system. The most common differentiation used by the HHC providers separates patients among acute, chronic patients under mechanical ventilation and chronic patients without mechanical ventilation.

Most of the surveyed HHC providers (15 of 16), subcontract services such as pharmacy, personnel, transportation (by a motorcycle, car or ambulance), collection of medical waste, equipment and laboratory among others. Even one of the providers subcontracts the whole operation. In terms of their strategic planning, 81% of the surveyed providers declared the implementation of some sort of a yearly strategic planning and service evaluation. Tools and methods declared for evaluating their performance include: Balance score card, indicators board, service projections, board control task, goals and historical information tracking.

The characterization of the 16 HHC providers showed two important results. First, the two main HHC providers belong to large health care and insurance companies in the country. However, most of the 16 providers operate in an informal scheme, despite their certification from the MHSP. These providers are small, familiar or single-person providers employing medical staff through service contract and provide the services as third-parties. This shows the need to improve control by health care authorities, as it is established in North America (Lahrichi, Lapierre, Hertz, Talib, & Bouvier, 2006) and Europe (van Campen & Woittiez, 2003). Second, there is an increase on the number and type of HHC services. Whereas some therapies remain the most common service, the inclusion of other services such as Specialist home visits and Auxiliary nursing care, increases the HHC portfolio up to 80 different types of health services.

Logistics Processes

The application of the logistics capability maturity model revealed that the average maturity level among the surveyed HHC providers is 3.2/5.0 for the Logistics Processes. To illustrate the performance of each

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process, the logistics maturity polygon compares the results (see Figure 3). Next, results for each of the Logistics Process are described.

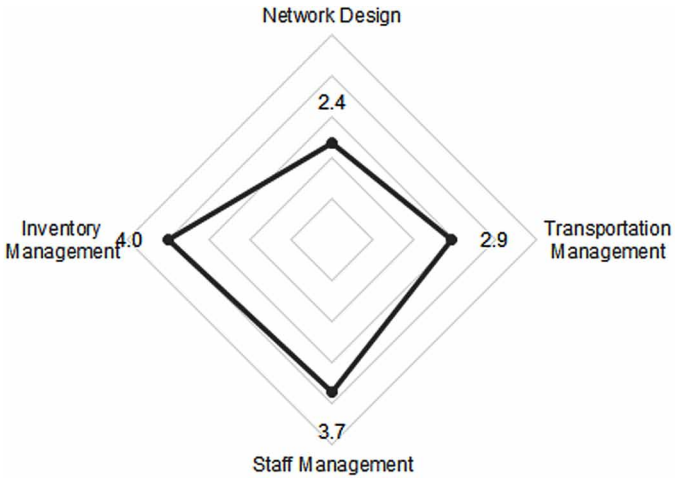
Network Design

This is a critical logistics decision in HHC systems. Five providers (31%) did not consider any criteria to locate their operations base. A 25% of the providers consider the base of operations locating costs, 13% consider the patient closeness and transportation costs, and 6% of them locate their operation base considering the closeness to their suppliers. From the studied providers, an 87% divide the area of coverage to minimize transportation times. Among those providers, the use of historical data (63%) and empirical methods (38%) are the most common inputs implemented. There is no evidence about the use of software to assist this process. Thus, the average level of maturity among providers in the process of network design is 2.3/ 5.0, and two providers declared the total absence of any kind of network design

The performance of the network design is measured by 56% of the providers considering the number of patients. Half of the providers incorporates the number of visits and the personnel allocated. A 44% uses the network design to balance the physician's workload, while 25% does not consider any criteria. Finally, 75% of the providers register the number of patients and visits per zone. However, only 50% of the providers has a network design team defining the size and workload per zone. A 31% of the providers considers costs in their network design, and 69% is seeking improvements in the process of defining the zones and network.

Eleven of the HHC providers (68%) reported the need to improve network and districting decisions through the implementation of software and the inclusion of neighborhoods' risk information. Previous works have studied this problem for HHC services (Bennett, 2010; Benzarti et al., 2013; Blais et al., 2003; Cortés et al., 2018; Gutiérrez & Vidal, 2015). These results indicate the need for models and methods to support districting decisions and allow managers to include aspects of the service in the context such as demand diversity, balanced workload assignment, and the assignment of medical staff to service delivery in the urban area.

Figure 3. Assessment of logistics capability maturity for logistics processes
Source: Elaborated by the authors based on results of the survey



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Transportation Management

A HHC system cannot function without transport facilities. Among the HHC providers, the application of the model revealed that 38% of the them owns their fleet to provide service. The type of vehicles used are: cars (38%), motorcycles (31%) and ambulances (13%). The survey illustrates that while providing service, 56% of the personnel use the company's vehicles, 69% uses their own vehicle, while 25% uses public transportation.

To manage transportation 25% of the HHC providers supports their operation with information technology to define the model of attention, the vehicle to use and the distance to cover. A 25% uses historical data, and 25% uses their own experience as an empirical strategy to transport decision making. The most common criteria for deciding the type of vehicle and the distance to cover are: area of coverage (56%), access to the zone where the patient reside (50) and the quality of the service and the budget (44%). Two providers consider crew security reasons, given the possibilities of thief, assault and even the control of the zone by illegal gangs. All providers have a teamwork assigning the visits.

Transportation management is under constant improvement by all providers. A 75% of them estimates the cost of the assignation process and the priorization of the visits. Transportation time and cost of the medical staff cannot be eliminated because service is delivered at patient´s location. However, this process can be improved through the use of quantitative techniques (Cissé et al., 2017; Di Mascolo et al., 2017; Fikar & Hirsch, 2017; Paraskevopoulos et al., 2017), allowing managers to reduce transportation costs, to maximize patients and staff satisfaction, and to improve the general quality of the service delivery.

Staff Management

The surveyed HHC providers reported the use of four types of contracts to manage their personnel. Fifteen providers (94%) have a direct contract with employees, where 11 of them also contract employees under three different levels of outsourcing services. According to the type of HHC services offered, providers employ auxiliary nurses (100%), nurses (100%), general practitioners (94%), therapists (88%), and specialists (56%). An 88% of the providers hire other kinds of medical staff such as nutritionist, psychologist, speech pathologist, social workers, anesthesiologist and chemists.

The average maturity level of the process to estimate the number of people to be hired to provide the service, is 3.0/5.0. Also, the survey revealed that 69% of the providers make decisions about hiring and type of contracts based on historical data. Another 38% of the providers considers the standards of the service and aid their decision making by using software. Similarly, the most common method implemented by the providers for programming the personnel's shifts is based on historical data. Five providers declared the use information technology for assisting the process of programming. The survey also found that 88% of the providers have a staff exclusively working on hiring and assigning shifts. The same percentage of providers declared that these processes are under constant improvement.

Fourteen providers (88%) reported a cost estimation of medical staff over the operative costs of the HHC system; four of them indicated that this cost represents over 40-80%, and the fifth indicated that this cost lies between 80-100%. This result indicates that staff management is a key point in HHC logistics management. Related decisions as Staffing, Shift Scheduling and Staff Allocation (Table 1) are complex problems, and there is a wide set of studies demonstrating the improvements achieved when implementing quantitative techniques in similar health services (Gutiérrez & Vidal, 2013b). Moreover, these decisions impact on the medical staff stability and team work, and therefore the service quality.

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Inventory Management

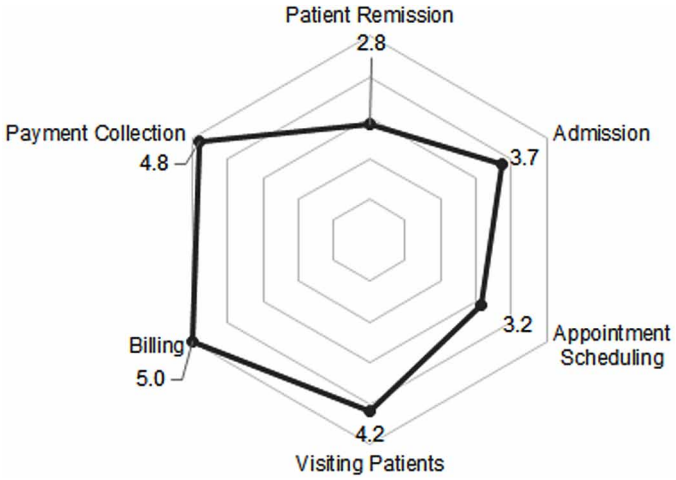
Inventory of medicines, supplies and medical devices, are managed with three different strategies: owned pharmacy service, in-house service, and a third-party service. All providers reported to manage the inventory of medicines, while only 94% manages the inventory of medical supplies and equipment. The supplier's selection is performed by 75% of the providers considering quality standards, the rest 25% is based on their experience. Four providers (25%) declared the use of information technology to perform this logistics process. Half of the providers use software and information technology to support their inventory decision making. The other half considers their own quality standards to guide their management.

Among the surveyed providers, 63% of them register inventory levels considering variability and inventory policies which depend on each service patient demand. Four providers register the level of their inventories considering the replenishment lead time. An 88% of them, also declared the existence of a staff exclusively working on inventory management and the estimation of the inventory management cost system and the improvement of the process. These results contrast with inventory management practices in countries with solid national health care systems. Previous studies reveal that most of HHC providers are internally responsible for controlling inventories along the HHC supply chain (Bennett Milburn, 2013; Chahed et al., 2009). Inventory decisions can be outsourced with third-parties, but better analytical and quantitative support must be provided to improve their management.

Service Processes

The assessment of logistics capabilities found that the average maturity in six main Service Processes is 4.0/5.0. The Service Process assessed are: Patient Remission, Admission, Appointment Scheduling, Visiting Patients, Billing, and Payment Collection (see Figure 4). In general, most of the providers offered a wide variety of services which are adapted to the patient needs. Additionally, the providers are under constant improvement of their services and sending reports, of the patient medical condition post-service, to the referral hospitals.

Figure 4. Assessment of logistics capability maturity for service processes
Source: Elaborated by the authors based on results of the survey



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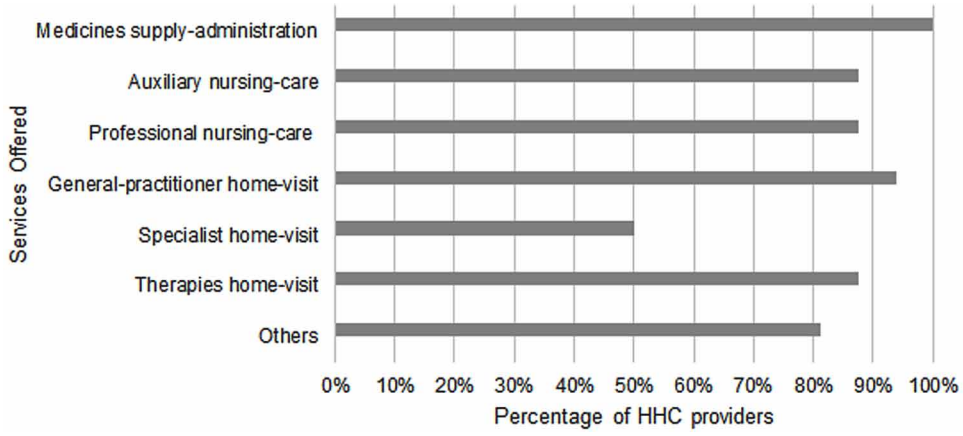
Portfolio of services offered by the *Valle de Aburrá* health care providers is presented in Figure 5. Results from the assessment found that 100% of the providers offer Medicines supply-administration, 94% offer General-practitioner home visit, 88% offer Therapies home visit Auxiliary nursing care, and professional nursing care. The least provided services are Specialist home-visit with half of the providers. Some of the additional services offered by the providers are: Nutrition, Psychology, Phono Audiology, Social Work, rent of medical equipment, laboratory and temporary nursing home.

The assessment allowed evidencing that most providers measure their capacity in terms of the number of patients per month, whose average is 609. Other providers have records with the number of visits per month, with an average of 9,195. The survey reveals that the largest provider attends 38,000 patients per year and 35,000 visits per month. On the other hand, 50% of the providers send to the referral hospital a post-service report on the evolution of the patient medical condition. As a strategic planning measure, 88% of the providers estimate the attended demand, and an 81% of them estimate the no-served demand. To estimate demand, providers use three methods: one provider uses information technology, 13 use historical data and two use empirical methods.

In the Patient Admission process, demand estimation is completed by 75% of the providers with existing data and using the key performance indicators of the standard process. However, the use of empirical methods is also common. Regarding the Appointment Scheduling process, the surveyed providers use different methods. The most common, by 50% of providers, is to support these decisions with existing data, exclusively, i.e., appointments are scheduled based on previous records, solely Additionally, six providers use their own experience, while 25% use information technology. A 63% of the surveyed providers delivers service based on standards, and four of them support their operation with the use of technology and constant improvement. All providers use software for Billing, and 94% for Payment Collection, which explains the maturity levels in these processes. In some cases, this service processes are supported using existing data, standards and performance indicators.

The assessment of the Service Processes and their maturity levels allowed identifying five main results. First, 63% of the providers consider several criteria for appointment scheduling to visit patients. The attended visits and the travel time to reach the patient's homes are among them. A 19% of providers consider the patient preferences regarding to the hour of the day to be visited or the genre of the nurse or

Figure 5. HHC services offered by providers in Valle de Aburrá
Source: Elaborated by the authors based on results of the survey



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physician in charge of the service. Only two of the 16 providers (12%) consider medical staff preferences as well. Some staff prefer to visit patients in communities close to their own home, and others in specific zones of the city. A 69% of providers stablishes a commitment to visit patients at certain hour of the day. Half of providers visits patients daily and restructure their scheduling when one new patient is admitted in the system. In general, the defined criteria for prioritizing patients is based on medical judgment.

Second, the assessment evidenced that, referring to the location from which the medical staff can departure to attend visits, a 63% of providers allow staff to start their shifts from the providers' base as well as their own home. A 19% of providers only allow departures from their base, and another 19% allow staff to departure from home. The assessment also evidenced that 44% of providers define and include breaks for medical staff in their scheduling process. However, 31% of providers define them, but do not include them in the process. The rest 25% of providers do not include resting time at all. Third, 75% of providers evaluate the route efficiency to visit patients with a set of key indicators: number of services, reached goals of visits per month, non-served visits, leaving and arriving times of vehicles transporting staff, waiting and traveling times. Similarly, to evaluate the scheduling of visits, an 8% of providers consider the number of visits per person, a 69% of them consider the distance between patients, a 63% of providers considers travel times and only 19% of the surveyed providers estimate travel cost.

Fourth, all providers evaluate the service promise fulfillment and use some system to measure patient's satisfaction. One provider declared to complete random calls to patients and surveys to measure the service as well as the health care professional. Additionally, a 94% of providers tracks the medical condition of patients, an also the service time. Fifth, twelve of 16 providers estimate travel times to visit patients. Finally, all providers acknowledged a proportion of scheduled visits are unfulfilling. These non-fulfillments are commonly attributed by 100% of providers to the absence of patients at the moment of the visit. A 94% of providers blame the traffic congestion, while 56% of them blame their own mistakes when scheduling visits.

CONCLUSION AND FUTURE RESEARCH DIRECTIONS

This chapter presented an assessment of logistics capabilities maturities of HHC providers, through the application of a logistics capability maturity model, with focus on the metropolitan area of the second largest city in Colombia. The assessment included the evaluation of maturity levels for four Logistics Processes and six Service Processes, based on an adaptation of the well-known maturity scale. The results of this study revealed how HHC providers make logistics decisions and how the service delivery process can be improved to ensure better service quality and efficiency. Furthermore, these results can be an input for designing and planning HHC services in the state and for benchmark studies.

The application of the logistics capability maturity model revealed its capacity for assessing the main characteristics of the HHC providers in *Valle de Aburrá*. The model estimates wide and focused key indicators allowing broad characterizations and specific insights about the providers' performance, operations and strategy. The model is also able to identify the main strengths and weaknesses of the providers and the challenges they face. As a part of a complex network of services in a large urban area, the model evidences the HHC limitations mainly regarding to logistic processes of network design and transportation. In this scenario, the assessment exposes opportunities for improvement since the main HHC services provided are the administering of medication, general doctor care, therapy and basic

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nursing care. These are transportation intensive activities which are completely constrained in a large urban domain.

The assessment also reveals the rising professionalization of the HHC providers. A comparison with a previous assessment of HHC logistics management *Valle del Cauca*, a similar region in Colombia (Gutiérrez et al., 2014), shows how in *Valle de Aburrá* there is a trend in the use of information technology, technological equipment and software to support the decision making process. Scheduling, staffing, balancing workloads and districting are becoming more prone to be performed under the use of standards, indicators and historical data rather than empirical expertise. Also, the assessment illustrates the rising presence of teams into the HHC providers whose work is exclusively focused on the performance and improving of logistics process. Furthermore, this assessment found the shared similarities with the *Valle del Cauca* HHC providers: their high level of heterogeneity in delivering service and management.

The characterization of HHC providers suggests three research directions. First, health care authorities should perform better control over HHC providers. The fact that 18% of the certified providers does not operate continuously and all logistics management is done empirically, show a need for implementing more rigorous methods used for planning, designing and operating HHC services. Second, there is a need for standardizing the metric used to measure the capacity of HHC providers. They must identify their capacity to meet service demand as well as it is mandatory for IPSs to determine the number of available beds when they offer hospitalization services. Although a metric of patients/year is a general one, the number of visits per patient can fluctuate significantly, and therefore a better metric can be the number of visits/year. Third, due to the increasing number and type of HHC services, the capacity measurement can be indexed by each type of service, to have a better knowledge of each HHC provider.

The assessment of Logistics Processes has identified the need for developing a more integrated health logistics network and standardization process to improve HHC delivery through quantitative techniques. More attention should be placed on Network Design decisions, especially on the districting configuration of services. Half of the providers indicated that this process needs to be improved using robust epidemiological criteria, service demand, and balance workloads for medical staff. Network Design and Transport Management decisions should be integrated, given the impact of travel times and costs in the efficiency of service delivery. Also, special attention should be placed on geographical dispersion of patients, appointment scheduling, estimation of service times, and assignment of patients to medical staff. Moreover, epidemiological information about disease prevalence and incidence, demographic profile (age, sex, fertility and mobility), socioeconomic level (income and education) of the population served, distances from health facilities, and communication infrastructure (roads, streets, transport, and telephones) are critical inputs to improve network design, transportation management, and efficiency of service delivery.

It is also critical to acknowledge the importance of the Staff Management in HHC services. A proper definition of staff requirements and its correspondent assignment to serve patients are critical decisions that directly influence patient service quality and the work conditions of the medical staff. All improvements based on the findings of this study should lead to more efficiency and better quality of HHC services for the most important party of the health care system: the patient.

The evaluation of Service Processes and their maturity supports two research directions for improving the logistics management of HHC providers. First, the strategic planning and the estimation of requirements for a HHC system can be improved through a detailed register of served and non-served demand of HHC visits, and its corresponding statistical analysis. These registers allow HHC managers the pos-

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sibility to complete an integrated analysis of the system capacity, and to identify resource requirements and their corresponding allocation to cope with demand variations. Second, maturity levels can only be improved if standards are defined. An average maturity level of 4.0/5.0 over service processes indicates a need for process standardization and improvement in HHC delivery. Processes such as Patient Referral, Patient Admission and Appointment Scheduling are not clear in several cases for patients, referral institutions and medical professionals, and only two providers deliver a medical feed-back report to the original referral source.

Finally, the assessment of logistics capability maturities suggests further research directions and improvement opportunities. The rising use of technology, standards and software is evidenced Service Processes, where professional teams focused to perform and improve services. The importance of this assessment for highlighting the interaction between the problem of HHC delivering and the imposed challenges by a large urban area, is the clearest contribution of this work. The assessment exposes the need of logistics adjustments whose implementation will contribute to increase the level of maturity and the wellbeing of the needed population.

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APPENDIX

Definition of variables included to assess logistics capabilities maturity are defined in Table 3 for Logistics Processes, and in Table 4 for Service Processes, based on Gutiérrez et al. (2018).

Table 3. Variables evaluated in each logistics process

Logistics Process	Variables Evaluated
Network Design	• Location criteria for HHC base operations facilities • Methods to complete districting of the coverage urban area • Performance criteria for districting • Demand registers by district • Work team to support network design • Cost estimation of the network design • Improvement opportunities for the network design
Transportation Management	• Nature of fleet for medical visits • Transportation modes for medical visits • Methods to select transportation modes • Criteria to select transportation modes • Work team to support transportation management • Cost estimation of the transportation management • Improvement opportunities for transportation management
Staff Management	• Employment modality of medical staff • Types of medical staff • Methods to determine capacity in medical staff • Methods to schedule shifts for medical staff • Work team to support staff management • Cost estimation of the staff management • Improvement opportunities for staff management
Inventory Management	• Types of inventory managed by the HHC provider • Methods to select suppliers • Methods to define inventory policies • Records of variability of inventory levels • Work team to support inventory management • Cost estimation of the inventory management • Improvement opportunities inventory management

Source: Elaborated by the authors based on Gutiérrez et al. (2018)

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Table 4. Variables evaluated in each service process

Service Process	Variables Evaluated
Patient Remission	• Size of the HHC services portfolio • Types of HHC services • Delivery of medical evolution report to the prescriber
Patient Admission	• Measurement of capacity to provide services • Demand records of patients served and not served • Methods for estimating the demand for services
Appointment Scheduling	• Methods to schedule HHC visits • Criteria to schedule HHC visits • Service promises for HHC visits • Assignment and sequencing of HHC visits • Criteria for assignment and sequencing of HHC visits
Visiting Patients	• Methods to provide and deliver HHC services • Evaluation of service promises for HHC visits • Patient satisfaction measurement system • Estimation of medical procedures times in visits • Estimation of travel times between visits • Record and reasons for total or partial non-fulfilment of visits
Billing	• Methods for the billing process
Payment Collection	• Methods for the payment collection process

Source: Elaborated by the authors based on Gutiérrez et al. (2018)

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Chapter 7
Measures to Increase Efficiency and Reduce Costs on Solid Waste Service Collection Operation

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ABSTRACT

The megacity of Lima generates daily around 9,000 t of wastes (organic and non-organic). This waste is collected by a network of municipalities with a customer service level of 43% and average cost of 38 $/t. This research is focused in Comas, a district of Lima. This district generates dairy 450 t of waste. The authors propose a key performance index to increase efficiency (customer service level) and reduce operating costs for waste collection service on Comas district (Lima) by using an on-line demand tool, based on the current population density and the waste generation of a certain area of Comas. They apply a reverse zone distribution (RZD), a term introduced in this study, as a result of an adapted methodology and supported by new technology trends, such as the internet of things. The RZD's value chain has many similarities with a commercial one; however, it differs fundamentally in the attention to the citizen.

INTRODUCTION

Urban logistics is a broad research and application field that led to a wide research-practice community (Ogden, 1992; Taniguchi et al., 2001; Macharis and Melo, 2011; Gonzalez-Feliu et al., 2014; Taniguchi and Thompson, 2015; Gonzalez-Feliu, 2018b, 2019). Although traditionally related to last-mile and urban B2B deliveries, urban logistics has evolved for more than 40 years and the variety and nature of flows

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considered in this field is nowadays wider (Gonzalez-Feliu, 2018b). Indeed, three main categories of external flows, i.e. those that contribute to road occupancy and pollution in urban roads, are nowadays considered as belonging to urban goods transport and logistics: inter-establishment flows (i.e. B2B deliveries), end-consumer movements (B2B and some C2C flows) and urban management flows (i.e. those that allow urban functions to be operational). That last category, although it represents about 4% of the total traveled distances and 8% of road occupancy issues (Gonzalez-Feliu, 2018a) of all urban goods transport and logistics flows, is crucial to ensure the city's function.

Worldwide, 2.01 billion municipal solid waste are generated per year. Likewise, the waste generated by people daily averages 0.74 k, but fluctuates between 0.11 to 4.54 k. The highest-income countries generate 34% of the world's total waste. It is expected that by 2050, global waste will grow to 3.40 billion. On the other hand, approximately 1,600 million t of greenhouse gas emissions equivalent to carbon dioxide were generated in 2016, which represents approximately 5% of global emissions. It is expected that emissions related to solid waste will increase to 2.6 billion t of carbon dioxide by 2050 (World Bank Group, 2018).

Waste management flows represent, according to Gonzalez-Feliu (2018a), 1% of total traveled distances and 2% of total road occupancy issues. Since waste is, in general, collected along each street, it is difficult to quantify it in number of trips. Indeed, a waste collection route is assimilated to an arc routing problem and not to a nodal vehicle routing one (Cattaruzza et al., 2017), i.e. waste collection routes are defined as a one-path route where freight, more precisely waste, is collected on an arc and not on a node, so it is not evident to define a set of trips as on classical deliveries (Holguin-Veras et al., 2005). On the other hand, waste collection is crucial in city management (Hoornweg and Bhada-Tata, 2012 ; Pires et al., 2019), since it ensures the continuance of street hygiene, as well as contributes to urban health and inhabitant's quality of life (Botta et al., 2002). In Latin American countries, socio-economic and cultural issues have an influence on a sub-efficient use and appropriation of the urban waste management systems (Berdier, 2014).

In 2016, Peru's urban household produced more than 7 million t of waste (Ministerio del Ambiente, 2019). Metropolitan Lima contains about one third of the total population of the country, so it is then the highest generator of household waste in the country (Durand and Metzger, 2009). The metropolitan area is divided into 50 districts, administrated as independent municipalities, of different nature and characteristics (Metzger et al., 2015).

Economic growth and movement towards urban areas influence the per capita generation of waste. The awareness of the amount of waste generated, particularly by rapid urbanization and population growth, as well as the types of waste generated, allows local governments to select the appropriate management methods, plan future demand, design systems with an adequate number of vehicles, establish efficient routes, establish objectives for the diversion of waste, monitor progress and adapt as waste generation patterns change. In addition, using accurate data, governments can realistically allocate budget and land, evaluate relevant technologies and consider strategic partners, for the provision of services related to waste management (World Bank Group, 2018).

In this context, the importance of improving the efficiency of the waste management system in a metropolitan area such as Lima is evident (Xantem and Michaels, 1960; Arnillas Lafert, 1998; Llerena et al., 2011), not only on a logistics viewpoint, but also from an "efficient use" perspective. To that, IoT and TIC can contribute to a better management and planning of such systems. However, to implement those technologies, it is important to know the current context and application field, as well as characterize the current waste collection logistics system in order to improve it.

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The aim of this chapter is to present, via a preliminary pilot in the district of Comas, Lima, the potential of IoT and TIC in the implementation of new urban waste collection and transport systems. The paper is organized as follows. First, background issues are presented. Then, methodological issues are described. The methodology includes a pre-study phase, based on a zone selection and characterization using the km^2 methodology (MIT Megacity Logistics Lab, 2014) that is adapted to forecast the most important waste generators and prepare the pilot, and a pilot phase, where IoT systems are positioned in the streets to support waste management. After that, preliminary results are presented and discussed. Finally further developments as well as managerial implications are addressed.

BACKGROUND

Reverse logistics is the recovery and economic use of products that fail to meet the needs of the consumer, which generates a flow of materials, information and products from the consumer to the producer. This type of logistics is the process of efficiently planning, developing and controlling the flow of materials, products and information from the point of origin to the point of consumption, so that the consumer's needs are met. This is accomplished by recovering the waste and managing it to re-produce them in the supply chain; also by obtaining added value and achieving an adequate elimination of the waste (Rubio & Bañegil). Reverse Logistics differ mainly from the popular conception that the supply chain management is "a one way" cycle. This branch encompasses all the activities and processes related to making used goods, which are no longer needed by the costumer, but can be reused in the market (Fleischmann et al., 1997). Given the difference between the logistic network and the classic forward logistic network, it can be noted that the first one has gained popularity. In order to gain competitive advantage, firms try to retrieve products efficiently from costumers, increasing satisfaction level and reducing costs (Dolgui, Soldek, & Zaikin, 2005). The literature indicates the existence of four major groups of analysis in reverse logistics: the inputs, the system structure, processes and outputs(Pokharel & Mutha, 2009).

The majority of literature regarding reverse logistics falls in the category of the systems structure, normally seeing optimization models for network designs, as seen in Demirel and Gökçen (2008), where general reverse systems are proposed, or the integration of both the *forward supply chain* and reverse supply chain, as seen in (Pishvaee, Jolai, and Razmi, (2009) and de la Fuente, M. V., Ros, L., & Cardos, M. (2008).

Other important part of the literature relates to the processes of the reverse logistic supply chain, which are not only more effective at delivering the product, but also reducing costs and increasing the surplus of the chain (Chopra & Meindl, 2013). The research is divided between discussing the impact of new modules for excess of products (Pokharel & Mutha, 2009; Guide Jr, V. D. R., Srivastava, R., & Kraus, M. E. (1997).) and various recovery systems for product recovery situations (Fleischmann et al., 1997). However, there is still a small number of papers that discusses the optimal ways to collect and deliver this service in an efficient way. According to Govindan, Soleimani, and Kannan, (2015), only 1.3% of the related literature focuses on the routing problems of reverse logistics, with researchers such as Kim, Yang, & Lee, (2009) or those of Machuca, Dorin and Garcia (2018), which minimize the distance travelled from the distribution centers to their respective distribution point (in this case recycling centers).

Currently, when an organization, whether local or foreign, has an initiative or solution to improve its operations, it must consider the social factor within the balance (Gregory & Keeley, 1994). Basically, it should be evaluated if its operation can be affected by the participation of citizens. Many projects

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that brought great savings for companies, both public and private, and benefits for society have failed or have not been executed correctly because the citizens have not put their part or collaborated to make them succeed (Blanco & Merchán, Cargo Mobility in Areas of High Congestion: Review of Existing Policies and Recommendations, 2017).

We can observe that in Peru the solid waste collection service represented 4.1% on average of GDP for the year 2012 (Ministry of the Environment, 2016). In 2012, 38% of municipal solid waste was disposed of in landfills; however, there are not enough landfills in Peru to treat more than 7.1 million t per year (Vice Ministry of Environment Management, 2012). The efficiency of the collection service is almost 43% (PWI - Peru Waste Innovation, 2011). Likewise, In Peru the companies of waste collection usually incur in cost overruns, basically because citizens do not have an adequate behavior (49.6%) and do not take their waste at the established time (PWI - Peru Waste Innovation, 2011), which causes the units of transport to make a double or triple trip to complete the contracted weight. We understand that civil disobedience occurs, which leads the citizen to go beyond the rules and regulations established by the authorities, and not to comply with them (Matos Mar, 1986).

In the district of Comas, Peru 169 425 t of solid waste was generated in 2017 (Ministerio del Ambiente, 2018), an amount equivalent to 0.9 k / inhabitant- day of solid waste, just above average (Ministerio del Ambiente, 2018) and with an operational cost of collection of solid waste at a national level of approximately $ 38 per t (Ministerio del Ambiente - Perú Limpio, 2015). With these data, the level of expected solid waste collection service should be around 68% according to the cost per t, the level of income according to the country and the level of generation of waste (The World Bank, 2012). However, this level of service does not exceed 43% (PWI - Peru Waste Innovation, 2011). In addition, an investigation finds that 94.7% inhabitants of the district of Comas are interested in an improved solid waste collection service (PWI - Peru Waste Innovation, 2011) and 46% of them would also be willing to pay for the service (PWI - Peru Waste Innovation, 2011). These numbers make the application of this proposal an interesting service alternative to the neighbors and an important factor of change in municipal management.

Those forecasts led to guide the objective of this research, looking for measures to increase efficiency and reduce operating costs of the solid waste collection service in the district of Comas, based on the logistics profile of the district per km^2 (Merchán, 2015), where the demand will be according to the points of reference with the highest population density (Merchán, 2015), the implementation of containers per density zones, the support of technology (IoT) to measure the fill and weight of these containers and the generation of solid waste (Ministerio del Ambiente, 2016).

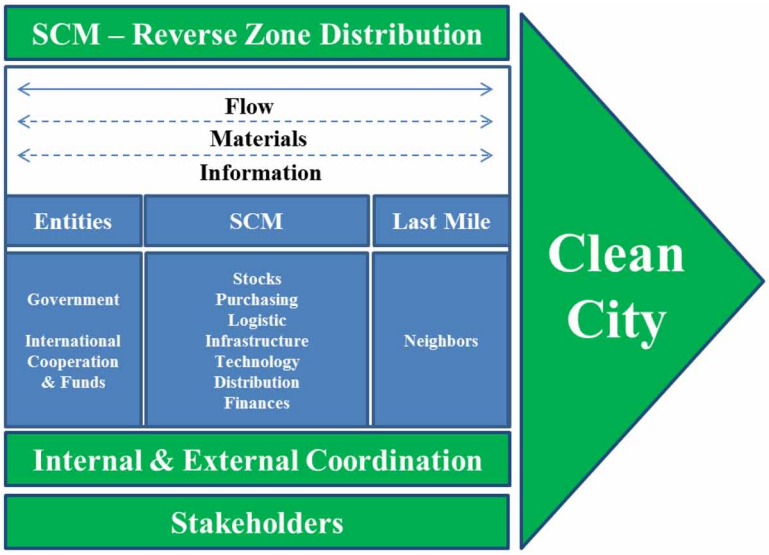
An efficient operation to improve the level of service to the citizen can be defined. The level of service will be based on the level of collection efficiency of solid waste in cost, time and quantity. For these purposes, we will apply an adapted Reverse Zone Distribution method. It will seek to focus on citizens (Yu & Yaclin, 2015), trying to provide a benefit to society, as shown in the first figure.

The idea is to achieve a cleaner city, by applying a logistical profile of the area based on its population density and define an efficient collection operation. The purpose will be the minimization of health risks, a concept that will result in "Cleaner streets = Happier Neighbors = Municipality Increase in efficiency = Healthy City". This reverse supply chain will seek to reach 9 million 111 thousand residents (Instituto Nacional de Estadística e Informática - INEI, 2017) of Lima.

On the other hand, the identification of the supply chain - Reverse Zone Distribution, invites its application to other supply chains such as recycling, urban mail, hazardous materials disposal, medicines

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Figure 1. Reverse zone distribution chain



(Chamorro, 2004), batteries (Chamorro, 2004) among others. Today, there are many successful projects related to a more efficient reverse logistics system. For example, both General Motors and Xerox focused on this type of logistics, achieving great success in the area (Pishvaee et al., 2009; Meade, L., Sarkis, J., & Presley, A. 2007; Üster, H., Easwaran, G., Akçali, E., & Çetinkaya, S. 2007). This will serve as referents for the results of the study.

METHODS AND PROCEDURES

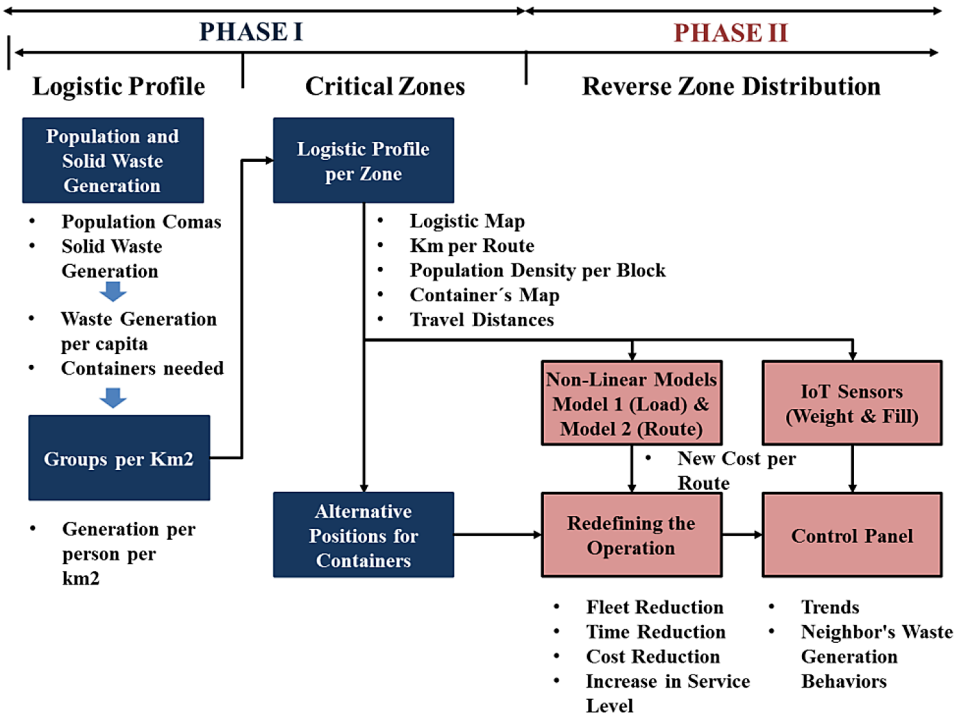
The proposed methodological framework is organized in two phases:

- The first phase aims to identify critical waste generation areas in Comas. Therefore, a characterization of the Comas municipality is needed; for this purpose, an adaptation of the km^2 methodology of the MIT Megacity Logistics Lab (2014) was used, first to characterize the area considered in areas of 1 km x 1 km, and then to identify critical zones. Each zone of 1 km^2 is characterized by a profile defined using 3 variables: population density, number of intersections and density of retail establishment by type. From these profiles, waste collection needs are defined by an empirical procedure.
- The second phase includes a pilot that indicates whether a container is ready to be picked up under certain weight and filling parameters, it determines which containers should be collected, it also monitors and updates the key performance indicators of the management. This pilot is based on a non-linear model to define the priorities in waste collection (therefore, assign containers to collect vehicles to define the optimal route).

The methodological framework is summarized in Figure 2.

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Figure 2. Methodology of reverse zone distribution



EXPERIMENTAL/NUMERICAL SETTING

The first analysis of the logistic profile is intended to group different zones of the district with a similar density of population by zones and commerce. The number of properties is 103 665, where homes represent 84.7% (Comas, 2016). The generation of solid waste is directly proportional to the population density of an area. There are 305 t/day generated in the properties, which represent approximately 65.7% of the total. The information about population and generation of waste by type of property (Comas, 2016) will be working with MapInfo System to identify the level of concentration of people per block in the district of Comas to define high zones of waste generation as seen in figure 3.

The district has been divided into fourteen (14) zones, according to the use of properties, population density, and waste generation. Considering that containers have a density of 0.134 t per m3 (Municipality of Comas, 2015); each container could store a maximum of two (02) t. According to the use of property, population density and waste generation the highest value will be divided into each area to obtain values between 0 and 1, where 1 is assigned to the area that has the highest value. With this information, it is possible to determine the logistic profiles of the 14 zones and their density levels, as shown below.

Zone # 6 has been selected for the simulation of the Reverse Zone Distribution (RZD), due to its logistic profile which is characterized by a large concentration of population and the presence of District's Wholesale Market, as shown in Figure 4. Zone # 6 will need 28 containers.

The designation for the physical locations of each container has been made based on the point of gravity between the population densities of each km2 and the capacities of the containers. While it is

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Figure 3. Population density: Comas (Peru)

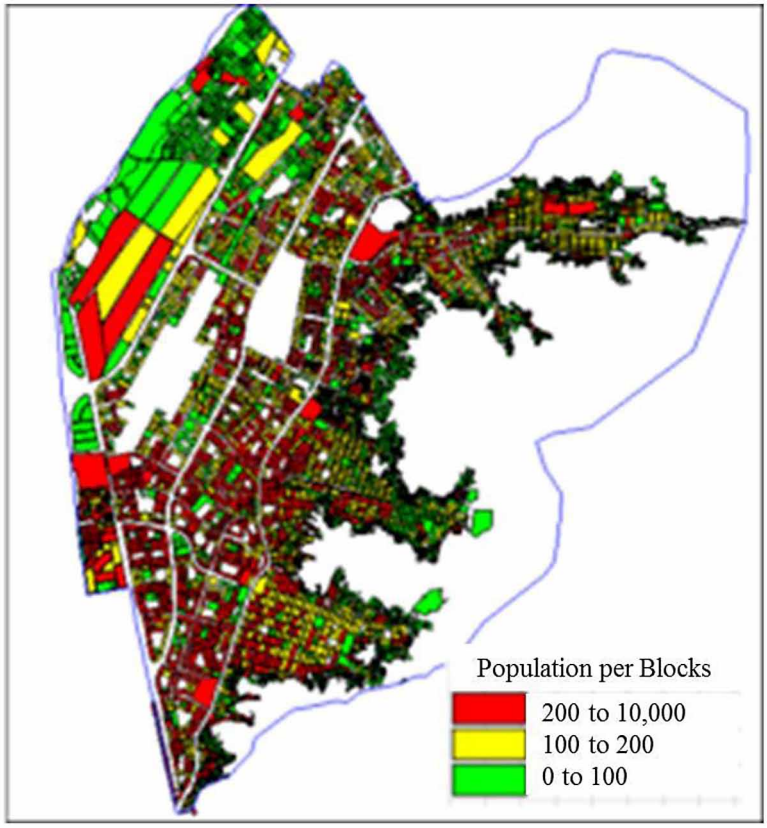
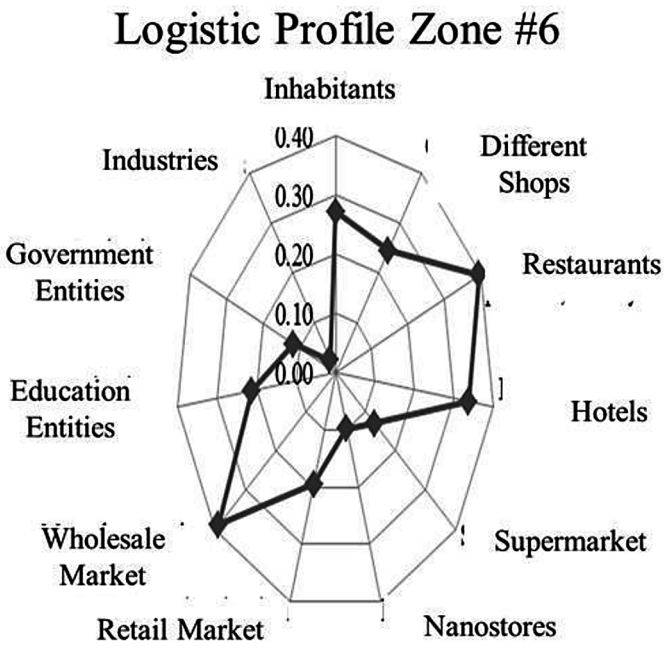


Figure 4. Logistic profile, zone #6: Comas (Peru)



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true that all this designation of containers contains a high theoretical component, it can not necessarily be met; the streets, sidewalks, and corners do not necessarily have free spaces. To do this, an alternative has been developed for the containers, which occupy 2.88 m2 of an area (1.6m x 1.8m). The area will sometimes be on the sidewalk or it will have an island occupying a small area of the street as shown in Figure 5.

The purpose of the two non-linear programming models used is based on the problem of maximum flow (Render, 2012) and the problem of the traveling salesman (TSP) (Lin–Kernighan, 1973). We will

Figure 5. Container´s position



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minimize the sum of the distances between the containers, identified for each trip in the first model, selecting the shortest route and minimizing the cost per t to be transported.

Once the sensors have been implemented and the container´s data has been obtained, the information will be fed to run the process. Likewise, we will proceed to obtain the results of the optimal route with online demand, according to the Non-Linear Model.

The proposed operation model contemplates the selection of the zone according to its logistic profile of km2- zone # 6, the location of the containers in designated pick-up points, the implementation with the IoT (sensors) to manage the demand and the optimization of the route through tools (load balance and shorter route), in order to reduce the current operating costs.

Eliminate Non-Linear Model: Minimizing Distances

$$Min \sum_{i \in V} \sum_{j \in V} Dist_{(i,j)} * X_{(i,j)}$$

Constrains:

$$\sum_{i \in V / i \neq k} X_{(i,k)} = 1 \forall k \in V \tag{1}$$

$$\sum_{j \in V / j \neq k} X_{(j,k)} = 1 \forall k \in V \tag{2}$$

$$U_j \geq U_k + X_{(k,j)} - \left(N-2\right) * \left(1 - X_{(k,j)}\right) + \left(N-3\right) * X_{(j,k)} \forall j \in V \ / \ j \geq i \cap j \neq k \tag{3}$$

$$U_k \leq \left(N-1\right) - \left(N-2\right) * X_{(i,k)} \forall k \in V, k \geq 1, N = 30 \tag{4}$$

$$U_k \geq 1 + \left(N-2\right) * X_{(k,1)} \forall k \in V, k \geq 1 \tag{5}$$

PRELIMINARY RESULTS AND DISCUSSION

The logistics sector of transport and final disposal of solid waste is growing. In this sense, the proposed model provides a reduction in operating time and costs, in addition to improving the level of collection service.

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The most satisfactory result, obtained after the simulation, is the considerable increase in the service level, which improved from 43% to 86%, a result well above the 68% efficiency level necessary to satisfy the existing demand. The average cost per t of solid waste was reduced, from an approximate price of $ 38 per t to $ 17.91 per t, reducing operating costs by more than half. Another important result after the distribution analysis of the RZD indicates that the average distance per route on a monthly basis is 50.11 km, with an average time per route of 103.40 minutes.

Through the application of the Reverse Zone Distribution, the operating cost reduction is 12.5% and the service level will reach 85% to 90%. This reduction leads to an improvement in gross margin per t of 9.8% for the collection service company. Approximately, the cost reduction per year will be US$0.540 million and for the whole contract (3 years) will be US1.62 million.

The investment for this project will be around US$2.19 million (including all the assets: new trucks, containers, sensors, such as fill and weight). The project will be totally profitable and sustainable, since the demand will be met online and we will control it through the control panel for the Reverse Zone Distribution (prototype).

It is important to mention that there are references of positive results about the use of these IoT sensors; for example, they have allowed substantial improvements in solid waste collection operations in Melbourne, Australia, where efficiency increased to 25%, which reduced the response time by 85%, even when selecting point-to-point (Ecubelabs, 2017). Similarly, in Shanghai, China, the collection of the same point was reduced from 4.6 to 0.6 times per day (Ecubelabs, 2017). In addition, in the city of Seoul, knowledge of the weight through the IoT allows an efficient allocation of resources for waste collection (Insung Hong, 2014).

One of the biggest risks of this business model is the municipal taxes paid collection (flow of money for the collection service company), thus the level of unpaid municipal taxes reaches numbers of 70% (Ministerio del Ambiente - Perú Limpio, 2015).

CONCLUSION AND FUTURE RESEARCH

Currently, in Peru, the cost of collecting solid resumes is $ 38 per t. The solid waste collection, transport and disposal sector represent a growing market due mainly to the increase in population. For the particular case of the district of Comas, there is evidence of the disposition of the residents regarding the payment of a better collection service; the cost for this district is US $ 21 per t. Through the application of the reverse zone distribution, the cost per t decreases to US $ 18 per t. The reduction in operating costs is 12.5% and will reach a service level of 85% to 90% as a minimum at a lower operating cost due to the use of IoT technology and route optimization models.

Regarding the analysis of external risks, the most important factor identified refers to the uncertainty of the demand, which entails a greater operative work and, therefore, a higher cost. The uncertainty of the demand is minimized by the proposed reverse zone distribution model, since, the demand is totally controlled in real time with the level and weight sensors, which provide the possibility of programming the recovery time with better response times.

For future research it is proposed to apply the Reverse Zone Distribution (RZD) in other chains such as recycling, urban mail, among others, and study its impact on the distribution of the last mile.

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Chapter 8
Analysis of Financial Flow for Small Producers of Colombian Coffee: A Systemic Approach

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ABSTRACT

The Colombian coffee that grows in the mountainous coffee zone, due to its qualities such as its clean rate, acidity, aroma, softness, and body, continues to have a representative share in the market. In this way, the intervention of the state has been necessary so that the sector can have sufficient income both to satisfy its basic survival needs and to guarantee the continuity of production. In this chapter, the impact of the own investment and economic support policies formulated by the Colombian government on the financial flow of the coffee farmers was evaluated through a systems dynamics model. To achieve this objective, the current conditions of the Colombian coffee sector were studied, the supply chain was modeled with systems dynamics, and scenarios were simulated alluding to the policies evaluated.

INTRODUCTION

The coffee agri-industry field has been a pillar of the internal economy of Colombia, closely linked to the origins of the national industry. It has served as a source of financing for the rest of the economy, allowing linking the national economy with the international economy, and occupying a relevant place in the generation of foreign currency in the country. The Colombian coffee is one of the favorites in the

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international market for its aroma[1], flavor, acidity, and different degrees of palatability, which makes it is desired by countless consumers, inside and outside the Colombian territory. The coffee sector in Colombia employs about 35% of the labor force in agricultural work (631,000 jobs per year) and its contribution to the total GDP is 0.6% (Perdomo, J. A. and Mendieta, J.C. 2007). On the other hand, coffee exports represent 5% of the total agricultural exports of the country, the total area planted with coffee is 974,100 hectares, corresponding to 0.85% of the area of Colombia, distributed in 32 departments of the 42 of the country (Perdomo, J. A. and Mendieta, J.C. 2007).

Notwithstanding the dynamics of the coffee system in Colombia, it has resulted in relatively unsatisfactory effects during the last years, in an international conjuncture of increases in world production, exports and consumption, which has affected the financial flow of the sector in Colombia. For this reason, it is important to study the behavior of the Colombian coffee supply chain, especially in the first link where small coffee farmers mainly operate. Thus, it is necessary to analyze the system to examine significant variables, identify the underlying systemic structures, as well as analyze the coffee policies that seek to support and contribute to improving the current behavior of the financial flow of the coffee farmer.

This chapter aims to propose a characterization of the financial flows for small producers of Colombian coffee. To study this problem, in this research the systemic approach was considered appropriate, characterized by a set of methods in which problems with dominant presence of complex systems are addressed. (Sterman, John 2000).

In the first part of this document, the development of the methodology used to approach the problem is presented, in the second part the results are presented and discussed and, finally, the conclusions about the results are exposed.

BACKGROUND

In humanitarian support organizations and actions, we find three main types of logistics problems: (1) social improvement logistics, related to distributing products to support everyday needs of poor and sensible populations and improve their social welfare, (2) humanitarian logistics in disasters (Kovács and Spens, 2007), which deals to efficiently and quickly react to a disaster and support populations in an emergency and sometimes dangerous situations and (3) post-disaster logistics, which aims to support populations in re-location and reconstruction of their daily lives after a disaster (Holguín-Veras et al., 2012). Although humanitarian logistics (both for disasters or post-disaster) is nowadays a popular research subject (Kovács and Spens, 2009; Apte, 2010; Chandes and Paché, 2010; Holguín-Veras et al., 2016), we find a lower scientific interest for social welfare logistics. Indeed, we find a first statement on the importance of logistics in supporting the social welfare, or social improvement, made by Orwell and Dawes (2007), after what we observe only three works related explicitly to the logistics of social improvement: Stock (1990) is the fist, to the best of our knowledge, that states the poor contribution of logistics research to evidence its contribution to social welfare; Adivar et al. (2010) focus on the notion of supply chain for social improvement and welfare; finally, Maldonado and Moya (2013) show the importance of combining social welfare policies with reverse logistics in developing and improving food banks actions and logistics schemes.

According to the FAO (2010), the improvement of sensible population social welfare is crucial to their development, but does not be only focused on decreasing hunger and malnutrition (Maldonado and Moya). To this fact, the *Latin America and Caribbean without hunger* initiative, by FAO in 2011,

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analysed the involved stakeholders and actions in that welfare increase. From this initiative, a core set of actions need to be deployed to fight malnutrition (Gonzalez-Feliu et al., 2013):

1. Primary economic improvement: initiatives that allow increasing the income of families to allow them buying the basic food and nutritional elements, such as subsidies and income transfer actions, but also improvement of current business strategies and transactions of small producers and retailers.
2. Cost reduction to increase accessibility to food: initiatives to reduce the cost of basic foods for sensible populations, such as subsidies to retailers, tax exemptions or programs of low cost basic baskets.
3. Food access initiatives, which increase access of sensible populations to basic food by providing them a set of basic products, like the development of food banks or the distribution of dietary complements to families.
4. Education and monitoring initiatives to support and promote the good habits, but also those that aim to steer and follow the risk of families and sensible populations regarding malnutrition.
5. Promotion and development of self-production: actions that help families of sensible population to produce themselves foot that allows giving them (partly or completely) their nutritional needs.

This chapter deals then with initiatives of type 1, and more precisely on value and revenue increasing of small producers of coffee. In the coffee supply chain, but more generally in agri-food supply chains, a set of logistics capabilities can be identified. Those capabilities allow to define the context and the potential of current supply chains. Moreover, it seems important to analyze those supply chains from a national or regional perspective (Padilla Solís, 2016), mainly in the context of Latin America food supply. The main capabilities identified in this context are the following:

- **Integration:** It seeks to create relationships of interdependence, internally and externally of the supply chain. In addition, it promotes that these relationships become organizational routines that are difficult to replicate among the competition. The purpose of this is to develop logistics operations of excellence that benefit all interested parties (Defee y Fugate, 2010; Esper et al., 2007; Gligor y Holcomb, 2012).

According to Gligor y Holcomb (2012), interaction and collaboration are important in the development of integration. Interaction between stakeholders is achieved through communication. While, in collaboration, it is important the disposition of departments or organizations to work together. The integration is made up of the following dimension:

- **Information management:** This capacity influences the success of the supply chain, it improves organizational processes, promotes integration capacity and improves competition in logistics (Shang y Marlow, 2005). Likewise, it is considered important because it facilitates coordination and decision making. Moreover, in environments of uncertainty and volatility it becomes even more relevant (D. M. Gligor y Holcomb, 2014). Information management is made up of the following dimensions:

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  - *Information technology:* It refers to the use of hardware and software to improve the processes of the organization and reduce costs associated with the supply chain (Defee y Fugate, 2010; Lu y Yang, 2010; Zhao et al., 2001).
  - *Exchange of information:* It consists in the determination of a company to share important and timely information with other members of the supply chain, in order to facilitate coordination (Defee y Fugate, 2010; D. M. Gligor y Holcomb, 2014; Shang y Marlow, 2005; Zhao et al., 2001).
- **Logistic learning:** It seeks to manage the knowledge that employees have about the organization and convert it into new capabilities. This capacity is conditioned by certain variables, including the organizational culture; a flexible, decentralized organizational structure that encourages learning processes among its employees; cross-organizational relationships and learning speed (Esper et al., 2007). It is also important to note, that this capability is influenced by the interaction between employees both internally and externally of the supply chain.
- **Measurement:** It seeks to monitor the logistic performance of the internal and external operations of the organization through a system of measures established organization (Esper et al., 2007; Moori et al., 2015). This important capacity to promote and develop strategies that lead to continuous improvement and better organizational results.

It is important to mention that in the deployment of measurement capacity, the different dimensions of information management become relevant. This allows monitoring of the goals set by the organization and communicating the results obtained to the people in charge of making decisions, in order to implement timely actions.

- **Customer focus:** It is also known as demand management capacity and it is intended to meet or exceed customer expectations through a series of activities associated with the service and response to markets (Esper et al., 2007; David M. Gligor y Holcomb, 2012; Mentzer et al., 2004). Some of the dimensions that make up this capacity are:
  - *Answer:* It is the ability of the company to react quickly to changing or unplanned customer requirements (Defee y Fugate, 2010; Ding et al., 2014; Mentzer et al., 2004; Moori et al., 2015). Flexibility is the ability to adapt to unforeseen operational conditions. Resilience is the ability to anticipate potential supply chain disruptions and recover when they occur. Both can be considered as components of this dimension (Shang y Marlow, 2005; Wang et al., 2015).
  - *Customer service*: It is oriented towards the needs and concerns of the customer, before and after the sales process. Within this dimension it is important to highlight aspects such as: product availability, quality in delivery and distribution and communication with users (Defee y Fugate, 2010; Ding et al., 2014; D. M. Gligor y Holcomb, 2014; Mentzer et al., 2004; Morash et al., 1996; Wen, 2012).
  - *Innovation:* It is the organizational ability to use resources, knowledge, new technologies and techniques in the development of new products, processes and systems that benefit the company (Defee y Fugate, 2010; Ralston et al., 2013; Wang et al., 2015).
- **Focus on the offer:** It is also known as supply management capacity and is focused on complying with the traditional vision of logistics, that is, reducing costs, capital and inventory; In addition to

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responding to changes in demand (Esper et al., 2007; David M. Gligor y Holcomb, 2012; Mentzer et al., 2004). Some of the dimensions of this capacity are:

- *Reduction of the total cost:* It is the ability of the organization to minimize its operational, logistical, distribution and inventory management costs (Lin y Chen, 2008; Morash et al., 1996; Wen, 2012).
- *Efficient logistics processes:* It is the search for timely and creative logistic solutions. Improving aspects such as: time management, inventory management, standardization, use of facilities and equipment and in security and risk prevention (Defee y Fugate, 2010; David M. Gligor y Holcomb, 2012; Lin y Chen, 2008; Wen, 2012).

It is important to mention that although in the logistic literature these two dimensions can be identified as components of supply-centered capacity; both could be integrated in a single dimension called "efficient logistics processes", due to the close relationship between them. The above makes sense, because efficient logistics processes, which seek the standardization of key activities, lead to the optimization of valuable resources for the organization, translating that into the reduction of costs.

In Colombia fresh coffee producers of small size have a strong contribution to the global production of coffee in the country (Giovannucci et al., 2002). Indeed, small farmers with less than 5 hectares of land are responsible for approximately 69 percent of coffee production in Colombia (USDA Foreign agricultural service, 2018). According to USDA and FEDERCAFE, it is estimated that coffee production is the main revenue of 560,000 families (USDA Foreign agricultural service, 2018). In such context, the revenue improvement and value creation is crucial to ensure the social development of small producers, and that can be done by a systematic and holistic study of first the current supply chains and second the potential of revenue increasing. To study suitable strategies of revenue increasing, it is first necessary to characterize and analyze transaction and financial flows of their logistics and value creation chains. We propose below a methodology to characterize and analyze those flows.

METHODOLOGY

Problem Statement

In recent years, the sector has had to face a series of events that have affected its productivity and competitiveness, which are related to the structural crisis that it faces. Among these is the crop renewal program, which has negatively impacted the composition of the planted area and, consequently, the production volumes and productivity itself. This is due to the fact that during the period between 2005 and 2008, the average of hectares renewed annually was 70,644 hectares, while for the years 2009 and 2014, 3,051 million coffee trees were renewed. This increase in the renewed area significantly decreased the productive area as of 2011, given that the process was practically carried out in the last two years and not in a staggered manner, which meant that about one third of the area planted was out of production in 2012, consequently meaning a fall in its production. Additionally, the renovation was not always done using resistant coffee varieties, so the renovated area has not increased its performance, as expected. Proof of this is the fact that 74% of the coffee park has been renovated to 2014 but only 55% of this has coffee varieties resistant to rust[2] . Indeed, recent reports from the National Center for Coffee Research - CENICAFE[3] reveal that the low production levels of the sector are a consequence of its reduction in

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productivity, going from 16-18 sacks / hectare in 2005-2008 to 12-13 sacks / hectare in 2009-2012 according to the National Federation of Coffee Growers (FNC). This explains the collapse of production, reaching 8-9 million bags in that period compared to 12-14 million historical bags. Comparatively, Brazil continues to be technified and bringing its productivity from 13-18 sacks / hectare in 2003/2004 to 24-25 sacks / hectare in 2012/2014. In this way, the differential with Colombia's productivity was extended from 10% -25% in favor of Brazil in 2006-2008 (period with the highest productivity in Colombia) to 63% in 2014. Increases in the price of fertilizers also affect the structure of production costs. Between 2007 and 2009, an increase in the prices of the main fertilizers affected all the producers of the agricultural sector and those of the other producing countries. Subsequently, there has been an upward trend, and currently the average price of the main fertilizers, as a whole, is US $ 600 per ton for 2015 (FAO, 2015).

On the side of the prices of cargo, both the international price and the national price of the grain have shown a high volatility in the last decade, which added to the revaluation of the peso and the aforementioned background, affect the low profitability of the business that suffer the small coffee farmers. The great social impact has generated in the last two years, protests of coffee farmers, claiming better economic conditions. The National Government tries to alleviate these negative effects, on the one hand, by providing subsidies to the coffee load, and on the other hand, postponing the elimination of the 4x1,000 tax[4] until 2015, in order to obtain 3 of the $ 5.2 billion (0.7% of GDP) budgeted by the Ministry of Agriculture and Rural Development . Of them, the Colombian treasury would contribute $ 1 billion in coffee subsidies-PIC [5] during 2014, but the reality is that these options are not enough and the sustainability of coffee activity continues to be affected. Even if the 2015 harvest will approach the production target planned (12 million bags), the problem would continue because the income level is currently far from covering the operating expenses of the sector. For example, the cooperatives of coffee farmers, who are in charge of buying the coffee harvested by the coffee growers, pay per load (125 kg) values lower than those estimated to be necessary to produce it. Thus, the income of coffee farmers has gone according to the National Planning Department from 0.8% of GDP in 2010/2011 to 0.5% of GDP in 2012/2014 (CONPES 3763, 2013).

A small country like Costa Rica went from 845 kilos per hectare to 1,066 kilos, an increase of more than 26 percent, which is equivalent to an annual increase of 3.2 percent. Countries like Peru and Guatemala also had increases in yields of 7.3 and 15.4 percent, respectively, in the same period. The most outstanding increase in yields was that of Vietnam, which in the same period increased by 54 percent, going from 2,160 to 2,250 kilos per hectare of green coffee, an annual increase of 5.8 percent, according to what is observed in Table 1.

Table 1. Coffee yields (Ton/Ha)

Green Coffee	2010	2012	2014
Vietnam	2.160	2.347	2.250
Brazil	1.346	1.257	1.433
Peru	0.757	0.903	0.971
Guatemala	0.995	0.972	0.992
Colombia	0.688	0.634	0.597

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At the other edge, many countries had decreases in yields such as India, Indonesia and Mexico, but the largest decrease among the main coffee producers was that of Colombia (International Coffee Organization - ICO, 2010).

The previous situation has also resulted in a significant decrease in national coffee production, which has led Colombia to import lower quality coffee for domestic consumption and thus be able to export the domestic production, which is of higher quality, according to the International Coffee Organization 2010.

The yield crisis is also shown in the fact that although the planted area increased 4.1 percent between 2010 and 2014, production has decreased by almost 14 percent in the same period. All of the above has led Colombia to lose the second place among the largest coffee producers, down to fourth place. According to the ICO[6], in 2014 the largest producer was Brazil with 43.5 million bags followed by Vietnam with 24.1, Indonesia with 8.6 and Colombia with 7.6 million.

Likewise, the Colombian countryside in recent years has faced the climatic phenomena associated with La Niña and El Niño, and finally, the recomposition of Colombian coffee farming that has been associated in part with the new opportunities that Colombian grain has in niche markets with higher added value such as the production of special coffees.

Proposed Framework

The proposed methodological framework is composed of three phases, briefly presented below:

Phase 1: Characterization the primary link in the Colombian coffee supply chain. In order to comply with the objectives set out in this research, it is necessary to know in depth the different elements that participate in the primary link of the supply chain of Colombian coffee, as well as the way in which they are related. To this end, the following was researched: history of Colombian coffee, production process, clients, economic, financial and social aspects, associations, state policies, international policies, management indicators, levels of decision of the different actors, endogenous and exogenous variables, systems of information.

Phase 2: Development of a system dynamics model that allows analyzing the behavior of the variables in the primary link of the coffee supply chain. The methodology proposed in the project through a simulation model in systems dynamics can be extended and generalized in order to be applied in any type of productive chain.

In detail, there are three stages for the construction of a system dynamics model, which are detailed below:

Definition of the core problem to study: This step requires full knowledge of the system and the problem to solve. The knowledge in detail will require the participation of experts, who will propose the possible interactions and activities carried out by the elements that stablish the system. In order to characterize the supply chain of the supply chain, a high level description of the of the Colombian coffee supply chain were constructed. The tool used were The SIPOC (Suppliers, Inputs, Process, Outputs, Customers) diagram.

Identification of variables and establish their relationships: The system should not necessarily be described in all its variables, which would make this step an arduous and very complex process. If the objective of the previous phase is fully met, only those variables involved in the problem

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to be studied will be taken into account, limiting the system to a simplified model, with behavior and results similar to the real model. The simulation model was developed in terms of: Variables, causal diagram, equations and Forrester diagram.

Construction of the model: We proceed to establish the complete map of variables and relationships, which conceive the system in a flow diagram. This model must be adapted to a software, such as Vensim, which facilitates its incorporation into the computer. Based on the identification of the parameters for defining scenarios and indicators of performance of the studied system, the problem map was constructed and Validation of the model.

Phase 3: Evaluate investment policy strategies, subsidies and incentives for Colombian coffee growers. The created model will need to be validated with reality, showing congruence with the results thrown in the simulation. As a last phase, the results will be analyzed identifying certain behaviors of interest. the model can be modified to generate alternative scenarios. Evaluation of results in terms of definition and evaluation of possible intervention scenarios of the problem. Different scenarios were proposed for coffee growers. The scenarios are based on the evaluation of policies to subsidize coffee crops, to encourage the use of fertilizers, to finance the needs of funds and to diversify crops. The long term effect of the proposed scenarios on the income (profits) of the coffee farmers is analyzed through the system dynamics model, analyzing the behaviors over time in variables such as production, the sustainability of quality, productivity, production costs, reinvestments and family savings.

RESULTS AND DISCUSSION

Characterization of the Supply Chain

SIPOC Diagram of the Primary Link of the Colombian Coffee Supply Chain

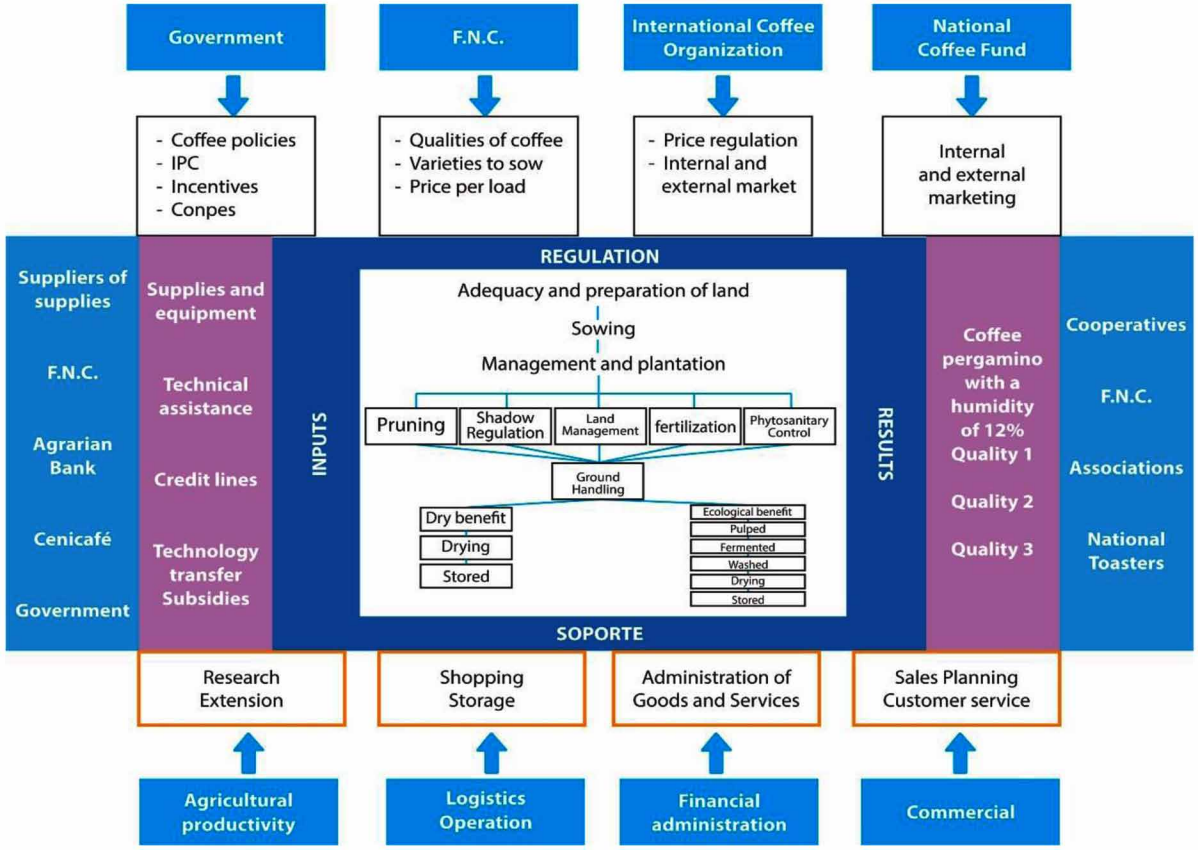
In the system under study, it is necessary to analyze a supply chain that is understood as the set of planning, execution and control activities that are carried out to deliver value to customers (Ballou, R. 1999). The actors of this supply chain seek to provide a product with quality characteristics and costs that make it competitive in national and international markets (Chopra, S., and Meindl, P.2001).

The tool used to characterize the primary link in the Colombian coffee supply chain is the SIPOC diagram, which corresponds in English to Suppliers, Inputs, Process, Outputs, Customers (Ovalle, O. R. 2004). The SIPOC allowed to have a high-level vision of the supply chain of the system and its environment; in that way, the system can be understood by identifying the relevant elements. (Ovalle, Oscar; Villarreal, Marco Antonio. 2009). (Figure 1).

The inputs of the system are: Supplies, equipment, technical assistance, credit lines, technology transfer and subsidies, which come from input suppliers, the National Federation of Coffee Growers, the Agrarian Bank, CENICAFE (National Center for Coffee Research) and the national government. Seventeen processes operate within the system, including: Adaptation and preparation, sowing and plantation management. The output is parchment coffee that varies in three different quality characteristics which also define different product prices. Finally, the clients are the coffee cooperatives, the National Federation of Coffee Growers, the Associations, the intermediaries and the national toasters.

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Figure 1. SIPOC diagram



The tool to relate structural variables of the system object of this study, is the causal diagram, which incorporates elements associated with the problem in question. This structure is the input to explain the current behaviors of the outcome variables of interest (García, Guillermo. 2009). This establishes the structural relationship of the elements related to the problem, which are "imported" from the SIPOC (figure 1).

Variables and Equations of the Model

Table 2 shows a description of the variables involved in the model.

Equations of the Level Variables

In this model, the level variables related to the finances of the coffee grower are: Gross cash, Cash after production costs, Net cash, total paid and debt. In this way, and according to the causal diagram of Figure 2, the level equations are given by:

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Table 2.

Name of the Variable	Description
CB: Gross Cash	Money resulting from income from coffee and other crops and production costs
INOC: Net Income Other Crops	Net income received for other crops parallel to coffee
IVC: Income from coffee sales	Gross income received from the sale of coffee
CP: Production costs	Costs generated by coffee production
FCCP: Cash flow after production costs	Money resulting from subtracting production costs from the gross cash
FCN: Net cash flow	Money available after assuming the main expenses of a coffee family
GF: Familiar costs	Expenses incurred by a coffee grower annually to meet basic family needs
CN: *Net cash*	Money available after costs
CP: Loan installments	Amount of money agreed to be paid to the bank
R: Reinvestment	Amount of money to invest from the net cash to support quality and productivity
$TP: total paid	Amount of money paid to the bank as a result of the interest and capital payments of the loan made
AD: Debt amortization	payments to the capital of the loan made
I: interest	Interest rate
CDCP: Cash after production costs	Money available after family expenses
CCV: Coffee loads sold	Represents the annual coffee production that is sold to the market
PIC: Internal Price of the Load	Express the value to pay for a coffee load according to the National Federation of Coffee Growers
ICC: Incentive for Quality by Load	Subsidy provided by the Colombian government to reward quality (number of healthy seeds per load).
TOC: Tons of other Crops	Crops complementary to coffee
PVOC	Sale Price for Tons of Other Crops
CPOC: Production Costs of Other Crops	Costs generated for having other crops parallel to coffee
PCP: Production of parchment coffee	Expresses the rate of coffee production per hectare per year
TP: Production Rate	Number of kilograms of coffee produced by one hectare
AP: Years of Production	Variable used to generate coffee production cycles
PA	Accumulated Productivity
AD	Amortization of debt acquired with the bank
$P: Loan	Money requested to the bank to invest in the crop
P_R: Period	Period of payment of debt
I: Interest	Loan interest rate
D: Debt	Remaining value of the loan
CPPH:	Budgeted costs per hectare
CC: Cost per load	Costs per coffee load
OC: Other costs	Other costs associated with production
IF: Fertilizer incentive	Amount of the cost of fertilizers subsidized by the government
CP:	Production costs
ET:	Total expenses
R: Reinvestment	Amount of money to reinvest in the crop

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Table 2. Continued

Name of the Variable	Description
RM	Maximum Reinvestment
TR	Reinvestment Rate
P	Productivity
MC: Maintenance of quality	Money invested to support the quality level of the coffee seed
MP: Maintenance of Productivity	Money invested to maintain the level of productivity of the crop
RRP	Delay of the effect of reinvestment in productivity
PB_{NY}: Price on NY Stock Exchange	Express the value to pay for a kilo of coffee according to the New York Stock Exchange
PEC: External sale price per load	Express the value to pay for a coffee load according to the New York Stock Exchange
NFF: Family financial needs	Budgeted basic expenses for a coffee family

$$\frac{d\left(CB\right)}{dt} = \{(INOC+IVC)-(CP+FCCP)\} \quad (1)$$

$$\frac{d\left(CDCP\right)}{dt} = \{\ (FCCP - FCN - GF)\ \} \quad (2)$$

$$\frac{d\left(CN\right)}{dt} = \{\ (CP+FCN-R)\ \} \quad (3)$$

$$\frac{d\left(TP\right)}{dt} = \{\ (AD+I)\ \} \quad (4)$$

$$\frac{d\left(debt\right)}{dt} = \{\ (-DEBT\ AMORTIZATION)\ \} \quad (5)$$

Equations of Flow Variables

FCCP: *IF THEN ELSE (CB-CP >GFP, CB-CP-GFP)* (6)

FCN: IF THEN ELSE (CDCP -GF>0, CDCP-GF) (7)

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IVC: IVC: CCV*(PIC+SC+ICC) (8)

INOC:IF THEN ELSE (TOC<=5.4, 0, (TOC*PVOC-CPOC)) (9)

PCP:((TP (AP))*(1+PA))/125 (10)

AD: DELAY FIXED (P/ P_R, 3, 0) (11)

I: DELAY FIXED (D*tem, 3, 0) (12)

Equations of Auxiliary Variables

The auxiliary equations of the system are presented below:

CPPH:(CC+OC-IF)*PCP (13)

CP:IF THEN ELSE(CB>GFP,IF THEN ELSE((CB-GFP)<CPPH, (CB-GFP), CPPH), 0) (14)

NF: IF THEN ELSE ((IVC+INOC-ET)< GFP, GFP -(IVC + INOC -ET), 0) (15)

R: IF THEN ELSE (CN>0, IF THEN ELSE (CN>=RM, RM, (CN)*TR), 0) (16)

P: DELAY FIXED (IF THEN ELSE(R>=0, R*MP, 0), RRP, IF THEN ELSE(R>=0, R*MP, 0)) (17)

PEC: (TRM* PB_{NY} *125) (18)

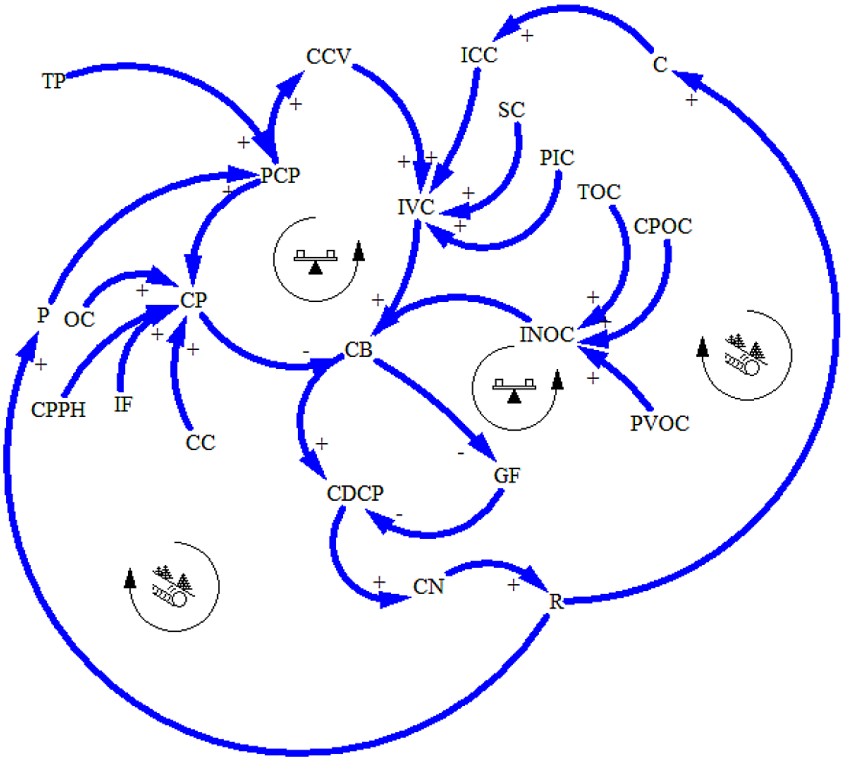
Based on the elements previously described, a system dynamics model was designed to perform the simulation. Tables 2 and 3 show the Causal and Forrester diagrams, which represent the dynamic interactions between the variables and parameters involved in the system.

The feedback loops identified contain the variables reinvestment, quality, productivity, production, production costs and family expenses; as well as the variables gross cash (after production costs) and net cash.

In the Forrester diagram we can observe the reinvestment flow of a part of the money that the coffee farmer receives (accumulated in the net cash), as the possibility of gradually improving the production

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Figure 2. Casual diagram



techniques and equipment, and which he uses during the whole process of sowing, harvesting and post-harvesting. This dynamic shows that the more money reinvested in the crop, the higher will be the levels of productivity and production, which will increase the income of the coffee grower and will continue the reinvestments in the crop.

However, this reinforcement cycle is limited by a compensation cycle that shows that the more production is generated, the production costs will increase as well as the expenses derived from the maintenance of the family, which will limit the growth of the income of the coffee grower.

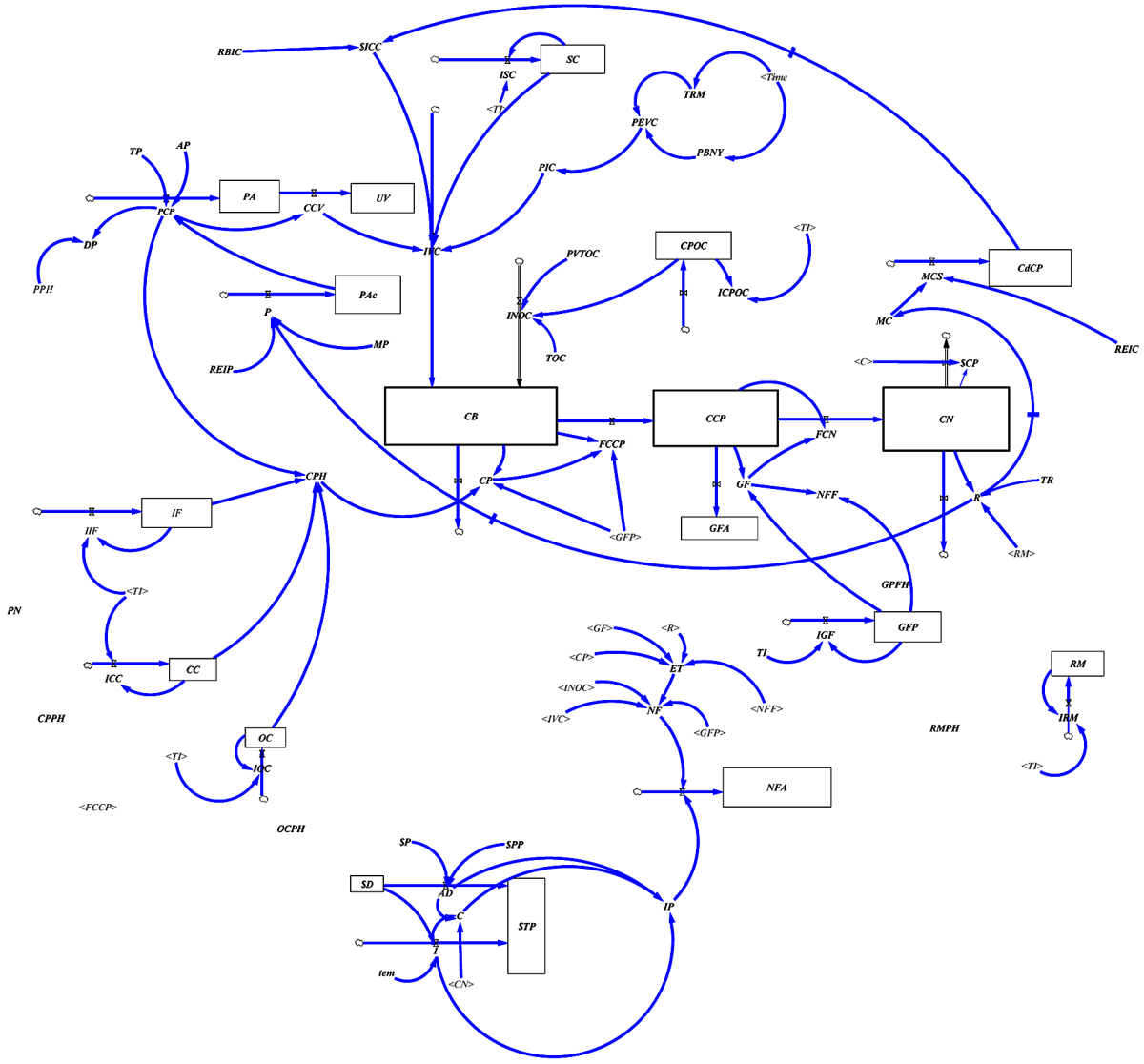
Description and Assumptions of the Model

For the elaboration of this system dynamics model, the generalities described in the following paragraphs were considered.

- Size of the farm: the number of hectares considered for a Colombian coffee grower is one. This value was taken from an investigation carried out by the national federation of coffee growers of Colombia, in which it was found that in Colombia there are more than 613 thousand coffee farmers, of which 94% have less than 5 Hectares in coffee. The total area of cultivated coffee is greater than 881,000 hectares and the national average is 1.3 hectares (DANE, 2010 -2014).
- Other crops: In Colombia, in coffee plantations it is recommended to plant other crops in parallel, for reasons such as food security and the need to improve the financial flow of the coffee grower.

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Figure 3. Forrester diagram



It was decided to consider the green plantain for its benefits in the generation of shade, serving as a protective barrier to the cultivation of coffee and the possibilities of generating extra income. (Duque, H. y Bustamante, F. 2002).

- Demand: due to low coffee production nationwide, these are absorbed in their entirety by international markets, which was represented in the model under the assumption that everything produced is purchased by coffee cooperatives (CENICAFE, 2007).
- Production cycle: the considered cycle was ten (10) years. In the first two years, no income is obtained from coffee production, because in Colombia the average time for a coffee plantation to produce quality coffee in a sustained manner is 2 years. As a result, the farm starts producing from the third year (Zambrano, R. 1991).

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Problem Map

The problem map (Figure 4) allows to graphically relate the parameters of scenario definition (inputs), the model playing the role of evaluation function, and the result or performance variables of the modeled system. The parameters of definition of scenarios to intervene in the system are: Incentives to fertilizers, Subsidy for load, Diversification and loans. The performance indicators of the chain are: net cash, savings and financial needs.

Validation of the Model

For the validation of the behavior patterns of the main variables of the model, a test run was made. The results on production cost per coffee load and on coffee production were compared with the results provided by the model. The behavior of these key variables was very close to the real behavior of the system. Table 3 presents a summary of the simulated scenario result.

These results generated enough confidence in the model, therefore proceeding with the generation of different simulation scenarios to see the behavior of the variables of interest.

Figure 4. Problem map

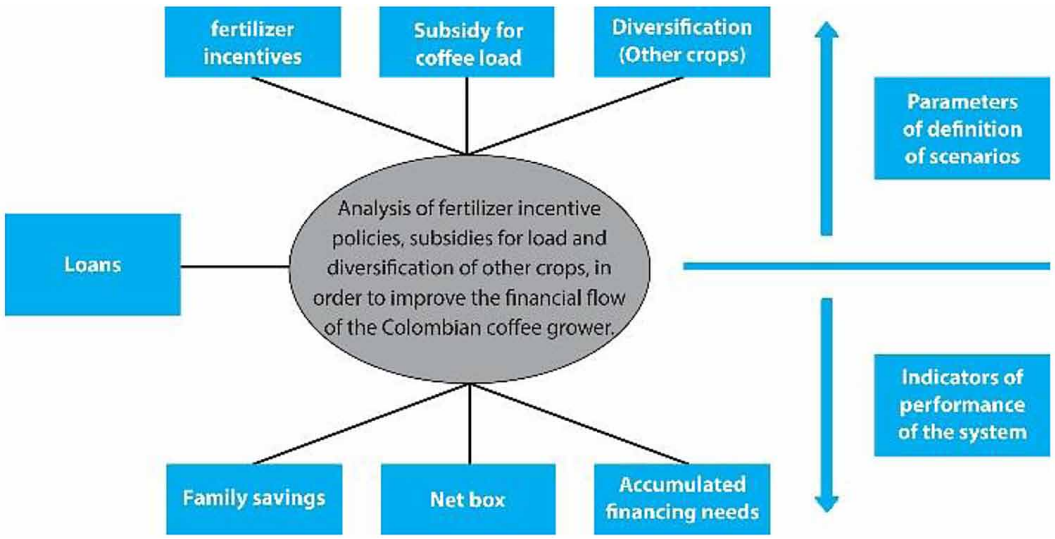


Table 3. Validation of the model

Variable	Range or Real Average Value	Simulated Average Value	Percentage Difference Regarding Average Value
Production cost per coffee load ($)	700.000	760.166	8%
Production of parchment coffee (Kg)	924	979.4.5	6%

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Evaluation of Results

The behavior of the model is shown below in the light of several proposed intervention scenarios. Four scenarios are tested:

Scenario One: Initial Situation

Methodologically, the current operating and performance conditions are listed as scenario one. In this scenario we tested the model with the actual conditions in order to evaluate its fidelity.

The scenarios whose results are presented below, were formulated from the modifications in those variables or attributes to be intervened, which really impact the determinants of the performance result defined in the problem map.

Scenario Two: Effect of the Allocation of a Loan

Currently, the profits that the coffee grower receives are null, for which it is proposed that the coffee grower can access a loan with a financial institution, with the purpose of having resources that allow investments in the crop, and thus improve productivity and quality of cultivated coffee, which could result in higher incomes and higher quality of life for coffee growers.

Scenario Three: Payment of Fertilizer Incentives

In this scenario we analyzed how the model behaves, when the fertilizer and incentive variables are modified, From the analysis of scenario three, it can be seen that the overall behavior of the annual profit of coffee growers improves as incentives increase, making it possible to infer that utility reacts in a synchronous manner with the costs of fertilizers, showing that it is necessary to reduce their price.

Scenario Four: Income from Other Crops

Other types of crops for a variety of reasons, including economic reasons, usually accompany Colombian coffee crops. In this scenario, it was decided to consider the green plantain for its benefits in the

Table 4. Variables of the initial scenario

Parameter	Value	Unity
Value of the coffee load	$ 730.375	Pesos
Incentives for fertilizers	0	Pesos
Tons of other crops	5.4	Tons/year
Period of production	1 a 20	Years
Familiar costs	$ 600.000	Pesos/month
Loans	$0	Pesos
PIC (Internal Price of the Load)	$0	Coffee load

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Table 5. Summary of simulation scenarios

Scenario	Modified Attribute	Modified Attribute Value	Output Variable	Variable Output Result	% Improvement Versus Scenario 1
1	Loans	-	Average annual net cash	$ 2.298.775	397%
2		$20.000.000		$ 9.145.121	
1	Fertilizer incentives	0%	Average annual net cash	$ 1.703.422	110%
3		20%		$ 3.582.531	
1	income from other crops	5.4	Average annual net cash	$ 1.973.309	460%
4		9.4		$ 11.066.960	

generation of shade, serving as a protective barrier to the cultivation of coffee and the possibilities of generating extra income.

CONCLUSION

The coffee sector in Colombia employs about 35% of the labor force in agricultural work (631,000 jobs per year) and its contribution to total GDP is 0.6%. On the other hand, coffee exports represent 5% of the total agricultural exports of the country, the total area planted with coffee is 974,100 hectares, corresponding to 0.85% of the area of Colombia, distributed in 32 departments of the 42 of the country.

During the last years, the sector has had to face a series of events that have affected its productivity and competitiveness, which are related to the structural crisis that it faces, among these is the program of crop renewal, coffee yield (Ton / Ha), price of coffee load, fertilizer prices, area sown and climate change.

Giving subsidies when the coffee market declines is not a sustainable solution, because the government cannot provide this type of direct resources for many periods of time and generates a stagnation in the sector. The government must evaluate plans that involve the entire coffee supply chain, and manage actions with greater impact on profits and long-term productivity, such as adding value to the product and shortening the chain so that the income received by producers is greater, and the profits do not only remain in intermediaries.

In the long term, the measure of granting subsidies is not an effective solution because it increases the dependence of the sector on external aid and does not generate actions to increase competitiveness in the market. It is noteworthy that this sector has unique characteristics because the market does not regulate the sale price, but it is affected at the macroeconomic level, which was evidenced in the relationship of the prices generated internationally with the profits perceived by the coffee growers. In this way it is very dangerous for the sector, to depend directly on prices. The country, referring to the sector analyzed, is not prepared to compete in the same way as large companies that generate economies of scale and that in general are more dedicated to the commercialization of the coffee grain than to its production which has higher yields. The sector should create collaboration strategies between marketers and producers, because if production declines, the behavior of the entire supply chain will decline.

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As a future work, the creation of new public policy scenarios generated around the increase in the productivity of small growers is proposed, in such a way that the profits are separated from the international price. It is also necessary to broaden the scope for the evaluation of long-term financial decisions of the small producer, such as decisions about the change of economic activity, possibilities of financing production and their impact on long-term coffee sustainability.

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ENDNOTES

1 Coffee tree rust (Hemileia vastratrix) Coffee rust is considered one of the most catastrophic plant diseases of all time. It is within the seven pests and / or plant diseases that have caused the greatest losses in the last 100 years. It is the main phytosanitary problem of high impact for coffee growing. The losses in Latin America are calculated at 30% of the harvests. The socio-economic impact that can generate an epidemic of coffee rust in Latin America is of incalculable dimensions.

2 Entity in charge of the aspects related to the production in the farms, the harvest, the benefit and the quality of the grain, the management and the utilization of the by-products of the coffee, and the conservation of the natural resources.

3 It consists in that for every one thousand pesos that you withdraw from a financial entity, four pesos are destined to the payment of this tax.

4 The PIC is the Coffee Income Protection Program-2014 effective as of January 1, 2014, which was adjusted to expedite delivery, expand coverage and reduce fraud events with resources that are solely for producers of coffee.

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[5] The ICO (International Coffee Organization) is an intergovernmental organization that brings together almost all of the coffee producing countries as well as the main importing countries.

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Chapter 9
Methodology for the Design of Traceability System in Food Assistance Supply Chains: Case Bienestarina, Colombia

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ABSTRACT

The food assistance programmes (FAP) has the mission to guarantee minimum nutrition requirements in a vulnerable population. Nevertheless, the small deliveries for a spread population, the social conditions, and the limited technological infrastructure could make it difficult to adequately aid supply. To solve these limitations, this chapter proposes a methodology for the design of traceability systems in FAP which allows increasing supply chain visibility, coordination between deliveries and social conditions, and therefore, possible impacts on public policy implications. A qualitative and quantitative comparison of the conventional frameworks is carried out and contrast with the needs of the programmes studied. Also, new criteria are also added to adapt the design to the technological infrastructure and the socio-demographic conditions of the territory. The methodological proposal is applied to the Bienestarina nutritional programme in Colombia, where the technologies and tools to subsequently design the traceability system are proposed.

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INTRODUCTION

The Food Assistance Programmes (FAP) aims to reduce social inequities, address the specific needs of vulnerable populations and improve their living conditions. For example, a set of these programmes seeks to improve food security through direct transfers of products (Tiwari et al., 2016).

Some examples of direct transfer programmes can be found in Argentina such as the Remediar programme that supplies medicines to the needy population (Argentina, 2015), in Mexico where dairy products are supplied (Liconsa, 2015) and in the United States through The Emergency Food Assistance Programme (TEFAP) which provides food to the vulnerable population. Those programmes set up supply chains that link the supply, production, storage and transport of aid with final beneficiaries.

Remediar programme distributed 76.082 first-aid kits and 16.721.152 treatments in the first semester of 2018, reducing four times the retail price (Ministerio de la Salud Presidencia de la Nación, 2018). The government investment overcome 34 million to supply the demand, covered 70% of the population (Secretaria de promoción y programas sanitarios, 2013). The Liconsa programme coverage is similar, in 2017 the government invested 2.845 million pesos to server more than 6.370 million of beneficiaries, among them: children between 0 and 12 years, teenagers between 13 and 15 years, nursing mothers, elderly and disabled people (Secretaria de Desarrollo Social - SEDESOL, 2018). These numbers represent the huge impact generated by SAP in society.

Within the supply chain management, traceability systems focus on managing the flow of information throughout the chain, thus preventing potential loss to the product (Aung & Chang, 2014; Opara, 2002; Wilson & Clarke, 1998), measuring the environmental impacts (Wilson & Clarke, 1998) and guaranteeing the delivery to the final customer. Systems and procedures are used to access information in real time and measure the performance of the system (Comunidades Europeas, 2002).

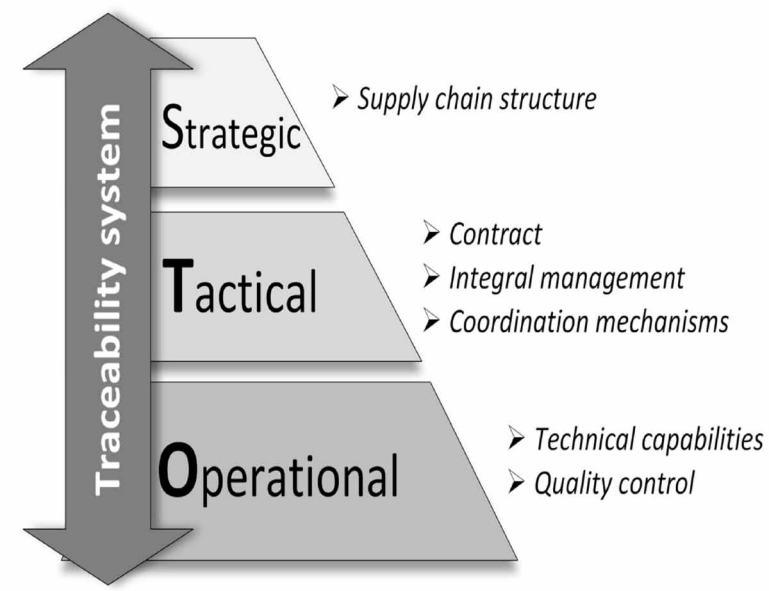
The traceability systems design requires technical and social factors. Nevertheless, social factors are not explicit in literature. For instance, Ringsberg(2014) and Mattevi & Jones (2016) considered factors as information management, production, quality and logistics as critical elements. Bosona & Gebresenbet (2013) refer to more specific guidelines such as regulation, quality and safety, technology, efficiency, competitive advantage, corporate image, product characteristics and internationalization. Note, the authors did not include social factors.

In the other hand, within scientific literature there are numerous attempts to quantify the effects of implementing traceability systems as can be seen in the works of (Alfaro & Rábade, 2009; Dabbene, Gay, & Tortia, 2014; Mithas, Krishnan, & Fornell, 2016; Opara, 2002). However, those papers focus on the impacts of an already implemented or ready-to-use traceability system, and not on the conditions and design elements to take into account in the system development. Those facts occur because the traceability systems are mainly related to manufactured goods which distribution chains, parcel and pallet transport and inventory management.

The implementation of a traceability system involves all decisional system levels (see Figure 1). In the strategy level must evaluate the supply chain structure, including not only their taxonomy, operational means and modes available, also idiosyncratic features or common customs that can be changed in one geographical area than another. In the same way, tactical and operational levels are implicated in

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Figure 1. Traceability in the planning levels



the traceability context, being the principal input to redefine the inventory policy, freight consolidation, stakeholder coordination, evaluate coverage, establish indicators, so on (Balcázar-Camacho, D. A et al., 2016; Castrellón-Torres, J. P. et al., 2015).

In food distribution, and mainly in local food production and distribution in developing countries like Colombia, with specific geographic, climate and demographic conditions, it seems relevant to deploy specific traceability systems that consider those conditions. Especially, in these systems where people without technical skills, majority volunteers, interact with the distribution and delivery process.

Countries like Colombia has many problems related to social conditions and by then, limited access to information technologies. For instance, just 48% of the population can manage a computer with Internet (Departamento Administrativo Nacional de Estadísticas - DANE, 2017b). Also, 41% of children under five years look after in community homes, child development center or public school, 62% of the rural zones have not water access (Departamento Administrativo Nacional de Estadísticas - DANE, 2017a), and 34.7% of the people consider that their incomes are not enough to cover the minimum expenses. These aspects affect the performance of the traceability systems when some of these people could execute the distribution process.

This paper will present a methodology for the traceability systems design, supporting in the Quick Scan methodology (Naim, M. M. et al., 2002), which includes social factors and allows the involvement of the distribution system and the population benefiting from the programme. First, an analysis of tracking and tracing technologies and their articulation in traceability systems is presented. Subsequently, the criteria to be considered for the design of a traceability system in social programmes are outlined and in the following section, the limitations for implementation are described. Finally, the methodology was validated in the nutritional assistance programme in Colombia called Bienestarina.

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BACKGROUND

The concept of traceability was defined as "The ability to trace the history, application or location of an entity using recorded identifications" (International Organization for Standardization, 1994), quoted by European Commission (2002); Moe (1998); Wilson & Clarke (1998). This notion arises from the need to create a collaborative work environment between suppliers, producers and customers throughout the logistics system. Previously, most operations depended on the manual information flow at each stage, which generated a lack of shared information (Renfroe, Mcdonald, & Bradshaw, 1988).

The development of traceability systems is intrinsically related to the use of Information and Communication Technologies (ICT), using technologies and tools as shown in Table 1. Through making the complete information about a product available at any time, ICT allows the optimization of production and distribution costs leading to increase in market competitiveness and achieve supply chain efficiencies and the integration of the members of the chain (Loebbecke & Powell, 1998).

Some of the parameters to be considered for the traceability design are: product data, calibration (standards for evaluating product quality), IT and physical integrity. Those allow ensuring the accuracy of the traceability (Jansen-Vullers, van Dorp, & Beulens, 2003; Moe, 1998).

The frameworks for the design of traceability systems proposed by Aung & Chang (2014); Bosona & Gebresenbet (2013); Kumar, Heustis, & Graham (2015); Regattieri, Gamberi, & Manzini (2007) consider factors such as: product identification, data tracking, product tracking and selection of measurement devices. These frameworks are generic, i.e. they do not make explicit recommendations for each supply chain. Likewise, the European Union (Comunidades Europeas, 2002) designs its standard which proposes guidelines for food supply chains, but only at the conceptual level.

In contrast, other authors propose more complex and specific traceability systems for certain products, for example Bosona & Gebresenbet (2013); Thakur & Hurburgh (2009) design traceability systems that in addition to product tracking between different echelons of the chain, establish specific requirements for the control of internal management and conservation conditions.

Models focused on the strict control of food quality and security (Dai, Ge, & Zhou, 2015; Mattevi & Jones, 2016), use a combination of statistical and technological tools to find a design that fits the needs of the system.

Based on the above it can be noted that it is necessary to design systems adapted to the specific requirements of each supply chain. Specifically, in the case of social assistance, success means that more aid is given thanks to the control and follow-up that takes place in the delivery of the products to the end user. One example is the Remediar programme in Argentina where a multiphase traceability scheme with real-time control was implemented (Fernandez et al., 2012).

Table 1. Information system and technologies in supply chain management

Information System	Technology and Tools
Document exchange systems	Fax, electronic data exchange tools (web-based or Internet-based), Internet, Smartphone applications, could computing.
Communications systems	Onboard radio, onboard/portable terminals, fixed-line phone, mobile phone, a multifunction portable terminal, Wi-Fi, GSM.
Tracking systems	Identification/codification, electronic lecture, barcodes, RFID, sensors, waymarks, recorders, memory system, IoT.

(Feng Tian, 2016; Gnimpieba, Nait-Sidi-Moh, Durand, & Fortin, 2015; Zhang et al., 2015)

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Programmes like one implemented in Argentina have been proposed in countries such as Brazil, Colombia, the Philippines, India and the United States. These have been promoted through public policy emphasizing the importance of traceability systems to control adulteration, improve inventory control and dispatch times and ensure that the patient receives the appropriate medication (Argentina, 2015).

There are other programmes focused on counteracting malnutrition such as Liconsa and Diconsa in Mexico, whose objective is to guarantee the right to food for optimal physical and cognitive development of beneficiaries that are below the established indexes (Gonzalez-Feliu, Osorio-Ramirez, Palacios-Arguello, & Talamantes, 2018; Liconsa, 2015). For this program, a need to implement georeferencing tools has been identified in order to guarantee the effective delivery of the product and allow the evaluation of the socio-demographic conditions of the population (Talamantes, 2016).

Other particularities of the supply chains for social assistance, a traceability system was designed that includes technological aspects, based on the geographical location conditions, education level and the penetration level of the service provided to the target population.

METHODOLOGICAL FRAMEWORK

Some essential elements for the design of traceability systems are related to the integration level, the technological devices, actors involved, the sector complexity, size of the company and specificity of the system.

The integration level refers to the connection between the traceability scheme and the chain processes. Zhang et al. (2015) explain the importance of the interoperability between the tracking system and manufacturing information schemes. The integration requires the link between sensors and physical devices, manufacturing data processing and application services.

Thus, technological devices can be located within a process, which is called internal traceability or can be located between the links in the chain, which is considered as external traceability (Aung & Chang, 2014; Ringsberg, 2014). In terms of the complexity of the sector and the size of the company (Aung & Chang, 2014; Scholten, Verdouw, Beulens, & van der Vorst, 2016), social problems are related to the coverage of the system, which is reflected in the number of beneficiaries, the geographic scope, the availability of communications infrastructure and the final devices that are used to interact with the system.

Other actors add factors related to the management of the supply chain. For example: efficient distribution and storage processes; inventory policies; the complexity of the traceability type; unique identification of the product, where the traceability parameters are specified; the information management relying on technological tools; transparency that involves the visibility of information along the chain; interoperability to ensure the operation of traceability system regardless of the heterogamous technologies (Feng Tian, 2016); production management and quality and safety requirements (Ringsberg, 2014).

According to Regattieri et al. (2007), the most important technical parameters for the design of traceability systems are: product identification, physical characteristics (volume, weight, dimensions and packaging); data tracking, level of detail of information, storage needs, reliability and availability; product tracking; technological tools (RFID, TAGs, GPS) (Costa et al., 2013; Feng Tian, 2016); identification of all the ingredients and the all products (where the products are and what its status is) and data linkage system (Aung & Chang, 2014; Ringsberg, 2014).

Based on the parameters proposed by these authors, the main guidelines in the traceability system have a technical nature as shown in Table 2, spite of the fact that these methodologies are not enough to

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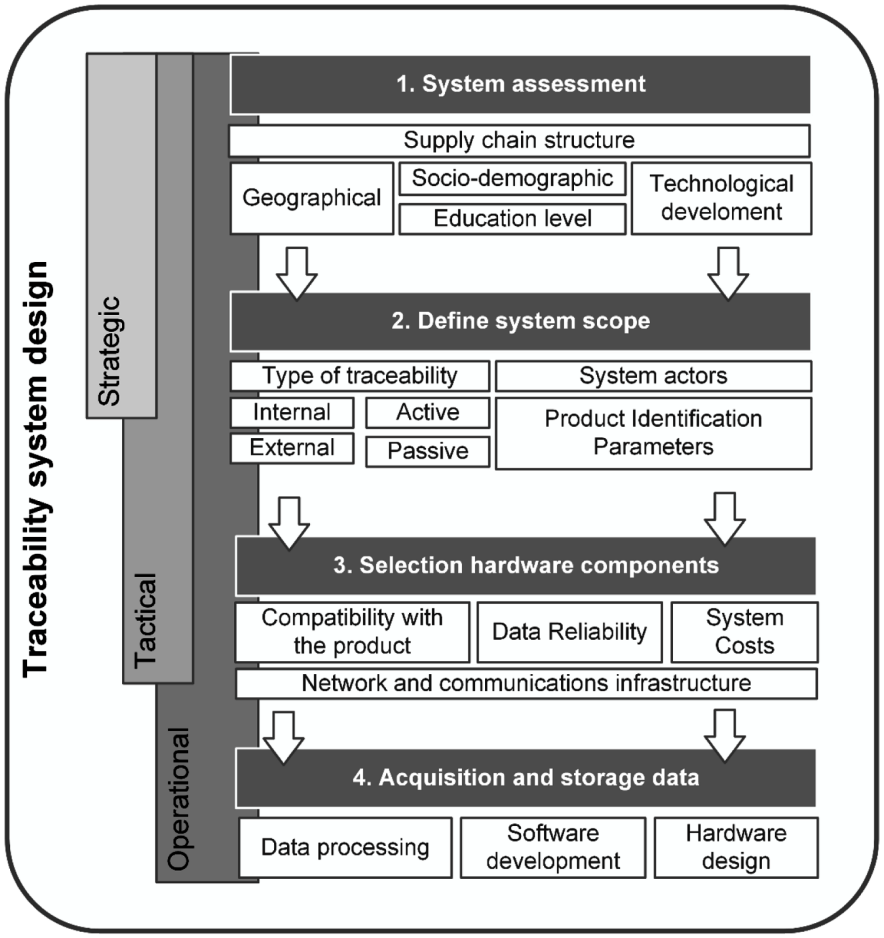
Table 2. Traceability system methodologies

Methodology Approach	Authors
Information system	Aung & Chang (2014); Renfroe et al. (1988); Ringsberg (2014)
Technology	Feng Tian (2016a); Gnimpieba et al. (2015); Jansen-Vullers et al. (2003); Regattieri et al. (2007); Wilson & Clarke (1998); Zhang et al. (2015)
Logistics management	Bosona & Gebresenbet (2013); Scholten et al. (2016)

design a system focused on programmes with social impact. To define the technological tools required, it is not enough to study the technological development of the country, it is necessary to regard socio-demographic, geographic and educational level characteristics; to determine the possible penetration level that the system would have in the target population.

The proposed framework for designing traceability systems of programmes with a social focus begins with the evaluation of the characteristics of the context. The complete methodology with its stages is presented in Figure 2. It is possible to identify the factors that affect the system, based on this characterization. Once the evaluation is done, the scope of the scheme should be delimited, defining the type

Figure 2. Framework traceability system



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of desired traceability, the stakeholders involved and the parameters of product identification by their physical characteristics.

The methodology proposed in this article is composed of four stages, which are executed sequentially as follows:

Stage 1: System Assessment

In this phase the evaluation of the geographical, demographic, social and technological development conditions, is carried out; in order to identify the initial conditions before the development of the design. According to evaluate whole aspects is required a supply chain diagnostic, including supply chain structure, planning and control mechanisms and company material flows (Naim, M. M et al., 2002).

As a result, the traceability design needs to determine the actual stage of the communication architecture, penetration of Internet service, use of terminals and mobile devices. This data will be used to select the best technological solution.

Stage 2: Define System Scope

In this phase, the requirements of the design are defined. Some of these requests are the traceability type (Aung & Chang, 2014), the actors involved, the product parameters and the identification parameters (Regattieri et al., 2007).

As mentioned earlier, the type of traceability depends on system coverage. If just need to track the good in a specific echelon, require internal traceability. In contrast, if the requirement is covered more than one echelon of the supply chain, talking external traceability (Aung & Chang, 2014; Ringsberg, 2014). The active and passive traceability rely on the dynamic that interacts the sensors and technological devices, sending and requesting data.

The identification and interaction between actors, determine the dimensions of the storage and process equipment. The amount of data to flow in the system, the format and weight of the transported data, are relevant parameters to calculate the capacity.

When all parameters are defining, the following step is the selection of the sensors and physical devices.

Stage 3: Selection of Technology Tools

In this phase, the technological devices are selected to perform traceability based on product specifications and the compatibility with the selected tool (Costa et al., 2013; Feng Tian, 2016). The reliability of data depends on the degree of accuracy of the measurement devices and the environment where it will be implemented (Abad et al., 2009) This stage includes the costs of implementing the proposed system and the description of the current infrastructure related to networks and communications.

Within the selection of the sensors and physical devices, the conditions of the environment where the system will be installed should be noted, as well as the technical specifications of each device (communication protocol, power consumption, scope, type of data collected) (Hashem Eiza, Ni, & Shi, 2016; JiaJu Wu, Gang Liu, Peng Liu, & ChuanYu Xi, 2005; Shi, Ding, Zuo, & Zillante, 2016; Wang & Xiao, 2010; Yuvaraj & Sangeetha, 2016). The necessary infrastructure to support the selected technological tool will depend on the factors mentioned.

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Stage 4: Acquisition and Storage Data

Once the technical specification is done, the next step is to select the method to process and store the data according to the amount of data, the information availability, frequency that the devices and actors interact with the system. Techniques like business analytics, big data, could computing, and blockchain (Feng Tian, 2016).

In the final step is required to design the devices with sensors and electronic components for the data acquisition (G.-Escribano, Garcia, Wissendheit, Loffler, & Pastor, 2010). Also, develop all software components, databases, interfaces, data processing, interoperable with the hardware design (G.-Escribano et al., 2010).

IMPLEMENTATION CONSTRAINTS

Some factors that obstruct the implementation of a traceability system are: lack of regulation, management between suppliers, lack of interoperability of systems between supplier and customer (Kumar et al., 2015), lack of standards, high costs of financing, lack of accessibility, lack of reliable technological devices, lack of final customer information and ethical and privacy issues (Mattevi & Jones, 2016).

Other significant drawbacks that can occur in the implementation of traceability schemes are the lack of guidelines to determine what data should be captured within the system, which makes it difficult to define the parameters of the product (Ramesh & Jarke, 2001). This flaw generates a more significant impact in systems where it is intended to track a product or a service related to a social programme, due to the data from the beneficiaries in most of these systems are segmented because of the restrictions of the handling of personal information (Canavari, Centonze, Hingley, & Spadoni, 2010).

One of the main challenges is the availability of supporting technological infrastructure. This infrastructure may restrict the implementation of real-time traceability systems and thus decision-making (Aung & Chang, 2014).

In the Colombian context, the implementation of a traceability system involves more challenges than technological infrastructure. The huge differences between the qualification levels, means availability, accessibility, communication, coverage, some aspects like cultural and ancestral according to the region; make the difference and represent the barries for the system implementation and development.

Based on the methodology proposed in this article for the design of traceability systems in Social Assistance Programmes and considering the limitations may be present in the stage of the implementation, this methodology is applied in the case of the Bienestarina nutritional program. Bienestarina is a strategy managed by the Colombian Institute of Family Welfare (ICBF), whose shortcomings have been identified in terms of the administrative procedures for delivering the product and in the current technological infrastructure which prevent the recognition of the beneficiary and the authorized Delivery Points (DPs).

CURRENT SCHEME OF THE BIENESTARINA PROGRAMME

Colombian Institute of Family Welfare (ICBF) manages direct transfers of food to the vulnerable population through the program called Bienestarina. The programme encompasses the production and

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distribution of a cereal mix food supplement entirely financed by the Colombian Government (Instituto Colombiano de Bienestar Familiar, 2014). As well, the programme is a strategy to attack the problems of malnutrition, especially in the cases of children and young people living in poverty (Departamento Nacional de Planeación; Departamento para la Prosperidad Social; Instituto Colombiano de Bienestar Familiar; Ministerio de Hacienda & Crédito Público, 2015).

Also, the program is closely related to strengthening the fundamental right to food security and is aligned with the ICBF policy of children and family protection (Departamento Nacional de Planeación - DNP, 2006). The annual budget allocation of around 40 US million has been set aside to cover a programmed quota of six million users annually until 2019 (Departamento Nacional de Planeación; Departamento para la Prosperidad Social; Instituto Colombiano de Bienestar Familiar; Ministerio de Hacienda y Crédito Público, 2015).

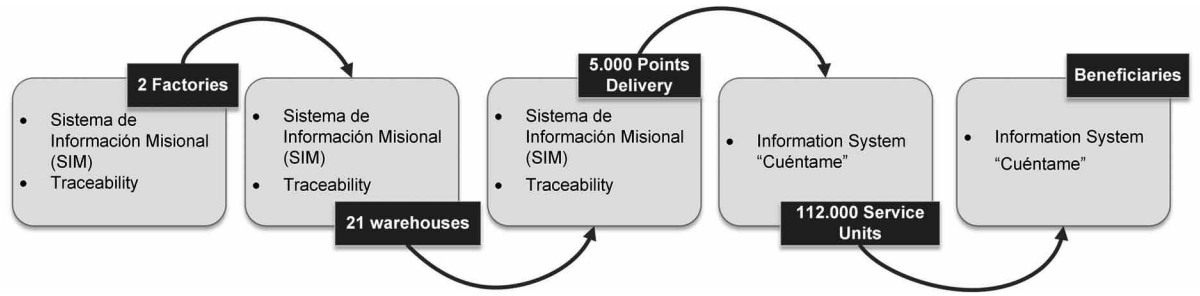
The structure of the Bienestarina Más® distribution system includes public and private actors. Among these actors are: the Colombian Institute of Family Welfare (ICBF), as the public entity in charge of leading the program, and about 15 private companies working as suppliers of goods.

Bienestarina Más® is a nutritional supplement of high nutritional value, composed of: flour, cereal starch, soy flour, whole milk powder, vitamins and minerals, whose expiration date is 6 months; this is produced by the ICBF to combat the malnutrition problem in the Colombian population (Instituto Colombiano de Bienestar Familiar, 2017). The distribution process starts at the factories and ends at the Service Units (SUs) that can be located: in associations, community mothers, homes of children or Child Development Centers (CDI); there, the aid is delivered to the vulnerable population that is enrolled in any of the programmes provided by the ICBF.

The distribution structure is composed of two manufacturing plants located in Sabanagrande (Atlántico) and Cartago (Valle del Cauca) as shown in Figure 3, once the production stage has culminated, the freight is distributed to 21 warehouses depending on the estimated demand in each region of the country. In 2017, the program delivered nearly 18 thousand tons produced in two factories, distributed through 21 warehoused and nearly 4.200 delivery points to about 2.5 million beneficiaries (Instituto Colombiano de Bienestar Familiar, 2018a). In the distribution process the Stock Keeping Unit (SKU) used through the supply chain until the Delivery Points is sacks, in the last mile change the SKU to bags that contain 900 grams of Bienetarina.

The production and distribution processes use a technological tool called Missionary Information System (SIM). With this tool, traceability takes place from the reception of the raw materials to the programming of shipments to DPs. This information system is supported by a network and communi-

Figure 3. Scheme Bienestarina supply chain



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cations infrastructure (Instituto Colombiano de Bienestar Familiar, 2016). In the next two echelons in the chain, there is an information system called Cuéntame which allows to record information about the beneficiaries and the SUs representatives, as shown in Figure 3.

CURRENT TECHNOLOGICAL INFRASTRUCTURE

At the technological level, the ICBF has several technological tools that support some processes related to the production and distribution of Bienestarina. For data management, there are two Information Systems mentioned previously. The SIM guarantees the effective delivery of the product to the DP, through the programming of orders. For this programming it is necessary to register the data of the freight receptors and their coverage, in order to calculate the rations dispatched and compare them with the Social and Financial Goals (SFG) proposed by the Nutrition Management (Instituto Colombiano de Bienestar Familiar, 2016).

This system allows controlling the inventories, estimating the delivery times and monitor the freight until the arrival to each DP, guaranteeing the traceability of the product until this echelon of the chain.

However, the process does not end in the DP because this echelon also sends products to beneficiaries or the SUs. Since the information flow can take these two possible ways, the product tracking to the final consumer is not easy. Furthermore, considering that the programme has nationwide coverage, it becomes necessary to subcontract logistics operators, to reach all destinations, which brings a coordination problem between multiple actors.

As an ICBF plan to counteract these shortcomings, the Institution is implementing the information system Cuéntame, which aims to record information concerning the programmes of the different modalities of the Early Childhood Division, in the two last echelons of the chain. This system collects and digitizes the information related to: data of the administrative entity of the service and its legal representative; contracts with each of these entities; human talent team involved in each SU, beneficiary data, the SU data and nutritional status of beneficiaries enrolled in the programmes provided by ICBF (Dirección de Primera Infancia - ICBF, 2017). However, even with the implementation of this new system, there are still gaps in terms of traceability, as there is no constant updating of information, likely resulting in the use of incomplete information in the medium and long term.

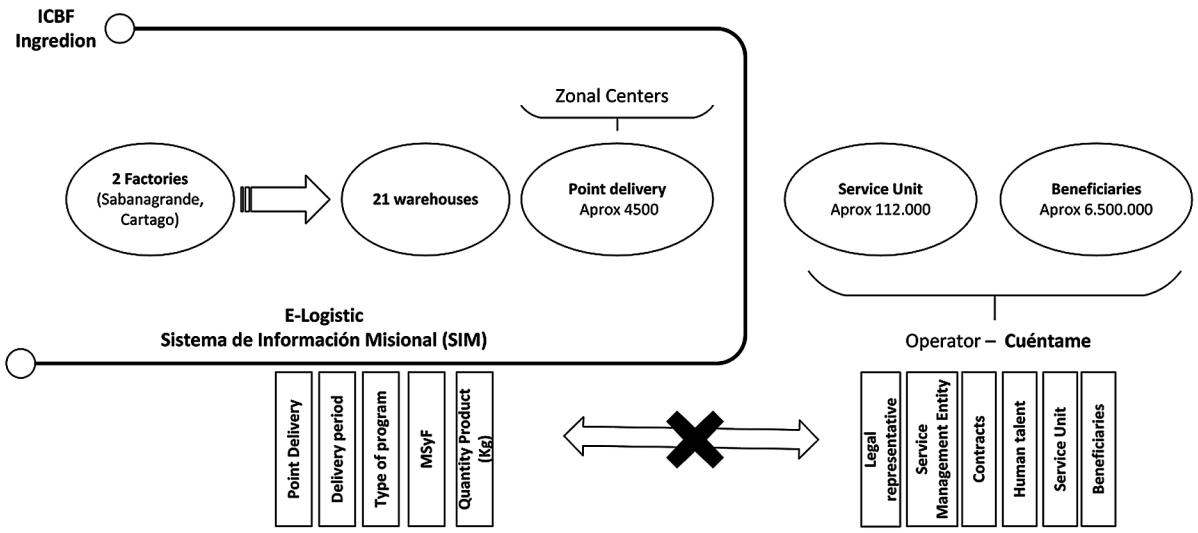
Additionally, in this system, the amounts of Bienestarina delivered to the beneficiaries are not recorded. Without this information, it is impossible to validate the impact of nutrition programmes despite having nutritional control for everyone. Also, this factor makes it difficult to estimate the actual demand, limiting the supply chain management.

The data collection that is being carried out in both Information Systems is necessary as an essential requirement for the recognition of the population. However, this is only the beginning of a unified system. Although these information systems cover all the supply chain as shown in Figure 4, the integration is required to enable interoperability between them.

Information systems are supported by the infrastructure of communications and network, which allows the connectivity between the interfaces with the devices where the information is managed (servers). To achieve this interconnection, the ICBF has an infrastructure with coverage from the general direction to the Zonal Centers. Zonal Centers can also act as a DP. At the general level, there are computer centers, physical and virtualized servers, storage equipment and databases. In terms of the communications infrastructure, there are fixed-line and mobile Internet service and local wired and wireless networks,

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Figure 4. Bienestarina supply chain information systems



which connect the main headquarters with the sub-directorates (Dirección Informacion y Tecnologia - ICBF, 2015).

Accordingly that, although there is infrastructure that supports information systems in the first echelons of the chain (until DP), there is no full coverage of the actors involved, nor tracking to the final consumer. In other words, the Bienestarina programme still has only partial traceability.

APPLICATION OF THE PROPOSED METHODOLOGY TO THE BIENESTARINA CASE

In order to apply the proposed methodology to generate a traceability scheme in the Bienestarina programme, the evaluation of the current system and the definition of its scope (stages 1 and 2 Figure 2) is carried out in order to select the appropriate technological tools that allow the unification of existing information systems. The application of stages 1 and 2 of the proposed methodology is mandatory, because these are differentiating stages of the analysis of social assistance supply chains. The remaining stages will be described in future publications and correspond to the application of the frameworks exposed in Aung & Chang (2014); Regattieri et al. (2007); Scholten et al. (2016) once social needs have been revealed.

System Assessment (Stage 1)

Given the Colombian geographical and socio-demographic diversity, it is necessary to carry out an evaluation considering rural and urban environments, since the parameters to be taken into account for the design of the traceability system vary considerably between them (see Table 3). For instance, in the socio-demographic area, there are differences in the degree of vulnerability in dispersed regions where there is a lack of entities who promote and control solutions to the population's social problems. In turn,

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Table 3. Scenario assessment

Scope	Parameter	Urban	Rural
Sociodemographic	Demographic concentration	High	Low
	Geographical dispersion	Low	High
	Education Level	High	Medium/Low
	Access to public services	High	Low
	Degree of vulnerability	Low	High
	Malnutrition level	Medium	High
Technological development	Technological appropriation	Medium	Low
	Internet Penetration (Mobile/ Fixed-line)	Medium	Low
	Access to terminals	High	Low
Communications infrastructure	Internet Coverage (Mobile/ Fixed-line)	High	Medium
	Diversity mobile operators	High	Medium
	Diversity transmission means	High	Low

there are differences in access to public services, especially in rural regions where only 60% of the population has access to the aqueduct service (Departamento Administrativo Nacional de Estadistica, 2017).

In terms of technological development, there is still a lack of access to end-user devices in rural areas, especially in the Pacific, Caribbean and San Andrés regions, where only 14.7% of the population in rural areas have a desktop, laptop and/or tablet computer (Departamento Administrativo Nacional de Estadistica, 2017). The penetration of Internet service in general is low, for example, in Bogota it is scarcely 21.7%, and in regions such as Guainía, Vaupés and Amazonas, the percentage of use of the service is less than 1% (Ministerio de las Tecnologías de la Información y Comunicaciones, 2016).

Regards to communications infrastructure, there is evidence of coverage by mobile operators in most of the national territory. In contrast, according to the survey presented by the (Departamento Administrativo Nacional de Estadistica, 2017), only 45.8% of households have access to the fixed-line Internet. Hence, in some dispersed regions is not possible to access to various transmission media, such as: cable, XDSL, optical fiber, satellite, WiMax, microwave, among others; significantly restricting access to the Internet (Ministerio de las Tecnologías de la Información y Comunicaciones, 2016).

In order to attend the different social and technical country conditions, the traceability system design is divided in twofold: one oriented to the dispersed regions, considered as non-interconnected zones, and the other one focused on concentrated regions, which have a higher degree of use of technological tools and therefore knowledge about their usage.

For technological development analysis, technological characteristics associated with the two proposed scenarios were identified as shown in Figure 5. In dispersed regions it is important to consider the lack of permanent Internet connection due to the limitations of wire connections. In contrast, in concentrated regions such as urban areas, consideration should be given to whether fixed-line and mobile Internet access guarantee an available and reliable connection.

To evaluate the current conditions of fixed-line Internet access in the DP, it begins with the identification of municipalities in Colombia that do not have Internet access through conventional technologies

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Figure 5. Technological features according to the region

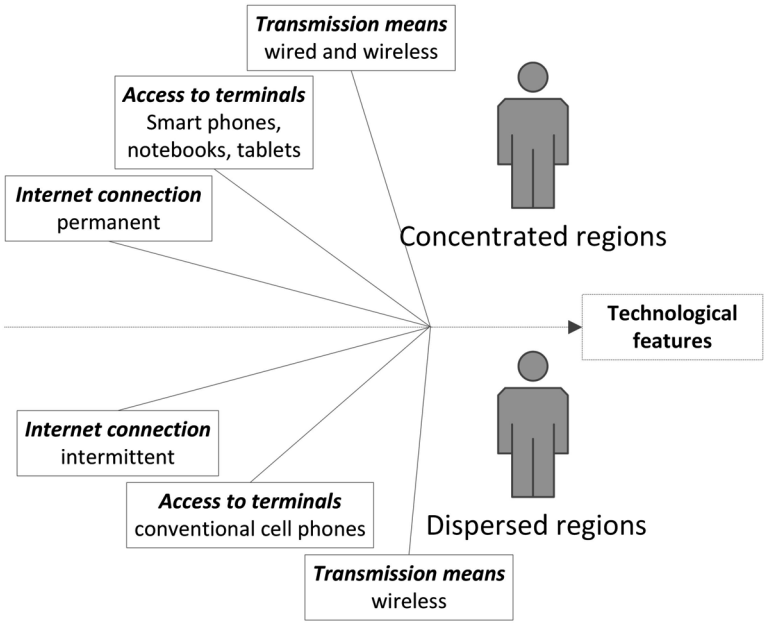
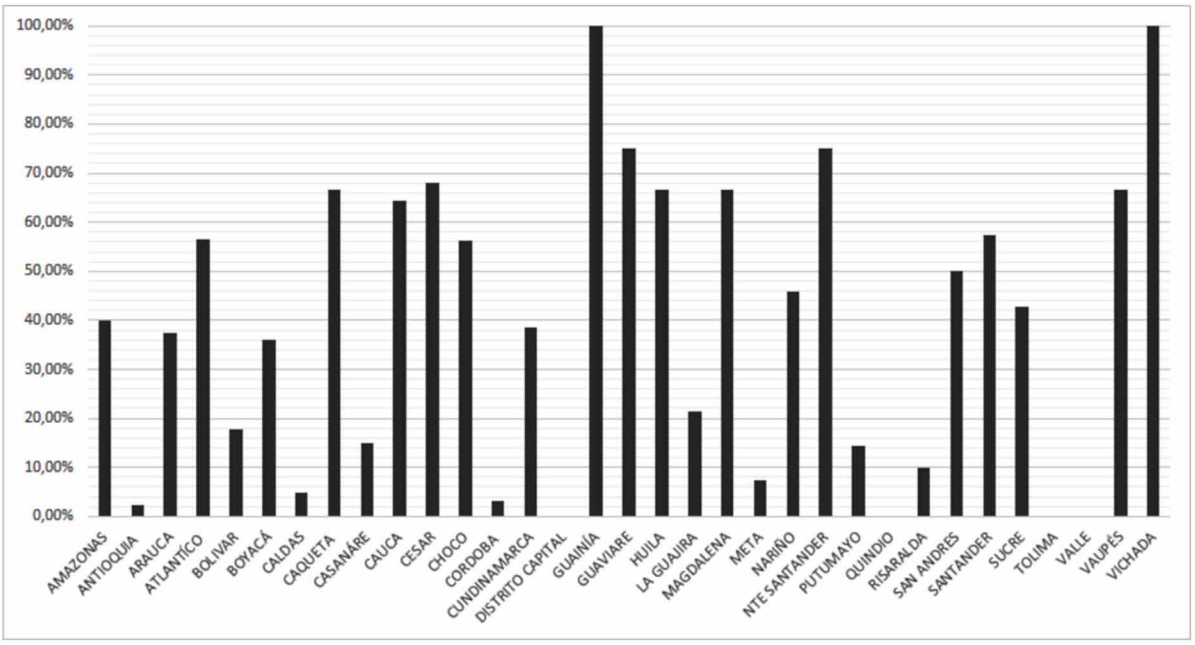


Figure 6. Delivery point without access to a fixed-line Internet



(Cable, XDSL). In these municipalities, access is only available through satellites or microwave links, which are expensive and difficult to access, generating a subscriber number of less than 50 per municipality (Ministerio de las Tecnologías de la Información y Comunicaciones, 2016). This data was extracted in the statistics made by the Ministry of Information Technologies and Communications.

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Once the municipalities with limited alternatives to access the fixed-line Internet are identified, the contrast is made regarding the location of the DPs. The analysis obtained that around 35.08% of DPs cannot access to a fixed-line internet. Thus, in departments such as Guainía and Vichada located in dispersed regions, there is no fixed Internet access, as shown in Figure 6. On the other hand, in regions with greater urban concentration such as Bogotá, Antioquia, Tolima and Caldas; the fixed-line Internet coverage reaches approximately 95% of the DPs.

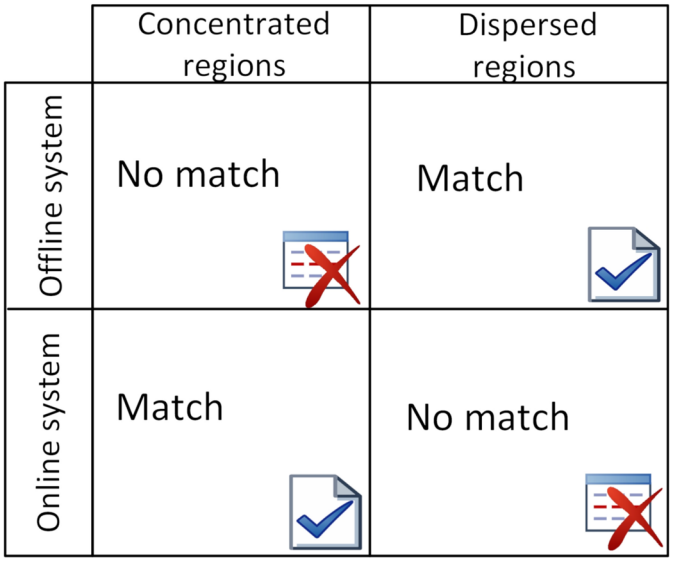
Based on the technical evaluation, the reach of the existing infrastructure in terms of connecting dispersed populations is analyzed, as shown in the matrix of Figure 7. In dispersed regions, the implementation of a traceability system design needs to consider the lack of infrastructure for fixed-line Internet connection, as well as the connection to a mobile internet as an alternative for the system update in cases of intermittent connectivity.

The twofold design has different implications for a system such as the one analyzed, because it requires having at least two designs of technological architecture, one for dispersed or non-connected areas and another for interconnected zones. While this distinction may seem obvious, in practice one-off traceability systems are usually designed, omitting the conditions of availability and fixed-line Internet access.

Define the System Scope (Stage 2)

The social assistance programmes can compromise its effectivity if the access level of the freight and technology for traceability are not coherent. This situation is evident in the system distribution of Bienestarina, where traceability of the freight covers the supply chain until the DP, omitting the connection between DPs and rough 4.5 billion of beneficiaries. In order to guarantee the coherence between the scope of freight and the beneficiaries who received the product the Bienestarina distribution process in the last mile was evaluated and the involved actors were identified.

Figure 7. Type of scenarios



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System Process and Stakeholders

Based on the system characterization in the previous stages, there is a feasible solution to implement the traceability system in the last mile. The distribution process starts with the registration of the inventory that arrives at the PD, through the barcode printed on the Bienestarina sacks. Each sack contained 25 bags of Bienesatrina with 900 grams per bag (Departamento Nacional de Planeación- DNP, Departamento para la Prosperidad Social, Instituto Colombiano de Bienestar Familiar, & Ministerio de Hacienda y Crédito Público, 2015). This condition inhibits the possibility of carrying out adequate control of the product, thus tracking each product is difficult. Therefore, SKU should be modified from sacks to bags in this echelon of the chain.

Once the delivery request is received, either by SU or beneficiary, the user authentication is performed, so that the person responsible for delivery can validate the registration of beneficiary in the databases and the amount of product to deliver. In this point of the process has two alternatives, one is directly transferred to the beneficiary, the other is to deliver to the SU and they transfer the product from there to the beneficiary, as shown as in Figure 8.

Given the importance to performing traceability in the last mile, it is necessary to consider DP, SU and beneficiaries as actors in the system, especially in the last segment in the supply chain as shown as in Figure 8. Some actors like a DPs and SUs can register beneficiaries, schedule Bienestarina deliveries, make inventory control and update information of the anthropometric profile of beneficiaries. Some anthropometries parameters are: weight, height, age, gender and so on.

The DP and SU actors should have a profile that can access the databases with records of the product's delivery and the users, to consult data before to be registered in order to avoid duplicate entries. In contrast, the beneficiary should be able to display its nutritional evolution and registered delivery. For this reason, is necessary to create three types of profile with role permissions with the follow features: the SU can register the beneficiaries, change the status of the beneficiaries, deliver product and inventory control; the DP have to transfer the inventory and deliver the product of beneficiary and beneficiary profile as described in Figure 9.

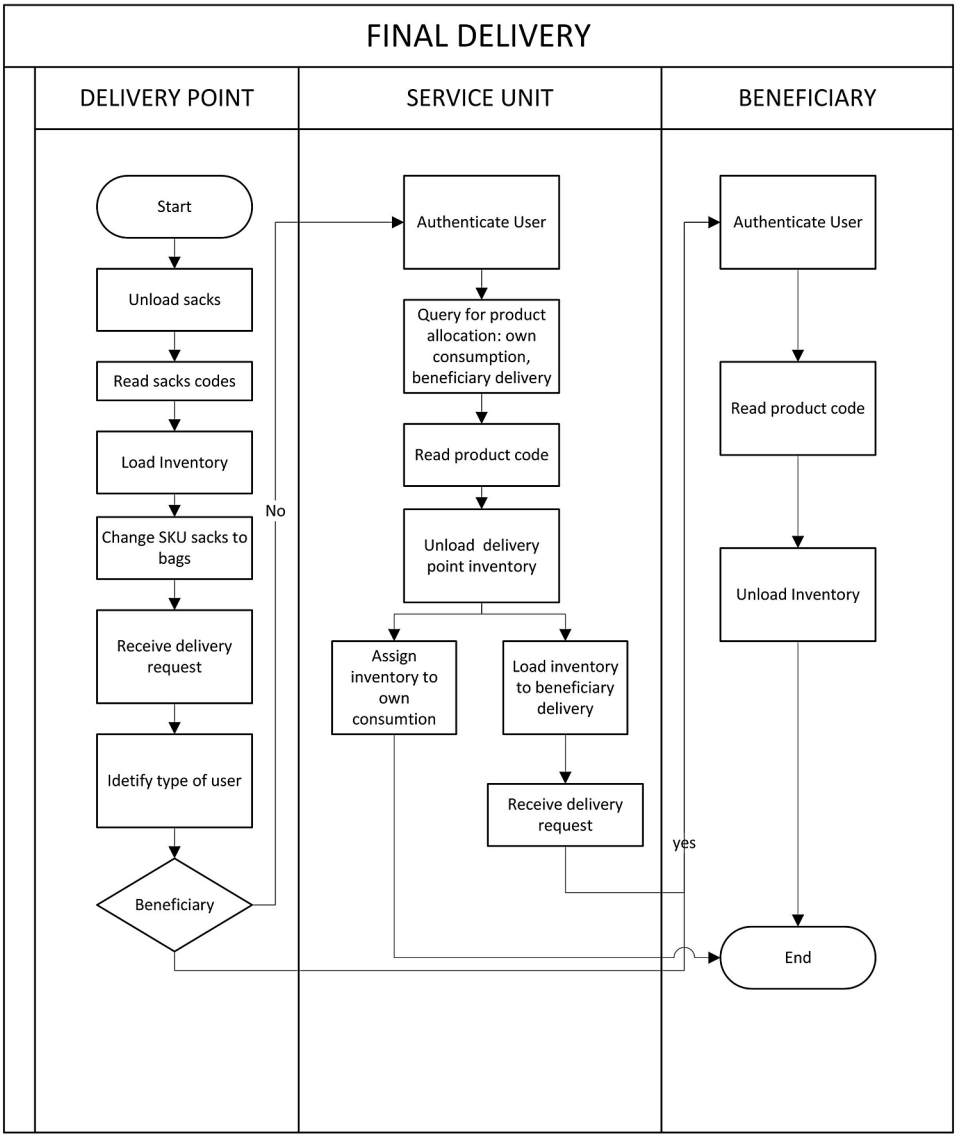
Once the process and actors identification were done (Figure 8 and 9), will propose a possible technological solution. To identify each actor that interact with the system, is necessary the use of ID card or biometric devices, so validate their authenticity. Other device requirements are the barcode lector to load or unload the product, depending on the process. Other elements that have to define are: the communication system, storage equipment and data processing method.

CONCLUSION

Through the methodology proposed in this paper shown particular aspects required in the complex systems. Each stage includes relevant factors that impact the strategic, tactical and operational levels in the organization. In the literature review researches like Jansen-Vullers et al. (2003); Regattieri et al. (2007) and Wilson & Clarke (1998) proposed methodologies to implement traceability systems that including technological features, being this important but not the only element to determine the implementation feasibility.

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Figure 8. Bienestarina last mile distribution process

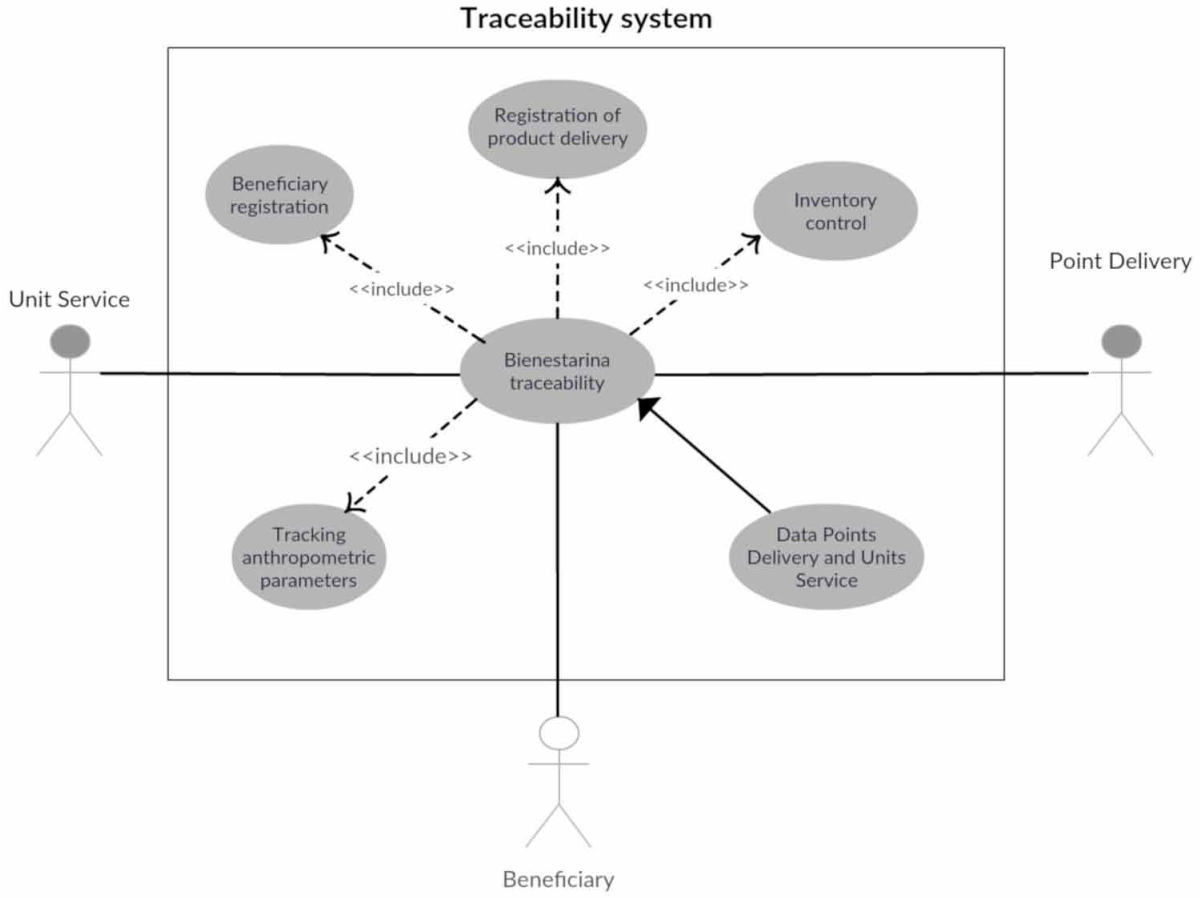


The guidelines of the traceability system design mainly based on the technical requirements, depending on where the process will be implemented (characteristics of the product, environmental conditions and stakeholders). Before selecting technology, it is relevant to assess the system, especially when the traceability involves Social Assistance Programmes.

The identification of the geographical dispersion of beneficiaries, heterogeneous conditions of communication networks and different educational level of the population, represent the complexity of the system. For that, emerge the importance to perform the system assessment along the supply chain structure, including all organization planning level, being these impacted with the traceability system.

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Figure 9. System actors, traceability in the last mile



In the evaluation of the case of Bienestarina above, the first stage included the current diagnosis of the context. With this analysis it was possible to identify technical requirements needed in the implementation phase. It was found that Internet access and technological appropriation are considered relevant factors. Also, if there is no previous assessment, it is difficult to have a homogeneous system that adjusts to all requirements.

The fixed-line Internet connection in the Delivery Point is 65% due to it is necessary to complement the technological infrastructure with alternative solutions such as a mobile Internet connection in order to guarantee the coverage of the system. Within the traceability system design it is crucial to consider two connection status for the storage of the database, online and offline. This way, it can be used the local storage in the final devices where there is no Internet connection. In terms of technology, it is necessary to incorporate tools such as: bar-codes and digital fingerprint scanners, smartphones or computers; in order to be sure that the actors have access to the system.

The implementation of traceability technologies in social assistance programmes as here presented is the first step to integrating information technologies around the user approach. In countries as Colombia is usual to have independent programmes around different necessities of vulnerable populations, as many views of the same subject.

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Fully integrated information, data analytics, freight traceability around the same subject could improve the basic necessities fulfillment for instance in education, health, security, and food assistance. Hence the user approach in social assistance programmes requires further research and further technologies development, especially in collaborative aspect.

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Chapter 10
Allocation Optimization Problem for Peruvian Food Bank

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ABSTRACT

Food insecurity is a recurrent condition in which members of a household do not have enough food to cover their nutritional needs; this condition contributes to increasing social vulnerability of those affected. In Peru, there are more than 9 million people who suffer this condition, which generates malnutrition and anemia, mostly in children. On the other hand, the waste of food is associated with production the large amounts of greenhouse gas emissions that affect global warming. According to reports in Peru, 20% of what is food produced becomes waste. This scenario in terms of food for Peruvians represents 3 billion calories in wasted food that could feed 2 million people. The Peruvian Food Bank manages food donations, ensuring this food can reach people in need through humanitarian aid entities. This applied research work uses the tools of operations research to determine a solution to the problem of maximizing the combination of food orders to be distributed based on their total nutritional value to the beneficiaries, seeking maximum coverage and minimum logistic costs.

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INTRODUCTION

Social vulnerability is expressed by the risk of households to suffer a deterioration in the conditions of quality of life, i.e. to fall into a state of poverty that does not allow the individual to cover their basic needs, including housing, education, work and food. In Peru, although there is an increase in the GDP, the percentage of citizens living in extreme poverty reaches 24.4% (INEI, 2017: INEI; National Institute of Statistics and Informatics).

In Peru malnutrition was reduced from 25.4% to 15.2% (PAN, 2012); despite this, child malnutrition in our country continues to be an important reason for death according to UNICEF data, with nearly half a million children under of 5 years, those affected. This is one of the reasons why projects such as food banks seek to recover food that is in the period limit and conditions of consumption do not turn into waste, to benefit less favored people, involving participation and solidarity of NGO's and companies, who participate voluntarily with their donations.

Food banks are non-profit institutions that have the function of acquiring food from different entities or suppliers (national and international), so that they can then be distributed to people to cover their basic nutritional needs of a specific population. Therefore, these institutions not only contribute to the health and welfare of society, but also contribute to preventing the generation of food waste and the preservation of the environment. According to the FAO (Food and Agriculture Organization of the United Nations), around a third of the foods in the whole world are wasted before people consume them and this becomes, therefore, garbage. The contribution of the food bank for this case is that foods that have already reached their life cycle or that are obsolete so that other organizations are redistributed optimally, and solid waste management is improved (FAO, 2013). Food banks seek to promote the social development of vulnerable communities, through the management of donations of goods, under a quality control system; that is, to serve as a link between donors and the vulnerable population that suffers from poverty, hunger and malnutrition, improving nutritional levels and sensitizing the community through volunteering (McCrindle. 2017; Delpish et al., 2018; Gonzales-Feliu et al., 2018).

Another important aspect to consider is the environment, since the production of food affects this with the waste that is generated every day and these foods could be used by food banks. Using these resources in vain would be a very bad decision. The waste will be in the form of solids, liquids, oils and more, which will then have to go through a process of biodegradation. In addition, we must consider the carbon footprint of wasted food that increases the emission of greenhouse gases and the effect it has on water, which we will drink later; as well as nitrogen emissions that directly affect the air we breathe. (Wang et al., 2006).

This work is presented following next order: first, a literature review about main theory frame is presented, after main issues related to Peruvian food bank supply chain is analyzed, an optimization model is proposed, and finally main results are discussed. The results show that the food loads to be sent can be maximized, increasing the coverage to the institutions from the current 24 to 69 at a lower transportation cost.

BACKGROUND

Because of seeking a solution for problems such as malnutrition caused by hunger and social vulnerability (Phil et al., 2017), Food Banks all over the world have occupied a very important place in dif-

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ferent societies, since they are responsible for the distribution of donated products to communities that do not have the possibility of acquiring food (FAO, 2012). The following lines show examples of these organizations and their effects in different countries.

In Australia, Foodbank has a presence in every state in the country and is responsible for distributing food to hungry people with the help of approximately 100 employees and more than 3,000 volunteers. They work with the entire Australian food and grocery industry (farmers, wholesalers, manufacturers and retailers, as well as companies that donate as social responsibility). Many Australians (45%) who experience food insecurity have skipped a meal and 28% have spent a whole day without eating (Foodbank Australia, 2017). Australians with food insecurity report more frequently lethargy or fatigue (42%), a decrease in mental health (38%) and a loss of confidence (35%) due to lack of food (Foodbank Australia, 2017). In 2017 alone, Foodbank provided enough food for more than 67 million meals to charities and schools in the country, being the main source of food for them and improving the quality of their lives.

In Brazil, the urban harvest, the name for the food collection process in good condition for consumption and distribution to institutions, is restricted only to the city of São Paulo and the metropolitan region. The synthesis of the 2017 Social Indicators reveals that more than 52 million Brazilians, the equivalent of 25.4% of the population, live on the poverty line, so they benefit from this program. According to the Activity Report presented by BA Brasil, 2017 was the year in which it was possible to collect the largest amount of food, reaching 610,886.12 kg, being able to serve 45 institutions and benefit 20,726 people served, being 69.64% adults, 26.04% Children and teenagers and 4.32% elderly.

Les Restaurants de Coeur, is a French association as other European initiatives (Booth and Whelan, 2014)., whose objectives is to help and provide voluntary assistance to the poor, especially in the food sector. There are currently 1,651 people with housing difficulties, of which 1,628 are in emergency with only 243 beds of emergency accommodation. For this, since its creation in 1990, there are 71,000 volunteers, 102 workshops, 84 local gardens and integration sites open all year. They have managed to distribute 135.8 million meals, of which 87.7 million are donations, bequests and events.

In the United States there is the Feeding America charity, which has offices in all states and feeds more than 46 million people. They not only have pantries, but also dining rooms. This country realized that in the United States 72 billion pounds of safe and edible food are wasted each year and this can help feed the entire country. That's why the Feeding America organization is focused on working with the help of farms, manufacturers and consumer-oriented businesses (Allen, 2015: 2018). For example, there are three innovative solutions to avoid food waste. The first is that trucks pick up unsold Starbucks food every night. The second idea comes from Second Harvest Food Bank of Middle Tennessee, which rescues not standard beans from culture. Finally, Meal Connect, helps to link food banks with restaurants or any place where food is sold, so when food is available, it is collected and sent directly to the food bank. The application of these three ideas has made it possible, during the last year, that 3,300 million pounds of food have been saved (Feeding America, 2018).

MAIN FOCUS OF THE CHAPTER

Theoretical and Methodological Framework

Diet problem is defined by the search for a correct allocation of food by minimizing the cost of the food consumed during the day without neglecting the nutrients that a person should consume (Czyzyk and

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Wisniewski, 1996). The problem of diets was proposed by George Stigler in 1945 under the name of "Cost of subsistence" and is to meet the minimum nutritional needs of a person considering raw material cost. This problem was solved by Dantzig (1990) using the simplex method. While Garille and Gass (2001) updated it with nutrition information and food cost data. Joseph Balintfly proposes in 1979 a modification to the problem raised by Stigler and names it the "The cost of a decent subsistence", in this case the problem is defined as the level of the minimum budget to satisfy the nutritional needs of an average person within a certain society considering their food preferences. Bas (2014) introduces a mixed-integer programming model for the dietary problem of glycemic load values of foods into objective function, it is well-known the relation between high glycemic load diets and chronic diseases such as obesity, diabetes mellitus, cardiovascular diseases, and various types of cancer. On the other hand, in a paper presented by Metecan and Egemen (2017) a genetic algorithm was used to simultaneously optimize two goals; Minimize the total cost of the supply chain and the variety of military battalion dishes. van Dooren (2018) presents a work that consolidates the diet problem by consolidating various proposals in the literature and the methods used.

The problem of the diet presented in the context of organizations such as food banks, has important considerations not considered in the original problem, such as the responsibility of food distribution by NGOs that try to reduce beneficiaries' food insecurity. Three goals are proposals for this food models; objectives of equity, effectiveness and efficiency are common in models that consider public services (Savas 1978). However, (Orgut et al., 2016) mention that these objectives may conflict with one another resulting in trade-offs for decision making, furthermore they propose food banks daily performs its activity seeking balance cost, access and quality. Equity implies serving the needs of the customer fairly. The definition of the term "equity" is subjective and can have different implications for different systems (Stone 1997). Savas (1978) defines equity in the public sector broadly as the fairness, impartiality, or equality of service.

Food Insecurity in Peru

According to INEI, chronic malnutrition in children decreased 5.2% in the last 5 years in Peru. It also indicates that the prevalence of chronic malnutrition, according to the WHO (World Health Organization), is higher in the rural area (25.3%) than in the urban area (8.2%). The highest rates were registered in Huancavelica (31.2%), Cajamarca (26.6%), Loreto (23.8%), Pasco (22.8%), Apurímac (20.9%) and Ayacucho (20%). Regarding anemia, in children from 6 to 35 months it was 43.6% in 2017, and in the last 5 years it decreased by 0.9%. In the rural area it was 53.3% and in the urban area it was 40%. The INEI reported that anemia affected more than half of the lowest quintile (55.3%), as well as children whose mothers did not have an education level or only had a primary education. The highest rates are found in Puno (75.9%), Loreto (61.5%) and Ucayali (59.1%). The Peruvian government has proposed reducing anemia from 43.6% to 19% in 2021, the year of the Bicentennial of Independence. The National Plan for the Reduction of Chronic Infantile Anemia and Malnutrition, which has been in force for more than 2 decades and is updated every 4 years, is now available. It is a policy aimed at addressing the problems of nutritional deficiency in the country. Currently, it is planned to cover anemia with new approaches, this means not only implementing micronutrients, but also promoting the consumption of iron-rich foods.

The Law for the Promotion of Healthy Eating for Children and Adolescents (Law No. 30021) is a law based on overweight and obesity that has increased in recent years in these groups. The law can include an improvement in many aspects, such as promoting the consumption of foods that are rich in nutrients

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and can fight school anemia, as well as having children that grow better because their protein intake is higher. What this law does is protect the most vulnerable groups, for adults, the decision to consume a food is more independent. What is sought is to provide information for these groups to make decisions and anticipate the change of attitude towards a healthy diet to prevent excess weight and thus prevent the onset of diseases such as high blood pressure, diabetes, etc.

Characterization of Lima-Callao Food Bank

On August 8, 2016, Peruvian national law N ° 30498 "Law that promotes the donation of food and facilitates the transport of donations in situations of natural disasters" is published in the official newspaper "El Peruano". The law was an important initiative of the Peruvian State in trying to reduce the amount of food destroyed due to its non-commercialization (Siesquén and Orbegoso, 2015). The objective of the law is not only to increase donations for the most vulnerable population, but also to reduce and subsequently prohibit the destruction of food by the food industry, since it is estimated that 20% of food that are produced are discarded (FAO, 2013) and still 30% of the population suffers from food insecurity (INS, 2013). Likewise, it seeks to improve the quality of life of communities in which the state has little or no presence due to its limited management capacity. For the law to be adequately enforced and the number of people suffering from food insecurity to be reduced, companies will be required to make the donated food fit for human consumption and they will be liable for any damage caused to the person that consumes food in poor condition. If it is proven that due to bad practices the organizations that receive the donated food damaged the food, they will be the legal responsible for the damages caused. In this way, the state ensures that the health of the people who receive the donations is not violated. To promote this measure, the state will deduct up to 10% of the income tax for donated food and will not consider the general sales tax for these items. For this the company must coordinate their donations with charitable institutions and social assistance or beneficiary to certify the amount donated and their condition. The donation will be made to receiving entities that will oversee the distribution in favour of the people in need. The food that is received cannot be marketed for any reason. Currently, in Peru there are initiatives whose main objective is the reduction of food insecurity in the poorest people, among which the most outstanding are the following:

- **National Program of Food Assistance (PRONAA)**: Its purpose is to help raise the food and nutrition level of the population living in extreme poverty through child feeding programs, dining programs, promotion of food security and food assistance to the affected population for a phenomenon or natural damage.
- **Qali Warma**: National School Feeding Program that aims to guarantee food service during every day of the school-year in public schools in vulnerable areas. This service aids with breakfasts and lunches aimed at the school population between 3 and 12 years. (Qali Warma, 2016).
- **Glass of Milk Program**: According to the Ministry of Development and Social Inclusion (MIDIS), it is a program that provides a daily food ration to a beneficiary population living in poverty and extreme poverty. Its main objective is to improve the nutritional level in these sectors, taking care of children, pregnant and breastfeeding mothers, the elderly and people affected by the illness TBC. Although this is a national program, each municipality is responsible for this initiative in their localities.

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The Food Bank of Peru (BAP) is a non-profit organization whose purpose is to reduce the food insecurity of the people in need by donating food. This entity receives food from its main donors such as supermarkets, food production companies, food business and logistics operators. Subsequently, these foods are distributed in the shortest time possible to community support centres belonging to their network for the distribution of food to the vulnerable population. This work is remarkable because in Peru there are more than 1 million people living in extreme poverty and do not have resources to feed themselves (INEI, 2017), in addition to 9 million people who suffer from food insecurity, which, it generates diseases such as anemia (INS, 2013). This organization considers of vital importance the reduction of hunger because this problem is linked to undernourishment, intellectual development, fewer opportunities and therefore, poverty, which generates a difficult cycle to break when faced with these realities.

BAP was founded in Peru in 2014, at the initiative of professionals and entrepreneurs in the food sector interested in an organization like this operating in the country. The food bank has built a strong network of contacts with donors and charities in these years of operation, however there are still many entities that need donations and for limitations in its logistics, the bank cannot supply them. Also, this organization is part of the Global Food Banking Network, so it is essential that it meets the quality standards that this organization demands of its members, for instance guarantee that the food donated will be distributed among the people who need it the most, ensuring the safety of food. The BAP distributes different products of first necessity that are apt for the consumption or human use. Table 1 will show the products received by this institution from the beginning of its operations. The diversity of the products will depend on the entities that make voluntary contributions to this organization

This institution has suppliers of manufacturing items, distributors and logistics companies that favor the viability of their projects. Table 2 shows the main companies that support the BAP as well as the description of their collaboration and the products they donate.

There are two types of donations, which follow two different flows; The first flow represents a cross-docking model – Type 1 (Figure 1) and in the second group the model is presented in which donations are received directly to the warehouse and an allocation of the received products is made (Figure 2).

Type 1 process in details consist in:

Table 1. Products distribute by BAP

	Product Category	Product
1	Meats and Derivatives	Meat of chicken, beef, pork, eggs, fish, etc.
2	Beverages	Mineral water, soft drinks, malt drinks, etc.
3	Cereals and Derivatives	Bulk wheat, cookies, pastry dough, brownies, etc.
4	Milk and derivatives	Milk, yogurt
5	Groceries	Oil, sugar, rice, condiments, mayonnaise, noodles, flour, spices etc.
6	Food supplements	Similac, PVO, Ensure, etc.
7	Fruits	Mango, tangerine, yacon, blueberries, grapes, apples, etc.
8	Vegetables	Lettuce, tomatoes, beets, etc.
9	Hygiene and Personal Use	Shampoo, soaps, detergents, etc.

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Table 2. Donating companies with support BAP activities

	Donating Companies	Type of Assistance Provided
1	Supermercados Peruanos	Fruits, vegetables, groceries, cereals
2	Plaza Vea	Fruits, vegetables, groceries, cereals
3	Backus	Beverages
4	Vivanda	Fruits, vegetables, groceries, cereals
5	P&G	Hygiene items and personal use
6	Agrícola Norsur	Meats and derivatives
7	Ransa	Logistical support (buses, trucks)

Figure 1. BAP cross docking process: Type 1

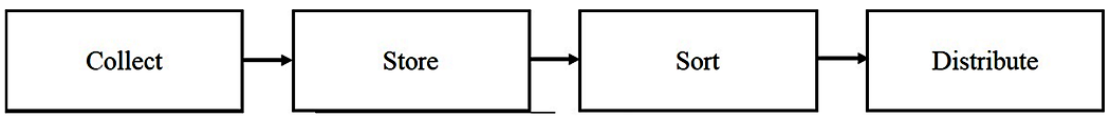


- Issue donation: The company communicates with the food bank and informs that in its stores there are products that can be donated to charities.
- Assign Donation: This allocation depends on the route established for each charity according to its distance to the donors' warehouses. In this process the bank communicates with these centres to inform them that there are products in certain stores and that they can be picked up at a certain time, in addition, informs of the capacity of the trucks for their pick-up.
- Collect donation: The beneficiaries, together with a voluntary representative of the food bank, receive the donation and verify that it is in good condition and suitable for human consumption. Subsequently, the beneficiary collects the products and returns to the point of departure.

Type 2 process in details consist in:

- Collect: This is the process in which all products donated by industrial companies are collected. In general, donations are transported by a logistics operator that provides the service at zero cost.
- Store: In this process we proceed to assign a space to donations in your warehouse waiting for their classification.
- Sort: The donated products are analysed and assigned to the favoured beneficiaries according to their needs of use. Currently the company does not have a prioritization process in this operation,

Figure 2. BAP storage process: Type 2



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in such a way that the donations are distributed according to the intuition of the manager and the logistics capacity of the charities.

- Distribute: In this process, transport management is carried out from the bank's warehouse to the beneficiaries' warehouse. This process can be carried out through the mobility of the beneficiary organizations or by logistics operators at zero cost.

The following Tables specify the activities of the BAP that they carry out to manage the donations to the beneficiary centres.

Table 3. BAP cross docking activities in detail

	Process	Responsable	Activities
1	BAP receives a request to collect donations	Customer service	The donor company communicates with the BAP by mail or phone call consulting if there is a charitable institution that can collect food for that day.
2	Donor sends information on quantity, format, weight and time window to BAP	Customer service	This information is communicated without any established format. According to these data, the necessary transports will be required. Inventory levels are reviewed.
3	BAP reviews list of sponsor carriers	Transport	The BAP analyzes the list of institutions that can provide the transport service and that meet the quality standards required by the products (eg, control of the cold chain).
4	BAP confirms pick-up between transporters and donors.	Customer service	Through continuous communications between donors and transporters, time windows are established for the collection of donations according to the capacities of the vehicles.
5	Donations are received in BAP warehouse	Warehouse	The transport company delivers the donations to the warehouse and delivers quality certification of the food provided by the donors.
6	BAP Volunteer validates inventory entry	Warehouse	The certifications and the discharge are validated by voluntary personnel to ensure the condition of the food upon entering the BAP.
7	Monitoring inventory levels to assemble donation packages	Warehouse	Depending on the type of donations received, the donation packages are assembled according to the maximum date of consumption.

Table 4. BAP storage activities in detail

	Process	Responsable	Activities
1	BAP receives request for donations	Customer service	The donor company communicates with BAP by mail or phone call informing the amount of food that is available for delivery.
2	The pick-up route is identified and assigned to the beneficiary	Customer service	Through a routing scheme, the route that each beneficiary institution must follow to collect the maximum amount of food is determined.
3	Beneficiary goes to the donor's headquarters	Transport	This transport is carried out by a unit belonging to the beneficiary institution.
4	Volunteer BAP validates donations to the beneficiary	Warehouse	Through a validation format, the amount and status of donated food is certified.
5	Beneficiary goes to his warehouse with the certified donation	Transport	The route should not be extended for a long time due to the transportation of perishable food.

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The process, as well as for cross docking and storage, begins in the same way, when a donor contacts the BAP and specifies the quantity of products that will be provided to them so that they can contact the beneficiaries and ensure the transportation service. From this moment both processes differ. Cross docking has the particularity that the beneficiary, to have the possibility of belonging to this system, must have its own transport to collect the donations. Once the beneficiary has been defined, a route already established by the BAP is assigned to them to have a route in which they can collect donations from different stores in the same route.

To validate the information provided by the donor and to comply with the quality requirements, the BAP assigns a volunteer to meet the beneficiary from the beginning of the route until the end of the route. Once the route is done and the donated products have been collected, the beneficiary proceeds to retire to their facilities. In this model it is complicated to establish food allocation criteria since it depends on the availability of the beneficiary's mobility and the donor's precision in describing their products. Donations that go through a storage process require more precise information management because an adequate space must be designated in the BAP temporary warehouse according to specifications such as type of product, quantity, weight and time-window or life time of the BAP. Likewise, the BAP must take charge of transporting the products to their warehouses and therefore must manage with various logistics operators so that they can perform this service at zero cost. In the BAP's warehouse, they can establish a food allocation criterion since the resources they have, are known exactly. Currently BAP serves 24 beneficiaries' institution.

Logistics Decisions and Optimization Problem

In this sense, a food bank model optimization is proposed seeking allocation of food in an equitable and effective way (Sengul et al., 2013; Martins et al., 2016, Delpish et al., 2018; Reihaneh and Ghoniem, 2018). The authors defined that they will achieve equity by reducing the absolute deviation between the proportion of food sent to an institution and their relative needs. Likewise, efficiency will be achieved by maximizing the amount of food distributed. It is important to emphasize that the costs will not be analysed because transportation costs between warehouses would favour easily accessible institutions and priority would not be given to the most distant and most needy charities. The objective function (1) minimizes the total of undistributed food, that is, the surplus. The restriction (2) ensures that the proportion of food distributed in each institution j does not vary by more than the limit K with their food needs. Restriction (3) ensures that the amount of food available is equal to the amount distributed along with the surplus. The restriction (4) represents the capacity of each institution to receive donations and the restriction (5) is the condition of non-negativity.

To maximize the amount distributed in the network, following a prioritization and respecting the limitations of the system, the following optimization model was designed by linear programming.

The objective function is available:

$$Max \sum_{i=1}^{n} \sum_{j=1}^{m} X_{ij} * P_i \tag{1}$$

Subject to the following restrictions:

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$$\sum_{i=1}^{n} X_{ij} * NC_{ik} + \sum_{h=1}^{s} W_{hj} * NB_{ik} \leq M_{jk} \forall j \in Institutions, k \in Nutrients \quad (2)$$

$$\sum_{i=1}^{n} X_{ij} * NC_{ik} + \sum_{h=1}^{s} W_{hj} * NB_{ik} \geq m_{jk} \forall j \in Institutions, k \in Nutrients \quad (3)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} X_{ij} \leq A_i \forall i \in Food \quad (4)$$

$$\sum_{h=1}^{s} W_{hj} \geq a_j \forall j \in Institutions \quad (5)$$

$$\sum_{i=1}^{n} X_i + \sum_{h=1}^{s} W_{hj} \leq C_j \forall j \in Institutions \quad (6)$$

$$X_{ij} \geq 0 \forall i \in Food, j \in Institutions \quad (7)$$

$$W_{hj} \geq 0 \forall h \in Drinks, j \in Institutions \quad (8)$$

The objective function is shown in equation (1) and represents that the total amount distributed is maximized respecting the given prioritization. The constraints (2) and (3) indicate the limits within which the amount of nutrients distributed to each institution must be found. Constraint (4) limits the total amount of food that can be distributed from donations for each type of food. The constraint (5) indicates the minimum amount of water that must be transported to the institutions. The constraint (6) represents the maximum amount that can be transported to each institution due to the capacity of the vehicles. The constraints (7) and (8) show the range of existence of the variables X and W, respectively.

This linear programming model was translated into the AMPL language and was run in the full student version using version 12.6.3.0 of the CPLEX solver. It ran on a core i5 laptop with 8 GB of RAM. Next, the model is shown in the interface within the AMPL IDE optimizer software.

```
maximize Coverage:
        sum{i in Food, j in Institution} QFood[i,j]*Priority[i];
subject to CotaMax {j in Institution,k in Nutrients}:
```


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```
        sum{i in Food} QFood[i,j]*CompositionF[i,k] +
sum{h in Drinks} QDrinks[h,j]*CompositionD[h,k]
<= MaxNutrients[j,k];
subject to CotaMin {j in Institution,k in Nutrients}:
        sum{i in Food} QFood[i,j]*CompositionF[i,k] +
sum{h in Drinks} QDrinks[h,j]*CompositionD[h,k]
>= MinNutrients[j,k];
subject to Availability {i in Food}:
        sum{j in Institution} QFood[i,j] <= FoodAvailable[i];
subject to DistDrink {j in Institution}:
        sum{h in Drinks} QDrinks[h,j] >= DrinkReq [j];
subject to Reception {j in Institution}:
        sum{i in Food} QFood[i,j] +
sum{h in Drinks} QDrinks[h,j] <= Capacity[j];
```

After executing the linear programming model, it was possible to distribute each food and drink following optimizations criteria's previously defined. The following table shows how much was distributed for each type of food and drink:

It should be noted that these results respected the limits of nutrition limits per institution and operational in terms of transport capacity.

RESULTS DISCUSSION AND PRACTICAL IMPLICATIONS

After executing the linear programming model, it was possible to distribute each food and drink appropriately to 69 institutions, that is mean 45 institutions more. Beneficiaries' institutions receive all kinds

Table 5. Results after executing linear programming model

Kind	Quantity
Food 1	1,084
Food 2	1,071
Food 3	1,364
Food 4	833
Food 5	731
Food 6	1,151
Food 7	800
Food 8	1,387
Food 9	773
Food 10	855
Drink 1	12,198
Drink 2	14,345
Drink 3	13,846

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of food from different donors' institutions, but there is no control or efficient distribution of food. In addition, it should be considered that beneficiaries do not work in the same conditions, since they serve different types of people and some institutions serve more people than others.

Other issues to be resolve, at present, is the donations are assigned to beneficiaries associations without any type of allocation criteria and there is no prioritization among the institutions that are part of the network. Then, according to the topic described above, it is proposed to model the greatest amount of food that is given to an institution with a high priority index. This will allow the Food Bank of Peru to meet its objective of reducing food insecurity under the criteria of equity, efficiency and effectiveness.

FUTURE RESEARCH DIRECTIONS

In the case of Peru, we must consider the percentage of citizens who consider themselves in poverty, which is 21.7% of the population, which means that all people survive with less than 338 soles per month, a figure that responds to basic needs, but not to food. (INEI, 2017). In addition, it should be noted that in 2017 poverty increased to 44% of the population in rural areas (INEI, 2017) and it must be considered that these data will never be accurate due to the centralization of the country and other factors.

On the contrary, the GDP would continue to grow although slowing down. For the year 2017, a growth of 2.5% is verified. This indicator contradicts the levels of poverty in the country and is also a research opportunity, as well as the factors that can be added to the model in this document to obtain a more precise result when it comes to prioritizing areas and quantities to deliver donations, that will be reflected in a more efficient supply chain and more distributed aid throughout the country.

CONCLUSION

The proposal integrates the development of different aspects, including the issue of nutrition, which is affected in the most vulnerable population of society, which is part of the main objective of the work. We identified different organized entities that integrate the constant feeding service within the social support provided to 24 direct beneficiaries, who belong to the population of Lima in a situation of malnutrition. Each organization that benefits will receive a specific amount of a specific food and water, according to the number of children and the necessary nutrients.

Through linear programming, we can take advantage of the data obtained by the zones, as well as the statistical studies, to maximize the aid in a more efficient way to people who are in situations of poverty. It must be borne in mind that in order to have an adequate distribution it is not only necessary to have an accurate planning, or with the food to distribute, but also an infrastructure that allows such distribution. Without distribution warehouses, enough and adequate means of transport, and without adequate communication channels, optimal distribution of food is also not possible.

It should also be considered that if what is desired is to combat malnutrition in the country, the problem does not end when all areas of Peru have the capacity to provide caloric protein needs to their population, either because they are self-sufficient or because They have received from other places, but it is also necessary that these foods are distributed properly among the population and that there is a control of the effects produced in the improvement of the nutritional problem until the complete elimination of child malnutrition in Peru.

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KEY TERMS AND DEFINITIONS

Food Insecurity: Refers to the lack of access to sufficient good, healthy and culturally appropriate food. Food safety is when a person is able to obtain a sufficient amount of healthy food daily. People who do not consume enough food every day suffer from food insecurity.

GDP: Gross domestic product. It is the monetary value of all finished goods and services produced in a country, which is generally measured every year.

Malnutrition: This term addresses three major groups of conditions: malnutrition, which includes weight loss (low weight for height), stunting (low height for age) and low weight (low weight for age); Malnutrition related to micronutrients, which includes deficiencies of micronutrients (lack of important vitamins and minerals) or excess of micronutrients; and overweight, obesity and non-communicable diseases related to diet (such as heart disease, stroke, diabetes and some types of cancer).

Poverty: Occurs when people cannot meet the basic physical and mental needs of a decent life, due to lack of resources (such as food).

Reverse Logistics: Means, for all operations, reuse, or products and materials.

Social Group: Any group of human beings who are, have been recently or anticipate being in some kind of interrelation or having certain things in common.

Utility: In the context of this document, it is worthwhile for some purposes, the goods provided by a certain process.

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Chapter 11
Characterization of the Key Actors Involved in Humanitarian Supply Chains at the Local Level From a Theoretical and Academic Perspective

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ABSTRACT

The incremental trends in the amount of human and material losses, added to a higher frequency of natural disasters, have generated greater interest from different sectors regarding the processes of disaster management. In this sense, it is recognized that the context of disasters is strongly marked by the high diversity and quantity of actors which seek common or conflicting objectives. The aim of this chapter is to present the actors involved in the humanitarian supply chains (HSC) and to highlight the importance of key local actors involved in disaster preparedness and response, the latter from an inter-sectoral perspective towards the importance implied by the coordination of the key actors in terms of the humanitarian purposes. The discussion developed allows for the inference about the critical role of local actors in disaster management and HSC, as well as several topics for the theoretical development of humanitarian logistics, such as the application of decision tools and information technologies, and the use of sustainability approach for disaster management.

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INTRODUCTION

Disasters are considered a serious disruption of a community of society and causes a strong impact on people, structures, and the environment, which exceeds the ability of local resources to cope with it (UNISDR, 2004; Hadiguna, et al., 2014). With this in mind, the global increase in the number of natural disasters highlights the need for better planning and operational management of the responsible agencies, as well as greater interest from the academic sector (Afshar and Haghani, 2012; Ransikarbum and Mason, 2014).

Logistics management of disaster relief operations, also called humanitarian logistics (Baldini, et al., 2012), encompasses the estimation, provision, storage, transportation, distribution and coordination of people, goods (such as food, drinking water, medicine and shelters), equipment and services in order to assist the population affected by a disaster (Mohan, et al., 2013; Day, 2014; Sharif and Salari, 2015). The main objective of humanitarian logistics is to provide emergency supplies quickly to reduce deaths and human suffering (Balcik and Beamon, 2008; Hasanzadeh and Bashiri, 2016).

Humanitarian logistics is framed within disaster operations management, which is comprised of four stages: mitigation, preparedness, response and recovery (Altay and Green, 2006; Van Wassenhove, 2006). Within these stages, it must be remembered that diverse resources and capacities are required for the pre- and post-disaster stages, given that different types of disasters need to be managed in different ways (Cozzolino, 2012; Owusu-Kwateng, et al., 2017; Rodríguez-Espíndola, et al., 2018).

Additionally, the complexity in humanitarian logistics is strongly marked by the high diversity and quantity of actors that are involved in preparedness and response processes, since each have different objectives, cultures, interests, capacities and logistical experience (Balcik, et al., 2010; Kumar and Havey, 2013; Yadav and Barve, 2015; Regis-Hernández, et al., 2017). According to Cozzolino (2012), key actors can be categorized as: governments, military, aid agencies, donors, non-governmental organizations (NGOs), and private sector companies.

However, inter-organizational coordination in humanitarian logistics remains as a research topic to be developed (Cozzolino, 2012; Anaya-Arenas, et al., 2014). In this regard, Remida (2015) recognizes the importance of new research that takes into account the complexity of humanitarian logistics from a systemic approach, which would allow for the consideration of all aspects and elements involved in disaster management.

Based on the aforementioned elements, the aim of this chapter is to briefly present the key actors engaged in the humanitarian supply chain (HSC) –considering their main functions within a complex and dynamic system–, as well as highlight the importance of the local actors involved in the different disaster management stages. For this, we will be applying the main theoretical and investigative contributions provided by the study of humanitarian logistics throughout our discussion in this chapter.

The remainder of this document is organized in the following way: in the next section, the complexity of disaster management is described; this complexity must be considered when developing a systematic approach required to lead humanitarian efforts. Later, main aspects that characterize the key actors in the HSC are shown, as well as the critical role that local actors play in a disaster scenario and in the zones that characterize higher levels of disaster risk. Complementing the conditions that affect participation of local actors, an analysis of local level participation and presence will be done. Finally, some research trends related to humanitarian logistics, future research proposals, and conclusive comments on the topics discussed will be presented at the end of this chapter.

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HUMANITARIAN LOGISTICS UNDER THE HUMANITARIAN SUPPLY CHAINS MANAGEMENT APPROACH

Firstly, it is necessary to comment on some aspects related to the disaster context. Disaster relief operations can take place anywhere, any day, and affect any number of people (Tomasini and Van Wassenhove, 2009). According to Holguín-Veras, et al. (2012a), the conditions inherent in disaster relief are: infrastructure and communication systems that are seriously affected, reduced communication capacity, and information that is unreliable, incomplete, or non-existent. During the preparedness stage, the development of response plans are marked by a high level of uncertainty, as there is no indication of when a disaster will strike, how many people will be affected, what infrastructure will be left intact, or what other obstacles may arise (Heaslip, et al., 2012; Paul and MacDonald, 2016).

In addition, humanitarian relief operations are also complex considering the interactions among the different sectors involved in these contexts, without considering the unforeseeable and temporary external actors that arise during the response processes. (Charles and Lauras 2011; Owusu-Kwateng, et al., 2017). Stakeholders in the humanitarian sector refer to actors involved in the relief operations, such as local government, donors, aid agencies, humanitarian relief organizations, logistic providers, the military sector, media, and local people (Kabra, et al., 2015), which can all have different perspectives towards the execution of preparedness and response processes (Kovács and Spens, 2007). Given this diversity and proliferation of actors, Nadi and Edrisi (2017) consider that the challenges in humanitarian relief are based on the fact that the roles in this process are considerably less clear than those laid out for traditional commercial logistics, which can lead to duplication of effort and waste of resources during humanitarian aid. Therefore, within emergency relief operations and humanitarian logistics it is necessary to promote knowledge about the specific roles that the different actors involved must execute during the disaster relief (Jensen and Hertz, 2016).

Considering the inherent characteristics of disasters mentioned above, the high diversity of actors involved, as well as the fact that logistics operations represent close to 80% of the humanitarian effort (Van Wassenhove, 2006), disaster operations management requires an integrated approach to supply chain management in order to effectively coordinate the processes and actors, and maximize the humanitarian performance (Tomasini and Van Wassenhove, 2009). For example, implementation of a systemic approach would allow integration of different aspects of complexity in the humanitarian environment, such as economic, social and technological conditions, as well as the individual and collective behavior of the actors involved, together with their available resources and capacities (Remida, 2015). Additionally, a holistic approach must be based on an overall system in which all actors are included improving the decision-making processes and resource management, both in the pre-disaster and post-disaster stages (UNISDR, 2004; Kaneberg, 2017).

Incorporating this information, the HSC can be defined as the system responsible for designing, deploying and managing the processes necessary to deal with disasters, through the coordination of the different parties involved (Day, et al., 2012). As in commercial supply chains, HSCs must manage information flows between the parties involved, monetary and financial flows, as well as material flows, which include a variety of products including medical, electronic, and relief supplies (Van der Laan, et al., 2009; Day, et al., 2012). Gavidia (2017) argues that the exchange of materials and information in the HSC should be carried out in a coordinated manner, in order to improve the use of limited resources through a systemic vision, as well as to promote the efficiency, speed and reliability of the critical disaster care processes.

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Given that the objective of humanitarian logistics and disaster management is to provide effective relief in order to reduce deaths and human suffering (Balcik and Beamon, 2008; Hasanzadeh and Bashiri, 2016), the performance of the sectors involved is fundamental for the fulfillment of these purposes. Thus, it is necessary to know what the essential characteristics of these actors are. The following section is devoted to describing the different sectors that are generally involved in the HSC, according to the classification proposed by Kovács and Spens (2007) and Cozzolino (2012): government, military, aid agencies, private sector, NGOs, and donors.

KEY ACTORS INVOLVED IN THE HUMANITARIAN SUPPLY CHAINS

As described above, during emergency operations, there are multiple stakeholders involved, each of which need to play different and specific roles with different needs and capacities (Jahre and Jensen, 2010; Sahay, et al., 2016; Lu, et al., 2018). Likewise, the growth of the humanitarian sector in recent times, in both the number of organizations and the amount of resources managed, intensifies the need to improve the performance coordination capacities among the different sectors (Van der Laan, et al., 2009; Rodríguez, et al., 2010; Besiou, et al., 2014). The purpose of this section is to describe the main characteristics of the actors involved in disaster preparedness and response processes.

Local Government

Taking into account that it is difficult to identify any central authority in many disaster management instances (John and Ramesh, 2016), the responsibility and key role of the local government in disaster management processes has been widely recognized in the literature (Balcik, et al., 2010; Cozzolino, 2012; Kabra, et al., 2015; Mora-Ochomongo, et al., 2016; Baskaya, et al., 2017). Local governments have the responsibility to establish protocols that reduce the probability of disasters (Dubey and Gunasekaran, 2015). With this in mind, a successful response depends heavily on local capabilities, because governments in charge have the control over political and economic conditions and directly affect supply chain processes with their decisions (Van Wassenhove, 2006; Das, 2016).

According to Kabra and Ramesh (2015) and Sahay, et al. (2016), local government plays the role of manager and central authority in both preparedness and relief operations; in other words, all organizations involved are obliged to abide by the laws of the country in which they are operating (Balcik, et al., 2010; Heaslip, et al., 2012; Sahebi, et al., 2017). In fact, local government has the authority to allow and control the entry of the actors who have the intention of contributing to the humanitarian cause, as well as allowing or restricting the entry of products, supplies and suppliers to the area affected by a disaster (Van Wassenhove, 2006; Balcik, et al., 2010; Cozzolino, 2012; Day, et al., 2012; Das, 2016). It is important to take this into account, as local government decisions can influence the action plans of other actors, as well as affect the supply chain processes (Das, 2016; Mora-Ochomongo, et al., 2016). Kunz and Gold (2015) state that this decision power should be acknowledged especially when a disaster-affected zone is confronted with a convergence of self-initiated organizations and unsolicited donations which disturb humanitarian supply chains by creating unnecessary bottlenecks.

However, when local governments give actors the permission required to operate in a specific zone, there is an opportunity to mandate adherence to certain procedures (Tatham, et al., 2017). In addition, the government can initiate coordination efforts with various humanitarian organizations, as it has hap-

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pened in real-world disasters (Yadav and Barve, 2015; Marcelin, et al., 2016). When a government has a cooperative behavior, it is easier for relief organizations to establish a supply chain that accommodates the requirements of the vulnerable population (Kunz and Gold, 2015). Moreover, it is important to remember that during preparedness and disaster response, local government, the community, and donors all need to get involved in the efforts for improving coordination towards the effectiveness of disaster management (Sahay, et al., 2016).

Regarding humanitarian resources, Tzeng, et al. (2007) and Ganguly and Rai (2016), consider the authority of the government to expropriate vehicles and buildings in order to increase overall capacity and help with the distribution of supplies during the period of relief. Ganguly and Rai (2016) and Abidi, et al. (2015), argue that governments and local administrations are responsible not only for taking field decisions and actions, but also for providing guidelines, basic support, facilities, and resources to improve the logistics processes in disaster relief operations. Therefore, humanitarian organizations can choose to carry out their disaster relief processes using facilities and resources offered by the government (Acimovic and Goentzel, 2016). On the other hand, governments play a fundamental role in the utilization of information and communications technologies (ICTs) in the humanitarian supply chain, as they should facilitate all the required resources to enhance its implementation (Kabra and Ramesh, 2015).

Governments are the authority responsible for the management of disaster relief and they should show their willingness to develop policies and regulatory initiatives. However, this is often not enough given critical problems including financial resources, information sharing and use of technology, and attitude of the humanitarian organizations (Kabra, et al., 2015). Additionally, governments frequently have different priorities, which may or may not give priority to disaster preparedness and can increase the vulnerability of their territories (Ganguly and Rai, 2016).

In this regard, local governments should organize a wide range of knowledge transfer activities such as regional training workshop programs, seminars, conferences, and expert group meetings (Kabra, et al., 2015). If local governments are faced with financial difficulties, Kunz, et al. (2014) propose that investments should focus on intangible preparedness activities, which include human resources, knowledge management, process management, resource management and work with the community. Sahay, et al. (2016), highlight that governments are using scientific tools such as Decision Support Systems and Geographical Information Systems, for improving preparedness and emergency response. Vitoriano, et al. (2015), offer an additional alternative for investments related to insurance policies that includes specific clauses for disaster management, given that some governments have devoted a specific part of the national budget for those affected by disasters.

Within the main functions of local government, the literature has highlighted the following responsibilities:

- Develop protocols and take action to reduce the probability of disasters
- Strengthen disaster preparedness
- Provide guidelines, laws, facilities, and humanitarian resources
- Implement knowledge transfer activities
- Initiate partnerships with local networks
- Streamline the coordination of actors involved
- Provide location and setting-up of distribution points and warehouses
- Serve as activator of humanitarian logistics actions
- Alleviate the suffering of its communities

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- Request international help
- Authorize operations and mobilize resources
- Authorize and control all entry and exit of goods and foreign organizations
- Conduct and coordinate the entire relief operation
- Take ground-level decisions and actions

While governments are reporting significant progress in investing and developing more effective disaster response and preparedness strategies, the required shift to anticipate risks in public and private investment remains a challenge for most countries (Sahay, et al., 2016).

Military

Use of military forces in support of humanitarian operations is a long-established practice, since there is often a high public expectation that the military will be involved in the immediate aftermath of disasters (Sebbah, et al., 2013). In many disaster relief operations, the capacity of national civilian organizations has proved to be insufficient to meet the needs of those affected. For this reason, governments often turn to the military for help as the military have certain resources immediately on hand (food, medicine and fuel), as well as logistical resources such as transportation modes, communications capabilities and human assets (Heaslip, et al., 2012; Tatham and Rietjens, 2016).

Militaries play an important role in disaster response because they bring much-needed expertise in agile supply chain coordination through the rapid flow of large amounts of supplies and personnel (Balcik, et al., 2010). The participation of the military sector is recognized as a very significant factor thanks to their sophisticated planning and logistical capabilities including transport (land, air, and sea), communications, tools and equipment, and security (Cozzolino, 2012; Sebbah, et al., 2013; Dubey and Gunasekaran, 2015; Remida, 2015). In this regard, Acimovic and Goentzel (2016) point out that the military can quickly mobilize an "air bridge" to take advantage of well positioned stockpiles.

The main humanitarian functions of military and police that are proposed in the literature are presented below:

- Provide primary assistance
- Search and rescue of victims
- Medical assistance, delivery of water and sanitation
- Provide logistics skills: military assets, knowledge and manpower, and transport
- Protection of refugees and displaced people
- Provision of security for humanitarian assistance
- Provide information on infrastructure and security
- Support to the flow of large amounts of supplies and personnel
- Hospital and emergency shelter installation
- Restoration of civil infrastructures and route repair
- Road/airfield construction
- Telecommunications services: radio and satellite communication

According to Sebbah, et al. (2013), military support in humanitarian relief operations depends on several factors including the type, scale, and location of the disaster, impact on mechanisms and infra-

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structure, and the needs of disaster victims. Additionally, the participation of the military may create occasional tension due to the significant differences between the humanitarian community and the military sector, but, there are also success stories about how they cooperate in humanitarian logistics (Balcik, et al., 2010). It is important, therefore, that military involvement is driven by principals of humanity, neutrality, impartiality and respect, because any military–civil coordination must first serve the principals of humanity (Sebbah, et al., 2013). Also, Kaneberg (2017) argues that military actors are often absent from disaster preparedness, therefore, their integration must begin in early planning stages in order to overcome difficulties with inter-agency understanding that may arise during implementation.

Aid Agencies

Humanitarian organizations have the responsibility to respond quickly to crisis situations, and provide medical aid, shelter, food, and water to victims (Charles, et al., 2016). These organizations "push" available supplies into the disaster area in order to transport relief goods on time (Day, et al., 2012; Baskaya, et al., 2017).

Aid agencies typically include key military branches, other national and regional organizations responsible for rescue efforts, and various agencies involved in planning for emergencies that affect transportation infrastructure, environment, and energy infrastructure (Connelly, et al., 2016). Within the humanitarian sector, aid agencies are legally independent entities with sometimes widely different mandates (Herlin and Pazirandeh, 2015). Moreover, the location and regional presence of a humanitarian organization determines its role in disaster relief (Kovács and Spens, 2009). The presence of a large number of organizations can cause a problem in coordination of services, as well. This problem is often exacerbated by the fact that the field workers for such organizations are frequently individuals who have come together to support the disaster relief and who may never have met or even worked for a humanitarian organization before (Tatham and Spens, 2011).

Aid agencies need connections to feasible donors, suppliers, NGOs, and other partners, but their operations are not activated until the catastrophic event takes place (Cozzolino, 2012), given that they depend on the declaration of a state of emergency (Kovács and Spens, 2009). In fact, most relief organizations cannot initiate a disaster response before donor funding becomes available (Balcik, et al., 2010).

Taking into account the diversity of humanitarian agencies in disaster management, some of the main functions that, in general, these agencies must fulfill are the following:

- Procurement and storage of relief supplies
- Search and rescue efforts
- Provision of medical aid and shelter to victims
- Transport and distribution of supplies to the disaster zone

According to Van Wassenhove (2006), humanitarian organizations have to work not only during disasters but also between disasters. However, lack of funding, particularly for the preparedness stage, hinders the planning and running of relief operations (Jahre, et al., 2015). In addition, resource levels for aid agencies also change over time, such as with staff turnover and a lack of sustainable funding to guarantee operations in the future (Muggy and Stamm, 2017). Likewise, efficiency should not be disregarded, since humanitarian organizations also need to demonstrate efficient operations from the beneficiary side, especially when a rapid-onset disaster occurs (Haavisto and Goentzel, 2015).

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Holguín-Veras, et al. (2013), argue that relief agencies incur the logistical costs associated with the purchase, transportation, inventory, and distribution of relief supplies. The presence of in-kind donations implies that products have to be stored, handled, transported and distributed to the beneficiaries (Charles and Lauras, 2011). Contrary to large organizations, which might have funding leeway, smaller and local organizations have strict budget constraints and therefore must define other priorities (Charles, et al., 2016). Based on the dependence on donations for survival, humanitarian organizations should focus on performance and increase coordination efforts (Eftekhar, et al., 2017).

Given the basic desire of all those responding to a disaster to support those affected, it is expected that there would be a high level of inter-agency coordination; however, generally this is not the case (Tatham, et al., 2017). The sheer number of agencies responding to disasters may overwhelm even the most well-intentioned participants (Tatham and Rietjens, 2016). According to Moshtari (2016) when humanitarian organizations have similar missions, provide similar services in similar geographical regions, or have access to similar donors, the level of competition among them increases and they begin to keep some resources for themselves, or even take actions that would negatively affect the other partner. For instance, results of Maghsoudi and Pazirandeh (2016) suggest that humanitarian organizations were not willing to share their information with the involved logistics providers during a disaster response, as they were interested in other shared resources such as warehouse space.

Additionally, the acquisition and delivery of adequate relief supplies is typically time-consuming and expensive; therefore, the pre-positioning of critical relief supplies in strategic locations is a strategy recently implemented by some humanitarian organizations to improve their capacities in delivering sufficient relief aid within a relatively short timeframe (Balcik and Beamon, 2008). Yadav and Barve (2015), argue that the local presence, complemented with education and the pre-positioning of relief items, is crucial for institutional capacity building. Because of this, and as part of their preparation for potential disasters, aid agencies often conduct a logistics capacity assessment; however, such evaluations frequently are prepared independently and the results may not be shared with other actors (Tatham, et al, 2017).

Agencies specialized in recovery operations may not coincide with the ones in charge of distribution of goods (Liberatore, et al., 2014). Additionally, humanitarian organizations often face lack of government support and basic infrastructure, and the funding constraints clearly reduce organizational flexibility in allocating their limited resources before the emergency (Ni, et al., 2015). However, these issues can be seen as an opportunity for a division of functions and more collaboration among organizations (Van Wassenhove, 2006).

Lead agencies are responsible for strengthening technical capacity and ensuring predictable leadership, accountability, and partnership in the humanitarian supply chain (Altay and Pal, 2014). Thus, aid agencies should prioritize their investments with consideration of both uncertainties and multiple conflicting criteria, such as health, safety, cost, and environment (Connelly, et al., 2016).

Outsourcing processes in the humanitarian context occur. For example, agencies do not typically own and operate vehicle fleets in a disaster-affected region; rather they often rent local vehicles and drivers (Balcik, et al., 2010). Thereby, the presence of the private-sector is increasingly growing in the humanitarian relief environment (Cozzolino, 2012). In this regard, quick establishment of trust is important in the pursuit of goals and specific outcomes related to the improvement of the overall supply chain performance (Pettit and Beresford, 2009).

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NGOs

Within the humanitarian setting, the general purpose of a non-governmental organization (NGO) is to assist the affected people by sharing resources and competencies (Akhtar, et al., 2012). After a disaster hits a region, a considerable number of NGOs become involved in humanitarian operations (Moshtari, 2016), since NGOs only can arrive in a country to deliver aid once donor funding becomes available (Balcik, et al., 2010). According to Balcik and Beamon (2008), a NGO's level of involvement in a disaster relief operation, in terms of the type and scope of logistical operations, may vary depending on factors such as type, location, and impact of the disaster and resource availability. In this regard, NGOs are normally specialized in one or more basic components of the relief task such as health care, shelter, or water and sanitation (Rodríguez, et al., 2012).

According to Dubey and Gunasekaran (2015), non-governmental organizations include a range of actors from influential international NGOs to small and micro-organizations based within local communities. International NGOs are highly organized, efficient, and well-staffed with experienced manpower whereas domestic NGOs tend to vary in their structures and ways of working (Ganguly and Rai, 2016). Additionally, domestic NGOs are not permanent organizations but are created to cover one particular crisis (Dubey and Gunasekaran, 2015). Nevertheless, local NGOs are more familiar with the current conditions and are able to reach disaster-affected areas faster before any external support arrives (Krejci, 2015; Ganguly and Rai, 2016). Thus, there is a need for relief NGOs to differentiate themselves, just as commercial companies do (Oloruntoba and Gray, 2009).

Unlike other actors, non-governmental organizations are not tied to the government bureaucracy (Octavia, et al., 2016). Therefore, due to their political neutrality, some NGOs can have access to politically instable countries which otherwise would not allow any exterior interference (Rodríguez, et al., 2010). In addition, funding sources to NGOs are donations from individuals, corporations and governments, so donors, as well as recipients of services, staff and volunteers are all stakeholders for a NGO (Beamon and Balcik, 2008).

As soon as the NGO receives notice of a disaster event, it starts a decision-making process which is intended to reach a conclusion about whether or not suitable conditions exist to initiate a relief operation. Usually, this decision must be based on the NGO's own internal information, such as funding, stockpiled resources, available personnel, as well as on knowledge and information available about the disaster case under review (Rodríguez, et al., 2012). Furthermore, during sudden-onset disasters, interactions and coordination activities with local NGOs generally emerge in the post-disaster phase (Balcik, et al., 2010).

Based on contributions in the literature, the main functions of NGOs in humanitarian processes are the following:

- Assist the affected people
- Provide services to minimize immediate risks to human health and survival
- Share resources and competencies
- Cooperate with local partners
- Establish permanent and reliable transportation, healthcare, housing, and food
- Offer help into transporting relief goods
- Relief distribution and delivering of food, water, and medical supplies
- Set up temporary facilities in the disaster area

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Given the diversity and nature of the NGO community, information is managed in a unique fashion in that, in most cases, each organization has developed as a result of custom and tradition (Tatham and Spens, 2011). According to Moshtari (2016), mutual trust and reciprocal commitment are the key drivers of collaborative performance between humanitarian NGOs, so they should share valuable resources or invest in developing strong human resources and relationship management skills. In this regard, governmental and non-governmental organizations can choose to stockpile disaster relief supplies, using locations offered by the government or other organizations (Acimovic and Goentzel, 2016). Charles, et al. (2016) state that the location of one central warehouse determined through agreements between governments and NGOs in order to decrease fixed costs is the most efficient option for small crises.

NGOs are becoming increasingly aware of the importance of performance measures, due to increasing sector competition for scarce resources and high demands from donors and the public to improve visibility and accountability (Beamon and Balcik, 2008). In addition, the reliability of the supplies delivered by NGOs is heavily influenced by the continuity of donations (Gutjahr and Nolz, 2016). According to Tatham and Spens (2011), the desired capability of an NGO to support those affected should consider the estimated effects of a future disaster; the capabilities of governments and fellow NGOs; and the implications of the physical environment. Inherent unique characteristics of disaster environments make performance measurement even more challenging for NGOs (Beamon and Balcik, 2008). Therefore, efficient humanitarian supply chain management has implications for NGO business continuity, since effective and coordinated relief operations are not only carried out to satisfy demand needs, but also to attract future fundraising and the continuity of the NGOs involved (Oloruntoba and Gray, 2009).

Logistics Providers

When a local government faces problems such as limited equipment, which is needed in transportation of goods and in rescue operations, and/or insufficient funds for the purchase of equipment or for the investment of infrastructure, it is possible to access the help of private logistic companies that could support the government in its operations to serve people and save lives (Bharandev, et al., 2016).

According to Vega and Roussat (2015), Logistics Service Providers (LSPs) have become important players in the humanitarian field, providing support for NGOs and governments when they respond to major disasters. For these authors, considering that LSPs are specialized firms that manage, control and deliver logistics activities, it should be logical that they are involved in the humanitarian logistics context.

Taking into account that the application of traditional SCM practices in humanitarian relief chains has been an area of research, the following logistical functions that are performed by LSPs have been proposed in the literature:

- Offer a set of emergency supplies for potential demand
- Collaborative procurement
- Warehousing of prepositioned stocks (receiving, storage, inventory control)
- Provide financial contributions or in-kind donations
- Picking and packing of supplies, supply labeling and order fulfillment
- Offer the service of transporting items from the supplier's depots to the demand points
- Share transportation resources

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- Providing logistic support and knowledge for NGOs and governments
- Share resources, assets, information and knowledge with their humanitarian counterparts
- Promote logistics integration for the members of the supply chain

It is necessary to acknowledge that the quantity of relief supplies and services to be dispatched by a provider should be known once the disaster has occurred; therefore, the relief provider needs to be prepared with security stocks (Chakravarty, 2014). In this sense, it is vital to develop long-term relationships with suppliers during strategic planning for situations that are likely to occur (Pettit and Beresford, 2009). Moreover, planning for post-disaster procurement includes identifying candidate suppliers that can provide relief items with the desired specifications (Balcik, et al., 2010).

There are several types of providers and relationships. Garrido, et al. (2015), define product suppliers and transportation providers. Cozzolino (2012) argues that LSPs could serve the humanitarian sector according to their integration level, as donors, collectors, or providers. Balcik, et al. (2010) distinguish between commercial relationships that involve monetary transactions, and philanthropic relationships that occur when private sector companies support or collaborate with humanitarian organizations in ways that do not include profit making.

Based on Schulz and Blecken (2010), the service provider is responsible for performing tasks in different areas (such as procurement, warehousing and transportation management), but finding a reliable service provider is strongly related to the level of trust between private and humanitarian sectors. Mistrust can occur because suppliers have their own motivations for participating in the humanitarian context: companies may be interested in building relationships with governments to identify new markets or they may be interested in re-establishing business continuity after the disaster occurrence; for some, humanitarian aid is another opportunity for new markets, and others see it as part of their corporate social responsibility (Cozzolino, 2012; Heaslip, et al., 2012).

LSPs have demonstrated important contributions and synergies at each stage of a disaster-relief operation through their logistics and supply chain management core capabilities, and they have established internal programs as an expression of a systematic approach to disaster response through the creation of teams that cooperate voluntarily and assume logistical responsibilities (Cozzolino, 2012; Dubey and Gunasekaran, 2015; Cozzolino, et al., 2017).

There are several factors that influence the decision to integrate a supplier into a humanitarian supply chain. Among these factors we highlight the following: the nature of the supply process, the availability of alternative suppliers, the quality and availability of suppliers, the quality and timeliness of customs clearance processes, supplier responsiveness, supply lead times, and proximity to local suppliers (Vaillancourt and Haavisto, 2016; Richardson, et al., 2016).

The existence of a strong local supplier base with enough capacity to deliver the necessary goods is a contingency factor that determines if local sourcing is a feasible option. In addition, local providers can provide the advantage that they have expert knowledge of their territories (Kunz and Gold, 2015; Vega and Roussat, 2015). Nevertheless, if local suppliers are overwhelmed by the disaster, their role becomes minimal. In this case, local supplies available are supplemented with supplies sent from abroad, if needed, and humanitarian organizations can use pre-purchased goods from other warehouses or providers (Mora-Ochomongo, et al., 2016; Vaillancourt, 2016). In Akhtar, et al. (2012) it is shown how the cost of supplies was increased due to few suppliers available during a disaster response.

Among the benefits of supplier management in humanitarian logistics are:

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1. Long-term contracts with suppliers that are designed to ensure the supplier will have certain quantities of certain items available when needed by the relief organization; this enables relief organizations to control emergency supply costs (Beamon and Balcik, 2008).
2. Capability for managing dynamic connections in the relief provider network can have an impact on resilience (Day, 2014).
3. Exercises, training, and planning sessions develop the relationships between relief providers to enhance the efficiency and responsiveness of relief efforts (Day, 2014).
4. Suppliers with sufficient capacity may benefit from increased order volumes, better visibility and capacity improved for planning and communication with buyers (Herlin and Pazirandeh, 2015).
5. Agile capabilities of supply chain networks due to adaptable capabilities like collaboration with 3PL, 4PL and other partners to reduce lead time and improve delivery of goods/services (Dubey and Gunasekaran, 2015).

Cozzolino, et al. (2017), argue that the relevant role of LSPs in humanitarian relief efforts has been widely recognized in the literature and by humanitarian organizations. In this regard, the presence of private-sector companies is expanding in the humanitarian relief environment and, based on the globally operating logistics industry, this trend is likely to grow (Dubey and Gunasekaran, 2015; Cozzolino, et al., 2017).

Donors

Donors are important actors in the humanitarian setting, as they provide the bulk of funding for organizations that carry out the disaster relief effort (Kovács and Spens, 2007; Cozzolino, 2012; Dubey and Gunasekaran, 2015). Generally, the funds provided by local governments are not sufficient to handle the severity of disasters, so donations are of high interest (Bharandev, et al., 2016). Typically, donations can be made through two main methods of funding: individual donations, and institutional donations that include governments and private companies, with the aim to finance humanitarian supply chains (Charles and Lauras, 2011).

Donors are significant actors in the humanitarian supply chains because they have a critical role to play in increasing the capabilities of humanitarian organizations (Das, 2016; Moshtari, 2016). The objective of donors is to relieve human suffering and save lives, and not to make a profit (Oloruntoba and Gray, 2009). In addition, donors have become particularly influential in prompting humanitarian actors to think about greater accountability and transparency throughout the supply chain (Das, 2016).

Donors (whether individuals or organizations) fulfill the following functions in the HSC:

- Provide the bulk of funding required for relief activities
- Provide in-kind donations and/or services
- Encourage humanitarian organizations to engage in collaborative initiatives
- Demand accountability, transparency, and efficiency of the whole supply chain

According to Thomas and Kopczak (2005) and Charles, et al. (2016), donors are demanding greater accountability and becoming less tolerant of inefficiencies in relief services and to the old "fire-fighting

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mentality" that characterizes many relief operations. Donors want their funding to be well utilized by organizations and have the most impact on the system (Acimovic and Goentzel, 2016; Anjomshoae, et al., 2017). Hence, if an organization inefficiently utilizes available resources, donors may discontinue funding; however on the contrary, effectiveness in the relief processes increase the organization's impact, and thus, could attract potential donors, which allows organizations to secure more funds (Maghsoudi and Pazirandeh, 2016; Vaillancourt, 2016).

Eftekhar, et al. (2017), argue that if a humanitarian organization applies for governmental funding, it needs to demonstrate success in previous projects; therefore, institutional donations are influenced by organizational performance. In this sense, Krejci (2015) states that the intention of a donor is often based on logistical performance of the NGOs in the most recent previous disaster, with the donor deciding what percentage of their donations to be allocated to each NGO on this information. Regarding individual donations, people typically do not keep track of operational performance; rather, they make the decision based on perceived organizational capabilities by visibility in public media (Eftekhar, et al., 2017).

Mora-Ochomongo, et al. (2016) state that the available supply for a disaster response can be very variable depending on the multiple-suppliers and donors. Another issue is what donors can or want to provide for the affected people does not always match with the needs at the affected site. Humanitarian organizations receive financial resources (in-cash donations) as well as goods and/or services for free (in-kind donations) (Cozzolino, 2012; Dubey and Gunasekaran, 2015). According to Day, et al. (2012), supply chain managers prefer to receive money but they recognized that donors often feel that giving goods constitutes a more concrete action. That condition could generate the receipt of resources that are not needed, and this may create bottlenecks (Day, 2014). Therefore, some organizations only accept the required items despite there might be disagreements with donors (Mora-Ochomongo, et al., 2016).

In relation to monetary donations, Bharandev, et al. (2016) highlight modes of donating through online banking or going directly to any government body or NGO, but reminds us that an opportunity to receive donor funds will be lost if any interested person does not have access to these donation modes. Furthermore, funding conditionality is an additional barrier to link disaster response, recovery and development of communities, as some donors tie funding to a specific phase of a disaster (Kunz and Gold, 2015). In this regard, relief organizations often neglect the pre-disaster stage, because donors insist that their money be spent directly on helping victims. It is recommended that donors should finance more preparedness processes especially in countries prone to disasters (Kunz, et al., 2014).

Additionally, donors are demanding that in addition to efficiency, operations be carried out with transparency (Haavisto and Goentzel, 2015; Vitoriano, et al., 2015). In this sense, the donor can be seen as the customer, applying the concept of customer as payer who provides funding for the organizations to procure staff and relief goods, as well as supports transport processes; in other words, humanitarian actors focus on the donor as a source of income for the supply chain (Oloruntoba and Gray, 2009). Makepeace, et al. (2017), propose this approach as a valid way in order to successfully reconcile the donor and beneficiary as simultaneous customers in HSCs. Humanitarian organizations that provide feedback to donors, in terms of statistics, pictures, and testimonials, have a higher and more constant flow of funding (Anjomshoae, et al., 2017). In addition, application of ICTs can offer more transparency and accountability to donors as well as other actors, increasing trust and coordination among humanitarian organizations (Kabra, et al., 2015).

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Local Communities

In the previous paragraphs, the key actors involved in the humanitarian logistics chain have been described. However, we consider it relevant to make some comments regarding another essential actor in the disaster management: the local community.

Ganguly and Rai (2016) argue that the local community has not been considered as a major subject of study in the humanitarian logistics literature, although communities can play an important role in the HSC in ground-level relief efforts. According to Fernando and Muthulingam (2015) and Osorio-Ramírez (2016), the involvement of the local community in processes of planning, preparedness, and response, is a key factor improving the capacity of the logistics system and effective attention to victims. In this sense, the lack of institutional and technical capacity of local governments to operationalize and inform emergency plans to their communities, hinder the success of the humanitarian action. Further, the people of a community have shown greater willingness to collaborate with the local government in processes, such as relocation to safe areas, when the local administration demonstrates sufficient institutional capacity and equity in the distribution of humanitarian aid; hence establishing trust of the community is one of the most challenging jobs for the government (Joshi and Nishimura, 2016).

The role of local people and communities must not be ignored in disaster preparedness and response (Owusu-Kwateng, et al., 2017). In this regard, some of the functions of the local community, described in the literature, are the following:

- Being the first line of respondents
- Showing interest in helping and saving as many lives as they can
- Sharing vital supplies such as water and food with disaster victims
- Often give the first information to the authorities about a disaster and its severity
- Can train to coordinate the first response by themselves
- Can participate in planning, implementation, and evaluation, since they have the capacity to identify bad practices in the delivery of aid

Banomyong and Julagasigorn (2017) show that the role of community leaders is key in the pre- and post-disaster phases as community leaders help with the integration of all sectors involved in the humanitarian processes. In fact, individuals and communities are often the greatest contributors to the reduction of deaths and livelihood losses (UNISDR, 2004). Given that the community is more familiar with the local reality, there is a need to develop local capacities to improve disaster preparedness and strengthen emergency response capacities (Sahay, et al., 2016). In this sense, although the training of local civilians would be extremely technical or intensive, it will be extremely useful in improving local preparedness as well as collaboration with the local government (Idris and Soh, 2014).

As mentioned, working together with local communities is a mechanism to reduce the impact of disasters. It also substantially reduces risk factors, given the fact that the involvement of local people should strengthen the capabilities of the first response (Tomasini and Van Wassenhove, 2009; Sahay, et al., 2016). Therefore, the role of the community in the processes of preparedness and response is gaining more interest in the practical and academic sectors, which are recognizing that the participation of the local population must be considered throughout the entire process (Heaslip, et al., 2012; Sheppard, et al., 2013; Makepeace, et al., 2017).

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Taking into account the aforementioned actors involved in the HSC, we have synthesized the theoretical findings that have been described in this section. To do this, we have based on the main characteristics and functions in which the different sectors participate at the local level in the humanitarian context. The characterization has been organized in Table 1.

Table 1. Characterization of local actors involved in humanitarian supply chains

Actor (Role)	Characteristics	Scope of Intervention	Main Functions
Local Governments (Central authority)	Local government are the main responsible of the humanitarian actions. Their main objective is to alleviate the suffering of its communities They must coordinate actors and processes, through the mitigation projects, emergency plans, and the provision of facilities and resources	Mainly pre- and post-disaster stages	Develop protocols to reduce disaster risk Initiate partnerships with local networks Provide location and setting-up of distribution points and warehouses Request external help Authorize operations and mobilize resources Authorize and control all entry of goods and foreign organizations
Military (Logistical support)	The main objective is to provide support to humanitarian efforts Their action depends of the local situation and conditions Military provide logistic capabilities and resources	Mainly post-disaster stages	Provide primary assistance Search and rescue of victims Provision of security for humanitarian assistance and affected people Support to the flow of large amounts of supplies and personnel Restoration of civil infrastructures and route repair
Aid agencies (Support and relief)	Their main responsibility is to respond quickly to crisis situations These organizations are independent and distinct from each other They do not take action until the emergency declaration	Mainly post-disaster stages They often only act in response because of the lack of resources in preparedness	Procurement and storage of relief supplies Search and rescue efforts Provision of medical aid and shelter to victims Transport and distribution of supplies to the disaster zone
NGOs (Support and relief)	The main objective of a NGO is to assist affected people by sharing resources and competencies NGOs are independent of the government bureaucracy and differ from each other They act once the emergency is declared and depending on the type and intensity of the disaster Local NGOs are not permanent organizations but are familiar with the local environment	Mainly post-disaster stages	Assist the affected people Provide humanitarian services Share resources and competencies Cooperate with local partners Offer help into transporting relief goods Relief distribution Set up temporary facilities in the disaster area
LSPs (Logistical support and providers)	The main purpose of LSPs: support in purchasing, warehousing and transportation Their involvement tends to improve local response capabilities They can act as suppliers of goods or services	They can act in both pre- and post-disaster stages	Warehousing of prepositioned stocks Provide financial contributions or in-kind donations Offer the service of transporting items from the supplier's depots to the demand points Share transportation resources Promote logistics integration for the members of the HSC
Donors (providers)	The objective of donors is to relieve human suffering and save lives Donors can be organizations or individuals They provide the resources in order that the actors of the HSC can increase their capacities	Mainly post-disaster stages	Provide the bulk of funding required for relief activities Provide in-kind donations and/or services Encourage humanitarian organizations to engage in collaborative initiatives Demand accountability, transparency, and efficiency of the whole supply chain
Local communities (Support and relief)	Local communities are more familiar with local conditions Their inclusion tends to improve the local capacities of the HSC Their integration is facilitated when local government establishes trust with community leaders	They can act in both pre- and post-disaster stages	Being the first line of respondents Save as many lives as they can Sharing vital supplies with disaster victims Give the first information to the authorities about a disaster and its severity Coordinate the first response by themselves Participate in planning, implementation, and evaluation of humanitarian efforts

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As can be seen in table 1, the general purpose of local actors is to serve vulnerable communities in their region. In this sense, the common processes among the actors are related to the operations of immediate attention of the victims in the post-disaster situations. These aspects generate several implications that we want to highlight below:

- Firstly, the need to integrate local actors through coordination mechanisms, which reduce duplication of efforts and improve the performance of the HSC processes (Afshar and Haghani, 2012; Akhtar, et al., 2012; Cozzolino, 2012; Diedrichs, et al., 2016).
- Secondly, and according to Sebbah, et al. (2013), Moshtari (2016), and Kaneberg (2017), some important actors at the local level are involved in humanitarian effort once the crisis situation has been manifested, in other words, they act during the post-disaster stages.
- Based on the aforementioned, it can be established that local actors participate in the post-disaster stages due the lack of sufficient resources generated by the absence of donations and investments during non-disaster periods (Balcik, et al., 2010; Jahre, et al., 2015). These situations lead organizations to neglect the pre-disaster processes; however, through the literature it has tried to increase practical interest in strategic and planning processes involved in disaster preparedness (Kunz, et al., 2014; Rodríguez-Espíndola and Gaytán, 2015).

In a complementary manner, some findings found in the literature, regarding the role played by key local actors, are described below.

Several Insights Related to the Importance of Local Actors in Disaster Management

As Kovács and Spens (2007) established, the actors involved in disaster management can be grouped into two categories: international actors, such as the UN, large humanitarian agencies and logistics service companies; and those agencies that exist in a specific region, such as local government, military, and local agencies. There is some criticism of this classification system however. For example, Vitoriano, et al. (2015) argue that by recognizing only these two levels (local and international), an operations management problem can arise with an unclear picture of who is responsible of the decision-making and how many actors are involved.

On the one hand, the largest humanitarian organizations, such as international NGOs, are highly organized entities, with personnel trained for the most demanding events, and have nuanced experience in disaster management (Ganguly and Rai, 2016). Additionally, the largest humanitarian organizations also often have specialization in specific roles or processes, which allows them to have high operational efficiency (Ganguly and Rai, 2016; Jensen and Hertz, 2016). Because of this, authors such as Besiou, et al. (2014) and Jahre (2017) argue that the literature has focused on international HSCs and major disasters, which makes it difficult to develop a generalization of all humanitarian actors.

On the other hand, local actors include local government, military, local emergency agencies, police, local businesses and the general population (Sheppard, et al., 2013). These are called to be the first line of response to a crisis because they are the main responsible party for meeting the needs of the community (Sheppard, et al., 2013; Bohtan, et al., 2016; Gavidia, 2017). In addition, foreign action can only be considered until local capacities have been overwhelmed (Saharan, 2015; Bohtan, et al., 2016).

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Therefore, it is necessary to address new research towards small and local organizations, since they are also key actors in humanitarian efforts (Ni, et al., 2015). Likewise, international organizations have shown a tendency not to participate directly in disaster preparedness in local communities (Jahre, et al., 2016).

Despite the fact that local organizations can be characterized by having scarce resources and limited capacities (Jensen and Hertz, 2016), their advantage is that they are experts in the social, economic and cultural conditions of their community (Day, 2014; Gupta, et al., 2016). Additionally, they have better understanding of the conditions of the region: climate, environment, and local networks (Balcik, et al., 2010; Charles, 2010). This facilitates the decision-making process at the local level and the specialization in specific types of emergencies in their region (Kovács and Spens, 2009; Ganguly and Rai, 2016).

Taking into account their proximity and presence in areas of high vulnerability, local actors not only participate in immediate response operations, but also in mitigation, preparation and recovery phases (Fontainha, et al., 2017), through the design of emergency plans during preparedness (Kovács and Spens, 2007), during preventive evacuations against imminent threats (De Leeuw, et al., 2012), and during disaster response and recovery phases (Banomyong and Julagasigorn, 2017). Therefore, based on Sheppard, et al. (2013), it is already necessary to transmit the responsibility for disaster preparedness and response processes from the international humanitarian community to the actors at the local level, through empowerment mechanisms for the development and implementation of effective disaster management plans.

In operational terms, Lorca, et al. (2017) suggest that during the preparedness stage, local actors should develop strategic planning based on the consideration of different possible disaster scenarios. Additionally, local actors can participate in the following logistical processes within the humanitarian sector:

- Local procurement, which has the advantage of allowing a rapid delivery of products required by the community (Duran, et al., 2011). In addition, local suppliers can help accelerate the recovery and development of the region, as well as reduce transportation costs (Ertem and Buyurgan, 2013).
- Prepositioning of inventories: Kovács and Spens (2009) highlight the importance of local humanitarian agency presence for helping with this subject. In this regard, a local warehouse allows for the reduction of fixed costs and agile response operations, taking into account that it is necessary to improve the management of shared inventory (Harke and De Leeuw, 2015; Charles, et al., 2016).
- Local transportation providers: LSPs are important agents in the HSC, as they are essential in the local distribution and last mile delivery of supplies (Balcik and Beamon, 2008; Kovács and Spens, 2009).

A significant number of countries have improved their risk management processes and disaster preparedness capacities at the central level; however, there is also a need to take these progresses to the regional and local levels for their successful implementation (UNISDR, 2004; Tan, et al., 2012). In this sense, a focus on the local context must be adopted in the strategic planning processes during the preparedness phase (Kabra, et al., 2015).

In specialized literature, the role of local actors in disaster management processes has been highlighted. Holguín-Veras, et al. (2012b) analyze the performance of post-disaster operations when local actors and community-based organizations structure logistical networks for disaster relief, based on a real case: the 2010 Haiti earthquake. Sheppard, et al. (2013) developed a theoretical framework focused on the participation of national, regional and local actors, based on a fieldwork with the municipal actors

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responsible for the disaster preparedness and response. Additionally, Osorio-Ramírez (2016) concludes in his work the need to involve local communities not only in relief processes but also during strategic planning and disaster preparedness, taking into account their role and relevance in immediate response in their territories.

Likewise, it is important that, at the local level, actors have a proactive and participatory understanding of the assigned roles (Sahay, et al., 2016). This can be achieved through the control of plans and processes as well as from an inter-organizational coordination approach, in which, as mentioned above, the local government takes the role of leader in decision-making (De Leeuw, et al., 2012; Marcinkowski, 2017). Thus, collaboration networks can be successful when actors and the community are involved, which allows increasing local capacities for a successful response through an effective coordination system. In this sense, Day (2014) argues that the proper use of local resources and capacities has a positive effect on the resilience of communities.

RESEARCH TRENDS REGARDING LOCAL ACTORS IN HUMANITARIAN LOGISTICS

The research areas that are currently developed within the framework of humanitarian logistics are diverse, taking into account the number of factors and actors that are involved in the dynamics of these systems and environments of high complexity. Our intention in the final paragraphs of this chapter is to summarize some of the research trends that are being developed in this emerging field.

Firstly, the literature offers interesting works that highlight the opportunity to develop and implement technological tools to assist in the logistics processes for disaster management. In this regard, several tools such as Decision Support Systems, Geographic Information Systems, simulation methods and communication systems, offer advantages such as: function allocation, enhancement the information sharing, more transparency among actors, as well as improving the effectiveness of disaster preparedness and response (Kabra, et al., 2015; Sahay, et al., 2016; Moshtari and Goncalves, 2017). In addition, Wilson, et al. (2018) suggest that local governments should take advantage of the potentials of using social media in disaster management processes. Kabra, et al. (2017) find that with greater efforts and investments, local governments and other responsible agents will be more willing to implement ICT systems.

The sustainability of logistics processes in the humanitarian context has also emerged as a research issue. Oloruntoba (2015) argues that sustainable humanitarian logistics must involve all the actors in the HSC, with the purpose of minimizing the negative impacts of operations on the welfare of communities while seeking a balance of economic, environmental and social goals. From the multiple dimensions of sustainability (economic, environmental and social), the purpose of the HSC must be the sustainable development of resources and capacities of affected regions and their populations (Kunz and Gold, 2015). In this regard, several authors have highlighted that processes such as planning development, legislative arrangements, and institutional capacity building, must be done with an approach that ensures sustainable socio-economic and ecological development (Fernando and Muthulingam, 2015; Yadav and Barve, 2015).

Based on the aforementioned, regarding to the coordination capabilities of the actors involved in the HSC, and the sustainability approach in the logistics processes, not only allow for a more agile response and better results from the implementation of emergency plans, but also imply a positive impact on the resilience among local communities (Day, 2014; Kunz and Gold 2015). In other words, humanitarian logistics processes are currently an essential factor in building resilience of cities and countries (Andharia,

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2015), as the resilience of a local community can be improved with better relief processes, support to local agencies, and ensuring proper governance at the local level (Umar, et al., 2017).

Finally, we want to emphasize the role of the academic sector in the development of the humanitarian field. UNESCO (2010) highlights the impact of new research in light of the great challenges facing our societies worldwide, in terms of access to health care, climate change, clean drinking water, disaster risk mitigation, environmental protection, and natural resource management, which must be addressed with a sustainable development approach for all humanity. In this sense, Van Wassenhove (2006) defines some areas of research in which researchers in SCM can contribute to humanitarian logistics. These areas include: supply chain design and management, systems and technology, coordination and strategic alliances, performance measurement and scorecards, and process standardization and control. Likewise, Sahay, et al. (2016) argue that the academic community plays a key role in disaster preparedness and response, through the definition of strategies for all sectors of society and people of the local areas, as well as the design of mechanisms and programs for development in the most vulnerable regions.

CONCLUSION

Throughout this chapter, we have discussed the phases of disaster preparedness and response within the framework of humanitarian logistics, an emerging field of research but of great relevance for current social and sustainable interests. In addition, and taking into account various factors that increase the complexity of disaster management, the need to change the process approach towards a more integral and holistic vision of the problem is highlighted. Thus, through the SCM approach, the system of actors involved in the HSC must achieve integration and coordination in order to improve the efficiency and effectiveness of disaster preparedness and response.

Based on the diversity and quantity of actors present in disaster operations management, we have sought here, to describe the main actors and sectors involved in the HSC, as well as identify the most relevant functions that actors carry out in the humanitarian efforts.

Additionally, emphasis was placed on the need to develop more research regarding local actors in the humanitarian context. The processes during disaster preparedness and inter-organizational coordination are also suggested research issues. Other research trends found in the literature refer to the design and implementation of ICT tools, adding to the concept of resilience and sustainable development in disaster management in cities and regions. Finally, the role of the academic sector in these fields of research is indisputable, because with basic knowledge coming from the traditional SCM approach, there is a valuable opportunity for the transfer of knowledge, which would allow for strengthening disaster resilience in cities, the sustainable development of regions and nations, and thus, a contribution to mankind as a whole.

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Chapter 12
Planning Methodological Framework for Humanitarian Aid System in Colombia

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ABSTRACT

This chapter proposes a planning methodological framework for humanitarian aid. The proposal combines project management tools and system dynamics to evaluate the effect of different operational strategies on the total system response time. System dynamics allows identifying humanitarian aid sub-systems and the feedback loops between them. The project management approach enables to recognize the response activities in each sub-system, to estimate the response time for each activity and the resources requirements. Also, the system dynamics tools enable the response times simulation under variability conditions. The proposal is tested in a retrospective way on the 1999 "Eje Cafetero" earthquake in Colombia. Additionally, the methodology framework provides a novelty approach to represent humanitarian logistics operations as a project. Finally, the integration of project representation, strategies selection, and system dynamic simulation is not enough studied in the humanitarian logistics field.

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METHODOLOGICAL FRAMEWORK FOR HUMANITARIAN AID SYSTEM APPROACH

Humanitarian Logistics: The Disaster Relief System as a Logistic System

Kalenatic, González, & Arias (2009), define the logistic system as a set of support systems, commonly organized in functional groups. Regardless of whether these systems are part of one or several firms, or are grouped or dispersed geographically. Support systems commonly handle specialized flows, but they share infrastructure.

Thus, this set of support systems, called the logistic system, is in charge of providing the personnel, resources and information that the central system requires to fulfill the organization's mission. The central system is the one directly responsible for fulfilling the mission of the organization; hence, it is the main client of the logistic system. However, it is necessary that the support systems carry out exchanges of personnel, resources and information, within the logistics system, in order to maintain their viability and support operations (Rueda-Velasco, et al., 2013).

Accordingly, the interactions of support systems are commonly performed internally, however, they also have interactions with their environment locally, regionally and/or globally. These interactions are regulated by the different logistic processes, which can be grouped and organized in a set of stages, in what is known as a logistic cycle (Kalenatic, Méndez, Valbuena, & Rodríguez, 2011).

The logistic cycle includes the minimum steps that a support system must fulfill in order to fulfill its task of support and/or generation of advantage. They include: the determination of needs or requirements, procurement of resources, delivery of resources (Tejada, 2008), maintenance of the asset or resource obtained and reverse logistics (Kalenatic et al., 2009).

As a characteristic of the logistic systems it is also possible to observe that, internally, one of the transversal support systems takes on the role of coordinator. Coordinatiom role means ensuring cohesion as well as regulate and optimize the performance of the system.

In this context (González, Kalenatic, Rueda, & Sarmiento, 2013), based on the concepts of (Thomas, 2005) from the Frizt Institute and from (Van Wassenhove, 2006), the following definition of humanitarian logistics is proposed: The management of the support systems that make up the humanitarian logistic system throughout the logistic cycle considering their internal interactions as well as the political, social and economic environment. Regardless of whether the origin of the disaster is human or natural, or whether it is of slow evolution or sudden onset, focus should be mainly on the exchanges of materials, resources, information, skills and knowledge necessary to support the operations of prevention and relief of vulnerable population and/or population affected by the disasters. In this way a rapid response of the system can be guaranteed, tending to maintain or restore the well-being of the population that is at risk or is affected.

In this conceptual framework, the supply chain is the part of the logistic system in charge of managing the physical, human and information flow to and from the affected area. Thus, while the supply chain concentrates on the flows directly associated with the fulfillment of the mission, the rest of the logistic system is focused on the flows and processes that allow the organization, operation and value generation of the chain of supply.

Like the logistic system of which it is part, the supply chain is organized functionally, and each functional set of the chain is known as a link. As evidenced in the literature each of these links can be made up of one or multiple actors, and be associated with its own or shared infrastructure (Blecken, 2009).

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It is important to emphasize that there is not necessarily a correlation between the support systems and the links. While there are support systems that are associated with a particular link, there is also another set of them that are transversal to the chain and thus support more than one link. The same happens with the actors (J Holguín-Veras et al., 2016).

In addition, it can be observed that in a highly variable and complex operating environment as the humanitarian one, a logistic system is commonly associated with multiple socio-technical supply chains (José Holguín-Veras, Jaller, Van Wassenhove, Pérez, & Wachtendorf, 2012) which manage and/or share different flows, directions, infrastructure and actors. Therefore, a coordination strategy is required that minimizes interference, such as problems of convergence (José Holguín-Veras, Jaller, Wassenhove, Pérez, & Wachtendorf, 2014), and thus facilitate the joint achievement of the mission.

These humanitarian supply chains typically consist of three groups of interconnected nodes or links: origin nodes or source nodes, intermediate nodes and destination nodes (Rodríguez, Kalenatic, Velasco, & Bello, 2012)

Origin nodes or source nodes are typically geographically immobile, high-capacity, strategic nodes. The intermediate nodes can be immobile or mobile. In this group maintenance centers, distribution centers, ports, pre-positioning facilities, and mobile hospitals, among others are included. In turn, the destination nodes are made up of the temporary or mobile units located in the affected area or its periphery as well as its service or support units (Kalenatic, Bello, González, & Velasco, 2011).

Associated with these nodes are actors such as public, private, national and international organizations as well as civil and military organizations and the community. These are mainly related through physical flows such as the flows of materials, donations, equipment and financial and information flows connected to the characteristics of the victims and their necessities (Balcik, Beamon, Krejci, Muramatsu, & Ramirez, 2010; Blecken, 2009), In this way supply operations, transportation, storage and distribution (Paho, 2001) are developed. Nor the flows of relief workforce and victims, nor operations associated with reverse logistics, have been explicitly identified in the literature reviewed.

Also, (José Holguín-Veras, Taniguchi, et al., 2014) identifies the local community as part of the humanitarian logistics system. The research identifies a set of social networks in the target nodes, and emphasizes the importance of collaborating with these local social networks, their organization, resources and knowledge to support the micro-distribution and delivery of aid to the victims (José Holguín-Veras, Jaller, & Wachtendorf, 2012).

Finally, it is essential to emphasize that in humanitarian supply chain networks, the flows depend on the stage of the process. Thus, in the immediate response there are large flows of information to the strategic nodes, which activate flows of support personnel and equipment to the affected area. Subsequently outflows of evacuees, wounded and deceased can be observed. As well as incoming flows of medicines, larger equipment (tactical-operational) and basic necessities needed to maintain the operation. Once the operation is completed, reverse flows are observed, related to the dismantling of temporary facilities, and the return of personnel and equipment to strategic positions or nodes (Eßig & Tandler, 2009).

The Operations of the Logistic System of Disaster Relief as a Project

A project can be defined as a unique process, consisting of a set of coordinated activities, required to reach a goal made up of specific requirements, which is subject to time, cost and resource constraints (Lester, 2006).

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Dobson (2004) relates each of these constraints to specific factors. The time restriction is thus related to deadlines, the occurrence of specific events and urgency. Moreover, the cost and resource constraints include money, personnel, equipment, supplies as well as general and intangible costs. He also proposes a third set of constraints called performance criteria in which he includes functional requirements, purpose and evaluation criteria.

In the context of humanitarian logistic operations as part of disaster relief, operations can be approached as a project as each disaster has unique characteristics (Paho, 2001). It is these characteristics that determinate the need to execute a set of activities such as the delivery of aid and evacuation of victims. All activities aim at a rapid and efficient recovery of the welfare of the affected population.

Besides, these systems are characterized by the interaction of multiple and varied actors with diverse interests, including the local population. They must also operate with constrained and shared resources with an infrastructure partially destroyed by the disaster, and their operation is evaluated according to multiple criteria such as the speed of response, efficiency and coverage, among others.

Also, Slack, Chambers, & Johnston (2010), identify six common elements in projects; these elements are clearly identifiable in logistic operations of humanitarian disaster relief (Table 1).

Meanwhile, Klein (2000), groups the phases of conceptual design and definition together, and consolidates the structuring, programming and allocation of resources in what he calls the planning phase. These two phases will be taken as a methodological basis, together with a proposed third phase of strategic analysis under uncertain conditions. Thus, it is concluded that disaster relief operations are viewed as a project subject to extremely variable demands and resources.

Table 1. Identification of the common elements of a humanitarian logistic project

Element	In the Context of Project Management (Slack et al., 2010)	In the Context of Humanitarian Logistics
An object or goal	A definable end product, result or output defined in terms of cost, quality and time.	Aims to recover the well-being of the affected population (González et al., 2013).
Uniqueness	A project is not repetitive; each project presents differences in terms of the environment, as well as the use and availability of resources.	Each disaster is unique in magnitude, type, location and effect (Paho, 2001).
Complexity	The relationships between the activities carried out to achieve the objectives of the project are complex.	The interaction of multiple and varied actors with diverse interests, including the local population, developing their activities with limited and shared resources, with an infrastructure that has been partially destroyed by the disaster (Rodríguez et al., 2012).
Temporary Nature	The projects have a defined beginning and end and are therefore commonly associated with temporary organizations.	Begins with the occurrence of the disaster and ends when the welfare of the affected population has been partially or totally reestablished (depending on the scope), (Min. Interior y Justicia, 2010).
Uncertainty	The projects are planned before their execution, which implies risk. The nature of a project is associated with uncertainty.	Uncertainty in demand, availability of resources and infrastructure, sociocultural reactions (J Holguín-Veras et al., 2016)

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Table 1. Continued

Element	In the Context of Project Management (Slack et al., 2010)	In the Context of Humanitarian Logistics
Life Cycle (consists of six phases)	Conceptual design phase: Here the need to carry out the project is identified, by own initiative or by a third party.	As a result of monitoring, the occurrence of the event is identified, the magnitude of the catastrophe is estimated and compared with the local response capacity, and the aid requirements for the affected area are determined (UNGRD, 2016).
	Definition phase: Here what is to be done and how it is defined. This translates into the objectives, scope and strategy of the project. The objectives of the project refer to the final state that is seeking to achieve and are the basis for monitoring the progress of the project. The scope of a project identifies the work content and the results or deliverables, here the limits of the project are established. The project strategy defines in a general way how the project objectives will be achieved considering economic, social, technological, legal and geographical factors, among others.	The role and activities that each actor will develop are determined based on the estimated needs and the environmental conditions, the scope of the operations and the actors to be involved (FEMA, 2008; UNGRD, 2016).
	Planning phase: consists of dividing the project into manageable work packages associated with specific activities. Here the duration and precedence of activities are estimated as well as the controllable and uncontrollable influential variables and the needs and availability of resources.	The need for the application of specific action protocols is estimated, depending on the magnitude and type of disaster or catastrophe, the selected actors, and the resources and donations available (UNGRD, 2016).
	Scheduling phase: Here a start and end time of each of the activities is decided and resources are allocated to each of them.	In order to avoid problems of convergence, the availability of resources, personnel, infrastructure and donations are ordered, especially considering the use of shared resources such as ports and warehouses. (José Holguín-Veras, Jaller, et al., 2014).
	Implementation phase: the activities are implemented, their progress monitored and corrective actions applied if necessary.	Humanitarian assistance activities such as securing the area, search and rescue, relocation, delivery of aid, infrastructure recovery and support services are implemented, among others
	End phase: consisting of the delivery of the project results and the closing of the project.	The area having been normalized and the well-being of the population restored, temporary facilities are dismantled and the different actors are redrawn (DGR & SNPAD, 2006).

METHODOLOGY OF ANALYSIS OF THE OPERATIONS OF DISASTER RELIEF AS A PROJECT

Given the particular characteristics of disaster relief operations, it is necessary to formulate a methodological framework that makes it possible to plan the structure of the logistic response or diagnose the existing structure. This is done through the projection of scenarios and the estimation of their effects on the affected population. A three-phase structure is proposed: conception and definition, planning, and finally strategic analysis under uncertain conditions. The first two phases are based on the life cycle and project planning process proposed by (Klein, 2000), while the fourth phase is proposed as a complement

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to the strategic analysis of the system given the conditions of high variability presented by the context of disaster relief.

Conception and Definition Phase

The proposed methodology starts with the selection of a potential disaster or catastrophic event to which it is desired to analyze the response of a given emergency relief system.

The targets for consideration should be defined by estimating the resource needs of the affected region. This will vary with the magnitude of the catastrophe, the type and size of the affected population, geographical location, local culture, socio-economic conditions, how the population has been affected, the surrounding infrastructure, as well as the degree of preparation that these population groups have for the emergency.

The above conditions allow for a definition of the scope of the event to be evaluated. They also define whether the scope is local, regional or national and thus if it is constituting an emergency, a disaster or a catastrophe. The differences between these three concepts vary in proportion to the society's capacity to deal with the emergency as stated in (J Holguín-Veras et al., 2016; José Holguín-Veras, Jaller, Van Wassenhove, et al., 2012). Another element of the scope is the definition of the limits of the relief response to be evaluated, that is, if it is only the immediate response to the disaster that is to be analyzed or if the stages of reconstruction and recovery are also to be included.

Based on the above, measuring the achievement of the objectives involves defining the performance measures for the system. These indicators should preferably reconcile the beneficiary's perspective in its social context with the actors' perspective from their strategic and organizational structure, as well as the supply chain perspective as a representation of the relationships between the different actors involved (Haavisto & Kovács, 2014).

Planning Phase

The planning phase according to (Klein, 2000), integrates the processes of structuring, scheduling and allocation of resources, as can be seen below:

Structuring

The analysis and identification of the subsystems that make up the logistic system of disaster relief are proposed to act as the starting point of structuring. These systems can usually be found in the official documents defining the structure of the national or local emergency relief system. An example of identification of subsystems by functional groups can be found in The Emergency Support Functions (FEMA, 2008) where the system is divided into 15 functions and its scope is declared. Some of the most common support subsystems are search and rescue, communications, transportation, medical services, food and energy, among others.

Subsequently, it is proposed to identify the actors involved in each of the subsystems. Generally, the actors of the system are represented by local and international organizations, both governmental and non-governmental, such as logistic service providers, military, NGOs, government, aid agencies and donors of all types (Kovács & Spens, 2007; R Oloruntoba & Gray, 2006; Richard Oloruntoba & Gray, 2009).

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However, given the recommendations by (J Holguín-Veras et al., 2016; José Holguín-Veras, Jaller, & Wachtendorf, 2012), special attention should be given to the identification of participants in Collaborative Aid Networks. This refers to networks composed of social or religious groups that are part of the community potentially affected by the disaster. Their role can be decisive in the relief of the community to which they belong.

The input information for the identification of the actors can be found in the official documents of the constitution of the system, nevertheless, in these documents the Collaborative Aid Networks are seldom mentioned, it might therefore be necessary to recur to different types of fieldwork such as interviews or visits to affected areas.

In parallel to the identification of actors, a detailed description of the activities performed throughout the response must be completed. Based on the scope and purpose of each subsystem, tools like the work breakdown structure can be useful. This project management tool allows a subdivision of the scope of each subsystem into work packages and these in turn into activities (PMI, 2008). In this way, the activities of each subsystem can be understood as a project that is implemented to fulfill the subsystem function, turning the logistic system into a multi-project system with shared resources and actors.

At the same time, it is possible to establish working groups necessary for the response but that have not been contemplated within the system designed by government entities, as a diagnostic function, when compared with the activities stated in official documents.

After that, it is necessary to plan the hierarchical assignment of each of the actors to each subsystem or project and in turn to the relief activities. This step can be done through tools such as organizational breakdown structure (PMI, 2008). For planning purposes, this stage supports the need for coordination of actors with low levels of specialization (Jensen & Hertz, 2016), assigning each a role to follow in each subsystem.

As a diagnostic component, this tool can identify role gaps, that is, activities that are not covered by any system actor. Also, it allows meeting the specific challenges of coordination such as the lack of clarity of roles to be performed by the participants, as well as situations of functional redundancy, described among others in (Jensen & Hertz, 2016).

Then, the structuring phase continues with the estimation of the implementation schedule of the activities by means of analyzing precedents in each of the projects or sets of activities of each subsystem. Likewise, the relation of the activities between subsystems must be defined. Subsequently an estimate of time and cost per activity must be made, however given the conditions of uncertainty and variability inherent to the humanitarian environment, it is insufficient to make deterministic or punctual estimates, as a minimum estimates need to be made in intervals.

Ideally, the variability of the system could be represented through probability distributions. However, the difficulties of systematically monitoring performance indicators in different disasters, together with the unique character of each event, make the estimation of such distributions difficult.

It is for this reason that an estimation of time and costs in intervals is proposed, represented in the most probable scenarios for the population affected. Setting scenarios of the affected population are a tool commonly used for the analysis of the uncertainty in humanitarian logistics, as can be seen in the works of (Chakravarty, 2014). These scenarios can be obtained through impact studies from official entities or interviews with experts.

The structuring phase ends with the diagramming and graphical representation of the activities and their hierarchic relations through, for example, networks with activities on the nodes.

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Scheduling and Resource Allocation

In this phase it is possible to determine the set of activities that make up the bottleneck of the response time through the analysis of the critical path for the different scenarios proposed. Likewise, it is also possible to determine, through the analysis of the resources involved, the resources whose capacity would not fully cover the needs of the emergency. As a diagnostic function, this analysis makes it possible to identify which activities would not be executed or would be delayed, due to scarce resources. As well as to determinate the critical resources in the disaster scenario and the actors involved in the deployment of these resources.

Strategic Analysis under Uncertain Conditions

Finally, based on the conclusions of the previous phases, the phase of analysis and feedback is reached. The purpose of this phase is to use the information obtained from the evaluation of scenarios for the possible improvements to the structure of the system.

Based on the above and with the diagnosis obtained, the identification and selection of management strategies are proposed through the use of techniques such as the Analytic Hierarchy Process "AHP", widely used in the operations management literature for the selection of alternatives, resource allocation and conflict resolution (Subramanian & Ramanathan, 2012). In the selection of management strategies, and therefore in the AHP, the criteria of experts and actors in the system should be presented.

Once the management strategies are selected, the use of simulation techniques is proposed to measure their effects. In particular, the use of systems dynamics as a technique that allows, among other things, the representation of the behavior and structure of the system. It also takes into account its delays and feedback loops, as well as capture the disequilibrium present in the real context. This allows an explanation of the behavior of the systems, to test improvement policies and to assess their impact over time (Rahmandad & Sterman, 2013)

The methodology can be seen in the graphic below. It should be noted that in each phase new findings can be discovered that allows for feedback to the system design and for making suggestions on improvement.

CASE STUDY: APPLICATION TO THE COLOMBIAN SYSTEM OF DISASTER SCENARIOS

The National Disaster Risk Management System is composed of a series of public and private entities coordinated by the National Disaster Risk Management Unit. It is structured as a decentralized system, organized hierarchically according to the area of coverage. Accordingly, under the National Disaster Management Committee there are regional or departmental committees as well as local or municipal committees called. It is at this last level that the primary responsibility for managing an emergency lies. The regional and national levels act as complementary support when the magnitude of the emergency exceeds local capabilities. Next, the diagnosis of the Colombian system is developed based on the proposed methodology.

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Conception and Definition Phase

To validate the methodological proposal, the response of the current system of disaster relief in a national catastrophe is to be evaluated. For this purpose, a case was designed of equal scale as the last earthquake of great magnitude that shook the "Eje Cafetero" in 1999. This earthquake affected five departments, left around 1186 dead, 1205933 people affected and an estimated 1.85 billion US dollars in total losses(PNUD & CEPAL, 1999).

The evaluation of this case will be made for the immediate response phase. Its performance indicator is the response time, understood as the total time elapsed between the occurrence of the disaster and the arrival of the aid to the affected population.

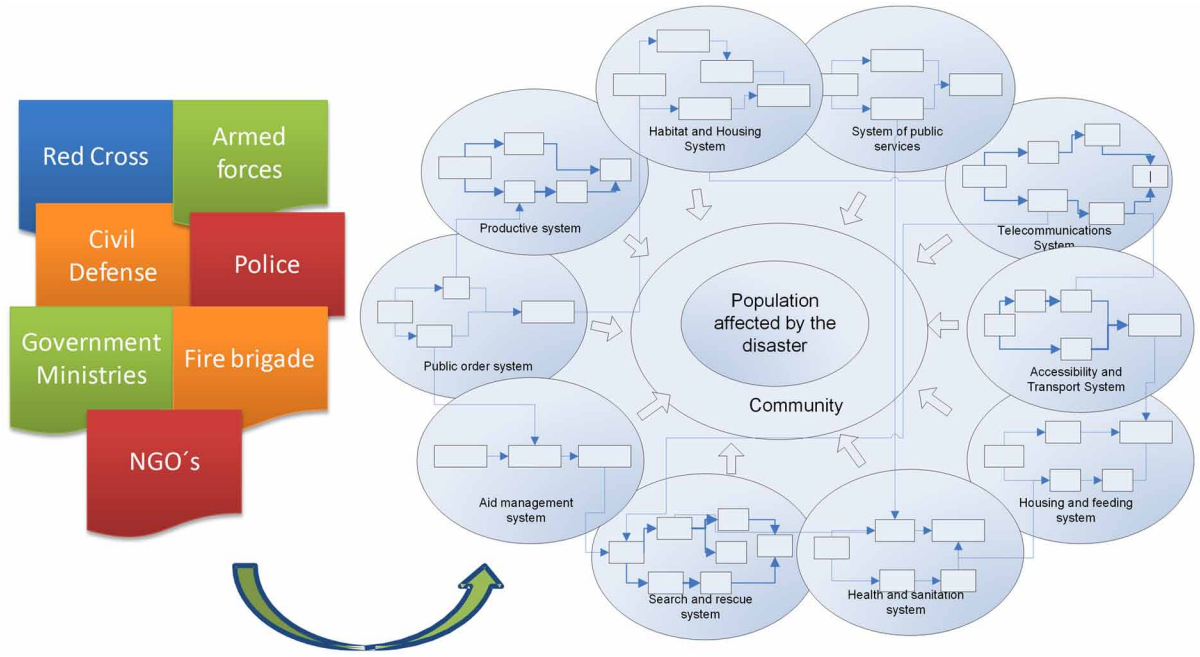
Planning Phase

Structuring

Base on (J Holguín-Veras et al., 2016; José Holguín-Veras, Taniguchi, et al., 2014; Jahre, Jensen, & Listou, 2009), data collection for system structuring was made through multiple sources integration as local risk studies, official and legal documents and interviews with disasters responders.

We identify six subsystems which support society functions in a disaster (Figure 1). The six subsystems are: Search and Rescue (S&R), Feeding and Shelter (F&S), Public Services (PS), Health and Sanitation (H&S), Aid Management (AM), Telecommunications (Tel), Public Order (PO), Transportation (Trans), Habitat and Housing (H&H) and Industry and Private Sector (Prod).

Figure 1. Humanitarian Logistic System in Colombia, Font
Author (República de Colombia. Departamento Nacional de Planeación., 2001; SNPAD, 2006; UNGRD, 2013, 2016)



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The analysis of associated entities, according to official documents, allows identifying at least 60 national actors which include national ministries, military forces, The International Federation of the Red Cross Federation (IFRC), Fire Department, Infrastructure National Agency, Telecommunications operators, private sector, among others.

The international actors and agencies are included in the system only as one actor. This situation makes the actor coordination as a function not easy to accomplish due to unclear role allocation to the agencies.

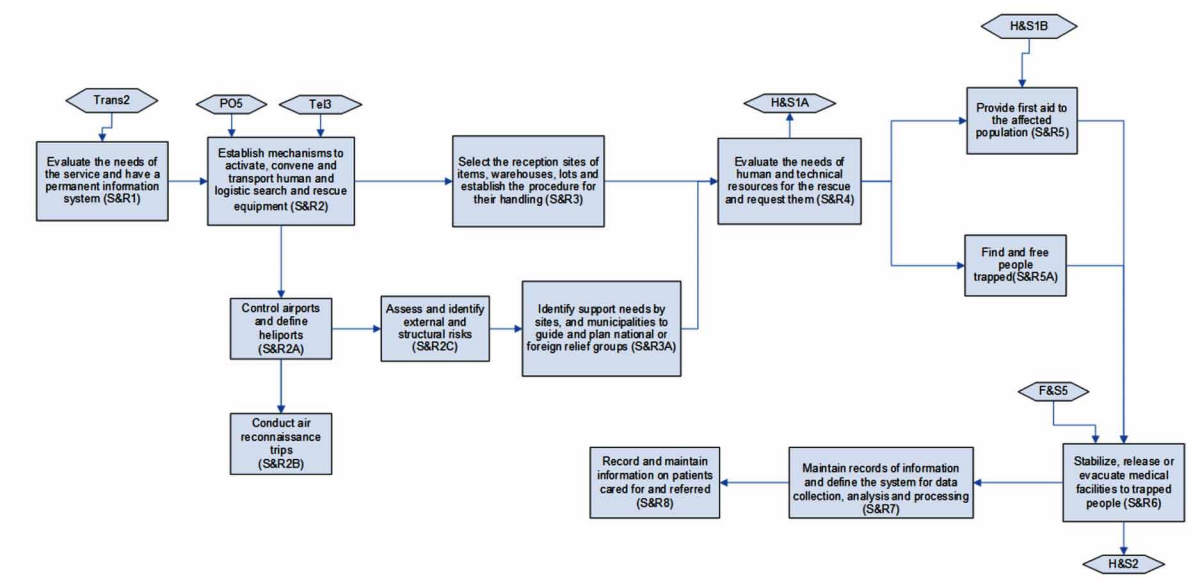
Additionally, the national system presents a high concentration of functions in a few actors as Military Forces, National Police, IFRC and civil defense. These actors are linked with all subsystems except to H&S and private sector activities. In the other hand, these actors participate in supply, storage and distribution of international aids and donations, which could cause a reduction in operational capacities. This problem as highly discussed as materials convergence problem (J Holguín-Veras et al., 2016; José Holguín-Veras, Jaller, et al., 2014)

In the same way, legal and official documents do not make explicit the role of Collaborative Aid Networks. Incorporation of this kind of networks in the response plans increase operative capacities and allow to improve the accuracy of aid distribution.

After actor analysis, the methodology continues with activity breakdown using a Work Breakdown Structure (WBS). Seventy activities were identified, an example of activity breakdown for the Search and Rescue subsystem is presented below. The activities on nodes diagram shows activities, precedence relationships and other subsystems interactions (Figure 2).

As usual in Project management approach and activity network analysis, total response times (project makespan) will be a result of interactions between activities durations and precedence relationships, it means, the system structure.

Figure 2. Activity on node diagram of Search and Rescue
(República de Colombia. Departamento Nacional de Planeación., 2001; SNPAD, 2006; UNGRD, 2013, 2016)



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Correspondingly with the next step in the methodology, we estimated the activities or jobs durations according to the interviews and documents findings for the "Eje Cafetero" earthquake equivalent disaster.

Scheduling and Resources Assignment

For the case of study, the analysis was limited to the computation of total response times. In this version, we do not consider the detailed analysis of the resources involved.

Total response time, due to the interaction of the activity network for all the subsystems, is estimated in 137 hours, it means around five days. Although, this is the estimated time for the critical path, which is defined as the project largest path, this is an optimistic estimation because any delay in its activities means an increase of the response time.

Figure 3 shows the critical path which contains 8 of the 70 response activities.

According to the analysis of critical path, the priority activities are related to the estimation of the number of affected families and their food and housing necessities, followed by the evaluation of specific shelter and feeding houses. Other activities that take part of the critical path are the management of aid request by the national committees and agencies responsible for the emergency, the coordination of the necessary logistics for the reception, delivery and administration of the aid to the affected regions, supporting for people, who have been affected in their habitat, usually through the implementation of temporary accommodation systems, temporary warehousing and donations in conjunction with community leaders, the determination of the internal, community organization and finally, the promotion of the active participation of people affected in cleaning, food preparation and other daily activities; as well as in the activities related to the profession of each of the housed, which permits the reconstruction process. Activities mentioned above are considered critical for the humanitarian assistance network.

By analyzing the sequence of the whole system it is possible to see that the support systems of telecommunications, accessibility and transport are transversal to the rest of support systems, that is to say, they are not considered the priority, however, a delay or failure in the execution of these system activities can generate delays in the operation.

Figure 3. Critical Path on national disaster risk management system- subsystems
(República de Colombia. Departamento Nacional de Planeación., 2001; SNPAD, 2006; UNGRD, 2013, 2016)

LIST OF CRITICAL ACTIVITIES		
Activity	**Code**	**Duration [hours]**
To assess the number of affected families	(Hs3)	96
To evaluate specific shelter and feeding housing	(F&S1)	2
To receive logistical resources and aid request from involved agencies	(AM1)	10
Request verification and confirmation	(AM2)	10
To coordinate resources aid reception and delivery	(AM3)	4
To organize shelters and aid allocation with community leaders	(F&S7a)	10
To coordinate community activities and functions in shelters	(F&S7B)	2
To promote community participation in functions and shelters operation	(F&S8)	3
CRITICAL PATH MAKESPAN		***137***



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It was also noted that the public order system, which is responsible for ensuring the security, mobility and accessibility of relief, health and coordination agencies, if delayed or failed, may delay the performance of the health and search and rescue system in the critical hours of the emergency. This aspect is accentuated in the doubly affected population, that is to say, those that besides suffering the effects by the disaster, are affected by armed conflicts or/and security problems that make them more vulnerable, typical situation in many Colombian populations.

Another important system that stands out when analyzing the Gantt diagram is the feeding and housing system, which is critical to ensure the welfare of the affected population survivor and is the system with the later onset, and in the other hand, it is the system that finally provides sufficient information so that the aid system can initiate the application process and confirmation of national and international aid.

Nevertheless, the activities of this system have as their predecessor the activities of the habitat and housing system, a support system responsible for assessing damage to dwellings and classifying the number of affected people. Then, these activities have to be considered as critical in the assistance network.

Strategic Analysis under Uncertain Conditions

After the analysis of the response times under deterministic conditions, a set of improvements was proposed, indeed, 14 improvements to the structure of the system. These improvements were evaluated by a group of 8 experts composed of 4 academics and 4 officials from 4 actors participating in the system. The proposed alternatives were compiled among the most cited in the humanitarian logistics literature, and they include information and material flow improvements and management of relations between system actors. The alternatives were evaluated through the AHP, whose criteria weight is shown in Table 2.

The alternatives were evaluated through by paired comparison matrices, with a final weighting as can be seen in Table 3.

According to the results obtained, the first two elements of higher priority are prioritized in the previous table. From this analysis, it is interpreted that the Colombian system has the priority to reduce information delays through knowledge management systems: communication and information and to improve the coordination of the actors in the system from its strategic perspectives, such as at the field level with NGOs and the private sector.

Therefore, the first strategy proposes the design, implementation and maintenance of an integrated information and communication system at municipal, regional and national levels as an alternative to reduce problems related to inaccessibility, inconsistency of data and formats, low priority of information, difficulty in identifying sources of information, misalignment of information storage media and poor reliability (Day, Junglas, & Silva, 2009).

Table 2. The relative importance of element selection criteria, Font: Author

Abbreviation	Criteria	Weights
TRR	Reduction of response times	0,438
IE	Ease of implementation	0,265
CI	Impact of the increase in coverage	0,188
CR	Reduction of system costs	0,110

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Table 3. Final weighting of alternatives- AHP, Font: Author

Score	Element
0,18131	Knowledge management systems: communication and information
0,16510	Development of coordination platforms in charge of coordination and communication of policies and strategies
0,12780	Coordination between governmental and non-governmental organizations, including NGOs in management systems
0,09021	Intra- and inter-organizational coordination between NGOs and the private sector
0,08308	Performance measurement
0,05625	Decision of decentralization and creation of regional units or centralization
0,04709	Decision of post- or pre-position resources
0,04691	Inclusion and strengthening of the local community capacity in care plans
0,04235	Resources management: Inventory and transport
0,03675	Standardization of protocols, processes, norms and procedures
0,03565	Cooperation between military and non-military organizations
0,03497	Generation of relationships of collaboration and trust
0,02949	Decision of temporal and non-temporal networks
0,02304	Improve capacity to absorb international help

The second strategy seeks to create a favorable framework for the joint action of all types of organizations: governmental, non-governmental, private sector, military organizations and community in general. In this way, the structure of the system is modified in such a way that the allocation of resources and actors is centralized in an office coordinating the system that guarantees the correct allocation of roles and areas of action, reducing problems due to geographical and functional redundancy (Jensen & Hertz, 2016), to modify relations with military forces and the private sector for the priority mobilization of aid and the use of facilities and inventories as described in (Wang, Li, Liang, Huang, & Ashley, 2015).

Given the above, the activities of every sub-system that would be affected by the implementation of each of the strategies were identified. It was found that the knowledge management strategy of the system through an information and communication system would reduce response times in subsystems such as transport where it would collect and communicate the location and number of affected information, collect and communicate the requirements, assess the accessibility and status of infrastructure after the emergency, improve information connectivity among actors, assess the state of public order and security systems in the affected region, among others.

The coordination strategy of the system focuses on the activities related to the management of national and international aid, on the timely action of the actors to give access to the affected area, for the timely evacuation of the wounded and their hospitalization, the timely delivery of aid to the vulnerable population, on the reestablishment of communications and public services, among others.

Based on the evaluation of impacted activities, the execution time scenarios were determined for each of the activities that were impacted by each of the strategies. Given the variability of the system, probability distributions were linked to determine the duration of the activities within the execution scenarios for each strategy, then the impact on the response time was simulated through system dynamics.

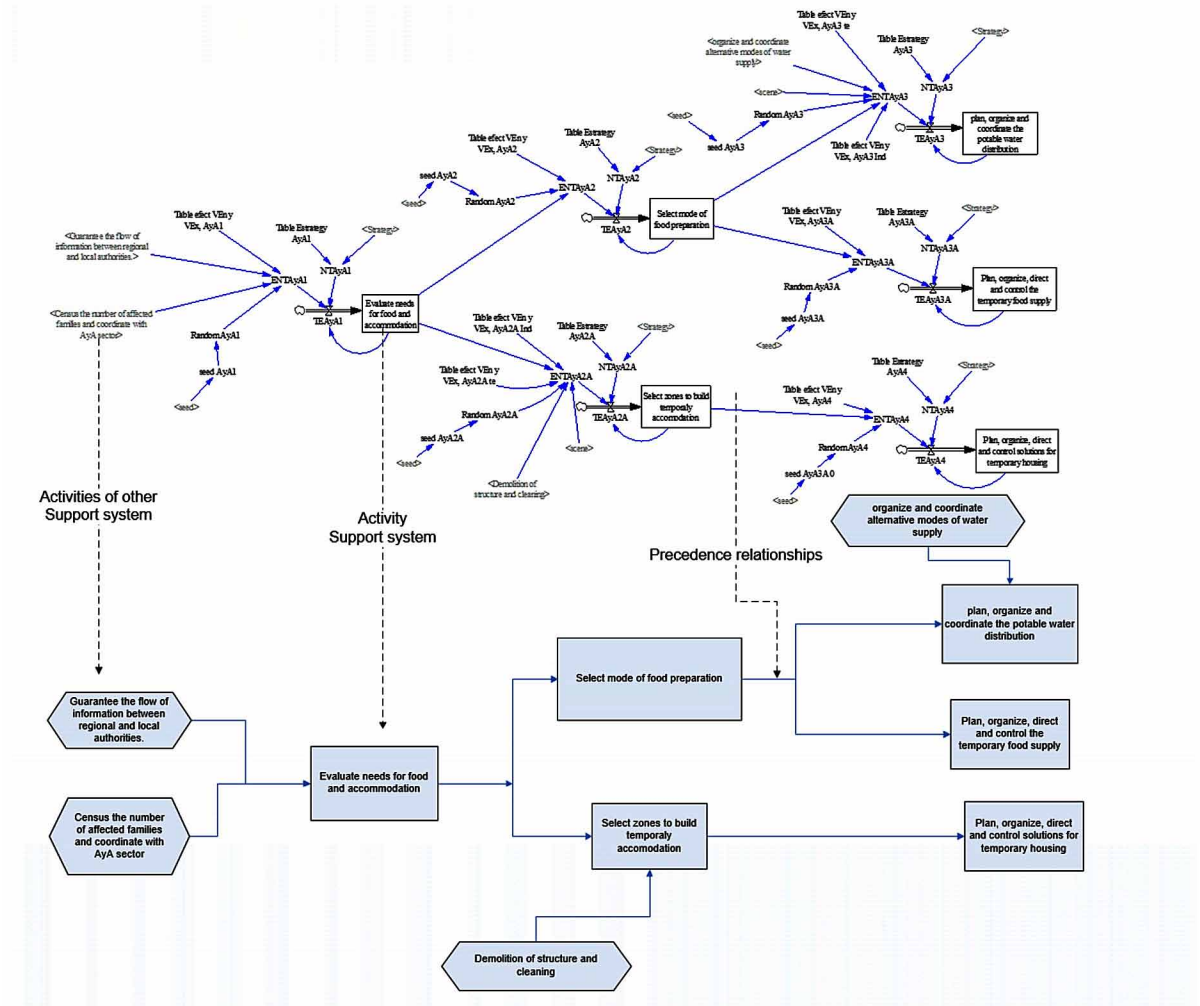
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A Forrester model for the entire system structure (projects) was made (Figure 4). We use a systems dynamics representation of a project based on (Kalenatic, Méndez, et al., 2011). In this model, each activity of the humanitarian system was modeled as a level.

Also, each level could increase its value until 100% of execution. If a level takes a 100% value, allows its followers to start. Activity executions vary in order to a rate linked with a probability distribution which values are limited between previously time scenarios. Total system response time is the result of the finish time in the last activity on the critical path, Figure 4 Shows a piece of a Forrester model and its representation as an activity network.

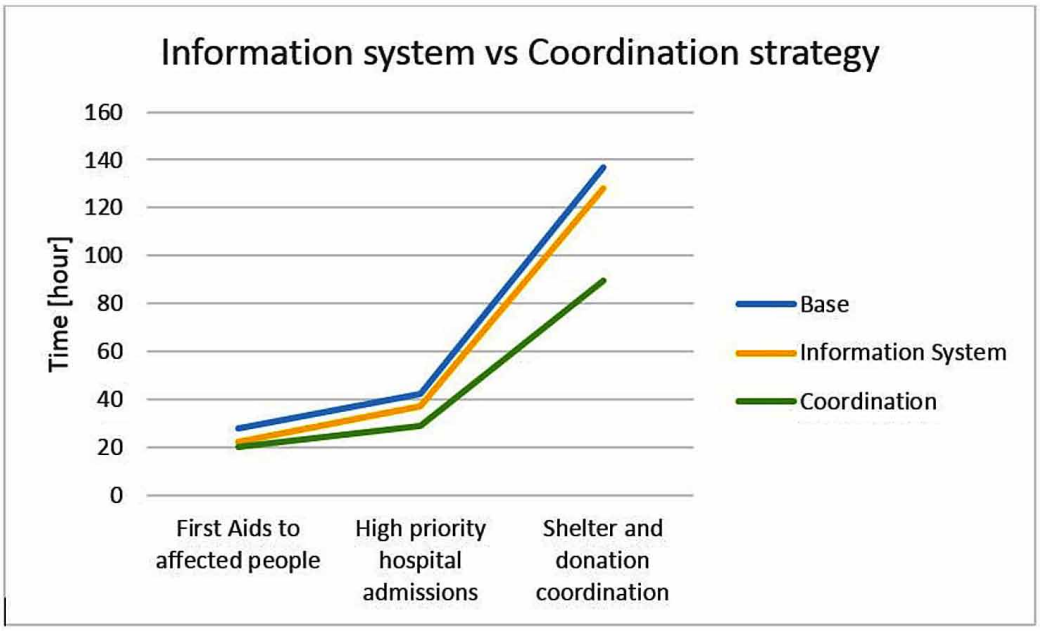
Simulation results show that total system response time decreases in coordination strategy more than information and telecommunications systems strategy. In Figure 5, the response time for three milestone activities is presented. Both strategies offer better response time than the base scenario.

Figure 4. Forrester model vs activity network model, National Disaster Risk Management System (fragment)
(República de Colombia. Departamento Nacional de Planeación., 2001; SNPAD, 2006; UNGRD, 2013, 2016)



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Figure 5. Response time simulated of each strategy
(República de Colombia. Departamento Nacional de Planeación., 2001; SNPAD, 2006; UNGRD, 2013, 2016)



Besides, the graph above shows rapid activity transition between first aid and high priority hospital admissions, however, transitions are slow after the first 48 hours. This fact is obvious when the time rate increases after high priority hospital admissions until shelter settlement, aid distribution and donation management activities in all scenarios.

CONCLUSION

The analysis of the disaster relief logistics system from the project approach allows integrating different perspectives of representation, from the perspective based on chains of supply focused on flows of information, plus the perspective of the actors and the resources involved. In this way this approach allows to diagnose the system from its structure, identifying the activities of the system that restrict the response, the functional allocation of the actors, the restrictions of resources in the system and therefore, identify gaps in the functional allocation, activities and actors that require an increase of resources for their proper functioning, etc.

The integration of the analysis of the structure of the disaster relief logistics system with simulation models allows the methodology to evaluate the effects of modifications on the system, enabling the identification of those parts of the system that are susceptible to improvement given their level of criticality.

In the characterization of the Colombian system, was found a high concentration of functions in a few actors as military forces, the Red Cross, Civil Defense and the National Police, which may mean an over-allocation of such actors that could naturally limit the response in a catastrophic event. Also from the documentary point of view, there is no formalization in the current legislation of the role of Collab-

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orative Aid Networks. A more in-depth study of the presence of such networks in the Colombian system would allow identifying actors with an additional capacity not yet contemplated among the national plans.

In order to improve the study of the Colombian system, the scope of the work can be extended to include the resources of the system, nevertheless, as shown in the development of the case, the communication and information integration platform is required in order to enhance the real visibility of the resources.

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Chapter 13
Characterizing Coordination in Humanitarian Supply Chains:
A Case Study in Colombia

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ABSTRACT

Coordination has been reported as a main issue in humanitarian supply chain. Although it is recognized as a potential driver for efficiency, it is not broadly studied in real cases. This chapter presents a case study for humanitarian supply chain. Using Lambert's framework for SCM, humanitarian supply chain is characterized identifying its structure, business processes, and management components. Once humanitarian supply chain is understood, a short review is performed to identify how coordination is being integrated into humanitarian supply chains body of literature, and principles, techniques, and technologies applied for coordination in humanities supply chain are identified. Finally, using content analysis methodology, coordination issues are mapped through humanitarian actors in Colombia by understanding the supply chain strategy of three principal actors for Colombian humanitarian supply chain.

BACKGROUND

Humanitarian logistics has received attention of the scientist since the events occurred in the Indic Ocean tsunami in 2004. In recent years the number, magnitude and impact of natural disasters has increased, and according with the United Nations Office for Risk Reduction, both natural and man-made disasters will continue to increase both in quantity and impact (Cozzolino, 2012; Leiras, de Brito Jr, Queiroz Peres, Rejane Bertazzo, & Tsugunobu Yoshida Yoshizaki, 2014).

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In this scenario logistics management is essential for reducing the impacts due to disasters since near the 80% of efforts in relief operations are related to logistics. The way in which different actors around humanitarian supply chain interact with each other can help logistics to be more effective. For instance coordination between actors is considered one of the main factors influencing logistics performance in disaster relief situations (Cozzolino, 2012; McLachlin & Larson, 2011; Seybolt, 2009).

Decisions in humanitarian logistics are taken under no standards, a lack of transparency and a high fragmentation, there's a poor coordination. Greater levels of coordination between the humanitarian supply chain actors, means greater performance level (Wassenhove, 2006). It is not enough with having more goods, services and funds, it is also important to understand and improve the relationships between actors through the humanitarian network, this could be achieved with adequate coordination mechanisms (Aslanzadeh, Rostami, & Kardar, 2009).

The following chapter presents a characterization for the Colombian care system for disasters in order to establish the actual deployment of coordination in the humanitarian supply network. For doing this a theorical approach for the conceptual system of humanitarian supply chain is presented taking into account definitions proposed by (Lambert, Cooper, & Pagh, 1998), then the real system description for humanitarian logistics is discussed., introducing its principal actors, processes and relationships, finally using the methodology presented in (Perez-Franco, Singh, & Sheffi, 2010) the humanitarian supply chain strategy is assessed looking to find how coordination is involved in the strategy of the different actors of the humanitarian network in Colombia.

THEORIES AND APPROACHES

(Lambert et al., 1998) proposed a framework for understanding supply chains. This framework is composed of three elements: the supply chain structure, the business processes and the management components. Supply chain's structure refers to the setup of the different network actors, having into account from the raw materials suppliers to the end costumer. Supply chain structure includes both horizontal and vertical dimensions. Examples of applications for Lambert framework can be seen in (Gonzalez-Feliu, Osorio-Ramirez, Palacios-Arguello, & Talamantes, 2018)

Regarding the business processes, Lambert (1998) defines eight key processes among the supply chain relationships: customer relationship management, customer service management, demand management, order fulfillment, manufacturing flow management, procurement, product development and commercialization and returns.

Finally, the management components are referred as the managerial variables by which business processes are integrated and managed, these are classified in those related with the physical and technical components (planning and control methods, work flow, organization structure, communication and information flow and product flow) and those related with the managerial and behavioral components (management methods, power and leadership structure, risk and reward structure and culture and attitude).

Differences Between Traditional and Humanitarian Supply Chain

There are multiple differences between traditional and humanitarian supply chain, understanding this difference is a first step in the characterization of humanitarian one. The first difference is about the

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objective. While traditional logistics concerns about minimizing the cost subject to some constrains, humanitarian logistics has as its principal objective the wellbeing, models build for humanitarian logistics have in consideration a privation cost, resulting of the lack of goods and services for the affected population (Holguín-Veras, Jaller, Wassenhove, Pérez, & Wachtendorf, 2012).

Another important difference is regarding the source and the flow of the distributed goods. In the traditional logistics the flows of the different goods are under the control of the members of the supply chain. In the other hand, in humanitarian logistics the sources of goods couldn't be more varied. A lot of supplies are sent by governments, communities and also by particular individuals. Traditional supply chain begins with raw material extraction, in humanitarian logistics its processes begin with the donation of finished goods (Pihl & Colleros, 2011).

Decision making process is also an important difference between both traditional and humanitarian supply chain. In the first case decision making is made by a few individuals, with a formal and defined structure with roles and responsibilities. In humanitarian supply chain, decision making is informal in most the cases improvised and in the least of the cases unified. In the humanitarian decision making process. it involves different independent supply chains which overlap, compete, inter-operate, cooperate and even fight for scarce resources (Holguín-Veras, Jaller, Wassenhove, et al., 2012).

Demand knowledge is one of the biggest differences between both supply chains. Traditional supply chain is setup for satisfying a known or forecasted demand, even though there can be variations in the patterns, uncertainty levels are small compared to those in humanitarian case. In humanitarian supply chain demand is dynamic, there is no information about it, and a scarce access to the area where demand is originated (Holguín-Veras, Jaller, Wassenhove, et al., 2012). This is summed among other differences like the frequency and volume of logistics activities and support systems.

Theorical Humanitarian Supply Chain

Having understood the principal differences with the traditional supply chain and considering the framework exposed above the following apart describe the humanitarian supply chain, its structure, businesses processes and management components.

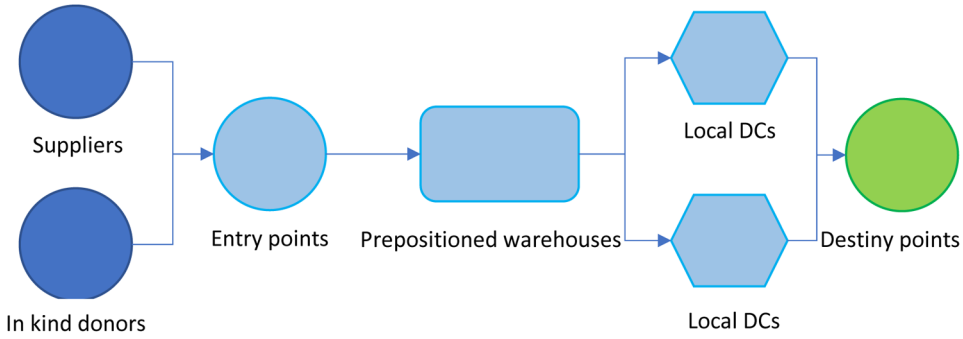
Humanitarian Supply Chain Structure

Literature regarding humanitarian supply chain allows to identify different structure models. The simplest model is composed of donors, entry points and destiny points, in this case both donors and destiny points (victims) can be hundreds or thousands of entities (Holguín-Veras, Jaller, Van Wassenhove, Pérez, & Wachtendorf, 2012). This simple model can be complexed adding other tiers, as local temporary distribution centers responsible of the last mile distribution (Beamon & Balcik, 2008).

Also, some pre-positioned entities can be included in the supply chain structure, these entities perform activities prior to the disaster occurrence. As in the simplest case, the source are donors with finished goods that arrive to the entry points, the next tier forward consists of prepositioned warehouses with established supplies, from where local distribution centers are supplied so they can reach the affected population (Balcik, Beamon, Krejci, Muramatsu, & Ramirez, 2010). The different structures for the humanitarian supply chain can be seen in Figure 1.

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Figure 1. Humanitarian supply chain typical structures



Humanitarian Supply Chain Actors

Along the humanitarian supply chain, a diversity of actors in the different tiers intervene. In general, the actors can carry out one of the following roles:

- Donors
- Humanitarian staff
- Victims or affected population

Donors are the first tier in this supply chain they act as suppliers of the complete supply chain, humanitarian staff is responsible for the logistics operations of provisioning, warehousing and distribution of the goods delivered by donors. Victims in the las tier are the ones that demand humanitarian aid managed by the humanitarian staff. From a geographical point of view Jaller Martelo (2011) identified the different actor's position. The disaster zone is presented as a series of concentric rings, where the disaster is pointed in the center, the next ring is the contiguous area, the next ring determined as the proximal area and the external ring called the remote area. In this description is important to highlight that the supplies flows go inbound of the rings, meanwhile information flows go outbound of the disaster zone.

Any of the described roles above, can be fulfill by a list of different entities, they could be governments, military organizations, aid organizations, donors, non-government organizations, as well as private firms (Cozzolino, 2012). There exists multiple relationship among these organizations with different cultures, purposes, interests, mandates, capacity and logistics expertise (Balcik et al., 2010).

Key Business Processes in Humanitarian Supply Chain

As well as in the traditional supply chain a series of business processes have been identified, in the humanitarian case also needs efficiency in certain activities for the achievement of its goals. A humanitarian logistics framework developed by (Blecken, Hellingrath, Dangelmaier, & Schulz, 2009) funded in two dimensions, a hierarchical decomposition distinguishing between supply chain management (SCM) tasks at strategic, tactical and operational levels, and the structural decomposition consisting SCM tasks related to assessment, procurement, warehousing and transport. Even more a vertical and horizontal support function is identified: report and support operations.

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Humanitarian Supply Chain Management Components

Decision making structure is one of the main focus regarding management components around the humanitarian supply chain. Humanitarian scenario is characterized by uncertainty and the rise of emerging structures, what makes decision making an informal and decentralized process, whereby relationships between multiple actors must be effectively managed.

Management components are classified according with Lambert's framework in (1) physical and technical components and (2) managerial and behavioral components. Regarding the second ones, humanitarian literature has put a lot of effort in characterizing relationships among multiple partners.

Relationships in the humanitarian case interactions between actors can be governed by means of the market, hierarchy or cooperation (Cozzolino, 2012). Each of these interactions use coordination mechanisms which provide tools for an effective management of these relationships.

Market interactions are related with transactions of goods and services between independent actors. These interactions have the characteristic of being adaptable to environmental changes through the decision making of autonomous entities involved in the transactions.

Hierarchical relationships occur between supraordinate and subordinated entities among the same organization or group of organizations, the main feature of this kind of interactions is that decisions are centralized, there are rules and formal patterns for the decision-making process in a regular environment.

Finally, cooperation relationships, which considers different interactions between the multiple actors of the humanitarian supply chain, around market and hierarchy relationships. Cooperation is based in common objectives of the different stakeholders and it is constructed through negotiations and agreements between them.

In these kinds of interactions there are different tasks that can leverage managerial components. The reference task model proposed by Blecken (2010), considers reporting for generating accurate information about assets availability in terms of location, condition and prices, this reporting serves as means of implementing and coordinating humanitarian operations, as well for monitoring efficiency and effectiveness of these operations.

On the other hand of managerial components, those regarding with the physical and technical component are more directly related with humanitarian objectives, which can be achieved through the application of two principles: agility and leanness (Cozzolino, 2012). Agility focuses on effectiveness while leanness does it on efficiency and cost saving. In both cases operations support tasks are important for enabling the effective and efficient flow of material, information, and personnel in the humanitarian supply chain.

Humanitarian supplies' source lies on donors, and it flows downstream to the beneficiaries, so donations or supplies are determined by donors as an external assessment of the real needs what makes really complex to fulfill demand (Howden, 2009). Information systems can improve humanitarian supply chain effectiveness providing accurate and opportune information.

COLOMBIAN HUMANITARIAN SUPPLY CHAIN

In Colombia the humanitarian supply chain its represented by the National Management System of Disaster Risk, this is an entity composed by many public and private entities, which principal objective is to carry out the social process of risk management with the purpose of offering protection to the people in the Colombian territory, improving security, wellbeing, and life quality as well as to contribute

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to sustainable development. Among its specific objectives it has the mission to develop, maintain and guarantee the disaster management process by means of the following actions:

- Preparation for the disaster response
- Preparation for the recovery
- Disaster response
- Recuperation

Organization, Direction and Coordination of the National Management System of Disaster Risk (NMSDR)

The nature of the entities that compose the National System can be of three kinds: Public entities, private entities for profit or non for profit, and finally the community that can aid an emergency activity.

Regarding its structure the National System has three different levels, the first one is carried out by the President of Colombia, the second level directed by the manager of the National Unit for Risk Disaster Management, and finally the third level is at the head of the governors and mayor at a local level.

Additionally, in the continuum generated by these three levels there exist several orientation and coordination instances which aims to optimize the performance of the different entities involved in the risk management execution, they are:

- National council for risk management, guides and approves risk management policies at a national level.
- National committee for the risk knowledge, advises and plans the permanent implementation of the risk knowledge process.
- National committee for risk reduction, is focused in the corrective and prospective intervention of vulnerability and threat conditions
- National committee for the risk response, advises the response to emergencies and disaster situations, as well as rehabilitation and reconstruction of the socioeconomical, environmental and physical conditions.

Figure 2 shows the different interinstitutional entities, the agents that compose them and relationships between them. Coordination for all these entities is an important issue, in this sense they have a centralized link through the Planning National Department and the National Unit for Risk Disaster Management, what makes them look coordinated (Suarez-Moreno, 2015).

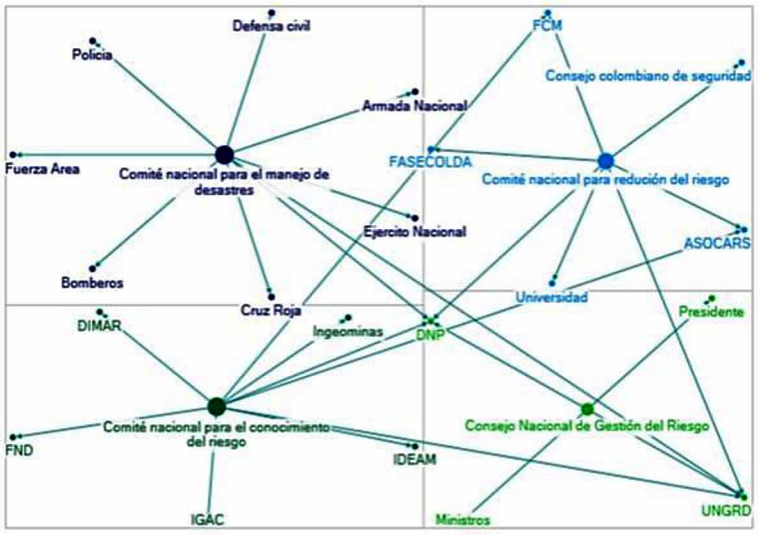
The following chapter test the previous hypothesis for the special case of the National Committee for Disaster Response, by means of assessing the strategy stated by the different entities around this committee by means of a content analysis.

Colombian Humanitarian Supply Chain Diagnosis: Response System

This chapter presents the result of a mixed methodology that allows to understand the different roles of the actors that compose the National Committee for Disaster Response. In a preliminary phase content analysis is used for understanding the strategy for the actors involved. Then these results are presented following Perez-Franco (2016) methodology for mapping supply chain strategy.

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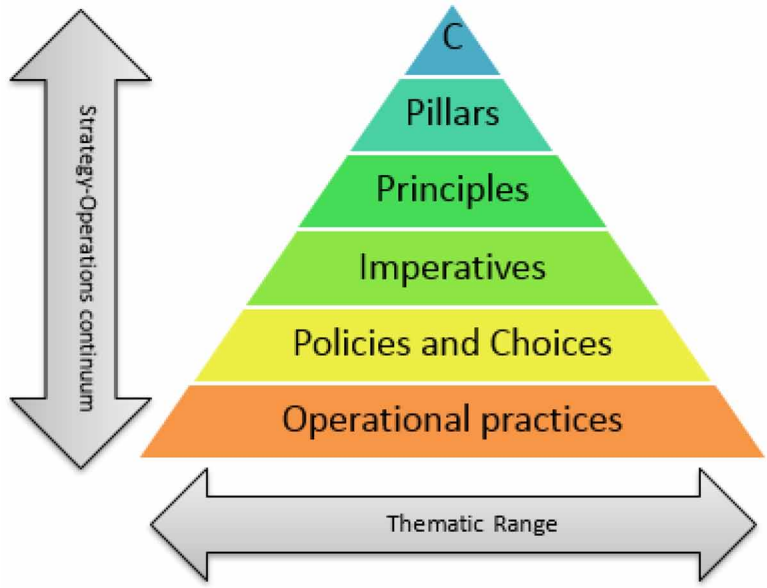
Figure 2. Relationships between the NMSDR actors



Supply chain strategy is defined as decision patterns related with supply chain activities in accordance with the corporate strategy. In this sense supply chain strategy can be found between both, the global strategy and the operational practices of the analyzed company what is called the strategy-operations continuum. Figure 3 explains the components of the supply chain strategy.

Supply chain strategy is composed by principles, imperatives and policies and choices. Principles are general objectives, imperatives represent specific objectives for supply chain areas, while policies and

Figure 3. Supply chain strategy components Colombia
(Perez-Franco, Phadnis, Caplice, & Sheffi, 2016)



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choices are related with specific decisions taken to support the specific and general objectives. Another way for understanding this, is that as we move down to the bottom of the pyramid, we can understand how things are being made, while if we move up to the tip, we can find the purpose of doing these things.

Capturing Strategy for Humanitarian Organisms

For capturing the strategy for humanitarian organisms that compose the National Committee for Disaster Response content analysis was performed to their strategic plans, the web sites of the different agencies were used as primary sources.

Content Analysis Methodology

As the purpose of this work is to assess at what level coordination is an important issue and how it is involved in the strategy of the different actors for the response system, the following analysis is only performed for those actors that have humanitarian actions as their core objectives. These are:

- National Unit for Risk Disaster Management
- Colombian Red Cross
- Civil Defense

The content analysis aims to present the data gathered during a specific evaluation study as a description of the behavior from the perspective of the informants. In general, the methodology followed in a content analysis is as follows:

1. Prepare a matrix of response categories
2. Assign a series of codes to each category
3. Assign a code to each relevant passage of the transcripts

For performing the content analysis axial coding technique was used. This process links different categories according with their properties and dimensions, coding the text around an axis or category. A category represents a problem, issue, phenomenon, or event that is defined as significative. On the other hand, a subcategory answers questions about when, where, why, how and with what consequences, giving categories a better explicative power.

For each of the reviewed documents information was classified in categories, subcategories, and codes. The categories used for the analysis of the several documents were selected a priori in compliance with the objectives of the current study. The codes were classified according to different elements that literature report as means for coordination.

Coordination in a supply chain is obtained by means of what literature has defined as coordination mechanisms (Albrecht, 2010; Giannoccaro & Pontrandolfo, 2004; Li & Wang, 2007). A coordination mechanism can be defined as an operational plan that aligns actions and plans of the different stakeholders towards a common objective.

Different taxonomies have been proposed for classifying coordination mechanisms, a first proposal classifies them as follows: coordination mechanisms for price, coordination mechanism for variables different than price and coordination mechanisms for product flow (Fugate, Sahin, & Mentzer, 2006;

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Sahin & Robinson, 2002). Another way for classifying the different coordination mechanism is using the methods that trigger them. Among the different methods used for coordination mechanisms there are the contracts, information technologies, information sharing and joint decision making (Kanda et al., 2008).

Even though coordination has been mentioned in humanitarian supply chain literature as a mean to gather efficiencies, implementing them can be difficult because a specific cost for coordination linked to physical flow and the coordination management, there is also an operational risk cost associated with failures in the ally's performance, avoidance of responsibilities or resistance to change (Osorio-Ramirez, 2017)

The following table details the different methods, this classification is used for the content analysis. The next sections present the content analysis for each of the selected actors.

National Unit for Risk Disaster Management (NURDM)

The following is the mission statement for the NURDM, this is the only fragment of the whole strategy that will be referenced in the text, but as it was said before, from this statement the whole supply chain strategy can be inferred. Even though the table below present the results for the content analysis for the whole strategy document.

We are the Unit that directs, guides and coordinates Disaster Risk Management in Colombia, strengthening the capacities of public, private, community and society entities in general, with the explicit purpose of contributing to the improvement of the quality of life of people and sustainable development, through the knowledge of risk, its reduction and the management of disasters associated with phenomena of natural, social, technological and unintentional human origin.

Regarding coordination the NURDM strategy is permeated by different element that articulates coordination. A first element is observed as one of the principles "Institutional coordination for the NMSDR", in the humanitarian context, as it was presented in Figure 1 there are multiple actors that intervene, so the articulation of the different actors is an objective of the NURDM.

Within the strategy there are other principles in which coordination is supported, such as the exchange of information and the use of ICT, these are the principles of: Private public alliances and the optimization of technological services.

Table 1. Coordination methods

Method Triggering Coordination Mechanism	Definition for Coordination Method
Contracts	Contract specify parameters within a buyer places orders and suppliers fulfill them. Contracts improve total benefits for the SC, reduce the cost due to inventory excess or scarce, and distribute risk among supply chain partners.
Information technology	IT improves inter—organization coordination, linking production and delivery points. IT allows planning, tracking and estimating lead times based on real time data.
Information sharing	Supply chain partners coordinate due to information sharing, the more information they share, greater the service levels are.
Joint decision making	A coherent decision making helps in resolving conflicts among SC members and in exceptions handling in case of any future uncertainty

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Table 2. Strategy analysis for the NURDM

Global Strategy	Pillars	Principles	Imperatives
Direct, guide and coordinate risk management	Strengthen the capacity of entities	Institutional coordination for the NMSDR	Articulation of the national, regional and local committees
		Strengthen the components of the NMSDR	Optimize management processes
			Technical assistance in local risk management
		Generate public-private partnerships	International cooperation management
			Public-private partnership management
		Optimization of technological services	IT management
	Risk management	Strengthen risk knowledge	Risks identification and prioritization
			Risk tracking
		Research and training	Articulation with the education system
			Training and qualification
		Prospective risk intervention	Prospective risk management
			Formulation of risk reduction initiatives
	Disaster response	Corrective risk intervention	Mitigation and reduction of risk conditions
			Formulation of risk reduction policies
		Response and recovery readiness	Improve readiness
			Readiness recovery
		Disaster recovery	Implementation of rehabilitation projects

Colombian Red Cross

Below the Colombian Red Cross mission statement can be found, the results for the content analysis for capturing its strategy can be observed in Table 3.

… prevent and alleviate, in any circumstance in which it is their duty to intervene, the suffering and the lack of protection of persons affected by occasional contingencies, with absolute impartiality, without discrimination on grounds of nationality, race, sex, religion, language, social condition or political opinion; protect the life and health of people and their dignity as human beings, in particular, in times of armed conflict and in other emergency situations…

The missionary activity of the Colombian Red Cross is to provide humanitarian assistance with impartiality. Therefore, most of its strategic pillars are oriented to this activity. However, within its strategy there are several elements aimed at coordination. For example, improve connectivity through ICTs, the creation of strategic partners to improve humanitarian response and the integration of plans, programs and projects of the different entities of the system.

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Table 3. Strategy analysis for theColombian Red Cross

Global Strategy	Pillars	Principles	Imperatives
Provide humanitarian assistance with impartiality	Prevent and alleviate suffering and lack of protection	Save lives through integral risk management	Disaster risk reduction
			Response for giving an opportune and effective action
	Protect life, health of people and their dignity	Enabling a healthy and safe life	Prevent and alleviate suffering and lack of protection
			Contribute to the access and adequate use of quality blood
		Promotion of health and social welfare	Strengthen resilience through health care programs
			Strengthen health services in the Red Cross
	Encourage volunteer work and service availability	Development of a simple and functional organizational model	Implement an agile and harmonious organizational structure
			Have standardized process and procedure manuals
		Have enough human talent, competent, open to change and committed	Strengthen quantitatively and qualitatively humanitarian staff
			Promotion of a positive organizational climate
		Guarantee adequate infrastructure to the network	Ensure physical infrastructure and equipment availability
			Improve connectivity through ICT
	Promote human rights, international humanitarian law and the fundamental principles of the Red Cross	Promote social inclusion and a culture of nonviolence and peace	Strengthen the normative framework for humanitarian action
			Guide the training processes towards these principles
			Strengthen comprehensive social management
		Strengthen the dialogue unit with external actors	Strengthen the integration of plans, programs and projects
			Create strategic partners to improve the humanitarian response

Civil Defense

The same process as performed for capturing the Civil Defense strategy, the results for this analysis can be found in the mission statement is presented next:

Colombian civil defense prepares and executes the response to emergencies and natural or anthropic disasters, participates in social and environmental rehabilitation throughout the national territory to contribute to peace, human rights and multilateral commitments in case of international requirement

Although the strategy of this entity is smaller in terms of scope, you can also see elements that seek coordination. In the same vein as the previous entities, they also have an interest in the use of information technologies and the modernization of the management system, and the creation of national and international agreements.

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Table 4. Strategy Analysis fot the Colombian Civil Defense

Global Strategy	Pillars	Principles	Imperatives
Prepare and execute the response to an emergency or disaster	Prepare and execute response	Expand the coverage and quality of emergency disaster training	Strengthen training for the prevention and care of emergencies and disasters
			Improve infrastructure for training
		Promote strategic alliances or cooperation agreements	Celebrate and implement national and international agreements to training in emergencies and disasters
		Implement the use of ICT Modernize the management system	Implement the use of ICT
			Modernize the management system
	Participate in social and environmental recovery	Improve the opportunity and quality of the emergency and disaster management process	Specialize rescue groups
			Streamline the emergency response system
		Consolidate social and environmental rehabilitation	Direct the environmental training and social action programs

Within the revised guidelines, only two elements, one from the UNGRD and the other from the Red Cross, talk about the articulation of the different entities of the SGNRD and the integration of plans between them. The most common initiatives are on the side of the implementation of information technologies in their operation. In general, for the three agencies it can be observed that the exchange of information is given by a common guideline which is the creation of private public alliances.

Other common initiatives within organizations is to improve their management processes and risk mitigation, however, this last is not presented as a joint plan, in addition to generating efficient organizational structures.

CONCLUSION

The elements in this chapter leave several issues for the humanitarian supply chain research framework. In particular how the humanitarian supply chain's structure can be modelled being adaptable for multiple scenarios. The characterization of the humanitarian logistics' network acquires relevance, given that it allows to understand the flows that appear in the aftermath of a disaster. As well as understand how the multiple actors that intervene in humanitarian logistics interact with each other.

The interaction of the agents that make up the humanitarian network produce particular emergent results that in real situations have proved not to be foreseen by the simulation models, largely due to the degree of abstraction of the interacting agents of the system. On the other hand, one of the aspects identified is how in the Colombian case institutions have adapted throughout history considering emergency situations in the past.

The principal elements presented in the chapter are: i) the existing differences between traditional and humanitarian supply chains, ii) the humanitarian supply chain's structure, iii) the process that take place in the humanitarian supply chain and iv) coordination in humanitarian supply chain. All of the above from the general logistic network point of view and considering the special case for Colombian humanitarian logistics.

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Finally, the core of the chapter corresponds to the characterization and diagnosis of the Colombian humanitarian supply chain, and how it considers strategies in relation to the humanitarian agencies that compose it. On the other hand, how the different entities that are part of the humanitarian logistics network in Colombia will interact with a series of elements that differentiate them from supply chains in other countries and areas. Additionally, the different entities that are part of the humanitarian logistics network are characterized considering their principles, functions and roles; both in the prevention and preparation, and in the response after the materialization of a disaster.

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Chapter 14
Constructing a Resilient Distribution System Using Cabotage:
Building a Resilience Delivering

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ABSTRACT

After a major disaster, commercial supply and delivery activities suffer serious problems because transport infrastructures can be damaged, destroyed, inactive, or restricted. During the first months of 2017 in Peru, the phenomenon of the coastal El Niño increased rainfall along the coast, which caused the blockage of numerous roads and bridges that affected one and a half million people. This situation caused many companies to halt their distribution logistics operations. For this reason cabotage was considered to replace traditional transport to merchandise by road. Maritime cabotage consists of the transport of loads and people considering short distances and low-medium loads. This research tackles increasing resilience distribution using cabotage as an option to transport merchandise in post-disaster scenario through a Peruvian processed food company based on empirical evidence. Results show that cabotage service is in process to mature in Peru. The company analyzed showed positive results during the coastal El Niño 2017 phenomenon.

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INTRODUCTION

Peru is one of the countries that will be most affected by the most negative impacts due to climate change due to its complex geography, this added to the state of its coastal cities, which are characterized by informal housing constructions, high population density and limited road infrastructure, create conditions of high vulnerability for their inhabitants and mass consumption companies that operate there. In 2017, Peru was impacted by El Niño Costero, a phenomenon whose effects are like those caused by El Niño phenomenon, that is, a significant increase in rainfall on the coast, which in turn caused landslides (called "huaicos" in the Peru), as well as overflowing rivers, etc. Northern regions of the country have the worst fall in 33 years of the regional GDP according to El Comercio (2017), impact per region was; Piura (-3.6%), Cajamarca (-2.9%), Áncash (-2.6%), La Libertad (-1.1%) and Lambayeque (-0.2%) and Tumbes (0,1%). Daily losses record was valued at US $ 31.2 million (Gestión, 2017). The climatic phenomenon mentioned from the point of view of goods' distribution affected many companies because of blockade of roads by the overflow of rivers, destruction of bridges by the force of the flow, villages flooded by the overflow of the rivers, etc.

The supply chains of mass consumption companies characterize by having multiple supply and supply points (producers, distributors, suppliers and logistics operators) were paralyzed or limited in their activities. The main food companies operating in the area had to put into operation various actions for keeping their operations, which already depleted by product losses such as lack of inventory at local distributors, stock breakages at local retailers, etc. On the other hand, the population was affected because it lived in a short time shortage of food in the different localities. All of which stimulated the search news solutions to continuing distribution of merchandise. This scenario of crisis described, motivates the company-case analysed in this paper, to seek new solutions for the distribution of merchandise in the Northern region, finding in cabotage an alternative to replace the traditional means of transport used under normal conditions.

Poor performance of the commercial supply chain due to disruptive events has been studied by several authors (Martha et Vratimos, 2002, Semchi-Levi et al., 2002, Helferich and Cook, 2002, Christopher and Lee, 2002, Chopra and Sodhi, 2004; Sheffi, 2005). They have highlighted the exposure of unreliable supply chains due to the configuration and design of networks that are vulnerable to risks and threats to unpredictable events, for example: natural disasters (Reed and Simon, 2011: Fujita and Nobuaki, 2012, Reed and Simon, 2014), shortages of parts (Latour, 2001, Rice, 2005), strikes (Treece, 2014; Pender, 2014), terrorist attacks (Thurm et al ., 2001), unforeseen changes in demand (Barrett, 2001), failures in computer services (Koch, 2004), illicit activities (Lemos, 2004), equipment failures (Kleindorfer and Saad, 2005; Olson, 2011), bankruptcy or poor state of partners' finances (Macalister, 2002).

This paper tackle on how increase transport's resilience of a mass consumption company under crisis state because the coastal El Niño 2017, in the Northern zone of Peru. It is presented through a company experience analysed which run an alternative transport means called cabotage, which let it keep its distribution operation into the most impacted Peruvian regions previously mentioned. To recovering company-case's learning experiences case method is used exposing its supply chain disruption during the disaster. This means of transport is not the regular because it is one made by boats of low load capacity in short routes instead regular road transport used for companies.

The article is organized as follows; first, it is present the background about transportation operations of mass consumption companies and in particular about company-case under coastal El Niño 2017

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in Peru,, then it is shown the cabotage as an alternative means of transport to those used currently in Peru by mass-consumption companies to distribute their merchandise, it is analyse its possibilities and limitations to be used in a disaster context, after an analysed about how transport resilience reach being improving is shown using a interview run to company-case distribution manager in a theorical structure propose in the literature to analysed how resilience is construct it. Finally, results, recommendations and future research directions is presented.

BACKGROUND

In the past, merchandise distribution done by companies not considered the relevant factors such as the control and management of inventories, this caused little productivity and high costs in the transport of goods. Currently, one of the fundamental objectives of logistics managers, in supply chain operations, is the physical administration of inventories. As Bowersox (2007) mentions today the importance of material handling and physical distribution, for companies is unquestionable, thanks to this it possible achieve a positive effect on money income, since short processing cycles of orders, reducing the accounts receivable periods (Langley, C. John Jr., 2002). Also, it is stated by Gonzales-Feliu (2013) in outbound logistics planning and management, decisions on the transport schemes and their effectiveness have direct on both operational costs and service quality. Therefore, it is important to adapt transport networks to the different logistics and territorial constraints. In Peru, the most used means to carry out the transport of merchandise in business is the road, port and rail, being the most important for local transport, the land medium by the broad geography of the country and low cost of freight. Even though the current regulations for this activity place the Peruvian state as the governing body of these activities (Mintur, 2017), some operators believe current regulations present ambiguities and unclear roles that companies must deal for provide the cargo service (PITS, 2018).

The coastal El Niño, is a climatic phenomenon consisting of warming of the marine waters in the Peruvian coasts due to the loss and weakening of the cold air currents (called anticyclone of the South Pacific) that cross the Peruvian coast (Ingemmet, 2017), direct consequence of the occurrence of this phenomenon is the excessive increase in rainfall, which causes the interruption of routes to coastal regions, especially those in the north of the country, as occurred in 2017 (Correo, 2017). Many economic sectors of the country were affected (international trade, mining, agriculture, and SMEs) by the increase in logistics and transport costs, particularly in the agricultural sector there were large losses, nationally disappeared 50514 Ha of cultivation, while 22674 irrigated canals were destroyed, the region with the most lost cultivation areas was La Libertad with 11557 Ha (Peru 21, 2017). This forced mass consumption companies to use new routes to supply their products to their customers, among the means of solving this problem was considered using air and cabotage transportation, which became feasible solutions to reach to the affected areas (Semana Económica, 2017). Being privileged among these alternatives the use cabotage for the competitive costs they have. According to (UNCTAD, 2017) maritime cabotage is defined as being transport of (passengers and) goods between two ports located in the same country, Maritime cabotage is a means to providing different services, such as domestic and intra-regional maritime transport services as well as transhipment. Providing these services requires different types of vessels (including small container vessels, ferries), which serve as feeder vessels, and tugs.

In this paper, it will be analyse the case of a Peruvian food processing company, which has operations throughout the South American continent, which decided to use cabotage during the coastal El Niño

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2017 event as an option to transport goods from its main warehouses in Lima (capital of Peru, located in central coast of the country) to the coverage areas of its market in the Northern regions of the country affected by the disaster; Trujillo, Chiclayo, Piura and Chimbote.

MAIN FOCUS OF THE CHAPTER

Theoretical and Methodological Framework

Because of globalization, the importance of information exchange, telecommunications, and transportation has increased; fulfilling these a fundamental role to achieve an effective circulation and distribution of people and things (Moiraghi de Pérez, Liliana E., 2003). Transport in mass consumption companies is important since it materializes the supply using logistics chains, which allow the physical distribution of the products (Antún, 1993). On the other one hand, there is the logistics factor of distribution, which are the steps to follow to move and store a product from the supplier stage to the customer in the supply chain and what happens between each pair of stages (Chopra, 2008, Gonzales-Feliu, 2013). Within it involves the planning of routes, selection of the type of transport, the location of the distribution and coupling centres. Therefore, it is sensible to say that distribution is the strategic part of an order delivery system. Moreover, transport is defined as the main activity aimed to move raw materials and products from a point of origin to a place of destination (Anaya, 2009). This seeks to meet the need to supply mass consumption products at the corresponding destinations such as markets, supermarkets, warehouses both in the capital and in the provinces (Arreola et al., 2013). Finally, if we differentiate it with the distribution, the transport is the execution of the planning of the routes carried out in the distribution (Calderón, 2017). Also, it is important to indicate that how logistics is done in the company has a great interest in estimate the economic outcomes are resulted. An important percentage of the cost of the final product is the cost per distribution, which is around 22% in companies that own their own fleet; and between 14% -15% on average in companies that outsource it (El Peruano, 2018). Likewise, a constant improvement in the management of transport, reducing its costs and choosing the right type of transport, opens the possibility of covering markets that used to be distant, because they could not support a high freight cost, that would do a company less profitable.

Transport in Peru

There are several options for moving merchandise depending on the type of merchandise, for example, for general, loose, bulk or containerized cargo, also depending on the costs that are requested. Thus, within a global economy where exportation and internal transfers are encouraged, within a country, in the mass market there are three most used transport options (Álvarez, 2018): land (including rail), maritime, air. The combination of any of them corresponds to what called a multimodal transport.

- **Air transport:** It is the one with the highest freight cost of the rest of the means of transport, consisting of the shipment of products by airplanes, light aircraft and cargo planes. It is usually used for luxury goods and pharmaceuticals, or for small volumes that require an immediate dispatch prompt (Álvarez, 2018). An example of a fast transfer is the shipment of asparagus,

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which still represent 70% of shipments by this airway, according to the General Direction of Civil Aeronautics of Peru (DGAC).

- **Maritime Transport:** It is the most used medium in world trade, it represents 80% of the volume of world trade (UNCTAD, 2013). It is the most used option in the transportation of large quantities of products. In Peru, the figures show a growth of 23.1% in the cargo traffic of 2017 compared to the previous year (ENAPU, 2017). Maritime transportation let exporters and importers trade large volumes of merchandise at a low cost, taking advantage of economy of scale in reasonable terms (El Comercio, 2017). In the case of shipments to cover short trips between the country's ports, cabotage is considered as an option (Gestión, 2018)
- **Ground Transport:** It is the most used alternative in developed and developing countries like Peru. The existence of a wide road network allows door-to-door collection and delivery. Although it is usually the most economical, however, it is required to reach certain quantities of cargo to make it competitive compared to local transport options with light-weight vehicles. If we consider only the shipments of merchandise within Peru, it is estimated that 99% of national cargo is transported by road and railroad which means that this transport sector is strategical for economy and it must be improved to avoid excess logistic cost (El Peruano, 2018).

Transport and storage of merchandise are directly linked to the proper management of inventories. Especially for mass consumption companies it is important to maintain a quantity of warehouses with which they can supply; Likewise, it is vital to identify how the elements of their respective supply chains are connected, since any interruption in any of the traditional communication channels can lead to a failure of the entire system (Figliozzi, 2010). That is why in contexts where the route which is connect with certain regions is blocked, it is important to identify alternatives so as not to lose presence and positioning in the affected areas. As mentioned by Caniato et al., (2003), to arrive at this, the causes of the interruption in transportation that may arise in the system must be identified, for example: interruption due to natural disasters, terrorist attacks, lack of capacity within communication networks, etc.

Transportation During the Coastal El Niño 2017

During 2017, Peru was affected by the coastal El Niño, which caused according to the official reports of INDECI (National Institute of Civil Defense of Peru), a total of 162 people died 500 were injured, 19 disappeared, 141000 victims and almost one million affected nationwide; being the most affected regions Tumbes, Piura and Lambayeque. The main sectors affected were livestock, agriculture and transport. The coastal El Niño significantly affected the roads of Northern coast of Peru, causing problems in the availability of transport (both for passengers and people) since certain routes were declared inaccessible. According to the INDECI reports, 4391 Km of roads were destroyed by the phenomenon, of which 2216 were from the Lima region. In Piura, the regional director of Transportation and Communications explained that between 70 and 80% of the 1200 Km of existing roads in the region had deteriorated, causing damage to local businesses. An example of this was the rise in food prices due to shortages, for instance lemons, an essential product in Peruvian popular cuisine, which went from $ 1.0 to $ 8.0 per kilo (El Espectador, 2017). The air transport sector was also affected by the increase in demand, likewise as land routes they were no longer accessible, that cause the price of tickets increased, there were cancellations of scheduled flights by domestic airlines, as well as reprogramming and delays departures.

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Cabotage as a Means of Transport

Cabotage in Peru is done with restrictions, because it is required to prove that only vessels with national flag can do it (Caro, 2017). However, this activity at the regional level is an instrument for improving services to support production and economic growth and the quality of life of the population (Sánchez, 2005) because it becomes part of the supply chain from various local companies. According to McBride (2013) regarding the use of cabotage and its limitations to developed in Peru says; "The problem arises, because we do not have our own merchant fleet and because the law prohibits Peruvian companies renting foreign-flagged vessels, which means that almost all of our foreign trade is forced to use flag-of-convenience vessels (a ship whose owner is from another country, but uses the registry of national ships that gives maximum tax advantages and requires minimum commitments), which originates freight payments to foreign companies for around US $ 2,000 million annually". Since the coastal El Niño caused roads to the Northern regions of the country were interrupted (Correo, 2017). According to Caro (2017), the rains and floods generated bridges collapsed (mainly in Chimbote and Virú) they were part of the planned route for the supply to the Northern regions, this forced companies to use new routes to supply their products to their customers. This interrupted the distribution of products, resulting in shortage in the company's logistics network. Alternative routes initially were considered; Libertadores, Carretera Central, Marginal and Olmos, however they were unattractive due to their high cost and the risks to be exposed to the recurrent landslides which blocked these roads. Other options were explored, such as air transport or cabotage, and the use of cabotage clearly stood out between the two (Semana Económica, 2017) due to its competitive cost and easily operation. Initially it was thought to carry out the cabotage with ships of the Navy of Peru, but they were not able to carry cargo containers. Subsequently, it was approval a temporary permission of ten foreign-flagged vessels to provide the cabotage service. This let an average of 50 to 200 containers were transported to the Salaverry and Paita ports.

The Proposed Case Study

The massive consumption company-case studied in this work, leads the Peruvian market of processed foods, elaborating and commercializing; noodles, cookies, flour, oils, etc. It operates in several Latin American countries (Argentina, Colombia, Brazil, Chile and Ecuador). The company supplies the demand in the North region of Peru by means of ground transportation arriving through the Pan-American Highway. The phenomenon of the coastal El Niño in 2017 caused heavy rains that caused increase course of the rivers and landslides in ravines. The company met with a group of companies from the food sector to evaluate the national situation, and likewise to evaluate the possibility of using cabotage as an option for transport, analysing the different aspects and restrictions of the activity currently exist to their use, such as legal barriers, over cost operative and deficiency of port infrastructure. It was concluded that the handling and wastes generated were very significant since there were no adequate ships for the operation. This forced coordination between the representatives of the companies and the government authorities, to find a way to implement this service. The result of this joint work allowed to enact the emergency decree of the Council of Ministers of Peru, DU 007-2017 (MTC, 2017), to create the legal conditions to support the execution of this option.

To recover the experience of the company in the use of cabotage as an option for the transport of the merchandise of the company, during the crisis described, for this work it was decided to carry out an interview with the Distribution Manager of the company, Eng Jorge Caro Paccini, whose answers were

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Table 1. Evidence of the construction of resilience in the distribution network for the use of cabotage

	Question	Enterprise Response Expert (Evidence)	Constructs
1	How did the coastal El Niño 2017 impact you?	*"... it affected us a month and a half, warehouses were flooded, the manoeuvring yards were damaged. The normal supply to the northern regions of the country was cut off. Local inventories were consumed. The freight surcharge in the distribution was $ 605,000…"*	Communication and information sharing to enhance collaboration
2	What preventive measures were taken?	*"... With 22 warehouses in the country, redundancy is sought in emergency situations. In situations such as El Niño company supplied in advance and the inventory is being renewed depending on how the event develops. Alternate routes for distribution are also handled…"*	Sourcing decisions and contracts for enhancing collaboration
3	What corrective measures were used?	*"... In the warehouses of Piura since the rains are frequent in summer, there is a drainage system in the maneuvering yards. During the coastal El Niño, we proceeded to replace or buy water pumps to drain the patios...."*	
4	What were the main actions taken to mitigate the impact?	*"... the cabotage service was launched...."*	
5	How do you come to determine that cabotage was an option?	*"…the transit time in cabotage is much smaller than one used in the road, for example, the case of Salaverry this is 14 hours by land and 2 days by cabotage. It was possible to overcome the limitations with respect to the current norms, port services and freights…"*	
6	Other companies joined the use of cabotage service?	*"…the company shared with others the cabotage service access information, also its containers for cargo shipment. The company believes that, in times of crisis, collaboration helps create healthy competition…"*	Trust to enhance collaboration

analyzed to highlight those learnings' experience lived in the field, feasibility of cabotage as a means of transport of companies for cases where their traditional means have been exposed to natural disasters of great magnitude that have seriously affected their traditional distribution network. To find principal drivers related to the process to construct resilience, it is chosen the work of Datta (2017) for analysis distribution's resilience construction using the cabotage. How organization must adapt their usual work practices; planning, control, coordination, etc. in the field (Madhusudan, 2011). Datta proposes three mechanisms to analyze how resilience is built when disruptive events are present. These are: (1) communication and information sharing to enhance collaboration, (2) sourcing decisions and contracts for enhancing collaboration and (3) trust to enhance collaboration.

SOLUTIONS AND RECOMMENDATIONS

Poor performance of the commercial supply chain in several cases of major disruptive events such as natural disasters have shown the vulnerability in which many companies are faced with disruptive events of operations for which the design of the supply chain system was not prepared. During the period of crisis experienced by the coastal El Niño 2017 in Peru, it was possible to identify a series of problems that avoided or limited the use of cabotage as an option to be used as means of transportation (legal norms, port services, etc.) by companies with local supply networks in regions where the impact of road closures, falling bridges, etc. causes the cut off of goods replenishment to markets where mass consumption companies serves. These problems achieve overcome, through the coordination and collaboration between the authorities and the companies, led by the company studied in this work.

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The cabotage service was carried out with adaptation and coordination requirements by company organization, successfully reasonable levels of operation costs and services were achieved, considering the scenario of crisis experienced. Thus, the company re-trigged distribution and supplying of goods to its customers in the affected regions in northern Peru. The experience gained let incorporated new processes and protocols that would be activated by the company in emergencies. This experience has allowed us to build a more resilient and robust distribution network in the face of disasters. Likewise, the cabotage service has been increased in the different ports of the country (ENAPU, 2017).

The exposure to risks from origin natural, economic, social and political, have made the management of the supply chains pay attention to the uncertainty, dangers and exposure under they find themselves; that is the modern business theory (Drucker, 1994) which demands a "change management", assuring new capacities to be competitive; agility, robustness, resilience, adaptability, etc. These configure what Drucker predicted, "... change is the norm" (Drucker, 1999). Therefore, new strategies, policies, tactics and means must be considered to implement a resilient logistics, where cabotage is an economic, competitive and robust transport option, which can be used in periods of crisis, originated for exposure to disasters of great magnitude, such as the one experienced in 2017.

FUTURE RESEARCH DIRECTIONS

It was possible to identify a series of problems that could overcome during the period of crisis experienced due to the coastal El Niño 2017, through coordination and collaboration between authorities and mass consumption companies. These problems generated issues that have created a baseline of challenges and research to be developed: a) cabotage is not currently an permanent option as a means of transport for distribution, due to legal issues governing the use of the service; accordingly a more flexible and robust legal frame to merchandise transport must developed, b) there is no port infrastructure to make the cabotage service profitable; furthermore new investment in ports must add cabotage's requirements, considering its multimodal capabilities integrated to other mean of transport, c) there is no Peruvian merchant marine so there are no Peruvian flag vessels and if there are very small, furthermore Peruvian government must create conditions to develop merchant marine, ensuring services must competitive with land transport.

CONCLUSION

The cabotage, service to shipping of low and medium load between local ports, is presented as a feasible option, in the process of development and consolidation for cargo transport in crisis situations caused by disasters that significantly affect land transport in Peru. The learnings obtained in 2017 by the company under study overcoming the limitations and problems presented. Learnings allowed the construction of a more resilient merchandise distribution; the increase of this capacity could be identified from the evidences had identified in the experience of the distribution network in the northern region of Peru affected by the coastal El Niño 2017 in Peru. Evidences was obtained by the interview made to the person responsible for the distribution operations of the company analysed.

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Chapter 15
Evacuation Plan in the Case of an Earthquake for a Peruvian Urban Slum

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ABSTRACT

Lima is a city of 10 million inhabitants, and 60% of its population lives in slums settlements. Due to its location in the Circum Pacific Belt of Fire, this is a high-seismic activity area. Despite this fact, there is a serious lack of urban planning and natural disaster planning. El Progreso sector located in Carabayllo, a Lima district in Peru, was selected as the case study because it is one of the slum settlements with the highest potential risk as it is located in a basin surrounded by hills due to the effects of informal constructions (such as ceilings). Filled with rocks and walls, their slopes have suffered much more deterioration than in other hillsides. In addition, this area is prone to debris avalanches, rock fragments, debris flows, among other geologic hazards. The proposal presents a mathematical model based on analyze a risk function through inhabitants' time evacuation, which may replicate in different urban context in real time in order to guide and ensure the most efficient evacuation.

INTRODUCTION

Peru is located on an area of high seismic activity, called "Pacific Ring of Fire", in which approximately 85% of worldwide seismic activity are present (Tavera, 2014), for this reason Peru is permanently exposed to earthquakes, e.g. in Misti volcano area, Arequipa on the XI Mercalli Modified scale (INDECI, 2006). During a lapse of 325 years, from 1552 to 1877, there was a record of fourteen large-scale earthquakes, of which at least six were greater than 8 on the Richter scale (INDECI, 2004).

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On the other hand, Lima is the capital of Peru, its surface represents 0.22% of the Peruvian territory; however, it concentrates 32% of the national population (INEI, 2014). Additionally, destructive earthquakes have shaken the Peruvian capital in the years 1908, 1932, 1940, 1966 and 1974, with magnitudes varying between 7.0 ° and 8.2 ° in the Richter scale (Kuroiwa et al, 2002). Within Metropolitan Lima, Carabayllo districts is some larger of its 43 districts, within a slum called El Progreso, as shown in Figure 1.

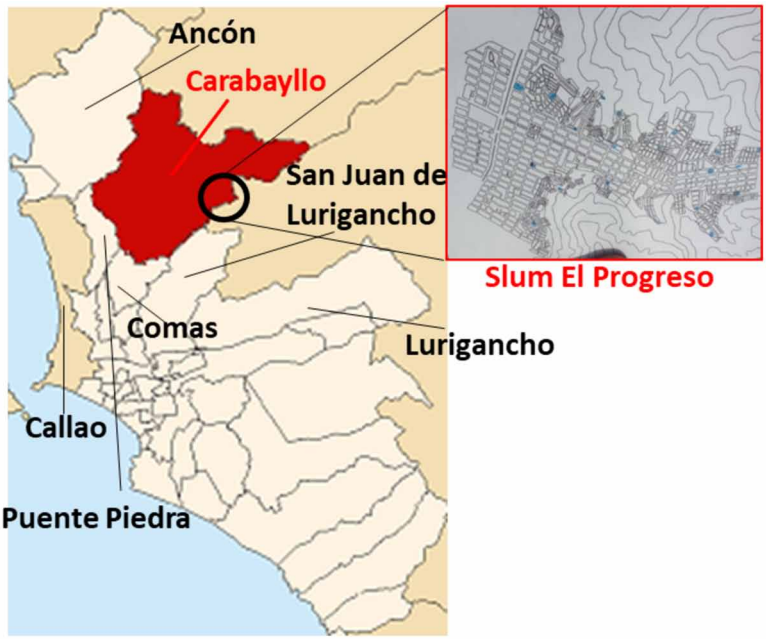
Slums is as human settlements that meet the following characteristics (UN, 2003): inadequate access to drinking water, inadequate access to sanitation and other infrastructure, poor structural quality of the houses, overcrowding and state of residential insecurity.

This work is organized as following; in the section 2 there will be a review of the literature on evacuation for pedestrians, in the section 3, the analysis of the diagnosis of the area studied, in the section 4, the development of the model and its recommendations, in the section 5, future directions for research and the section 6, conclusions.

BACKGROUND

Pedestrian evacuations play a crucial role (Hoogendoorn et al, 2014) under post disaster, because they allow reducing the number of victims and injuries (Bohannon, 2005), by facilitating that victim abandoning the areas of greater danger (Horner et al, 2011). The impact of a disaster can be road blockages, stampedes, buildings collapse, fires, etc (Yamamoto & Li, 2017). The types of evacuation are classified by the size of the area of the danger zone (Fang et al, 2012), and for the time of warning before the disaster (Chiu et al, 2007), independently if the latter are by natural or anthropic origin.

Figure 1. Geographical location of Slum El Progreso



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There are a relation among size area of danger zone and some small, medium and large-scale evacuations. Small-scale evacuation is an evacuation in a limited area, such as in complex or high-rise buildings (Fang et al, 2012) or crowded places like shopping centers or theaters (Pelechano et al, 2008). Medium-scale evacuation is defined as evacuations to go out from buildings to emergency shelters. For example, the "Mesa Redonda" fire killed 277 people, 247 were injured, of which 137 suffered burns, 45 asphyxiation and 38 polytraumatisms, 180 were reported missing, the material losses reached about ten million US dollars (Arce-Palomino, 2008), and this happened because of a nonexistent planning of disaster management. Another example happened in the 9/11 attack (twin towers) the danger zone was Manhattan and residents were asked to leave the city even though only a limited number of buildings had collapsed (Chiu et al, 2007). Finally, large-scale evacuation is defined as that which is carried out considering a massive evacuation between different districts by different types of disasters, such as, the arrival of a hurricane of great magnitude (Fang et al, 2012).

For the case of the notice time, the evacuations are divided by being of previous warning and without warning (Chiu et al, 2007). In case of prior notice evacuations, are those that have a warning time of between 24-72 hours (Wolshon et al, 2002), allowing risk management agencies to determine a priori evacuation strategies based on the expected spatial-temporal impact of the disaster. Examples of prior notice evacuations are events for the arrival of hurricanes and frosts. On the contrary, an evacuation without notice occurs when a large and unexpected incident occurs; in this case, the evacuation is carried out, without having obtained enough information about the disaster (Zimmerman et al, 2007). When an evacuation without notice is required, it is recommended that a pre-conceived evacuation plan be executed immediately. Examples of evacuations without notice are earthquakes, tsunamis and terrorist attacks. For all these reasons, traffic control and routing strategies need to be updated quickly and frequently according to traffic conditions at the time of evacuation.

It should be noted that, for each type of evacuation, there is a series of events that make up the total time of the evacuation. Cuesta (2016), found the composition of the time applied for the case of fire; this composition can be adapted to other types of disasters. Through a timeline model, it is considered that the total time occurred during a disaster (RSET) is divided into the times of; detection, alarm, pre-evacuation (which is divided into recognition and response times), and travel. Travel time is the time needed for evacuees to walk to safe areas. The total evacuation time will depend, in large part, on the type of evacuation. For example, if the evacuation is on a large scale, the travel time will be longer and if the evacuation is a prior notice, the pre-evacuation time is minimized.

An example of the treatment of large-scale evacuation and without notice found in the literature is that carried out in the Metropolis of Tokyo (Yamamoto & Li, 2017). When a seismic disaster occurs, a guide leads inhabitants to the temporary evacuation areas, using the routes found on smart maps, using the Disaster Imagination Game (DIG), later they are informed of the situation of the damages caused. Primary and secondary schools, as well as parks, are assigned as evacuation areas according to each neighborhood association. After verifying the damage situation, if the place of temporary evacuation is considered dangerous, a second evacuation will be made to a refuge of wider area. The Tokyo Metropolitan Government assigns sites that have more than 10 hectares and cannot be affected by the radiant heat of fire. In Figure 2, the disaster prevention map of the Metropolis of Tokyo is presented, which is available online (Tokyo Metropolitan Goverment, 2018).

Within this map, there are 2 types of shelters which are symbolized as follows:

Temporary shelters are defined to provide urgent intervention (e.g. people injured) meanwhile permanent shelters are defined to arrange regular service that will supply to affected by disaster people

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Figure 2. Prevention map of the metropolis of Tokyo

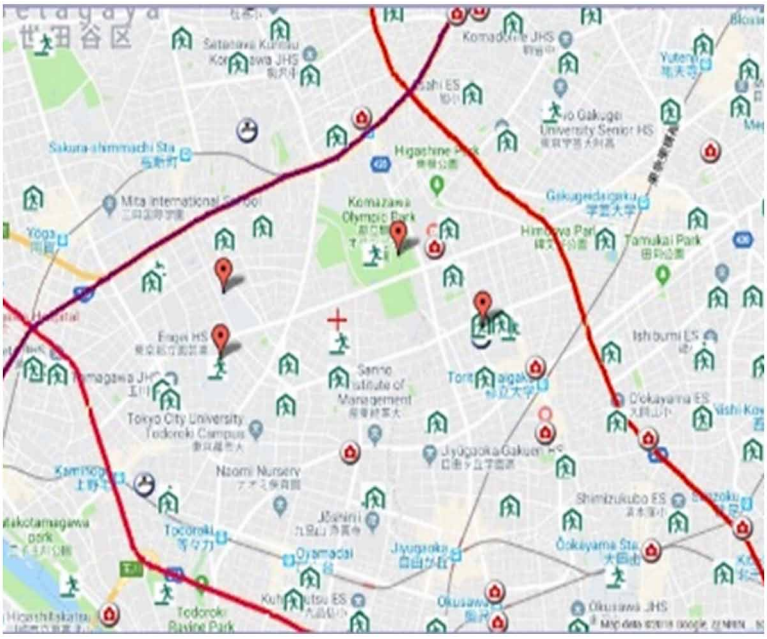


Figure 3. Legend of the metropolis of Tokyo



(e.g. inhabitants without housing). Not necessarily in all evacuations will be required to make use of permanent shelters. It will depend on the intensity of the event and the strategy to follow.

Mathematical Models of Evacuation

To evaluate and determine an original proposal, we reviewed previous literature about pedestrian evacuation models for cases of natural mass movement disasters such as earthquakes, landslides, avalanches and other ones related to geology.

Zhang et al (2015) attempted to measure evacuation risk in different scenarios through a function that considers eight pre-existing limiting factors in the community: road width, slope of nodes, safety intersection, road resistance coefficient, hazard of building, backflow of pedestrians, parking of illegal vehicles and traffic flow. This mathematical model can guide emergency evacuation in real time. While Pelechano et al (2008) & Bellomo et al. (2016) sought to simulate evacuation of buildings evaluating the possibilities of use and limitations of commercial software, considering factors within dynamic processes associated with the psychology and physiology of pedestrians in the models. On the other hand, Chiu et al (2007) presents a network transformation approach with specification of demand for an evacuation

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model without notice as a model of dynamic traffic assignment considering the area of the danger zone, evacuation destinations, final evacuation node and transshipment nodes (connectors). Yao et al (2013) considers an evacuation through transport networks in an uncertain environment, focusing on the uncertainty of demand to prevent loss of lives and property. On the other hand, Yi et al (2007) describes an integrated distribution model to coordinate logistical support and evacuation operations in response to disasters, where logistics coordination involves the selection of zones that allow maximum coverage of medical needs in affected areas, the proposed model is a mixed multi-commodity network flow model that considers vehicles as whole variables instead of binary variables. Finally, Bretschneider (2013) & Santos et al. (2004), presents an extensive summary of the evacuation literature of urban areas, where the models of linear programming of mixed integers and presented heuristic algorithms were developed for evacuation problems, which have been tested and validated. The main reason of why this model is applied to the reality of a Latin American country is because there are no previous studies in case of an earthquake in a slum, not even in the first world countries.

Issues, Controversies, Problems

In Peru, 34.2% of the population lives in slums, a high percentage for Latin American where Colombia, Brazil and Ecuador attaint respectively 13.1%, 22.3% and 36.0% (DATA WORLDBANK, 2018). The slums in focus is named El Progreso, belong to Carabayllo district. This slum has an approximate population of 21160 inhabitants, who mostly live in hills like one shown in Figure 4.

First problem of community is the non-compliance with the minimum standards recommended by Sphere Project (2011) so that a home can be considered as adequate, which are the following:

1. Sufficient space and protection against cold, humidity, heat, rain, wind and other health threats, such as structural hazards and disease vectors.
2. Availability of services, facilities, materials and infrastructure.
3. Affordability, habitability, accessibility, location and cultural adaptation.
4. Sustainable access to natural and common resources, to drinking water, to a source of energy for cooking and heating houses and for lighting, to sanitation services and hygiene facilities; means to conserve food, to dispose waste, to a sewerage system, as well as to emergency services.

Figure 4. Example of households in the El Progreso slum



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5. Proper location of settlements and housing should facilitate safe access to health care services, child care centers and other social facilities, and opportunities for livelihoods.
6. Construction materials and policies related to construction of houses must adequately allow expression of the cultural identity and diversity.

The second problem in El Progreso is there is only 0.1 m2 of green areas per person when Sphere project suggests 3.5 m2 per person as minimum area per person housed and World Health Organization (2010) recommends 9.0 m2 per person.

High slopes of hills generate another problem in some earthquake case, detachment of fragments of rocks located in higher zones could would fall down to reach houses, thus it will generate a latent risk by movement of mass, aspects that will be detailed in the risk chapter. In Figure 5, an example of the location of the rocks around a house is shown.

Another problem it is postponement by national authorities to resolve urban policies on security at suburbs, even though these areas are the most affected in case of natural or anthropic disaster. This happens because of fear of government to legitimize informality around land property of inhabitants and high cost of formalizing them. Due to this, main problems presented, an evacuation plan due to an earthquake is proposed in this study to reduce the risk, even though the best a priori solution is relocation. The reason why it is not considered in this study is due to the high costs for the government of relocating all the people who are in areas of high seismic risk, which for the case of El Progreso is about 85% of its population, estimated in 18000 people.

It should be noted that, in the case of the El Progreso, the type of evacuation due to an earthquake of great magnitude proposed in this paper is a medium-scale type without warning, because pedestrians need to be evacuated from their homes to safe points within the danger zone and is without warning, because you cannot predict when an earthquake will occur, in addition that its effects occur immediately.

Preliminary information on territory was obtained through a cadastral map, such as total number of homes and inhabitants registered up to 2016. To determine evacuation centers, as recommended by

Figure 5. Fragment of rocks on top of the houses in the El Progreso sector



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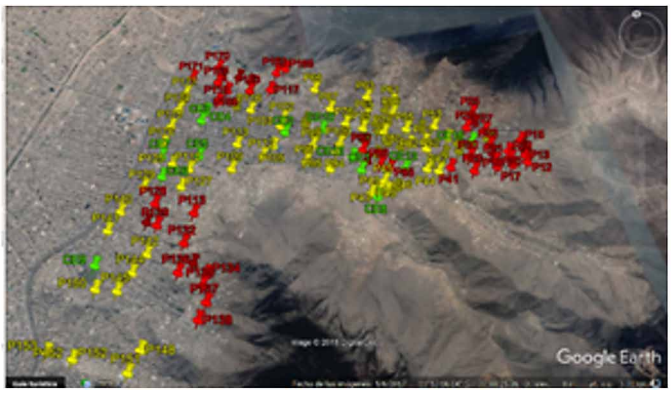
Sphere Project, where it is mentioned that it is essential to take into account the measures that affected population takes to get temporary or permanent accommodation using their own resources and capabilities, Google Maps was used to measure the total area of the existing sports fields and the available green areas. It is chosen CGCOII (2018) recommendation about occupation capacity in 0.25 m2 per foot, this precise people standing with possibility of carrying wounded people. Thank to interview done in field is know this slum green and safe areas to be used are scarce; 15 in total considering an educational center.

The total capacity of evacuation points was determined achieve to potential capacity to 17047 inhabitants, which is below the demand of the existing population (21160 inhabitants), this 4113 pedestrian gap, corresponds to the number of people who could not be evacuated due to the limitations of the capacity of the evacuation points. To overcome this situation, two schools and a clear land will be added as evacuation centers, obtaining, in this way, a total capacity of 21620 inhabitants. Even though, there are probabilities these two schools collapse in an earthquake, but, for the simplicity of this model, it is assumed that this will not happen. In Figure 6, initial nodes (temporary evacuation) are shown in yellow and red, identifying those places where pedestrians begin to evacuate, if they are in danger zones due to mass movement, they appear in red and the evacuation nodes they present in green, the intermediary nodes that are nodes where pedestrians simply transit momentarily also appear in yellow.

To quantify the number of homes exposed by the hazards of mass movements, it was founded that 627 houses are in a high slip hazard zone, 632 houses in a medium slip hazard and 442 houses in a low slip hazard.

Subsequently, Google Maps was used to determine the average width of streets. A sample of 30 data was taken, obtaining an average of 6.7 meters. In the case of slopes, the contour lines presented in GPS Visualizer were used; the difference in height between 2 points on the distance between them, results in these slopes. To determine the distances, Google Earth and Global Mapper were used; thus obtaining the coordinates WGS84 in the southern hemisphere to initial, intermediate and final nodes in the evacuation. Coordinates WGS84 are a geocentric global system whose origin of coordinates are in the center of the earth, the Z axis, in the direction of the reference pole of the International Earth Rotation Service, the X axis, at the intersection of the meridian origin defined in 1984 by the BIH and the plane of the Equator and the Y axis is perpendicular to the X and Z axes (Civil Engineering Bloggers Templates, 2009). Therefore, using the Pythagorean formula and adding the root factor since it is a non-Euclidean distance, the distances between the nodes were obtained.

Figure 6. Map of the El Progreso sector with the nodes used



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Risks Evaluation

The risks evaluated for the evacuation in this study are by: (1) Mass movement defined as critical for El Progreso (Díaz, 2015) and (2) Risks inherent in the routes, known as the road resistance (Zhang et al, 2015).

1. **Risk due to Mass Movement:** Geological hazards are the main threat for inhabitants in earthquake case, since many of them can cause direct death of pedestrians. These risks are classified in:
   a. **Geodynamic Risks:** They are conformed by reception and deposition zones, conduction channels. Being the hills the zones of reception or beginning, and the areas of deposition in many cases, main avenues of the slum, where will deposit debris flow, debris avalanche, alluvial deposits and steep slope.
   b. **Geological Hazards:** Those risks derive from different types of slum rocks. It is measured by lithological conditions such as; unconsolidated deposits, sedimentary rocks, metamorphic rocks, presence volcanic rocks and intrusive rocks.
   c. **Geomechanical Risks:** They are the structural conditions of ravine, as well as deformation processes and dipping conditions of discontinuities. Five structures or geotechnical stations have been selected in the stream; structures # 1, structures # 2, structures # 3, structures # 4 and structures # 5.
   d. **Geomorphological Risks:** They come from the inclination of slopes and alluvial cones, areas where the deposition of the alluvial materials (debris flow) takes place, reason why they are prone to the floods. Among these risks are the colluvial deposits and hills of mid slopes.
2. **Road Resistance:** Zhang et al (2015) make an analogy with electrical resistances to calculate road resistance, which would then be directly proportional to the road length and indirectly proportional to the road width. As can be seen in Figure 7, the next step would be prioritize risks and calculate the risk function for each existing arc of nodes. This last calculation is critical because this part of the risk function which seeks to minimize.

Hierarchy of Risks

After defining the risks, we will proceed to evaluate them through an AHP hierarchical analysis process that allows us to quantify the importance of each risk with respect to the others, obtaining the factors for each risk shown in Figure 8.

Then the risk cost of each arc ij is determined with the following formula:

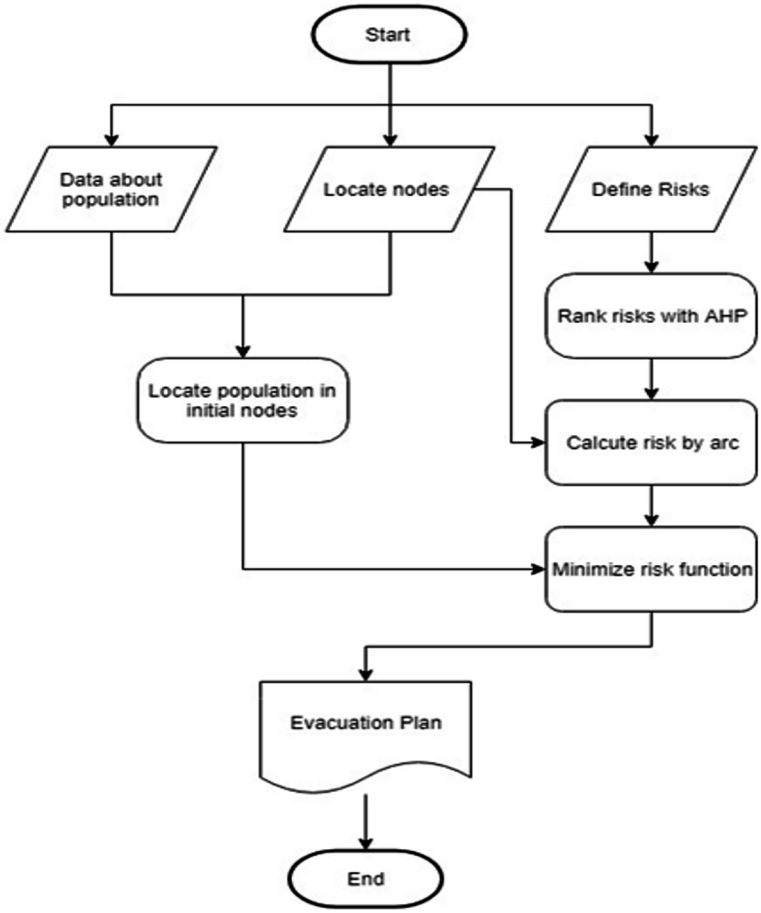
$$C_{ij} = w_{rc} * R_c + w_{ma} * a \quad (1)$$

Said C_{ij} expresses the level of vulnerability that people who follow the path of the arch ij possess, where:

R_c : Road resistance.
m: Average slope factor of the road interval

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Figure 7. General flowchart of the operation of the models



s_t : Type of soil
L: Road length
W: Road width
W_{ef} : Effective width of the road
w_{ma} : Mass risk weight
a: Mass movement risk assessment
w_{rc} : Risk Weight of R_c
C_{ij} : Cost of the arc ij

To calculate the risk by mass movement the following values are assigned based on the clustering of risk levels carried out by the Peruvian College of Engineers on the map of Figure 9:

- Very high hazard (in red), where a = 1 000 000
- High hazard (in orange), where a = 3
- Medium hazard (in yellow), where a = 1

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Figure 8. Risk Factors

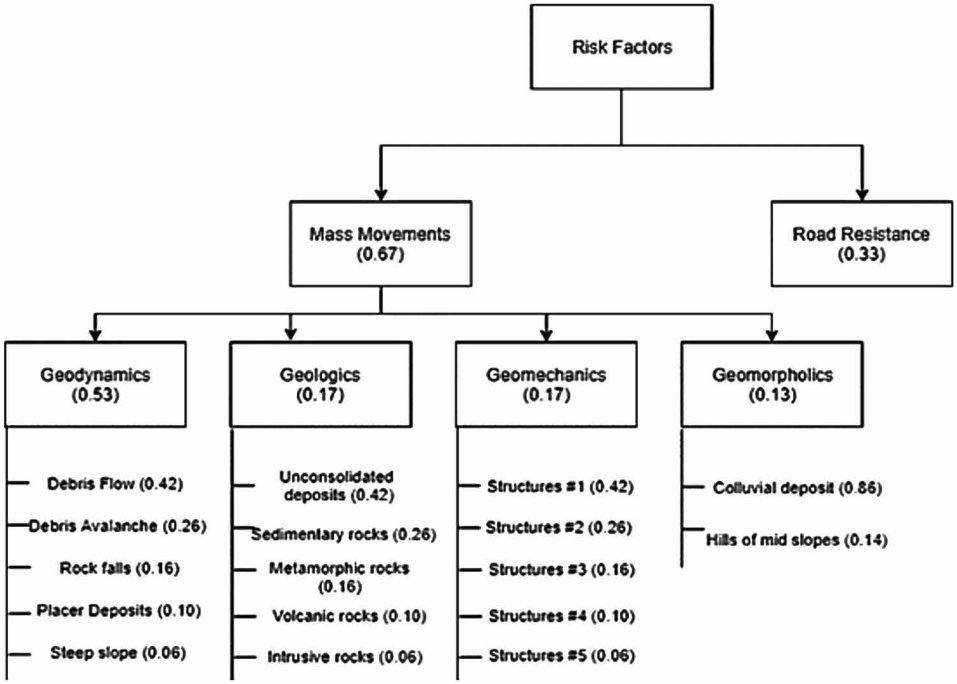
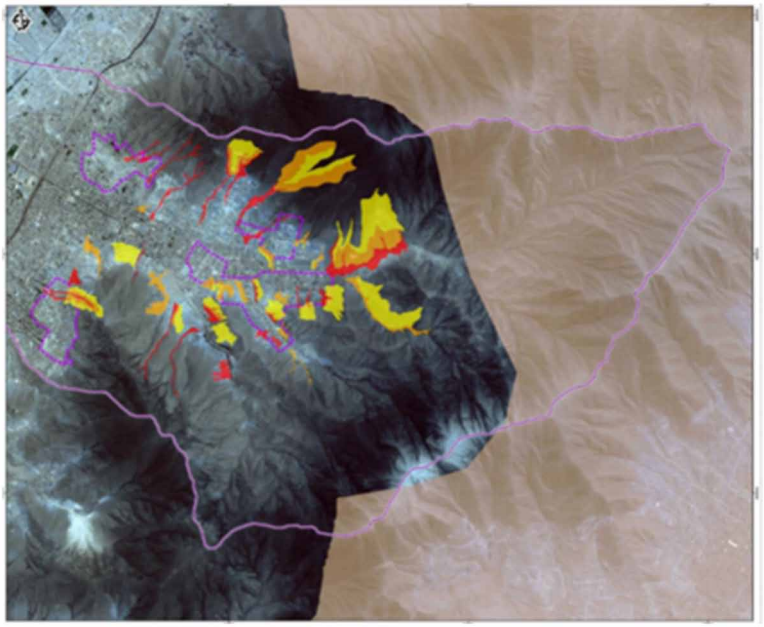


Figure 9. Risk map of mass movements



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To calculate the resistance of the road R_c is proposed in this study to add the factor of the average slope of the arch and the type of soil for the equation of Zhang et al (2015), obtaining:

$$R_c = m * s_K * \frac{L}{W_{ef}} \tag{2}$$

Effective width of the road W_{ef} will determined by subtracting the interference in the width of the road W, such as obstacles as debris, illegal motorcycle taxis parking areas, cars, traffic congestion etc. The type of soil will be determined by whether it is cement or truck trail where, if the soil is cement, it will have a value $s_1 = 0.33$, if it is a gauge, $s_2 = 1$. In the case of the slope factor in each arc, the following assignment of values is proposed:

- If the average slope < -6%, then m = 3
- If the average slope ranges are [-6%, 0%[, then m = 2
- If the average slope ranges are [0,4%[, then m = 1
- If the average slope > 4%, then m = 3

Road Capacity

According to Fruin (1971), that optimum space for a walk in an evacuation must be greater than 3.7 m^2 for each person. A space smaller than 3.7 m^2 restricts walking speed people and produces clashes among people. Having a safety factor for congestion at certain points at the beginning of the evacuation, we consider multiplying by a factor of 1.5 the optimum space proposed for Fruin, obtaining in this way an ideal space of 5.5 m^2 for each person. This data will be used to quantify the maximum capacity of the arcs in the following way:

$$C_{arco_ij} = \frac{L * W_{ef}}{5.5} \tag{3}$$

In order to calculate the capacity of the arcs, if the arc ij has different W_{ef}, the smaller one will be taken because it is a bottleneck to calculate the capacity of the arcs.

Models Construction

From previous literature review two models for evacuation in real time are chosen, they will be adapted to particularities of case under study including restrictions and the objective function.

The main objective of Model I is to minimize the risk of how to evacuate the pedestrian. Therefore, the decision variable will describe which route must follow how many pedestrians from which initial node to reach the evacuation centers or final nodes. In this case, the time dimension will not be considered. In model II, unlike the previous model, the time dimension will be considered within the decision variable.

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In both models, restrictions are evacuation capacity of the centers and streets capacity for the evacuation flow. The assumptions of both models are:

- No injuries or deaths in the evacuation flow.
- All evacuees have the same characteristics.
- No fires due to earthquake.
- Each initial node has a guide or leader who knows appropriate route to evacuate.
- All people are in their respective initial nodes at the time of evacuation, and it is assumed that the evacuation occurs at night avoid determine no inhabitant people in the zones.

Model I

The mathematical formulation of Model I is based on traditional minimum cost flow model.

Decision variable:

x_{ij} : Number of pedestrians departing from initial or intermediate node i to node j.

Index:

R *index* $r \in R$ *a set of evacuation or final nodes i.e.* $r = 1, .., R$
K *index* $k \in K$ *a set of intermediate nodes where* $k = 1, .., K$
N *index* $n \in N$ *a set of initial nodes where* $n = 1, .., N$
I *index* $i \in I$ *, a set where* $i = 1, \ldots N$ *,* $N+1,.., N+K$ *i.e.* $N + K = I$
J *index* $j \in J$ *, a set where* $j = 1, \ldots R$ *,* $R+1,.., R+N$ *,* $R+N+1, .. R+N+K$ *i.e.* $R+N+K = J$

Parameters:

C_{ij} *: Cost of the arc ij*
$Qevc_i$ *: Number of pedestrians in the initial and intermediate node j*
$Qrun_r$ *: Capacity of pedestrians in the evacuation or final node r*
C_{arco_ij} *: Maximum capacity of pedestrians in the arc ij*
Lt_{ij} *: Length of time elapsed to move from node i to node j.*

$$\text{Min} \sum_{j=1}^{J}\sum_{i=1}^{I} x_{ij} \cdot c_{ij} \tag{4}$$

Subject to

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$$\sum_{i=1}^{I} x_{irf} = Qrun_{r}, r \in R \tag{5}$$

$$\sum_{i=1}^{I} x_{i,j} - \sum_{j-r}^{J} x_{i,j} \leq -Qevc_{j-r}, j \geq r+1, i \in I \tag{6}$$

$$x_{ij} \leq C_{arco_ij}, i \in Iyj \in J \tag{7}$$

$$x_{ij} \geq 0 \, and \, integer, i \in I, j \in J \tag{8}$$

- The linear function (4) minimizes the level of vulnerability of pedestrians depending on how they evacuate.
- Restriction (5) refers to relation of pedestrians evacuating with the capacity of the areas where they evacuate, as they should not exceed the capacity of evacuation nodes.
- Restriction (6) refers to equilibrium equation of initial, intermediate and final nodes where the pedestrians are evacuating.
- Restriction (7) is the maximum capacity of pedestrians who can evacuate in each arc as they have a length and width as limitations.
- Restriction (8) refers the variables must to be positive and integer.

Model II

The mathematical formulation is based on the generic flow model proposed by Bretschneider (2013) with some variations:

- Initial and final nodes are real and not fictitious.
- Evacuation nodes presented in this model have a limited capacity unlike the equations proposed by Bretschneider because in this case evacuation of pedestrians and not vehicles consider for her
- Waiting times will not be considered in the transshipment nodes, because in this case, pedestrians, rationally, do not wait for a road to be vacated, but will look for another one that is available to continue evacuating.
- Evacuation time is not critical, because most important goal is pedestrians as far as possible go far away from the arcs where the hazards are, so it will not considered as an additional cost in the objective function.
- The mode is based on final time of the movement that performs pedestrians in the arc and not based on the initial time that is when they begins to traverse the arc.

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Decision variable:

x_{ijt} : Number of pedestrians that leave the initial or intermediate node i towards node j that arrive at time t.

Index:

The only index that is going to be added compared to model I is time, which will be a discrete variable with integer values (0, 1, 2, 3, etc).

T *index t ∈ T a set of time nodes i.e. t = 0, .., T*

$$\text{Min} \sum_{t=0}^{T}\sum_{j=1}^{J}\sum_{i=1}^{I} x_{ijt}.c_{ij} \tag{9}$$

Subject to

$$\sum_{t}^{T}\sum_{i=1}^{I} x_{irt} = Qrun_{r}, r \in R \tag{10}$$

$$\left(if\ t \leq 2Lt_{ij}\ then\ 0\ else - \sum_{i=1}^{I} x_{i,j,\left(t-Lt_{ij}\right)}\right) + \sum_{i=1}^{I} x_{j,i,t} \leq -Qevc_{j}, j \in J, t \in T \tag{11}$$

$$x_{ijt} \leq C_{arco_{ij}}, i \in I, j \in J, t \in T \tag{12}$$

$$x_{ijt} \geq 0\ and\ integer, i \in I, j \in J, t \in T \tag{13}$$

- Linear function (9) is similar to the model I, with inclusion of time dimension within the decision variable, where time represents how many pedestrians take to get from point a to point j.
- Restriction (10) is similar to the restriction (5), but in this case, the pedestrians can arrive at any moment to an evacuation node.
- Restriction (11) has a significant difference with the restriction (6) which is the inclusion of the parameter $Lt_{(I,j)}$. If $2 * Lt_{ij} \geq t$, pedestrians are prevented from reaching j because the time to travel from i to j is longer than the final time. Therefore, any $x_{i,j,\left(t-Lt_{ij}\right)}$ that meets the condition mentioned above will have a value of 0.

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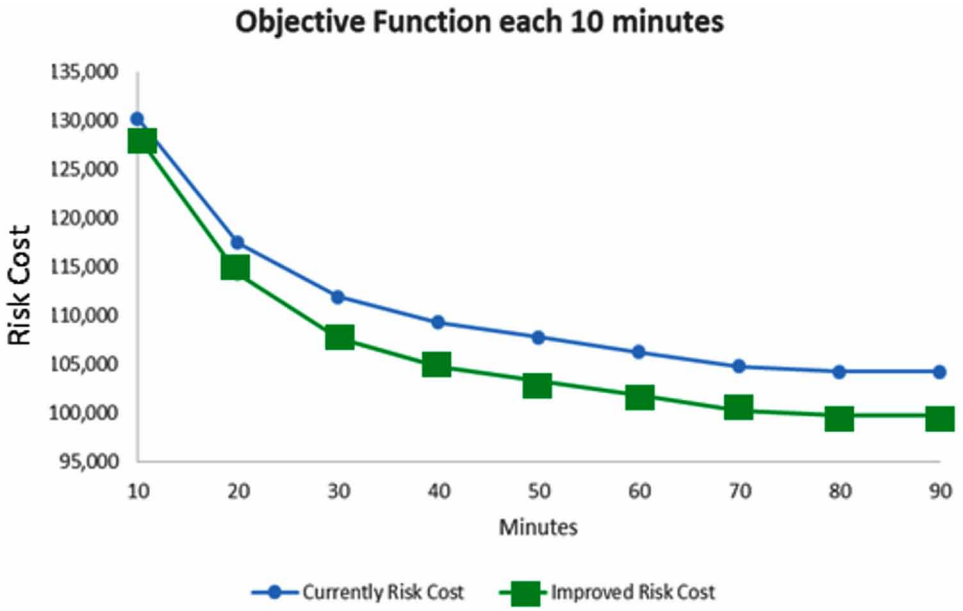
- Restriction (12) is the maximum capacity of pedestrians that can evacuate in each arch since they have a length and a width as limitations. As in equation (11), another limitation of these capacities is time, because at a given moment, there could be a limit number of pedestrians in the arc; however, at another time, these pedestrians already moved to another arch, so that this arch could be occupied by different pedestrians from the previous moment.
- Restriction (14) refers to the variables must be positive and integer.

RESULTS

Models I and II were solved using the CPLEX software with the AMPL programming language. Subsequently, the two models are compared, where for the first one an objective function of 367 159 775 is obtained, while for model II, after having discretized the time with integer values (> = 0) with one minute of difference between each value, an objective function of 313 340 is obtained in the minimum possible time (t = 5 min, previous times were not feasible). Therefore, a significant reduction in the cost of risk is achieved by 99%, which means that in model II pedestrians evacuate with 99% more efficiency than in model I.

Model II is tested in two scenarios for different time instances of 10 minutes in 10 minutes. The first scenario is the current situation of El Progreso, the second scenario includes the improvements proposed in the slum: eliminate illegal parking, relocate the market and pave the path. Where different risk values are plotted in a blue line for the first scenario and in a green line for the second scenario as shown in Figure 10.

Figure 10. Objective function each 10 minutes



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For the time t = 10 with the improvements proposed in the second scenario a reduction of 1% is obtained, in time = 30 minutes the second scenario obtains a risk reduction in 4% versus the scenario 1 and the objective function of both remains constant from t = 80 minutes to t = ∞.

In addition, Figure 9 also shows that there is an inverse relationship between the risk cost function and the defined time horizon; that is, the greater the evacuation horizon, the risk decreases. In the case of the earthquake, the evacuation time is not crucial, but the cost of risk. Figure 11 shows a small example of how pedestrian movement occurs in Model II for t = 10 minutes.

As can be seen in this example, at time t = 0, 84 people start their evacuation process going from P22 to P23 in a time of 2 minutes, respecting the capacity of this route that can contain a maximum of 108 people. Subsequently, these people meet other people who come from other points in P23 to, in this way, evacuate all (202 people) to the evacuation center 15, where the capacity of the road can contain 265 people and the evacuation center has a capacity of 2404 people.

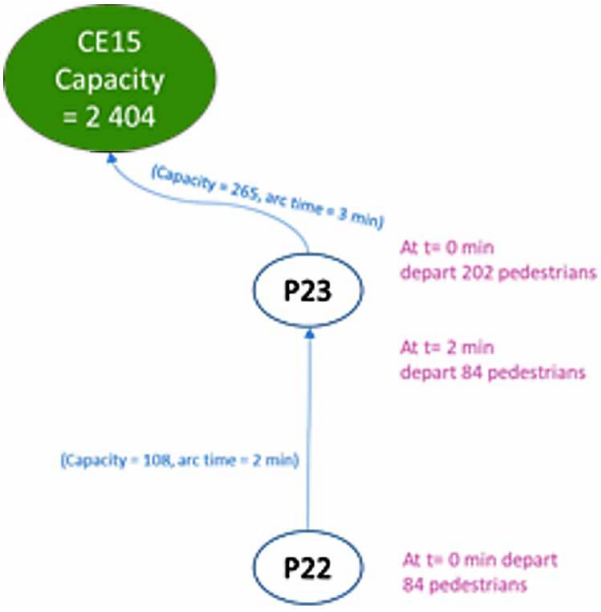
FUTURE RESEARCH DIRECTIONS

It is suggest place strategically wayfinding in street in order to improve discipline when evacuating. These models with some adjustments for dynamic environments can be implemented in the future smart cities.

Elder pedestrians and persons with disabilities need special guides by each initial node. Migrate people who lives in place most threatens to social housing is mandatory to save their lives. Evaluate safety and optimal locations to social house complex.

This model can be a basis for future models of evacuation simulation in this sector. To do this, the capacity restriction must eliminated and the evacuation evaluated, first without an evacuation plan (shorter route model) and with a plan (risk cost flow model). The proposed model is a tool for evaluating evacuation risks in urban planning.

Figure 11. Example of how pedestrians move according to model II



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CONCLUSION

The two proposed models offer a quantitative assessment of urban development and safety improvements to reduce risks during evacuation, presenting optimal routes to evacuate under an earthquake case. Model II significantly reduces the evacuation risk by 99% with respect to model I, but its implementation is much more complex due to the coordination effort required. Comparing model II with the results obtained by Rodríguez et al (2018) there is no significant difference, so it can concluded that the logic in this model is correct and the travel time it takes for the last person in Rodríguez et al (2018) model, that goes from an intermediate point to an evacuation point is very short.

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KEY TERMS AND DEFINITIONS

Carabayllo: It is the most extensive district of Metropolitan Lima with an area of 346.89 Km^2. Located in the north of the city, it is bordered by Santa Rosa de Quives in the province of Canta in the north, in the south by the district of Comas, in the east by the province of Huarochirí and in the west by the districts of Puente Piedra and Ancón.

Disaster Imagination Game (DIG): It is a method developed for disaster drills, which uses maps, transparent overlay and designates, among the participants, members of the virtual command post of disaster relief activities with the objective of facilitating the training of directing activities to help people.

INDECI: El Instituto Nacional de Defensa Civil (translated as the National Institute of Civil Defense in English) is a public executing agency that advises, coordinates and articulates in the three governmental levels of Peru the processes of preparation, response and rehabilitation of disaster risk management, through the formulation and proposals of policies, standards, plans and programs with the objective of protecting the life and physical integrity of the population, before the occurrence of emergencies and disasters.

INEI: El Instituto Nacional de Estadística e Informática (translated as the National Institute of Statistics and Informatics in English) is the body responsible for regulating, planning, directing, coordinating and supervising the official statistical activities of Peru, as well as providing and disseminating the official Peruvian statistical information.

Pacific Ring of Fire: It is located on the shores of the Pacific Ocean and is characterized by concentrating some areas with the most important subduction processes in the world, which results in intense seismic activity.

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Proyecto Esfera: El Proyecto Esfera (translated as the Sphere Project in English) is a project initiated in 1997 by a group of non-governmental organizations and the International Red Cross and Red Crescent Movement with the objective of developing a set of universal minimum standards for humanitarian responses.

Wayfinding: It is a signaling system, which, in addition to having implemented signs and posters, also contains different information artifacts (such as maps, plans or directories), with the aim of guiding people more easily to their respective destinations.

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Chapter 16
Distribution of Humanitarian Aid Through Different Clustering Strategies Using Optimization

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ABSTRACT

Natural disasters produce enormous human and material losses. This is amplified if there is poor relief aid humanitarian distribution. Logistics seeks to obtain efficiencies related to response reducing transportation costs; according to humanitarian institutions, they constitute the second largest general expense after labor. Humanitarian distribution challenges are reduce costs, maintaining distribution service, and designing reliable delivery routes in a context where infrastructures may be non-existent, unavailable, or inoperative. This chapter addresses the problem of optimizing the distribution of humanitarian aid by comparing different clustering strategies for the medicines warehouse in charge of the national hospital services entity in Metropolitan Lima and Callao. The chapter is organized as follows. First, a review of the literature on problem of vehicle routing for resilient networks are presented. Then the proposed model will be shown considering those limitations to humanitarian delivery in a post-disaster context; finally, feasible solutions will be compared.

INTRODUCTION

According to (Wijkman A., 1984), natural disasters are events that refer to the enormous human and material losses, other definitions such as those of (Cuny, 1983) affirm that the effects of a disaster could be amplified if it exists poor human settlements planning, poor security measures, poor emergency plans and lack of early warning systems, in short, poor preparation to deal with these events. That is why it is necessary to act quickly and efficiently to prevent further pos disaster events from affecting more people.

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Emergency relief operations, logistics are required to support the organization and implementation of response operations to ensure their timeliness and efficiency. Mobilizing the staff, equipment and goods of humanitarian assistance organizations, the evacuation of the injured or the resettlement of those directly affected by the disaster, requires a logistics system to maximize effectiveness (PAHO, 2017). The relief of the victims and the allocation of humanitarian personnel plays a leading role in these events (Caritas, 2009). Pedraza-Martinez, Stapleton, & Van Wassenhove (2011) confirms that transport is the second largest general budget of humanitarian organizations after staff. In Peru, governmental institution in charge of these activities is the National Institute of Civil Defense, INDECI (INDECI, 2003; PNUD, 2011). Medical supplies to be used in Lima's disaster cases INDECI have pre-set two Central Warehouses (AC) by INDECI. Humanitarian response recognizes two phases after a disaster: the reaction and the recovery (Alexander (2002). In Thévenaz and Resodihardjo (2010), authors show a two-stage process; the life-saving and the life-sustaining actions. The first one consists in carrying out activities that aim to preserve life, such as the removal of debris and the rescue of victims. The second one involves the provision and supply of aid kits and services such as food, water, temporary shelter, medical care and protection (UNDAC, 2006). This paper tackles the problem of last mile distribution for medical humanitarian relief, which seek manage aid relief (medicines) transport from Central Depots (ACs) to Medical Local Supplies (AMs). Vulnerability factors which represent current state in the location affected is considered as model's inputs. Different VRP techniques to solve the problem are applied after application of clustering methods are considered to evaluate for minimal routing cost. Different operative results are considered to achieve feasible solutions considering minimal time to disaster victims' attendance. This paper is arranged as follows: the next chapter presents a review about areas exposed to earthquakes in Lima and its districts. Then, four-path methodology is presented to determine vehicles assignment. At the end, results and discussion are exposed; mains criteria about assignment of cargo, number of trips and vehicles assignment are presented. Finally, the conclusions and future research are proposed.

HUMANITARIAN INTERVENTION

An intervention is considered effective when victims are rescued from life-threatening conditions. Otherwise, a crisis may result in an event called second disaster (UNHCR, 2007). For instance, an improper burial of corpses could result in an infectious disease, killing the remaining survivors.

The widespread premise that humanitarian response cannot achieve its goals without a well-performing logistics is based on the field results received by humanitarian entities on disaster intervention. Gatignon, Van-Wassenhove, and Charles (2010) remark that during the Yogyakarta's earthquake, the International Federation of Red Cross and Red Crescent Societies (IFRC) implemented a decentralized logistics management called the three B's of the supply chain excellence: Bucks (money), Bytes (information) and Boxes (material), which is an efficient, fast and cheap supply chain. A decentralized supply chain means an intensive usage of pre-established depots. About them, Harrison and van Hoek (2008)] say that the right location of finished goods is a well-known way of responding quickly to the demand that has emerged. Also, Baker (2008) mentions that in most companies, distribution centers constitute the key to keeping a good service level for their end customer. In the same context, Frazelle (2002) confirms that for logistics operations, in many companies the distribution centers are critical to success or failure in attending their markets. Moreover, in the supply context, in Klibi and Martel (2012), the authors say that random customer orders are fulfilled from pre-assigned depots using different transportation. In addition,

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under disaster situations, depot networks are not expected to achieve responding adequately, because it is likely that their storage and distribution capacity will lose their nominal operability. As it is mentioned in Hall (2011), the initial relief dispatch is more targeted to beneficiary communities in a timely manner, while waiting for the initial disaster assessment to be completed. Thomas and Mizushima (2005) and Peres, Brito, Leiras and Yoshizaki (2012) noticed that configuration and scale of humanitarian supply chain operations are made under a state of urgency, uncertainty and complexity, driving humanitarian entities which pursue to enhance their overall effectiveness.

A case of inefficiency in the humanitarian response distribution is presented in Chandes and Paché (2010). In Pisco (Perú), on August 15, 2007, a 7.9 Richter scale earthquake killed more than 500 people and more than 655,000 were impacted, the same who demanded water, food, shelter, clothes, etc. Assistance for victims was distributed through multiple civil defense committees led by the Civil Defense Institute, (Institute of Civil Defense, INDECI), which proved not being able to manage the humanitarian response. It recorded the following observations: (i) receipt and transport of humanitarian donations were improvised; (ii) humanitarian aid was distributed haphazardly; (iii) duplication of supplies occurred in some areas while more isolated areas received partial support; and (vi) there was distribution of unsuitable food or even food unfit for consumption (for instance rotten food, due expiry date of drugs, etc.). After Haiti earthquake in 2010, humanitarian practitioners to figure out a lot of barriers to achieve an effective response because many vital transportation, power, and communication infrastructures rested inoperative (Action Plan for National Recovery and Development of Haiti: APNRDH, 2010). In 2017, Peru was affected by El Niño Costero, a climatic phenomenon that causes an increase in sea temperature, which increase rainfalls on the coast of the country, that generates an increase in river water, mountain landslides (called as huaycos in Peru). At April 12, 2017, more than one million people were affected and approximately 165 000 affected (COEN, 2017). Since the beginning of the event, many terrestrial roads were damaged or destroyed. Important national roads, such as the Central Highway (from Lima to the east) or the Pan-American Highway that crosses the country along the coast from north to south, were impassable in various sections of the roads or restricted to traffic of people transport and goods. 300 bridges were destroyed throughout the country (INDECI, 2017). 63 national roads under the Ministry of Transport and Communications (MTC) were left with limited traffic due to damage caused by heavy rains, while 10 were left with access is completely interrupted (COE-MTC, 2017).

MAIN FOCUS OF THE CHAPTER

Theoretical and Methodological Framework

In the literature, the problem of vehicle routing in the city is proposed to cover two main objectives; the first, reducing congestion and increasing mobility of freight transportation services in urban areas at minimum cost. The second is to contribute positively to the environment and to the sustainable development (Cattaruzza et al, 2017).

Pillac et al. (2013) present different types of models to resolve vehicle routing problems: classic capacitated VRP (CVRP), where each customer has a demand for a good and vehicles have finite capacity; the VRP with Time Windows (VRPTW), where each customer must be visited during a specific time frame; the VRP with Pick-up and Delivery (PDP), where goods have to be picked-up and delivered in specific amounts at the vertices; and the Heterogeneous fleet VRP (HVRP), where vehicles have dif-

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ferent capacities. Routing problems that involve moving people between locations are referred to as Dial-A-Ride-Problem (DARP) for land transport; or Dial-A-Flight-Problem (DAFP), for air transport and VRP with Stochastic Demands (VRPSD), can be seen from both perspectives. From a static perspective, the problem is to design a set of robust routes a-priori that will undergo minor changes during their execution. From a dynamic perspective, the problem consists in designing the vehicle routes in an online fashion, communicating to the vehicle which customer to serve next as soon as it becomes idle. The proposal presented in this paper is in a hybrid model VRSPD that contains static pre-established inputs but also add dynamic conditions to be incorporated over time given the intrinsic evolution factors of characteristics, whcih describe the vulnerability state of an area and population in study. This has allowed designing a robust model.

Works covering different routing problems related to post disasters scenarios are for instance, in Pidd et al., (1996), the authors present a spatial decision support system for emergency planning, this proposal is based on the Geographical Information System (GIS) software. (Gong and Batta, 2007) propose an ambulance allocation and reallocation to improve the victim rescue process, for this, the authors used a spatial clustering, combined with fuzzy logic, to allocate the correct number of ambulances to each spatial object grouped into a cluster after an earthquake at the beginning of the rescue process. For experimentation, the authors used data associated with the earthquake scenario in Northridge, CA. (Balcik, Beamon and Smilowitz, 2008) present a a mixed integer programming model that determines delivery schedules for vehicles and equitably allocates resources, based on supply, vehicle capacity, and delivery time restrictions, with the objectives of minimizing transportation costs and maximizing benefits to aid recipients. On the other hand, Campbell et al., 2008 proposal a holistic model using two objective functions for the classic traveling salesman problem (TSP) and 2 vehicle routing problem (VRP): one that minimizes the maximum arrival time (minmax routing) and one that minimizes the average arrival time (minavg routing). These objective functions are based on the literature on fairness. And, Van Hentenryck, Bent and Coffrin (2010) considered a single commodity allocation problem for disaster recovery, using a complex stochastic optimization problem that combine resource allocation, warehouse routing, and parallel fleet routing, the algorithm was validated on hurricane disaster scenarios. Meanwhile Vargas, Lauras, Okongwu and Dupont (2015) propose a model capable of designing a coherent network that is still able to manage the response to a disaster despite failures or inadequacies of infrastructure and potential resources, through a stochastic multi-scenarios program, recurrent earthquakes application case in Peru is presented. Later, in (Linet and Onur, 2012), authors propose a mathematical model and a hierarchical clustering and routing procedure for coordinating vehicle routing in large-scale post-disaster distribution and evacuation activities. In this paper, the authors illustrate the implementation of their proposal on a clean water distribution scenario, which might take place after an earthquake hits Istanbul.

The Proposed Case Study

The resolution of the problem of supplying goods from collection points to various users plays an important role in the management of logistics systems and proper planning can mean considerable savings in time and money. Within the Classical Heuristics of the VRP, (Vehicle Routing Problem) the Methods of Assigning First - Routing After and Routing First - Assigning After are the most applied, developed in the present work. As a starting point, for the presentation of the proposals, the central warehouses and the potential warehouse of medical supplies previously identified by INDECI were located, initially an

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ideal condition of vehicular traffic is proposed, after this situation will be modified including obstacles of pos-disaster roads such as accessibility, exposure to seismic risks among others.

Warehouses are named by the abbreviations indicated in Table 1. According to INDECI, Metropolitan Lima and Callao can be associated to four different territory levels considering the type of seismic vulnerability where they are located in. Once the stores of medical supplies have been defined, the central warehouse that will supply them must be identified. The criterion that will be applied to identify which Central Warehouse (AC1 or AC2) that will supply the local Medical Supplies Warehouses (AM_i) will be the shortest distance travelled from each central warehouse to the collection point (AM_i); that is, if the distance from Central Warehouse 2 (AC2) to AM1 is less than the distance from Central Warehouse 1 (AC1) to AM1, then Central Warehouse 2 will supply AM1. Table 2 shows the 25 stores AM_i assigned to one of the central warehouses AC1 or AC2.

Clustering Strategies

- **Proposal 1:** Assign first by proximity of points and route after

For this method, we proceeded with grouping of points considering their proximity, the central warehouse that supplies them (AC1 or AC2) and the seismic vulnerability in which they are located (low, relatively low, high or very high), note the colour associated with each vulnerability in each store (Figure 1). Then

Table 1. Location of central warehouses and medical supplies warehouses

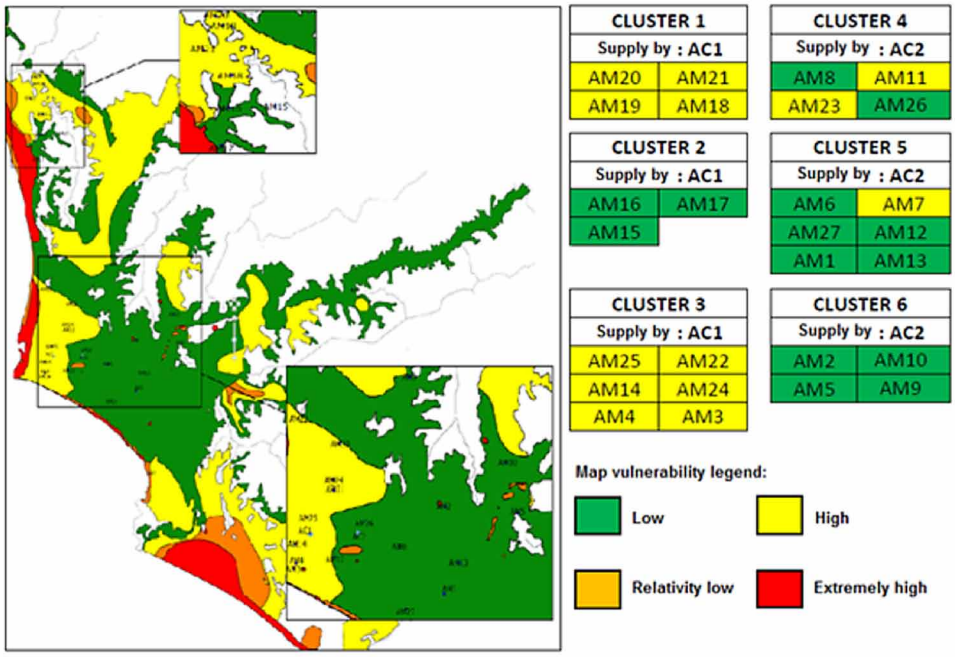
N°	Warehouse type	Warehouse	District	Abbreviation
1	Central	Almacén PRONAA	Callao	AC1
2	Central	Almacén CARITAS	Carmen de La Legua	AC2
3	Medical supplies	Almacén ESSALUD	Jesus María	AM1
4	Medical supplies	Almacén DISA V RIMAC	Rimac	AM2
5	Medical supplies	Almacén CPCED DIRESA Callao	La Perla	AM3
... continue the list of warehouses, locations and abbreviations used				
29	Medical supplies	Almacén Fospoli	Jesus Maria	AM27

Table 2. Distance between central warehouses and medical supplies warehouses

N°	Medical supplies warehouses	AC1 (Km)	AC2 (Km)	Central warehouse assigned
1	AM1	9,03	6,29	AC2
2	AM2	8,39	6,06	AC2
3	AM3	2,06	4,32	AC1
4	AM4	1,77	4.16	AC1
5	AM5	13,09	10,21	AC2
… continue the list of medical supplies warehouses assigned to one of the central warehouses AC1 or AC2				
25	AM25	1,13	5,36	AC1

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Figure 1. Clusters defined by Method by Proximity of Points



a route is created that visits all the points of the new clusters created by applying the Clark and Wright Method (also known as the Saving Method).

For the application of the Clark and Wright Method, the application on Cluster 3 will be taken as an example, for which the distances between each point were initially identified and which are shown in the matrix that is detailed in Table 3.

Then the savings matrix was defined, obtained from the application of the Clark and Wright algorithm, considering the matrix defined in Table 3.

In the savings matrix obtained, the points to consider in the preparation of the route are in the boxes marked in grey and those that have not been considered for not meeting the restrictions of the method (by generating sub-routes or concluding the route before meeting the union of all points) are white. The route obtained for Cluster 3 is shown below:

Table 3. Matriz de Distancias entre AM's – Cluster 3

	AM25	AM14	AM4	AM3	AM22	AM24
AM25		1.62	2.58	2.79	4.99	2.44
AM14	1.62		0.97	1.26	6.46	4.06
AM4	2.58	0.97		0.32	7.4	4.8
AM3	2.79	1.26	0.32		7.65	5.1
AM22	4.99	6.46	7.4	7.65		3.89
AM24	2.44	4.06	4.8	5.1	3.89	

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Table 4. Savings Matrix – Cluster 3

	AM25	AM14	AM4	AM3	AM22	AM24
AM25		0.55	0.32	0.4	2.01	1.76
AM14	0.55		1.85	1.84	0.45	0.05
AM4	0.32	1.85		3.51	0.24	0.04
AM3	0.4	1.84	3.51		0.28	0.03
AM22	2.01	0.45	0.24	0.28		5.05
AM24	1.76	0.05	0.04	0.03	5.05	

AC1 – AM24 – AM22 – AM25 – AM14 – AM4 – AM3 - AC1

Calculating the total distance travelled:

3,07 + 3,89 + 4,99 + 1,62 + 0,97 + 0,32 + 2,06 = 16,92 Km

So, it can be concluded that the final distance travelled for cluster 3 comprises 16.92 km and the order of visit of the points is AC1-AM24-AM22-AM25-AM14-AM4-AM3-AC1. Following the same solution procedure, the route obtained for Cluster 1 is the following:

AC1 – AM20 – AM19 – AM21 – AM18 – AC1

Calculating the total distance travelled:

24,87 + 0.68 + 1,69 + 1.87 + 28,87 = 57.98 Km

Likewise, the routes associated with the other clusters were identified following the same procedure. The described method was also contrasted with the linear programming method (PPL) using the software Lindo 6.1. As an example, Cluster 1 will be taken and the necessary parameters for its application will be set, which are shown below:

‘Objetive Function:

MIN 21.58xo20+24.37xo21+24.87xo19+22.87xo18+

2.03x2021+0.68x1920+3.49x1820+

1.69x1921+1.87x1821+

2.89x1819

‘Constraints:

s.t.

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xo20 + xo21 + xo19 + xo18 = 2

xo20 + x2021 + x1920 + x1820 = 2

xo21 + x2021 + x1921 + x1821 = 2

xo19 + x1920 + x1921 + x1819 = 2

xo18 + x1819 + x1821 + x1820 = 2

end
int 10
Result of the final route for Cluster 1:

AC1 – AM20 – AM19 – AM21 – AM18 – AC1

It is observed that the route obtained by the software Lindo coincides with that obtained through the application of the savings method. It proceeds similarly for the rest of the clusters and, for these cases, the results obtained were the same in all the routes applying the method of savings or the PPL method.

- **Proposal 2:** Assign first by the sweep method and route after

The Sweep Method consists of grouping the collection points considering the smallest angle measured taking as reference an imaginary horizontal line drawn until completing a 360 ° rotation in a counter clockwise direction and incrusting each AM according to the order of location in the turn of this line. Once the new clusters were created, also considering the vulnerability of the area where they are located, the Clark and Wright algorithm was applied again, obtaining new routes and results.

Warehouses supplied by Central Warehouse 1 (AC1):

AC1 – AM24 – AM25 – AM15 – AM18 – AM16 – AM19 – AM20 – AM17 – AM21 – AM22 – AM14 – AM3 – AM4 – AC1

Table 5. Summary Route Sizing - Point Nearness Method

	Routes	Ideal distance (Km)
1	AC1 – AM20 – AM19 – AM21 – AM18 – AC1	57,98
2	AC1 – AM15 – AM16 – AM17 – AC1	41,45
3	AC1 – AM24 – AM22 – AM25 – AM14 – AM4 – AM3 – AC1	16,92
4	AC2 – AM26 – AM8 – AM23 – AM11 – AC2	19,01
5	AC2 – AM12 – AM27 – AM7 – AM1 – AM13 – AM6 – AC2	30,86
6	AC2 – AM5 – AM9 – AM10 – AM2 – AC2	57,08

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From the group shown above, the Clark and Wright algorithm was applied to identify the clusters, trying to maintain a proportionality between the number of collection points assigned. Results found:

Cluster Route 7: AC1 – AM24 – AM15 – AM18 – AM16 – AM25 – AC1

Cluster Route 8: AC1 – AM17 – AM19 – AM20 – AM21 – AC1

Cluster Route 9: AC1 – AM22 – AM14 – AM3 – AM4 – AC1

In the same way as in proposal 1, the resolution of the proposed case will proceed, considering the same clusters, but now instead of the application of the saving algorithm, the linear programming method will be used again through Lindo 6 It will be applied on Cluster 7.

´Objective Function:

MIN 3.07xo24 + 19.78xo15 + 21.58xo18 + 19.71xo16 + 1.13xo25 +

17.03x1524 + 18.92x1824 + 17.11x1624 + 2.44x2425 +

2.66x1518 + 2.1x1516 + 18.91x1525 +

1.86x1618 + 20.62x1825 +

18.9x1625

´Constraints:

s.t.

xo24 + xo15 + xo18 + xo16 + xo25 = 2

xo24 + x1524 + x1824 + x1624 + x2425 = 2

xo15 + x1524 + x1518 + x1516 + x1525 = 2

xo18 + x1824 + x1518 + x1618 + x1825 = 2

xo16 + x1624 + x1516 + x1618 + x1625 = 2

xo25 + x2425 + x1525 + x1825 + x1625 = 2

xo15 + xo16 + xo18 + x1524 + x1624 + x1824 + x1525 + x1825 + x1625 >= 1

end

int 15

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The route obtained coincides with the one found with the savings method:

AC1 – AM24 – AM15 – AM18 – AM16 – AM25 – AC1

For the rest of the established clusters, the same routes were obtained through the linear programming method. Next, the summary of the results obtained by applying the Sweep Method or applying the algorithm of Clark and Wright and PPL is presented.

- **Proposal 3:** Route first by the Grand Route method and assign later, using the Clark and Wright algorithm

In this proposal we proceed in an inverse manner to that of the first two options. First, the route that visits all the collection points is elaborated (Grand Route - 1) they are supplied by the Central Warehouse 1. Second, the second route that visits all the collection is elaborated (Grand Route - 2) they are supplied by the Central Warehouse 2. After, it does the clusters in both, applying the Clark and Wright Algorithm.

As in the method for Proximity of Points, the boxes marked in grey were those used for the preparation of the routes and the white boxes were not considered because they cause overlapping routes or close the route before all points are visited.

First Grand Route (Warehouses supplied by Central Warehouse 1):

AC1 – AM24 – AM17 – AM16 – AM18 – AM19 – AM20 – AM21 –AM15 –AM22 – AM25 –AM14 – AM3 – AM4 - AC1

Now we will proceed with clustering. It is worth mentioning that the saving algorithm was applied once again, for each new cluster.

Cluster Route 13: AC1– AM24 – AM18 – AM16 – AM17 – AC1

Cluster Route 14: AC1 – AM15 – AM19 - AM20 – AM21 – AM22 – AC1

Cluster Route 15: AC1 – AM25 – AM14 – AM3 – AM4 – AC1

Table 6. Summary Route Sizing by Sweep Method

	Routes	Ideal distance (Km)
1	AC1 – AM24 – AM15 – AM18 – AM16 – AM25 – AC1	44,65
2	AC1 – AM17 – AM19 – AM20 – AM21 – AC1	49,35
3	AC1 – AM22 – AM14 – AM3 – AM4 – AC1	15,68
4	AC2 – AM11 – AM23 – AM8 – AM26 – AC2	19,01
5	AC2 – AM6 – AM13 – AM1 – AM7 – AM27 – AM12 – AC2	30,86
6	AC2 – AM2 – AM5 – AM9 – AM10 – AC2	57,08

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Table 7. Savings Matrix

	AM3	AM4	AM14	AM15	AM16	AM17	AM18	AM19	AM20	AM21	AM22	AM24	AM25
AM3		3.51	1.84	0.26	0.29	0.11	0.34	0.34	0.32	-0.42	0.28	0.03	0.4
AM4	3.51		1.84	0.2	0.27	0.07	0.34	0.35	0.29	0.24	0.24	0.04	0.32
AM14	1.84	1.84		0.45	0.52	0.3	0.51	0.63	0.47	0.41	0.45	0.05	0.55
AM15	0.26	0.2	0.45		37.39	33.92	38.7	39.02	38.88	38.22	11.67	5.82	2
AM16	0.29	0.27	0.52	37.39		35.02	39.43	39.5	39.33	39.23	11.5	5.67	1.94
AM17	0.11	0.07	0.3	33.92	35.02		35.04	34.98	35.02	34.94	11.57	5.36	1.78
AM18	0.34	0.34	0.51	38.7	39.43	35.04		43.06	42.96	42.58	11.87	5.73	2.09
AM19	0.34	0.35	0.63	39.02	39.5	34.98	43.06		48.56	45.55	11.79	5.63	2.21
AM20	0.32	0.29	0.47	38.88	39.33	35.02	42.96	48.56		45.71	11.77	5.58	1.98
AM21	-0.42	0.24	0.41	38.22	39.23	34.94	42.58	45.55	45.71		11.77	5.48	1.99
AM22	0.28	0.24	0.45	11.67	11.5	11.57	11.87	11.79	11.77	11.77		5.05	2.01
AM24	0.03	0.04	0.05	5.82	5.67	5.36	5.73	5.63	5.58	5.48	5.05		1.76
AM25	0.4	0.32	0.55	2	1.94	1.78	2.09	2.21	1.99	1.99	2.01	1.76	

Next, the summary of the results obtained through the application of the Grand Route Method is presented in Table 8.

- **Proposal 4:** Routing first by the Grand Route method and assigning later, using linear programming

The first step will be to determine the route to be followed considering the points supplied by the central warehouses. Due to the complexity and quantity of the nodes involved in the routes described, the software Grafos v.1.3.5 (http://arodrigu.webs.upv.es/descargas/) has been chosen. The following results were obtained:

The Great Route 1 obtained was the following:

AC1 – AM4 – AM3 – AM14 – AM25 – AM22 – A17 – AM16 – AM18 – AM21 – AM20 – AM19 – AM15 – AM24 – AC1

Table 8. Summary of route sizing using the Grand Route method

	Routes	Ideal distance (Km)
1	AC1 – AM24 – AM18 – AM16 – AM17– AC1	43,42
2	AC1 – AM15 – AM19 – AM20 – AM21 – AM22 – AC1	50,46
3	AC1 – AM25 – AM14 – AM3 – AM4 – AC1	6,03
4	AC2 – AM11 – AM27 – AM7 – AM23 – AM8 – AC2	41,17
5	AC2 – AM13 – AM1 – AM5 – AM9 – AM10 – AC2	61,05
6	AC2 – AM2 – AM6 – AM26 – AM12 – AC2	16,56

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Then we proceeded to use again the software Grafos v 1.3.5. To find the internal routes to travel:

Cluster Route 1: AC1 - AM4 - AM3 - AM14 - AM25 - AC1

Cluster Route 2: AC1 - AM22 - AM17 - AM16 – AM18 - AC1

Cluster Route 3: AC1 - AM21 – AM20 - AM19 – AM15 – AM24 – AC1

The summary of the results obtained by the Grand Route method with the application of Linear Programming is shown in Table 9.

- **Proposal 5:** Assign using the hierarchical ascending classification and route after

The importance of this proposal lies in the fact that the allocation of the clusters, in addition to being based on the seismic vulnerability of the areas where the collection points are located, will also be based on socio-economic vulnerable conditions, vulnerability due to poor accessibility, to exposure to hazards (which takes into account the population density, type building material, typology, conservation status and height of dwellings housing) and the proximity of the collection points with respect to the central warehouse that supplies them.

The Hierarchical Ascending Classification method represented graphically by dendograms is used as an efficient technique for the identification of clusters that combine different characteristics (Villardón, 2007). For the application of this method, the software XLSTAT 2013.6.03, an advanced statistical analysis tool, was used.

INDECI provides a qualitative assessment for each type of vulnerability considering the impact levels of the disaster. In some cases, the scale includes values from 1 to 5 and in others from 1 to 4; as summarized in Table 10. First, considering the assessment associated with each type of vulnerability described above and the district in which they are located, the summary is shown in Table 10.

Then we proceeded with the standardization of the data through the method "Maximum Magnitude of 1", (Justel, 2008) which consists of dividing each value of each variable between the maximum value of each category to obtain data between 0 and 1. The results obtained for AC1 are shown in Table 11.

With this data the new clusters will be obtained using the statistical program XLSTAT 2013.6.03.

The horizontal dotted line identifies three types of classes (class 1, class 2, and class 3) that generate 3 clusters formed by the collection warehouses.

Table 9. Summary Route Sizing by PPL Method - Grand Route

	Routes	Ideal distance (Km)
1	AC1 – AM4 – AM3 – AM14 – AM25– AC1	6,10
2	AC1 – AM22 – AM17 – AM16 – AM18 – AC1	41,68
3	AC1 – AM21 – AM20 – AM19 – AM15 – AM24 – AC1	50,81
4	AC2 – AM26 – AM8 – AM11 – AM23 – AC2	23,27
5	AC2 – AM2 – AM10 – AM9 – AM5 – AM13 – AC2	58,13
6	AC2 – AM6 – AM1 – AM7 - AM27 – AM12 – AC2	28,80

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Table 10. Rating by type of vulnerability

AC_i	AM_i	Socio-economic	Day accessibility	Night accessibility	Exposure to hazards	Seismic activity	Distance AM_i to AC_i (Km)
AC2	AM1	2	4	1	2	1	6,29
AC2	AM2	2	4	2	5	1	6,06
AC1	AM3	2	4	3	5	2	2,06
AC1	AM4	2	4	3	4	2	1,77
AC2	AM5	2	5	3	3	1	10,21
… continue the list of AC_i to AM_i							
AC2	AM27	2	4	1	2	1	4,96

Table 11. Standardized Data - Collection Points Supplied by Central Warehouse 1

AC_i	AM_i	Socio-economic	Day accessibility	Night accessibility	Exposure to hazards	Seismic activity	Distance AM_i to AC_i (Km)
AC1	AM4	1,0	0,8	0,75	0,8	1,0	0,06
AC1	AM14	1,0	0,8	0,75	1,0	1,0	0,04
AC1	AM15	0,5	0,8	1,0	0,6	0,5	0,70
AC1	AM16	0,5	0,8	1,0	0,6	0,5	0,70
AC1	AM17	0,5	0,8	0,5	0,6	0,5	0,62
… continue the list of AC_i to AM_i							
AC1	AM25	1,0	0,8	0,5	0,8	1,0	0,04

Clase 1: AM3 – AM4 – AM14 – AM25

Clase 2: AM15 – AM16 – AM17 – AM18 – AM19 – AM20 – AM21

Clase 3: AM22 – AM24

Step 3, now proceed with the application of the Clark and Wright Algorithm considering the established clusters, by proceeding in the same way as the previous methods, here it is show the results.

Cluster 19: AC1 – AM17 – AM21 – AM20 – AM19 – AM18 – AM16 – AM15 – AC1

Cluster 20: AC1 - AM22 - AM24 - AC1

Cluster 21: AC1 – AM4 – AM25 – AM3 – AM14 - AC1

The same process is used for the points supplied by AC2. The result is presented using the Hierarchical Ascending Classification Method to clusters formation (Table 12).

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Figure 2. Dendograms generated for Warehouse AC1

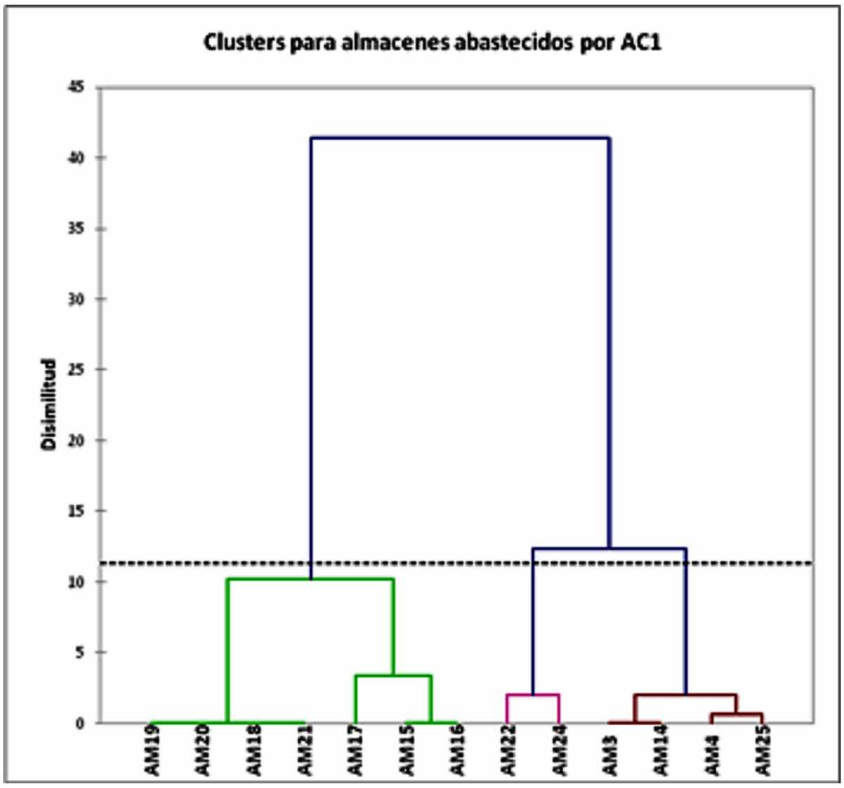


Table 12. Summary Route Sizing by Hierarchical Ascending Classification Method

	Routes	Ideal distance (Km)
1	AC1 – AM17 – AM21 – AM20 – AM19 – AM18 – AM16 – AM15– AC1	52,15
2	AC1 – AM22 – AM24 – AC1	12,83
3	AC1 – AM4 – AM25 – AM3 – AM14 – AC1	7,63
4	AC2 – AM9 – AM7 – AM11 – AM23 – AC2	68,93
5	AC2 – AM5 – AM8 – AM10 – AC2	37,35
6	AC2 – AM12 – AM27 – AM1 – AM13 – AM2 – AM6 – AM26 – AC2	21,59

SOLUTIONS AND RECOMMENDATIONS

Considering the Real Distances

As mentioned, the routes do not consider the configuration of the streets or the traffic. A relevant analysis need know the true distance that would be covered in each proposed route and possible complications presented such as blocking routes. When real distances are included, the proposal with the lowest distance

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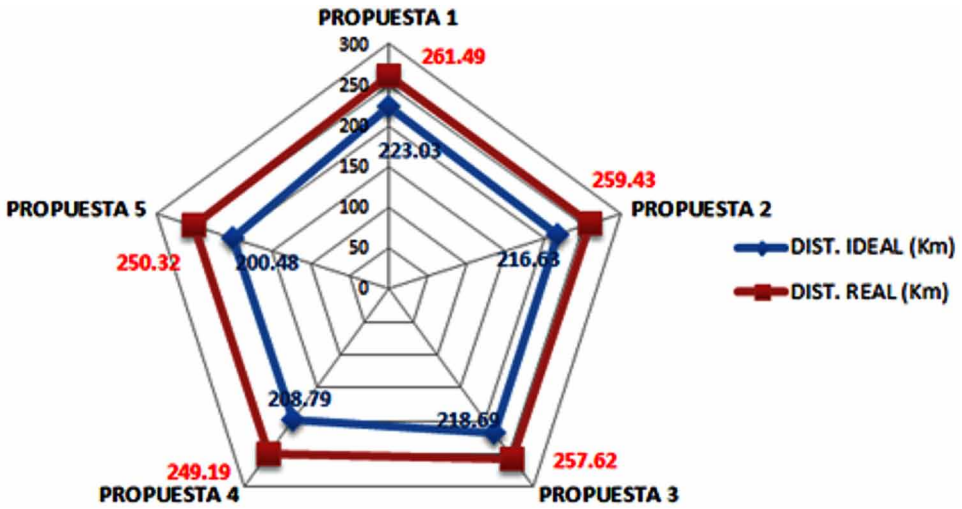
traveled is the proposal 4: Assign first, Route after (Grand Route - PPL) with approx. 249.19 Km and the proposal with the greatest distance traveled is the first: Assign First - Route After (By proximity of Points) with approx. 261.49 Km.

Distribution Expenses

According to Pedraza (2011), the best vehicles to use in the distribution of humanitarian aid due to their capacity and power are the 4 x 4 pick-up vehicles; In addition to this, for the calculation of the resources used to attend to the victims, the specific standard characteristics of said vehicles and the demand, represented by the people to be attended, will be taken into account. The packaging unit used is the one recommended by INDECI (2018), which suggests it must supply at least two (02) people with an average recommended load of 8 kg, which corresponds to a backpack with a capacity of 20 to 40 L (UNHCR, 2007; IFCR, 2012). Considering a load capacity per vehicle of 3 m3, a capacity of service per vehicle of 200 beneficiaries is determined.

Unlike the first stage where clustering was carried out taking into account the characteristics of each model (proximity of points, points ordered for route visits); In this case, the provinces of Lima and Callao were grouped into 4 large sectors: Norte, Sur, Centro, Este and Callao, as indicated by PREDES (2009), and the number of victims follow those recommended by Serpa (2014). There are districts that do not have a medical supplies warehouses and others that have more than one warehouse, therefore it was decided that each warehouse would support the victims of the sector they belong to and provide support proportionally to the number of total collection warehouses that are in your sector. Based on the best clustering and routing alternative determined (option 4), the number of beneficiaries per route was determined, considering the total route of routes needed to meet the total of beneficiaries, the cost per fuel was determined at approximately $ 42,300.

Figure 3. Summary of sizing Ideal and real distances



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Service Coverage

The number of people served per trip and days used will decrease as more vehicles are assigned. Considering an average speed of 40 km / hr, the number of trips per route was established. Considering 250 vehicles available after a major disaster, it would be possible to serve 50 000 people in a single trip of the total fleet, taking approximately 10 days to assist 100% of the victims. Initially, a permanent fleet of 50 vehicles could be counted on, and then the difference was subcontracted.

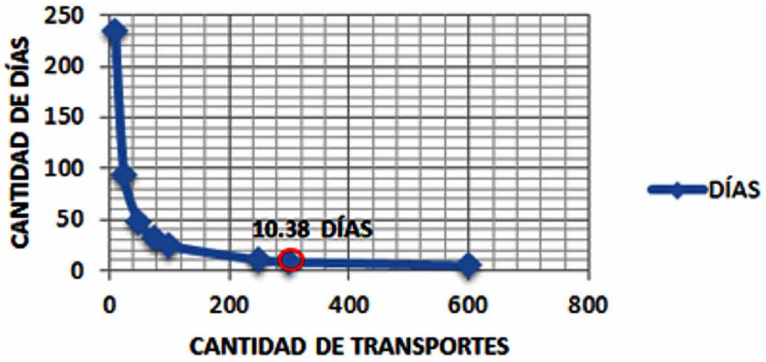
There is an important social benefit generated by proposal 4: Routing first by the Grand Route method and assigning later, using linear programming, because it provides a better alternative in the response capacity for the shortest route encountered. Proposal 5 emerged as the second-best option, since the allocation of clusters was based on the consideration of influencing factors such as the seismic zone, socioeconomic vulnerability, accessibility, exposure to hazards, among others.

FUTURE RESEARCH DIRECTIONS

On the model it would be useful to calculate the times of loading, unloading and the times associated with traffic caused by roadblocks, since it can increase or reduce transport times and therefore the distance travelled would not be the only important factor to analyse. It is recommended to include a sensitivity analysis by type of transport and supply capacity of the fleet, as this could considerably increase or decrease the resources used.

Regarding the application case, it could be complemented with the consideration of different types of collection points, such as food collection points, shelters, hospitals or others and evaluating possible extensions in the number of warehouses to be included in the described models. Additional information could be considered about the probabilities of roadblocks due to its geography, which would be included in the model which in turn would yield a result not only based on the shortest distance travelled but also on the route with the best access considering possible landslides. It could include a correction factor that punishes the transfer times from one point to another considering the new damaged state of the road, traffic congestion, blockades and stops; this factor could be updated in real time according to the geographic information according to the reports of the state of the emergency.

Figure 4. Number of Days vs. Amount of Transportation



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Institutional government actors such as INDECI, MTC, are recommended to focus on similar studies to be able to implement them to achieve an efficient and effective improve humanitarian distribution operations.

CONCLUSION

Humanitarian logistics seeks to obtain efficiencies related to response capacity by reducing transportation costs for intervention. Distribution as part of humanitarian logistics has several challenges, for example; reduce costs by seeking the best use of resources, maintaining an acceptable distribution service, designing reliable delivery routes in a context where infrastructures may be non-existent, unavailable or inoperative. This research work addresses the problem of optimizing the distribution of humanitarian aid by comparing different clustering strategies for the drugs depots in charge of the national hospital services entity in Metropolitan Lima and Callao, Essalud.

The article presents a model considering those limitations to humanitarian delivery in a post disaster context, feasible solutions are compared. The results show that the best alternative by fuel cost, responsiveness and covering results, is the route solution that follow the heuristic of assigning first, then routing, solving the routing problem with linear programming (Grand Route method).

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Chapter 17
Microbusiness Collaboration as a Strategy to Increase Resilience in Natural Disasters: The Case of Coastal El Niño in Peru 2017

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ABSTRACT

Microbusiness, MB, importance for the global economy is uncontestable; they have huge participation of the world's production. In Peru, small-and medium-enterprises, SMEs, are 99% of the total of existing companies and contribute approximately 47% of the country's GDP; MBs are grouped within SMEs. They are the greatest generators of employment, although this may be informal and of poor quality. MBs confront difficulties, mainly due to their limited human and financial resources. Theories around how to deal with it have been developed mainly with big enterprises in mind, and this has little connection with what happens inside MBs. Accordingly, this chapter offers "collaboration" as a response strategy in case of a disruptive event to support MB resilience construction. This is contextualized from the experience of the Peruvian Costal El Niño 2017 and illustrated through the actions that a MB case (a beekeeper) took to deal with it.

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BACKGROUND

MBs are usually grouped inside the concept of Small and Medium Enterprises (SMEs). SMEs importance for world's economy is uncontestable as they account for at least 70% of the world's production (Moore and Manring, 2009). They often constitute more than 90% of all enterprises inside a country (Poon and Swatman, 1999; Cull et al., 2006; Ozgulbas et al., 2006). Ates and Bititci (2011) cite a European Commission report, which asserts that SMEs perform a significant role in EU competitiveness. In the particular case of Peru, the influence of SMEs is also important, as they represent 99% of the total of existing businesses (INEI, 2014). According to Vásquez (2015), SMEs contribute to almost 50% of Peru's GDP, and are the largest generators of employment; even though, these jobs may be informal and low-paid. In the particular case of micro-businesses (MBs), these are the most common size of business organization in the World. For example, more than 90% of businesses in the European (EU28) formal economy are MBs, which employ 30% of the workforce, and contribute with more than 20% of the added value to the European GDP (Muller et al., 2014). In Peru, to be considered a MB current legislation states that it should generate annual sales below USD $187 thousand or have less than 10 workers.

Even though MBs have positive impacts for the economy, they suffer a high-mortality rate. For instance, in Peru, it is estimated that 200 thousand companies close every year (Diario Correo, 2014). Zorrilla (2013) says that after two years of operation, 50% of the SMEs, and particularly new ventures, close. This phenomenon is not restricted to Peru; for instance, in UK only 4 in 10 survive after 5 years (ONS, 2016). There are several reasons for such a level of attrition. A survey, carried out by Avolio et al. (2011) concerning eleven Peruvian SMEs, determined that 46.3% of the tasks that can limit their growth are associated with supply chain challenges; for instance, the control of their inventories, the management of suppliers and sales, and the conducting of market research. This coincides with the wide-held view that logistics and supply chain management are key disciplines for achieving the success and competitive performance of firms (Kherbacha and Mocan, 2016). Furthermore, companies are no longer just competing between each other; with the supply chains where they participate are the new arena for competition (Holland, 1995; Christopher, 2005).

Negative effects can be found in the intersection between logistics and supply chain management and disasters, man-made or of natural origin. Concerning the latter, climate change has been associated as a cause of natural disasters. Lately, these have been of greater magnitude and frequency (Benedon and Stephenson, 2004; Thibault and Brown, 2008). The effects of natural disasters on supply chains can provoke negative consequences in their performance; for instance, the volcanic eruption of Eyjafjallajökull in Iceland (April 2010) that stopped Europe-America commercial flights, or the Japanese tsunami (June 2011) that impacted negatively Toyota's international supply operations. There is a multitude of studies concerning the risks associated to natural disasters, and their impact on the supply chain (Chopra and Sodhi, 2004; Christopher and Lee, 2004; Helferich and Cook, 2002; Martha and Vratimos, 2002; Semchi-Levi et al., 2002; Sheffi, 2005). These works highlight the lack of organizations' preparation to deal with disturbances, due to vulnerabilities present in their organizational design and architecture. Several categories of supply chain risks have also been discussed, Christopher and Peck (2004) consider: (i) internal risks to the firm (processes and controls), (ii) external to the firm but internal to the supply chain network (demand and supply), and (iii) external to the network (environmental issues). In addition, Kleindorfer and Saad (2005) state there are two kinds of risk; those arising from the problems of coordinating supply and demand, and those arising from disruptions to normal activities. Further, Grossi and Kunreuther (2005) indicate how uncertainty affects stakeholders' risk in the modelling process on

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catastrophes. Wagner and Bode (2006) propose an analysis of supply chain vulnerabilities based on their drivers: (i) supply side (i.e. supplier network), (ii) demand side (i.e. customer dependence), and (iii) supply chain structure (i.e. global trade coordination). Tang (2006) presents an extensive review about different quantitative models for managing supply chain risks, such as supplier order allocation under uncertain demands. In addition, Banks (2006) analyzes the impact and severity of those called disruptors or catastrophes. Finally, others have investigated specific supply-chain vulnerabilities due to natural or man-made origin, for instance: criminal activities (Lemos, 2004), failure in support services (Koch, 2004), of suppliers (Macalister, 2002) or in technology (Kleindorfer and Saad, 2005; Olson, 2011), fire (Latour, 2001), shortages of parts (Pender, 2002; Treece, 1997), single provider dependence (Latour, 2001; Rice, 2005), terrorism (Rice and Caniato, 2003; Thurm et al., 2001), unexpected changes in demand (Barrett, 2001), and unforeseen events due to earthquakes (Fujita and Nobuaki, 2012; Reed and Simon, 2011a, 2011b). What these previous works have in common is that they show how supply chains are impacted by man-made or natural disasters. However, what seems less discussed is how to make organizations more resilient against such unfortunate events and in particular with MBs (Herbane, 2010).

Downes et al. (2013) consider that the concept of resilience comes from a wide spectrum of disciplines across the social and natural sciences. Over time, the concept has evolved and been adapted to different contexts. For instance, within ecology, Holling (1973, p.17) defined it as a condition that "determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist". Within sociology, resilience has been defined as "the ability of groups or communities to adapt in the face of external social, political or environmental stresses and disturbances" (Adger, 2000, p.347). Resilience has also been adapted to the supply chain management sphere and has been associated to the ability of a network to re-establish itself (Sheffi, 2005; Vargas-Florez and González, 2016). This variety of perspectives has triggered several academic works that compare different definitions of resilience and supply chain resilience (SCR) (Datta, 2017; Kamalahmadi and Parast, 2016; Mamouni-Limnios et al., 2014).

This paper will follow Datta's (2017) SCR definition: "SCR is a dynamic process of steering the actions so that the organization always stays out of danger zone, and if the disruptive/uncertain event occurs, resilience implies initiating a very rapid and efficient response to minimize the consequences and maintaining or regaining a dynamically stable state, which allows it to adapt operations to the requirements of the changed environment before the competitors and succeed in the long run".

Abubakar et al. (2017) and Datta (2017) agree on the need to propose key constructs to build a theory of supply chain resilience. Both propose a resilience architecture more or less similar to understand such resilience's constructs. Datta proposes nine constructs: agility, collaboration, complexity, operational vulnerability, risk, risk management, supply chain understanding, uncertainty and vulnerability. Collaboration is a common topic when studying supply chains (Gonzalez-Feliu and Morana, 2011; Muckstadt, Murray, Rappold and Collins, 2001), but this paper goes beyond as it explores collaboration in terms of its contribution to develop resilience to natural disasters in MBs. The rationale behind this preference is the understanding of supply chain risk management as "a shared process, developed in collaboration with the partners in the entire supply chain, to deal with the risks and uncertainties resulting from logistic activities and resources" (Verbano and Venturini, 2013). Datta defines collaboration as an intervention to reduce vulnerability against all types of disruptions, creating strong capabilities to manage effectively a vast number of interrelated operations, from multiple tiers of suppliers to customers. Datta also propose mechanisms to develop resilience under collaboration scope: (i) communication and information sharing to enhance collaboration, (ii) sourcing decisions and contracts for enhancing collaboration and

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(iii) trust to enhance collaboration. In this paper, this construct is illustrated through one vignette, where collaboration is the engine that moves individual MBs to engage into a community-based project (Rogers et al., 2016), due to the pressures from a distressful natural disaster, Coastal El Niño in Peru 2017.

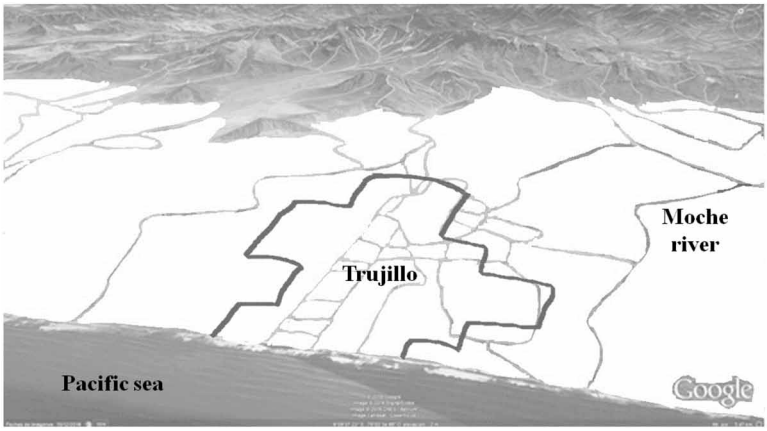
The structure of the paper is as follows; first is presented background information to describe the impacts of a particular disruptive event in Peru, named the Coastal El Niño (El Niño Costero) in 2017; second, is presented a vignette to illustrate how MBs develop in the face of such natural events; third, analysis is made and the type of supply arrangement is demonstrated. Following this is presented a second analysis highlighting links between collaboration and the increase of resilience. Then a generalization about how build resilience using a collaboration strategy is proposed and finally, a discussion about the limitation is developed. The vignette concerns a MB located in the surroundings of Trujillo, capital of the region La Libertad, north of Peru. This organization suffered the effects of the Coastal El Niño in 2017. The vignette relates to an apiculture MB sited in Quebrada de San Galindo, district El Porvenir.

COASTAL EL NIÑO IN PERU

At the beginning of 2017, Peru suffered weather conditions like El Niño phenomenon, called Coastal El Niño. The latter resulted in some intense rainfalls that intensified in mid-January. Such precipitation overloaded the rivers, originating landslides (called 'huaicos' in Peru) in the foothills and flooding in the lowlands. There is a wide literature describing the Coastal El Niño 2017 disaster and its effects (Delaitre, Sierra, Barroca, and Florez, 2018; Lavado-Rondon and Rivero-Cortijo, 2018; Martínez and Takagashi, 2017; Ramírez and Briones, 2017; Villanueva-Benites, 2018). This paper focuses in the city of Trujillo before the event with the network of open and channeled rivers. Figure 1 shows on the right side, the effects of Moche River. An expansion of the city that almost reaches the edge of the river can also be noticed in this area. In the top of the figure, a series of mountainous elevations (Sierra de Trujillo) and ravines that feed the rivers can also be seen.

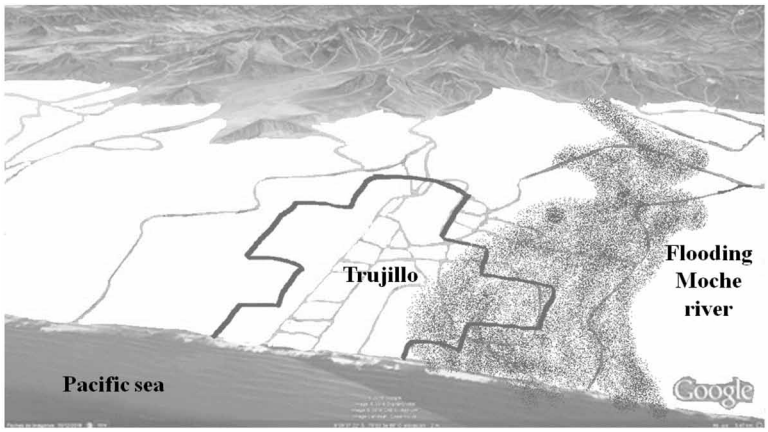
Figure 2 shows the city of Trujillo during Coastal El Niño. Flooding from the river Moche is noticeable in the east of the city, covering almost 25% of the whole city. In the elevated areas, new tributaries

Figure 1. Valley Trujillo rivers in rural and urban territory (before Coastal El Niño 2017, Peru)



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Figure 2. Valley Trujillo rivers in rural and urban territory (during Coastal El Niño 2017, Peru)



created by the accumulation of water can also be identified. It is in these zones where the conjunction of the increase in rainfall, steep ravines, type of non-compacted soils and accumulated water that overflows from the heights, resulted in huaicos. As a result, settlers were killed, infrastructure destroyed, and farming areas invaded. In summary, Coastal El Niño affected around one and a half million people in Peru, with more than $3,100 million USD in damages.

RESEARCH DESIGN

The trigger to conduct this research concerned the wish to answer the research question; how to increase MBs resilience? This initial question derived into others, such as: How do natural disasters affect MBs? How can organization reduce their vulnerability in face of natural disasters, in Peru? Is the resilience of micro, medium or large companies different? Further, are there any strategies to develop resilience inside MBs? Accordingly, the contribution of this paper concerns the exploration of 'collaboration', as a strategy that may support the process of effective decision-making inside MBs, which strive to develop resilience in the face of natural disasters. It is important to bear in mind that in this paper 'strategy' is understood as a "system of management that will facilitate the capability of the organization to respond to an environment that is essentially unknowable, unpredictable and, therefore, not amenable to a planning approach" (Dobson et al., 2004, p.2). This meaning remarks the importance to have a proper decision-making strategy to matches with the characteristics of the environment that MBs face when dealing with natural disasters. MBs usually centralize their decision-making in the owner's authority (Hodgetts and Kuratko, 1995). Empirical observations of the dynamics observed inside MBs and the way their owners constitute networks suggest these are fundamentally based on considerations of uncertainty (Perry, 1999). The quality of such decisions directly defines the well-being of their SME organizations (Hendry et al., 1995).

MBs supply activities suffer from fragmentation and specialization (McGrath and O'Toole, 2013), which do not seem to favor the jointly development of strong resilient responses to natural events. MBs have characteristics that suggest the need for changes in the usual interpretation of supply chain analysis, which normally centers on large companies (Hingley and Vilalta-Perdomo, 2017). For instance, SMEs

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lack human and financial resources (Bannock, 2005), and this makes them more vulnerable. Such vulnerability suggests the need to strive for resilience capabilities (Wedawatta et al., 2010). SMEs are usually flexible in their plans or programs, have a simple organizational structure, take decisions fast and have close collaboration with partners (Hemilä and Vilko, 2015). These features, therefore, may present alternative spaces in which to develop resilience.

To study the contribution that 'collaboration' may offer to MBs resilience, this study involved one organization that suffered disruptions due to Coastal El Niño. Visits to a MB were carried out as part of a collaboration program between academics from the engineering departments at the Pontifical Catholic University of Peru (PUCP) and the Catholic University of Trujillo (UCT). Data collection was done through interview made to the owner of the MB. This interview was conducted at the beginning of August 2017, with the support of the Director of Research at the UCT and people from GRIDES (Risk Management of Disasters and Adaptation to Climate Change), a local NGO working in risk management to Trujillo's population. GRIDES has been working in the area since 2009, with the support of its contacts inside the local municipalities, they created a communication network using mobile phones and social communication networks (Whatsapp and Facebook), to inform several actors (local or national authorities, social networks and media) about their interventions. According to GRIDES officers at Quebrada de San Carlos in Trujillo, the date when the emergency began was the 14th of March 2017. It involved the closure of pedestrian, carriage, asphalt and bridge roads, and left extensive urban and rural areas isolated from each other. Furthermore, that day a temporary closure and loss of capacity of productive activities and local services was reported. The footwear manufacturing industry and local agriculture around the Moche River (which crosses the city) were mainly affected. The MB analyzed in this paper concerns a family-owned beekeeper company. It is presented as a vignette to illustrate and discuss if "collaboration" strategy may develop resilience insides MBs. Main capacity for dealing with natural disaster pressures. A framework concerning food supply arrangements for food micro-enterprises was considered (Hingley and Vilalta-Perdomo, 2017) to understand how decisions are taken. This classification proposes four types of food micro-enterprises arrangements:

1. **Food Direct Distribution (FDDs):** FDDs are direct food suppliers to markets. In terms of decision-making concerns, FDDs micro-business goals have close link to short-term owner's objectives.
2. **Food Supply Chains (FSCs):** FSCs involve a big and powerful organization that organize the supply chain according to its own criteria. The control on the operations upstream and downstream resides in the big organization and micro-businesses must comply to it if they want to participate.
3. **Food Supply Networks (FSNs):** FSNs usually involve a series of interconnected FSCs, and fragmented and specialized overarching regional, commercial, operative, or umbrella groups. The different collective actors engage both vertically and horizontally with others to reach end customers.
4. **Food Supply Communities (FSComms):** FSComms usually involve an umbrella group that seeks to emphasize and exploit cohesiveness for the benefit of their whole member base. They follow individual expectations and preferences, encapsulated within community self-organizational principles.

For the analysis of the vignette, first a presentation about its operation is made, how the organization is lead, and how production and service activities are carried out. Then the information on Coastal El Niño impact is presented. After that, the beekeeper supply arrangement is identified through characteristics that better describes its operation. For this work evidences have been collected in interviews carried out

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with the owner. They are classified and presented (see Tables 1 and 2); this is done to establish the type of organization and its elements present in it. Continuing with the analysis, the collected answers are used to identify the type of strategy followed by the beekeeper to achieve resilience. The evidence will be classified according to a structure of classification for constructs applied for resilience in the supply chain propose by Datta (2017): (i) communication and information sharing to enhance collaboration, (ii) sourcing decisions and contracts for enhancing collaboration and (iii) trust to enhance collaboration.

MAIN FOCUS OF THE CHAPTER

Theoretical and Methodological Framework

The beekeeping company is a family-owned MB lead by a 60 years-old farmer (Mr. C) from the Laredo Valley, Trujillo. This MB maintains between 45 and 60 bee colonies per year. These colonies are made of wooden boxes. The number of them can be reduced or increased according to the conditions of the queen bee in the hive. According to information received from Mr. C, each colony produces during a normal season between 3 to 4 litres every three months.

The MB headed by Mr. C is a company that works independently. However, there are two cases where the company works collaboratively with other MBs owned by relatives and neighbors of Mr. C. The particular cases in which the MBs are collaborative, are; (i) to protect hives from frequent adverse weather events in the Trujillo region such as Coastal El Niño and (ii) to offer pollination services in agricultural areas, with customers from inside and outside Trujillo Valley. Mr. C and other producers can collect up to 300 colonies. The rationale behind such associations considers a reduction in the costs of transportation. It also allows them, as a collective, to provide a stronger service to their potential customers. According to Mr. C, Coastal El Niño affected the entire area of the Valley, either by the loss of resources (agricultural area, machinery and personnel). From INDECI (2017) those impacts on La Libertad region can be summarized as follows; La Libertad was: the region with the second largest casualties, the region with the most damage on housing, the region with the most damage to rural pathways, and the region with the most damage to agricultural areas in Peru. The direct impacts of Coastal El Niño in apiculture activities were: (i) a reduction of temperature in climate, which delayed the development of the bees in the hive; (ii) an increase in rainfall, which reduced the presence of pollen in flowers; (iii) an increase of huaicos, which damaged crops and flowering expected for summer, and (4) an increase of floods, which cut transport routes used for suppling and trading activities by beekeepers.

Microbusiness Arrangement Identification

There is wide literature concerning microbusinesses and nanostores (Duarte and Bressan, 2014; Fransoo, Blanco, and Argueta, 2017; Gray and Jones, 2016). In relation to the beekeeping case in Trujillo, under normal conditions, all the beekeeper MBs operate following their own distribution channels. According to Mr. C, "honey is sold in the farm, fairs, local events, wholesalers, local merchants and exporters". Each beekeeper follows their own decisions, usually related to economic reasons. Its organization principle follows individual adaptive strategies and its transactional direction is towards the customer. Therefore, the supply arrangement for the beekeeping MBs, under normal conditions, can be considered as Direct Distribution (DD) arrangement. In Table 1, evidences take from the interview support this categorization,

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Table 1. Supply arrangement characterization in normal operation

No	Criteria	Evidence	Characteristics
1	Challenge	"We help them, and they help us ..."	Survival
2	Driver	"Due to the phenomenon, there was only one honeycomb that served to feed the honeycomb ..."	Dependent on producers' expectations
3	Organizational principle	"It is possible gather up to 300 panels to pollinate..."	Adaptation
4	Transactional direction	"Honeycombs are rented to pollinate ..."	Towards the customer
5	Power structure	Power structure "Honey is sold in farm, fairs, local events, wholesalers, local merchants and exporters ..."	Based on direct customers' relationships

they are shown, the components structure for the analysis following Hingley and Vilalta-Perdomo (2017) proposals to this analysis. In a nutshell, the company belongs to different individuals, with independent mind-sets that distribute their products through personal direct relationships with their customers.

However, this type of supply arrangement is not always followed. For instance, in the case of a disrupting event, such as Coastal El Niño, other behavior appears. This event challenged the beekeepers' capability to survive. Their plan was to move the hives to other areas where no effects of Coastal El Niño would be felt. Mr. C and other honey producers (relatives and neighbors) contacted beekeepers of the Arequipa region to request help from these producers, by receiving the hives while the effects of Coastal El Niño in Trujillo lasted. The level of complexity of this operation may be reckoned by considering that 300 hives were moved to the Arequipa region, 1500+ kilometers south from the city of Trujillo, where Coastal El Niño did not have any negative effect. Even though the main reason why the different beekeepers decided to join efforts was to survive this catastrophic event, this purpose could only be achieved with the collaboration and participation of several micro-entrepreneurs, as the cost for transportation would become prohibitive, if they decide to do it independently. By collecting a significant number of beehives, they collectively achieved the economy of scale required to minimize the cost of transport freight. For the case of Mr. C, who has about 55 beehives, the cost of transportation was significantly lower after gathering a group of micro-entrepreneurs, who collectively possessed 300 beehives.

The other case where we observed collaboration between beekeepers was when they were providing pollination services for farmers. This service consists of bringing the beehives to agricultural areas, so that the bees can pollinate the harvest. To successfully cover several hundreds of hectares of agricultural land demands an important number of bees, and individual beekeepers alone are not able to provide the service because they usually only possess between 20 to 50 beehives. This is not enough to cover the areas of agriculture required. Mr. C is the biggest owner with 50+ hives. To provide pollination services, between 100 to 300 hives are usually needed. This motivates the micro entrepreneurs to collaborate, to offer a viable service capacity. Both cases, the sending of beehives to Arequipa and the provision of the pollination service, are based exclusively on relationships of trust between micro-entrepreneurs. Their schemes of collaboration do not involve any formal contract. This is not unusual among micro-entrepreneurs of the area and even more among those belonging to the informal sector (Stepick, 1989). The only instances of formal contracts are present with the transportation companies or the clients who are farmers of the pollination services. Therefore, the behavior found for the protection of the hives against

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natural disasters and of pollination services suggests that, Mr. C and his fellows' beekeeping MBs, act as Supply Community (SComms) arrangement. In Table 2, some extracts from the interview are shown.

Strategy Analysis

Collaboration is seen as a strategy in supply chain management (Matopoulos et al., 2007). Collaboration may be conducive towards increasing resilience, when coping with disruptions (Huxham and Vangen, 2005; Heifitz, 2009). According to Datta (2017) nine research constructs are useful to study resilience in supply arrangements. Collaboration has received attention (Mamouni-Limnios et al., 2014; Quick and Feldman, 2014) to recognize its contribution in the processes of resilience building.

Datta (2017) proposes three mechanisms to analyze how resilience is built when disruptive events are present. These are: (1) communication and information sharing to enhance collaboration, (2) sourcing decisions and contracts for enhancing collaboration and (3) trust to enhance collaboration.

When looking at the cases of collaboration between beekeepers, it is possible to identify actions conducive to communication and information sharing. Even though collaboration may support the alignment of interests between participants, this is not always required. Beekeepers showed a bivalent behavior, as a unit able to coordinate complex actions and, at the same time, as autonomous entities, in terms of how they continued managing their own customers and internal operation. The beekeepers' behavior in times of crisis indeed suggests some sort of alignment, which helped them engaging in a collective learning process, to search for alternative solutions. But at the same time, each beekeeper became a resource for the rest of them, a resource able to facilitate the operational cost of moving their own hives, by creating a temporary collective ownership. This joint effort allowed them to handle the crisis with adaptability, and the positive recovery from the crisis instilled in them the persistence to continue collaborating.

The second and third constructs; and trust to enhance collaboration, are intimately linked because the development of trust in the relationships of the micro companies expresses the commitment and decision making to carry out the collaboration. Micro-enterprises support many of the collaborative decisions they make in the group, based on the quality of the trust that exists among its members. Confidence, as Fukuyama (1995) says, is the catalyst for the development of business networks. The trust created

Table 2. Temporary supply arrangements characterization during collaboration

No	Criteria	Evidence	Characteristics
1	Challenge	"We help them [Arequipa beekeepers] and they help us". Note: Colonies were sent to Arequipa to avoid being exposed to the rains	Collaboration
2	Driver	"Honey is sold in farm, fairs, local events, wholesalers, local merchants and exporters ". Note: Different business rationale is followed by each owner	Different drivers
3	Organizational principle	"It is possible to gather up to 300 colonies to [offer the service of] pollinate". Note: Colonies are owned by different people, Mr. C relatives and neighbors	Internally self-organized
4	Transactional direction	"Due to the phenomenon (Coastal El Niño) there was only one colony that served to feed the rest". Note: Critical reduction on honey production triggered internal consumption to ensure colonies' viability.	Towards the producer
5	Power structure	"Honey is sold in farm, fairs, local events, wholesalers, local merchants and exporters". Note: Owners from the different colonies sell to a variety of customers, accordingly to their individual preferences	Decentralized

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between the members of the group validates or not the interaction and decision making in the collaboration, in a learning process of the relationship the micro-entrepreneurs decide to continue or not working together. It is in function to the obtained results that the confidence obtained expressed in the action by the collaboration is increased or reduced.

These reflections escape a simple rational analysis of benefit cost, this falls within a deeper reflection with the value judgment that the result has achieved in each one of the members of the group. This allows beekeepers to take risks and decide to work collaboratively to increase their supply capacity, adding each one, with the amount of hives they should to sum a total offer, which allows them to access better price and control conditions, environmental and market risks. In Table 3, answers that support this analysis are shown.

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

An important limitation of this study is the need for follow-up of the process of building resilience through collaboration, after the crisis triggered by the costal El Niño to the vignette presented here. Additional supportive information should be collected to include the perspectives of other actors. Further attention will provide knowledge on what happen to each of the actors after the crisis, such as the beekeepers in Arequipa, the transport companies who made the transfers between Trujillo and Arequipa, and the pollination farmers. With such information comparisons between different perspectives on how much the organizations changed through the crisis and after could be drawn. Some research questions emerge from this; for instance, how long did changes last? How much did this change in time affect the organizations? What other business opportunities opened up from other new adaptive configurations? What limitations does it have for the company to assume this chameleonic capacity in the face of disruptive and demand events? All these questions and others are open to be answered in a deeper analysis and study of MBs, to which must be added the complexity of working in formal and informal economies, macro aspects of businesses that have opportunities and limitations of their own dynamics and that directly affect microenterprises and their supply arrangements.

This paper uses the model of Hingley and Vilalta-Perdomo (2017), who classify micro-business arrangements, and this could be further applied to wider MB contexts. It should also be mentioned that the other constructs proposed by Datta (2017), could be studied with examples of disrupting events, where the systemic elements, characteristics and dynamics of the interrelation for the development of resilience would be analyzed.

Table 3. Evidences about a collaboration strategy

No	Criteria	Evidence
1	Communication and information sharing to enhance collaboration	"When they need hives the rest (of beekeepers) is called"
2	Sourcing decisions and contracts for enhancing collaboration	"When we have a significant number of colonies, we hire a truck to transport them"
3	Trust to enhance collaboration	"When we need each other (beekeepers) we support each other"

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CONCLUSION

This paper shows that strategies that build resilience in micro-businesses (MBs) are fundamental for MBs viability. There are alternatives available to define and implement such strategies, however these need, first, to fit with environment, physical and human-made and, second, to consider the supply arrangement structure. Resilience construction is based on a previous architecture of pre-existing relationships, where supply arrangements are configured not just by individual decision also for group interest. Supply arrangements are collective constructions, where the organizations involved not only take part in their operations; they also may change these collectives, and/or modify their own business in a permanent and circular adaptation, co-creation.

The resilience, in a vignette analyzed in this paper, can be recognized, managed, developed and increased through a clear strategy: a collaborative strategy that may support the increase of resilience in MBs. This is contextualized from the experience of the Peruvian Coastal El Niño 2017, and illustrated through the actions that one MBs collective of beekeepers took to deal with it.

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Chapter 18
Assessing a Vulnerability Index for Healthcare Service Facilities: A Logistics Perspective

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ABSTRACT

The rapid growth of cities in the 21st century along with the congestion of road infrastructure and high population density makes urban spaces highly vulnerable to disasters. After a disaster occurs, health services infrastructure is critical to support medical operations for injured patients. This chapter presents a methodology for evaluating the vulnerability of health services infrastructure from a logistics perspective, based on several layers of information such as population density, road congestion, and hospital location. The methodology uses computational and business intelligence techniques such as fuzzy inference systems, geographic information systems, graph theory, and visualization. The purpose of this methodology is to generate a unique score of vulnerability that identifies each health services facility, providing decision makers with the analytical framework of a spatial multicriteria analysis to evaluate their options for facing a disaster.

INTRODUCTION

Mainly urban areas have absorbed the accelerated increase in the world's population in the past four decades. By 2050, the world's population will reach 10 billion inhabitants, of which about 66% is projected to be urban (United Nations Department of Economic and Social Affairs, 2014). As fragile socioeconomic systems, cities are highly vulnerable to the impacts of environmental hazards, creating

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the premises for various disasters (Parker & Mitchell, 1995). In the context of an explosive increase in value of the damage caused by natural disasters, the need for evaluating and visualizing the vulnerability of urban areas becomes a necessity for helping practitioners and stakeholders in their decision-making processes (Armas, 2012).

Disasters such as the 2001 U.S. terrorist attacks, Hurricane Katrina, and the 2008 Chengdu earthquake have highlighted the need for improved public health and medical disaster response capabilities (Brandeau, McCoy, Hupert, Holty, & Bravata, 2009). Healthcare systems play a critical role in recovering and mitigating the effects of natural disasters and deliberate attacks (Arboleda, Abraham, Richard, & Lubitz, 2009).

While natural and human-hazard events will occur, the capabilities for coping with the effects of an event developed by a system or a nation will not be perceived as responsive to a major disaster (Kovács & Spens, 2007). An evaluation of the risks and a defined contingency plan for a quick response are crucial.

In this response, healthcare facilities become an important part of the support infrastructure. Furthermore, assessing the vulnerability of healthcare facilities is an important part of a contingency plan to mitigate the impacts of disasters in the population. Thywissen (2006) defines vulnerability as a dynamic and inner feature specific to any system, which usually becomes visible during a disaster. As Armas (2012) states, the need to define and measure vulnerability is necessary for a better understanding of the factors that determine when hazards become disasters.

Vulnerability assessment with respect to natural hazards is a complex process. Several works had taken different approaches to construct a vulnerability index to numerous hazards. U.M.K. Eidsvig et al. (2014) focused on landslide vulnerability for several European regions, they proposed an index using an additive model where each dimension was assigned with a weight based on its importance during a disaster. To compute this index, dimensions such as vulnerable elements, preparedness and recovery were analyzed. Since the scale of the calculated index is relative, a single score becomes difficult to interpreted. It was necessary to apply this model to different regions; from which the results form a base to interpret the single score. A more recent work, Zin Zin et al (2016), assesses earthquake vulnerability based on georeferenced land use conditions, population and building density. They used analytic hierarchy process (AHP) to set level of influence on pairwise comparisons of variables. Similarly, Lorenzo C. et at. (2017) evaluated both social (mortality, resources, poverty, population density) and physical (economical, infrastructure, social loss) attributes. They combined AHP to define weight priority for each attribute and fuzzy logic to build a final vulnerability score. On the other hand, Reza A. et al. (2018) proposed a systematic approach to measure the risk value of landslides through different factors. They applied a mamdani fuzzy inference system to build three factors: vulnerability, consequence and a likelihood index. Then a final risk value was calculated by a Takagi-Sugeno fuzzy system, using the previous indices as inputs. Fuzzy models are among the most powerful techniques in handling the inherent uncertainty (Reza Azimi et al, 2018).

In this chapter, a methodology to evaluate the vulnerability of healthcare facilities using Fuzzy Inference Systems (FIS) is presented. For this evaluation, multiple georeferenced layers of information may be used (such as population density or road connectivity) as inputs to the FIS, which in turn possesses a set of rules to process and merge available information into a unique score. The main advantage of this methodology is the expert's input. By evaluating changes in the rule-base, a quick and efficient facility scoring may be presented to decision makers in order to motivate data driven public policy for healthcare facilities.

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This chapter is organized as follows: Section 1 presents a brief revision of the problem statement, motivating the need for a vulnerability score for facilities and infrastructures. Section 2 states the problem of the case study. Section 3 presents the methodology to evaluate the vulnerability of different facilities with the focus on healthcare facilities via a fuzzy inference system, dealing with different steps in the decision-making process. Section 4 presents the results from a case study to evaluate the vulnerability set of 522 hospitals in Lima, providing an evaluation of vulnerability when facing a disaster. Finally, Section 5 concludes with a discussion of the practical implications of this research work and indicates some future research paths.

PROBLEM STATEMENT

In Peru's case, its location in the fire belt, its high levels of poverty, and the impacts of climate change makes the country a highly vulnerable area to natural disasters. The Inter-American Development Bank reports that during the period 1970–2009, Peru was affected by 105 disasters, 71% of which were caused by hydrometeorological phenomena (drought, floods, wet landslides, and frosts), and 29% the result of geophysical events (e.g., earthquakes, volcanic eruptions, and dry landslides). These disasters caused more than 74,000 deaths and affected 18 million Peruvians. During this period, Peru was the Latin American country with the highest number of deaths and the second highest in affected people (Tolmos et al., 2011). Disasters such as *El Niño Costero* phenomenon in 2017, which came in mudslides, have shown weaknesses not yet covered. Finally, Peru is among the top 10 countries in terms of disaster mortality in 2010 (Guha-Sapir, Vos, & Below, 2011).

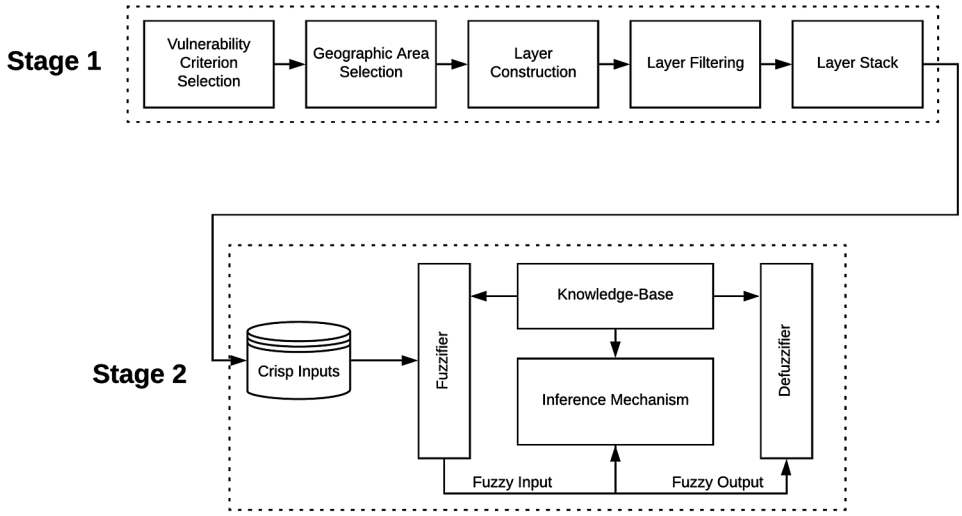
Lima, the capital city of Peru, is particularly vulnerable to natural disasters such as earthquakes and mudslides that result in hundreds of deaths and millions of people affected. In addition, Lima is considered a megacity with approximately 10 million inhabitants, but this growth of population was followed with poor urban planning (Vargas, 2009). As such, Lima's vulnerable population is around 30% in terms of poverty, location, and exposure to danger (Sistema Nacional de Gestion del Riesgo de Desastres, 2014). This population is located mainly at the outskirts in the hills surrounding the city. Lima is a vulnerable city in case a disaster occurs, due to its geographic location and characteristics, and should be prepared in terms of humanitarian logistics (Zarate, 2018). Healthcare facilities are highly vulnerable to these disasters, as reported by the National Institute of Civil Defense–INDECI. During *El Niño Costero* phenomenon of 2017, 20 healthcare facilities were destroyed and 81 were affected in Lima, which prevented prompt attention to more than 97 injured

METHODOLOGY

In this section, the methodology applied to produce a single vulnerability score to evaluate facilities (i.e. hospitals, universities) in disaster scenarios is presented. It is split into two main stages: the generation of georeferenced information layers, as data collection and preprocessing, and the implementation of a Fuzzy Inference System (FIS) to assess vulnerability for different facilities. A summary of this methodology is presented in Figure 1.

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Figure 1. Flow diagram of the proposed methodology



Georeferenced Layer Generation

The purpose of this stage is to gather georeferenced information layers based on the surrounding area of each facility, which will serve as input to the FIS. This stage can be divided into five sub-stages. These will mainly focus on vulnerability criterion selection, selecting the geographic area of study, layer construction, layer filtering (into areas of interest) and layer stacking.

For the first stage, the different variables used to measure vulnerability must be selected. This is a crucial stage as these variables will shift the scope of the evaluation (e.g. into a logistic, economic or infrastructural perspective) and they will serve as inputs for the FIS. Once the variables are set, in the second sub-stage the measurements are bounded to a specific area of study. These can range from 1 km2 areas to districts or city blocks. By using geographic aggregation different patterns may rise and interesting insights may be obtained.

As the third sub-stage, the layer construction focuses on aggregating data into the selected geographic area. Based on a "blank" or base layer, via geographic information systems or other software, data on higher or lower resolution is composed into the area of study selected in the previous stage. For each criterion, a georeferenced layer mapping the values from each source to this aggregation level is created. As such, one can have between 1 and N layers (denoted by $\mathrm{L}_1 \ldots \mathrm{L}_N$).

The fourth sub-stage focuses on selecting a set of regions R, such that $R \subset L$ where each region contains one or more of the facilities to be evaluated. This selection also acts as a filter, leaving out regions and facilities with missing data or possible outliers. Finally, since each layer is spatially the same, the layers are "stacked". This essentially means mapping the values from each layer to the facilities. In the end, a facility will have N characteristics based on the regions they were located in.

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Fuzzy Inference System Implementation

The second stage focuses on mapping the input criterion to a single score. This is achieved by implementing a FIS. As per Mendel (1995), a FIS can be deconstructed into four main components (aside from inputs and outputs): rules, a fuzzifier, an inference mechanism and a defuzzifier. In this sub-section the mathematical background to understand each component will be presented.

Formally, a fuzzy system is a "static nonlinear mapping of its inputs and outputs" (Passino, 1998). The system has inputs $\mathrm{u}_i \in \mathrm{U}_\mathrm{i},\ \mathrm{i} = 1, 2, \ldots,\ \mathrm{n}$ and outputs $\mathrm{y}_\mathrm{i} \in \mathrm{Y}_\mathrm{i},\ \mathrm{i} = 1,2,\ldots,\ \mathrm{m}$. Both of these are crisp (or continuous), not fuzzy sets. As part of the system, the inputs and outputs will be referred to as linguistic variables (each linguistic variable has a linguistic description of its characteristics) and U_i and Y_i as universes of discourse.

Linguistic Variables, Values and Rules

Similar to the values u_i and y_i can take over U_i and Y_i, respectively, the corresponding linguistic variables $\tilde{u}_i$ and $\tilde{y}_i$ take "linguistic values" that describe the characteristics of the variables. Therefore, let $\tilde{A}_i^j$ denote the j^{th} linguistic value of the linguistic variable $\tilde{u}_i$ and $\tilde{B}_i^j$ denote the j^{th} linguistic value of the linguistic variable $\tilde{y}_i$.

With this, the formal definition of linguistic rules can be presented. In a fuzzy system, the mapping of inputs to outputs is performed by a set of $\mathrm{condition} \rightarrow \mathrm{action}$ rules (or If premise Then consequent). The inputs are usually associated with a premise and the outputs with the consequent. This gives room for multiple ways to represent the rules. The two standard forms, as per Passino (1998), are multi-input multi-output (MIMO) and multi-input single-output (MISO) rules. Formally, the MISO rules to be used in this methodology take the form

If $\tilde{u}_1$ ***is*** $\tilde{A}_1^j$ ***and*** $\ldots$ ***and*** $\tilde{u}_n$ ***is*** $\tilde{A}_n^l$ ***Then*** $\tilde{y}_q$ ***is*** $\tilde{B}_q^p$

Fuzzy Sets and Logic

To quantify the meaning of linguistic variables, values and rules specified by the expert, fuzzy sets and logic are used. To introduce the concept of a fuzzy set, first it is necessary to define a membership function. Is essence, a membership function $\mu\left(\mathrm{u}_\mathrm{i}\right)$ maps U_i to the interval [0,1]. This mapping represents the "certainty" that an element of U_i, u_i, with a linguistic description $\tilde{u}_i$, may be classified linguistically as $\tilde{A}_i^j$. It is important to note that membership functions are subjectively specified from experience or intuition, usually in the form of triangular, trapezoidal or gaussian functions.

With membership functions introduced, a fuzzy set can be defined based on a linguistic variable $\tilde{u}_i$ (with a linguistic value $\tilde{A}_i^j$) and a membership function $\mu_{\tilde{A}_i^j}\left(u_i\right)$. A fuzzy set, denoted by $\tilde{A}_i^j$, is defined as

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$$\tilde{A}_i^j = \left\{ \left(\tilde{u}_i, \mu_{\tilde{A}_i^j}\left(u_i\right) \right) : u_i \in U_i \right\}$$

From this definition it is important to note that a fuzzy set is, at its core, a pairing of elements (from the universe of discourse) and their membership function values. Fuzzy logic focuses on set-theoretic and logical operations over fuzzy sets. For this methodology, the mathematical framework for fuzzy intersection and union will be presented.

Both of these operations take fuzzy sets as inputs and output fuzzy sets. The computation of fuzzy intersection can be defined by calculating the minimum of the membership values as follows:

$$\mu_{A_i^1 \cap A_i^2} = \min \left\{ \mu_{A_i^1}\left(u_i\right), \mu_{A_i^2}\left(u_i\right) : u_i \in U_i \right\}$$

As such, the computation of fuzzy union can be defined by calculating the maximum of the membership values:

$$\mu_{A_i^1 \cup A_i^2} = \max \left\{ \mu_{A_i^1}\left(u_i\right), \mu_{A_i^2}\left(u_i\right) : u_i \in U_i \right\}$$

These expressions can be used to quantify the terms in each premise in the MISO rules, where each "is" operation is replaced by the fuzzy set quantifying the meaning of each premise leaving only operations between fuzzy sets.

Inference Mechanism

In a fuzzy system, the inference mechanism has two basic tasks: determining which rule is relevant to the current situation (matching) and drawing conclusions using the inputs u_i and the information in the rule-base (inference step). For a detailed discussion on the matching process, we refer the reader to Passino, 1998. To perform the inference step there are two main alternatives. The difference focuses on determining the "implied fuzzy set" or the "overall implied fuzzy set". For this methodology and the computational implementation, the second alternative will be used. This involves the computation of the fuzzy set $\hat{B}_q$ with membership function

$$\mu_{\hat{B}_q}\left(y_q\right) = \mu_{\hat{B}_q^1}\left(y_q\right) \oplus \mu_{\hat{B}_q^2}\left(y_q\right) \oplus \ldots \oplus \mu_{\hat{B}_q^R}\left(y_q\right)$$

where $\oplus$ represents the fuzzy union operation. This membership function represents the conclusion reached when considering all the rules in the rule-base at the same time.

Defuzzification

As in the inference mechanism, the defuzzification strategy varies between using the implied fuzzy set or the overall fuzzy set. For this methodology, the focus will be on using a defuzzification strategy for

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the overall implied fuzzy set, specifically, the Max Criterion. Max Criterion is used to compute a crisp output y_q^{crisp} as the point at which the overall implied fuzzy set $\hat{B}_q$ reaches a maximum over the universe of discourse Y_q

$$y_q^{crisp} \in \left\{ \text{argsup}_{Y_q} \left\{ \mu_{\hat{B}_q} \left(y_q \right) \right\} \right\}$$

where "$\text{argsup}_x \left\{ \mu\left(x\right) \right\}$" returns the value of x that results in the supremum of the function $\mu\left(x\right)$ being achieved.

Case Study: Lima, Perú

As an application of this methodology, a set of hospitals from Lima, Peru was selected as the facilities to be evaluated. Following the first stage of the methodology, to assess the vulnerability of these facilities two criteria have been selected: population density and road infrastructure (specifically, betweenness centrality).

For stage two, both of these variables were collected at a 1 km2 resolution. Population density, collected from satellite images using LandScan (Bright et al., 2013), provides a 1 km^2 grid where the intensity value in each pixel represents the average population density for a day (averaged over a year) in that area. With the grid defined by this data source, using OpenStreetMaps (OpenStreetMap contributors, 2017), the graph corresponding to Lima's road network was split into this grid. To calculate betweenness centrality (a metric that indicates how centric a node is to a network and how well connected that network is), the OSMnx package from Boeing (2017) was used. For reference, lower values of betweenness centrality represent a more connected network. Finally, each healthcare facility is assigned the values from the region they geographically belong to. In Figure 2, both of these layers can be visualized at a 1km^2 resolution.

With the dataset prepared, consisting of 522 healthcare facilities with two characteristics, the input and output membership functions, as well as the rule-base are defined to structure the FIS. In Figure 3 the general abstraction of the fuzzy system is presented as a block diagram. On the left side, the membership functions of each input are presented (In Figure 4 a detailed version of these functions is presented). These are composed of trapezoidal and triangular functions, mapping the inputs to three fuzzy sets (Low, Medium and High).

With the membership functions constructed, five Mamdani MISO rules are proposed (Cordón, 2011). These rules were designed to give priority to the population layer, which will represent the potential amount of people affected in the region in case of a disaster.

1. If **Population** is **Low** and **Congestion** is **Low** then **Vulnerability** is **Low**
2. If **Population** is **Medium** and **Congestion** is **Medium** then **Vulnerability** is **Medium**
3. If **Population** is **High** and **Congestion** is **High** then **Vulnerability** is **High**
4. If **Population** is **Medium** and **Congestion** is **Low** then **Vulnerability** is **Medium**
5. If **Population** is **High** and **Congestion** is **Medium** then **Vulnerability** is **High**

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Figure 2. Input layers. Population density (left, a) and Betweenness Centrality (right, b)

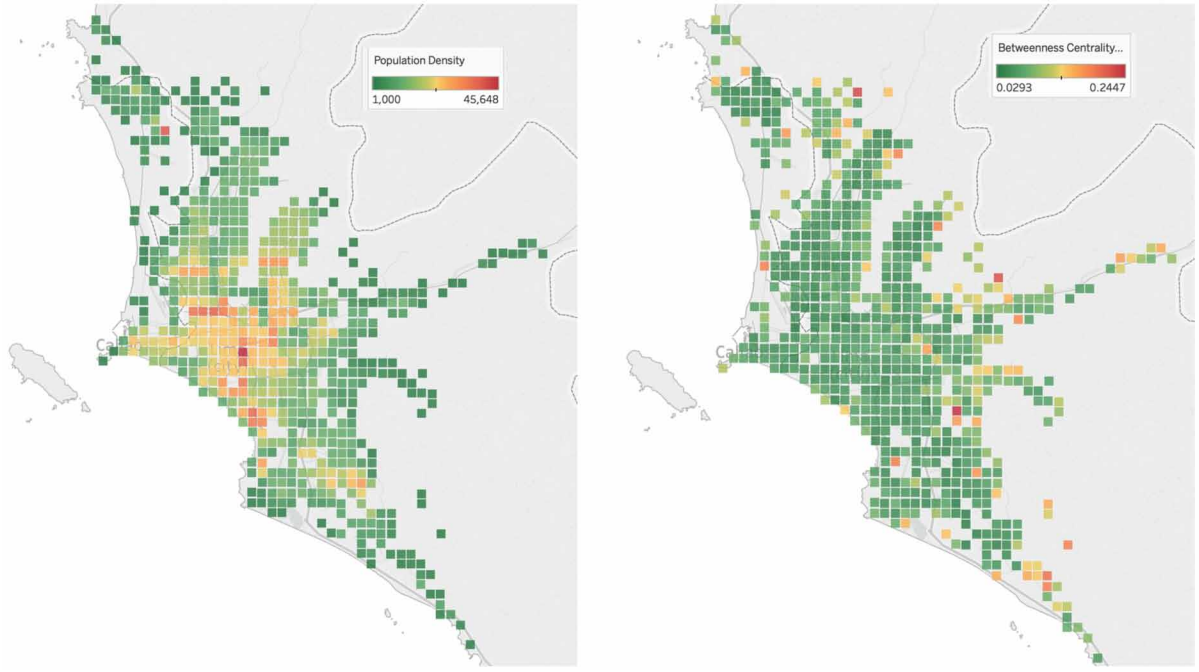
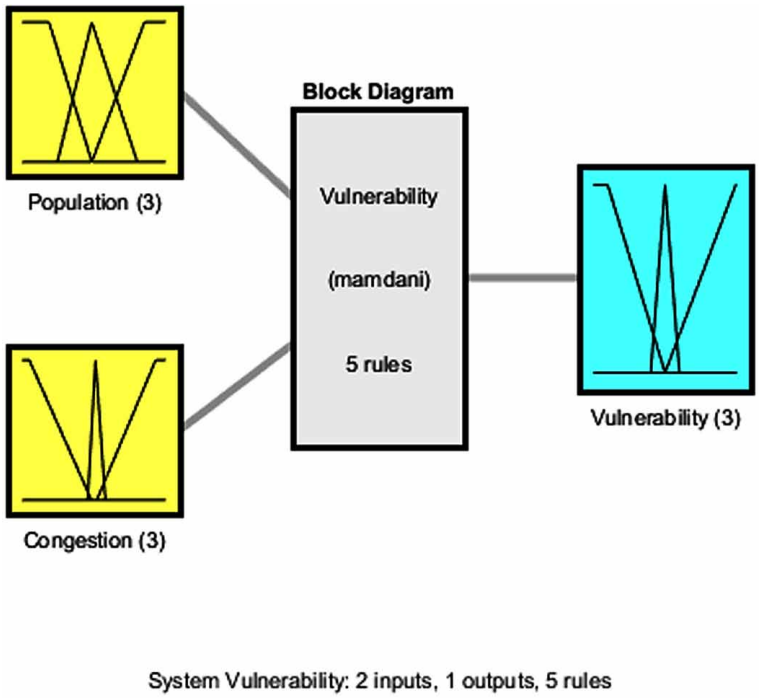
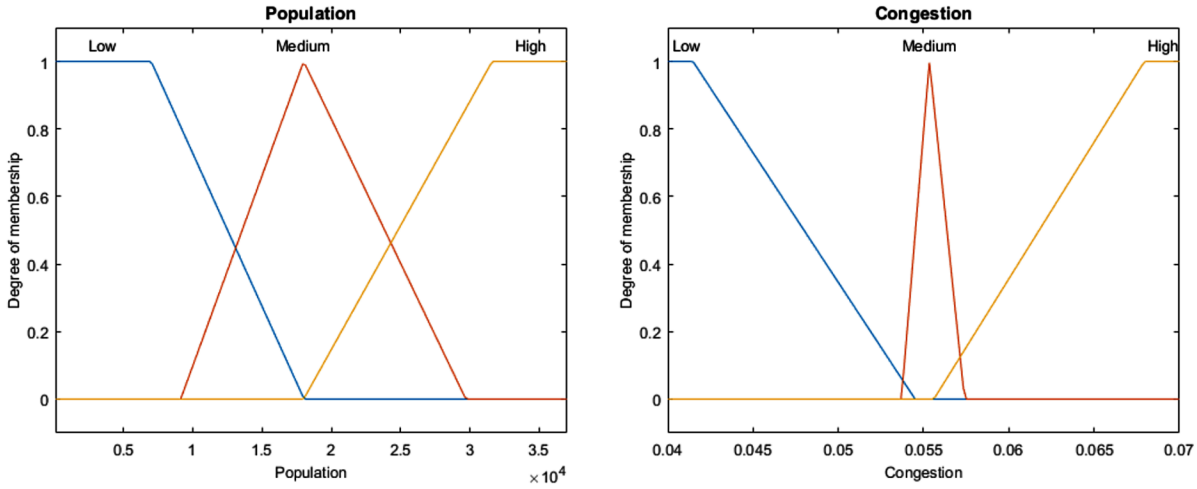


Figure 3. Block diagram for the fuzzy system



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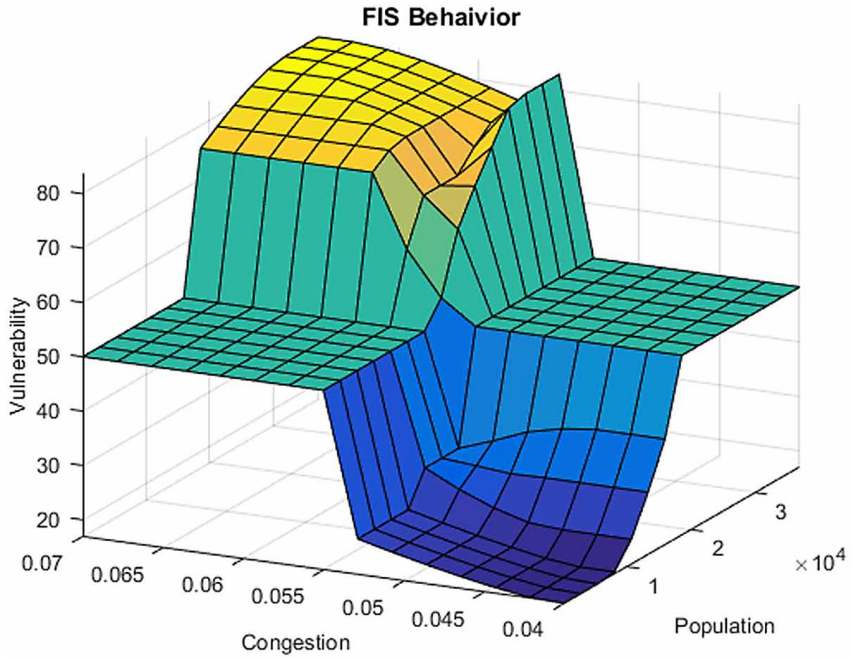
Figure 4. Membership functions for the input layer



RESULTS

This section presents the results from the application of the methodology to evaluate the vulnerability of a finite set of hospitals in Lima. The first set of results consists of a surface that visualizes the outputs (Figure 5) from the Fuzzy Inference System (FIS) and a map visualization for the vulnerability assessment for 522 healthcare facilities obtained through the FIS. The second set consists of the individual evaluation of six hospitals from Lima, selected using random sampling.

Figure 5. FIS system behavior

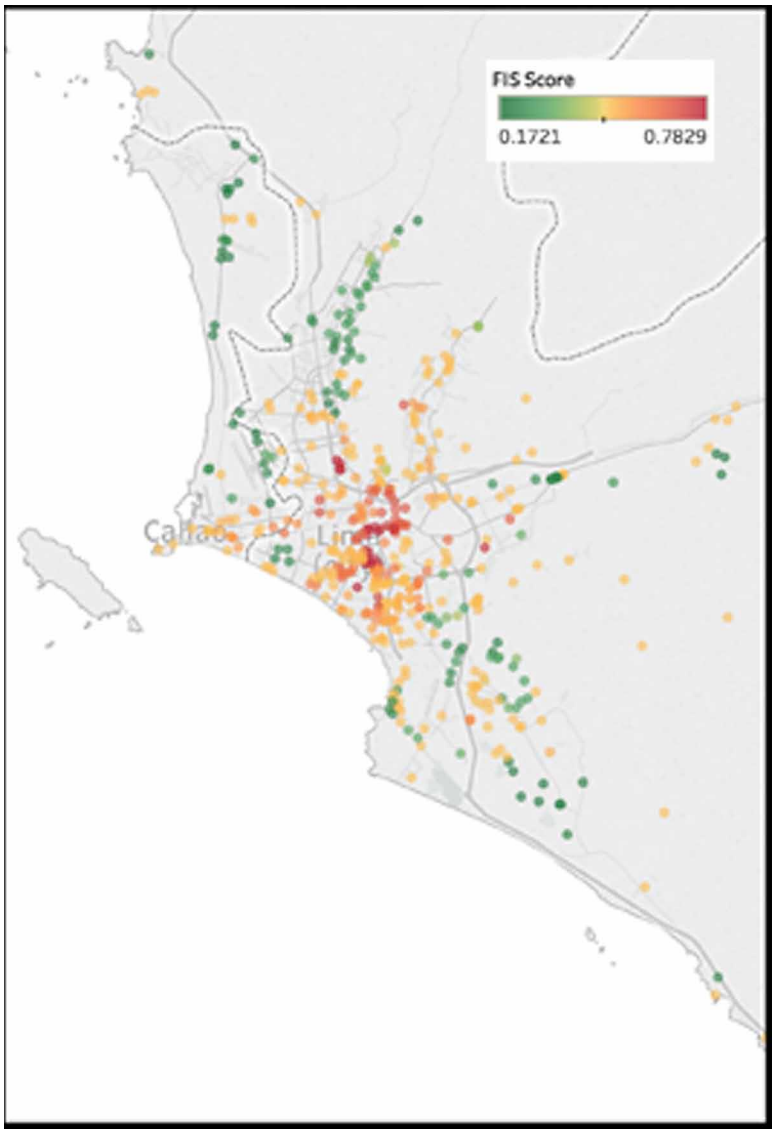


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The FIS behavior surface (Figure 5) provides a visualization of how the whole inference system merges the inputs and maps the final evaluation in a scale from 0% to 100%. Within this surface, different peaks and valleys represent the influence of rules in the mapping, and the blue and yellow corners signal low and high evaluations, respectively. The slope between the highest and the lowest evaluations represents the combination of the input values and the rules within the system. As the input values get lower (or higher), these inputs are mapped in the surface and are assigned a color from a blue-to-yellow gradient based on the fuzzy set they belong to (yellow for High, green for Medium, and blue for Low). It is interesting to note that flat, green-colored zones in the surface represent values that have not been subject to a set of rules, or else the defuzzifier maps them to a flat 50% vulnerability.

Figure 6 shows the result of the vulnerability assessment for 522 healthcare facilities in Lima using the proposed methodology. In the map, each facility is represented by a circular marker; each marker is

Figure 6. Visualization of the FIS output for 522 healthcare facilities in Lima



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assigned a color from a green (for lower scores)-to-red (for higher scores) gradient based on its vulnerability score obtained by using the FIS. As shown in Figure 6, most hospitals have vulnerability scores of 50% or less, and there is a strong concentration of vulnerable facilities in Lima's downtown. Additionally, the highest vulnerability scores from Figure 6 correspond to the facilities with the highest population density (Figure 2a) and the highest levels of congestion (Figure 2b).

The second set of results focuses on the evaluation of the set of hospitals from Lima. As shown in Table 1, each hospital was evaluated with the FIS. From the FIS Score column, the two hospitals that show the highest vulnerability are the Hospital Edgardo Rebagliati and the Hospital Nacional Arzobispo Loayza, with 72.74% and 79.21% respectively. From the FIS rules, both hospitals are mapped to the high set of both layers. In terms of population, each hospital (Rebagliati and Loayza) has an average population surrounding them of 24,455 and 24,484 people respectively. For congestion, each hospital has a 0.056239 and 0.0509849 betweenness centrality coefficient, respectively. Even though the differences are small, the difference of 6.47% in the final scores comes from the higher level of congestion and the slightly higher level of population. Aside from these two hospitals, the lowest score was obtained by the Hospital María Auxiliadora, given that is has the lowest levels of both population and congestion. Because the information for both layers corresponds to the Low set, this hospital gets 16.93% as its vulnerability score in case of a disaster. The two hospitals that get 50% as their score (Hospital Solidaridad Villa El Salvador and Hospital Jose Agurto Tello) get this evaluation due to the combination of rules and the fuzzifier. When looking at the membership functions and their specific activations for these hospitals, the value of each information layer is either in the High set or Low set, which then gets mapped to a medium set or to the flat zones in the surface with 50%.

CONCLUSION AND FUTURE RESEARCH

The conclusions of this chapter can be outlined as follows. A methodology to evaluate the vulnerability of different facilities with a unique score, based on several layers of information from their surroundings, is proposed and applied to the case of hospitals in Lima. This methodology is based on computational and business-intelligence techniques such as fuzzy inference systems, geographic information systems (GIS), graph theory, and visualization. The main advantage of this methodology is the application of a fuzzy inference system, which yields several benefits such as expert input when generating rules and flexibility when selecting the layers to be used as inputs.

Table 1. Vulnerability evaluation to each hospital

Hospital Name	Population	Congestion	FIS Score
Hospital Solidaridad Villa El Salvador	12 663	0.068746	50.00
Hospital Edgardo Rebagliati	24 466	0.056239	72.74
Hospital Nacional Arzobispo Loayza	24 484	0.059849	79.21
Hospital Municipal de San Juan de Lurigancho	20 381	0.054043	69.66
Hospital Jose Agurto Tello - Chosica	17 625	0.063405	50.00
Hospital María Auxiliadora	188	0.037638	16.93

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When generating the rules, the benefit stems from the value of expert input. Such input can focus the priorities of the system on a specific set of variables and guide the rules to comply with a set of regulations from a government entity. The flexibility of the system when choosing which layers go is a benefit, because an application of this methodology is not limited to the number of vulnerability criteria. For this chapter, the number of layers was set to two to fit a last-mile scope, but the computational power needed for a fuzzy inference system to work with a high number of vulnerability criteria is not a limitation. Even so, this application is still very general, as it does not take account of several criteria (e.g., the different tiers of healthcare facilities). As such, this methodology can fit different applications and take in as much information as needed to generate a unique score for the vulnerability of a facility.

Visualization plays a key role in this methodology. The final user will have less knowledge of the mathematical framework behind the model. Through visualization, further understanding of the interaction between the vulnerability criteria, the rules, and the inference system can be gained, and more informed decisions can be made, based on the knowledge extracted from this interaction.

Finally, a platform can be built on top of the fuzzy inference system to provide dynamic interactions between the decision maker and the model. Accordingly, decision makers and experts can set rule selection, input variables, and layer visualization in real time to enhance the performance of the system in its specific application.

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Chapter 19
Resilience of Urban Infrastructure in Latin American Cities

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ABSTRACT

Resilience is the capacity of a society or infrastructure to resist, adapt, and recover after being impacted by an extreme event. In this chapter, the authors focus on measuring how much the road infrastructure is able to withstand the appearance of extreme events. An extreme event will be represented by an intentional (e.g., perpetrated attacks) or unintentional (e.g., as result of climate extreme event) damage on the routes or intersections of the road network within a city. To do this, the authors measure the primary characteristics of urban networks in order to understand their morphology (i.e., the way in which they were constructed). Then, they evaluated the resistance capacity of different points of the road networks with three types of attacks: random, directed, and localized. The first results of this study show the fragility of some roads and intersections before the appearance of extreme phenomena. These results can be exploited by those in charge of public management and then converted into policies.

INTRODUCTION

A Japanese proverb defines resilience as "build again, but better". Resilience covers a group of capacities that an individual, a society or an infrastructure must have to continue functioning under adverse conditions or after an extreme event (Flemming & Ledogar, 2010). Currently, governments, environmental associations and society are concern about the adverse effects of a severe environmental event. This nega-

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tive effect can alter the resilience of infrastructure in three different ways. First, when the infrastructure does not fully recover its original state, becoming less resilient. Second, when the infrastructure recovers its original state, without altering its resilience. Third, when the infrastructure exceeds its original state, becoming more resistant to face future events. From the previous categorization, it is evident that the first state is the most worrisome. Therefore, state-of-the-art research is focused on this state (*i.e.*, first state).

Resilience is closely linked to vulnerability or fragility. Thus, it is necessary to quantify the risk factors for reducing vulnerability opportunely (Smokowski, 1998). In this context, the present study focuses on the vulnerability analysis of road networks in urban areas, notably, in densely populated cities like Lima-Peru and Quito-Ecuador. We have represented the road networks of both cities using graph models to compare their morphology and other properties. Then, we have analyzed the resilience of the road networks by simulating closure of roads and intersections. Finally, we have measured how the closure of roads and intersections makes it more difficult for people to reach health infrastructure such as hospitals.

The present chapter is organized as follows. Section 2 introduces the essential background and state-of-the-art. Section 3 explains the theoretical framework of our approach. Section 4 presents the methodology we have followed, while Section 5 describes our case study in two Latin American capitals. Finally, Sections 6 and 7 indicate some solutions, recommendations and future works, respectively.

BACKGROUND

Resilience is a concept of positive connotation. This term was used a hundred years ago as an indicator that allowed measuring the invulnerability or invincibility of infants, as an individual entity, as part of a family, or collectively or culturally (Glantz & Johnson, 2002). Later, other works in the literature reference to resilience as the possibility of intervention, prevention and positive adaptation to recover the vulnerabilities of individuals at risk. Other works related to resilience focuses on how to correct the vulnerability of a society and its infrastructure. For example, (McLellan et al., 2012) and (Eldosouky et al., 2017) assess the risk of global warming affecting critical infrastructures. (Meyer et al., 2018) (Godschalk, 2003) and (Kao et al., 2017) analyze repeated disturbances and focus on assessing the possibility of failure of a system facing a disaster. Also, Duijnhoven et al. (2014) and Marchant & Stevens (2017) conceive resilience as the capacity for mitigation, adaptation and recovery of a social or environmental structure affected by extreme climate changes.

In developed countries, resilience is used as an instrument to measure society's risk face to an adverse phenomenon, to prevent or intercept threats before they appear.

In the United States, there are organizations such as The National Academy of Sciences NAS, and the U.S. Global Change Research Program. These organisms offer a framework to analyze extreme events caused by a climatic phenomenon. They propose a sequence of systematized steps to discover and to document climate hazards. Then, they propose viable actions to reduce risks. These steps include measuring the initial damage caused, monitoring the recovery process, and assessing the existence of irreparable permanent damage. However, it is also possible to restore the initial state and improve the conditions to face similar disturbing events in the future.

On the other hand, the European Union and the European Commission (EC), in their document, Joint Communication to the European Parliament and the Council evokes the term resilience as a means of prevision. The idea is to make the population aware of natural disasters and how they can impact the vulnerability of society, especially in the poorest countries. The fragile components they consider are

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food, poverty and long-term sustainable growth. For this, the EC proposes to strengthen the resilience of the states in the prevention of catastrophes by supporting good governance, responsible institutions and working directly with civil society.

In South America, the study of resilience has aroused a vital interest in research projects and dissemination events that continue to increase in the last three years. This interest is driven by organizations such as UNESCO, ECLAC or foreign researchers who conduct research in the South American continent. For example, Ecuador has a group of Japanese experts who research, train and execute actions focused on strengthening resilience, risk analysis and disaster recovery. Likewise, in the rest of the countries like Chile, Peru, Colombia and Brazil they are working for disaster risk management and governance.

Resilience has two fronts the humanitarian, which evaluates the individual capacity of resistance in terms of poverty or nutrition and the vulnerability of social infrastructures like cities, buildings, agricultural buildings, among others (Pitrenaite-Žileniene & Torresi, 2014). Therefore, the challenge is to select the indicators to measure resilience to manage disasters adequately.

Measures and Indicators

Periodic and more intense disruptive events are causing new challenges for researchers on how to measure resilience. The proposals to measure resilience are provided from different perspectives that include disciplines such as, ecology, social science, psychology, engineering, among others (Florin & Linkov, 2016). In this context, some efforts capture several perspectives. For instance, Cutter et al. (Cutter et al., 2010) analyze 38 attributes grouped into five aspects: social, economic, institutional, infrastructure, and community. The authors study the resilience of counties within the U.S. Federal Emergency Management Agency's (FEMA) Region IV belonging to eight states. These states are characterized by abundant rainfall and frequent thunderstorms expressed in severe floods. Besides, these regions are also vulnerable to hurricanes and earthquakes. To select the best indicators, the authors use two criterions: 1) justification based on the existing literature on its relevance to resilience; and, 2) availability of consistent quality data from data sources. Also, authors were selected the less correlated attributes using the Pearson coefficient, and the Chronbach's Alpha Reliability/Item analysis. As a result, the authors provide two approaches: 1) a visual representation - in the form of a regional map - about how resilient is an area; and, 2) an empirical ranking of the ten most and least resilient counties.

Other studies analyze urban metabolism, social dynamics, the environment and network governance to identify strategic resilience indicators for cities. In (Normandin et al., 2009) the authors use nine baseline studies to select the best indicators of city sustainability. Later, the authors use a well-known methodology belonging to two main steps: 1) indicators developed by studies of vulnerability and city resilience were compiled and we analyzed by their frequency; and, 2) 273 indicators used in the sample of the 9 reviews where categorized in four key themes to understanding the resilience of urban systems: metabolic flows, governance networks, social dynamics, and built environment. As a result, authors select the 31 most used indicators and they conclude that there exist different ways to measure the risk, vulnerability and/or resilience of cities, which results in a large variety of indicators.

Furthermore, other efforts study the resilience measures focused on a specific field of study. The measures must quantify the capacities of resilience in terms of resistance, damping, adaptation, recovery, risk, vulnerability, failure rate, autonomy, connectivity, among others. For example, an indicator such as the volume of traffic can be associated with the resilience of urban infrastructures (Jayasinghe et al., 2015) (Wang, 2015) (Amini et al., 2015) and (Ganin et al., 2017) . In this context, resilience is

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evaluated based on indicators constructed from the monitoring of risk elements, such as routes intersections (Pitrenaite-Žileniene & Torresi, 2014). Other works measure the sustainability of cities based on increased pedestrian flow and reduced vehicle mobility (BOERI et al., 2017) and (Cariolet et al., 2015). Other authors use models based on Bayesian networks or Markov chains to measure the probability of failure of the physical components of critical infrastructures. Resilience can also be assessed through tests and comparisons with connectivity indicators to reduce vehicular congestion.

In the literature, several works focus on the study of resilience through the analysis of road infrastructure. (Wang, 2015) Analyzes the resilience of two large cities such as London and Beijing based on centrality as well as random and targeted network attacks. On the other hand, Masucci & Molinero (2016) and Calvert & Snelder (2017) measure the level of resilience by taking individual road stretches. The idea behind this work is to estimate how long it takes to recover a traffic flow of disturbances in a road network. The percolation technique is also used, which consists of eliminating a defined group of vertices one by one (intersections of a street) together with the connected edges (sections of streets) (Newman, 2010) (Li et al., 2014) and (Arcaute et al., 2016). Finally, Ganin et al. (2017) evaluate urban transport systems and the generation of public policies to reduce delays. In this effort, we focus on the analysis of the resilience of densely populated cities. To do this, we represent transport routes through graphs and evaluate them using intermediate and close centrality measures.

In the present work, we will represent a road network through a graph. Said graph was constructed through the Open Street Map library (*i.e.*, osmapi) using Python. Specifically, we will analyze the districts of San Juan de Lurigancho and San Borja in Lima-Peru; and Quito Norte, Quito Sur in Quito-Ecuador. Once the graphs are constructed, they will be analyzed through measures of centrality and betweenness. Then, we will simulate attacks to specific vertices to measure how accessible they are still, the health structures, after the elimination of their access routes. In our model, these vertices represent a health center.

THEORETICAL FRAMEWORK

In this section, some basic concepts about graph theory were introduced. Also, strategies to measure the resilience of the road networks of two populated districts in Peru and Ecuador were described in the next paragraphs.

Graphs

A graph is a set of nodes and edges, which join represents a binary relation (Xiong & Zheng, 2010). Formally, a graph is defined as an ordered pair $G = (V, E)$, where V is a set of vertices or nodes, and E is a set of edges or arcs. A graph is used to represent a series of objects and their relationships, for example, people who know each other, set of electronic devices connected between them, street networks and all those elements that have relationships.

Graphs, depending on their structure and construction, have specific measurable characteristics. These measures vary depending on the topology and the features of the network or road network. For this study, we selected a set of measures to determine the properties of an urban structure (*i.e.*, road network) by assessing the degree of resilience or vulnerability. The measures to be used in this study are:

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- **Appearance and Form:** These criteria describe the morphology of the graph. On the one hand, according to the appearance, the graphs are classified as regular, woody or organic. On the other hand, considering the shape of the network, there are circular, expansive, linear or fractal networks. In most cases, urban networks respond to self-organized growth; that is, they do not have a defined expansion plan.
- **Grade of a Graph:** The degree of a vertex $v \epsilon V$ in a graph G denoted as $dG(v)$, is the number of edges $e \epsilon E$ of G arriving at v. In a graph, there is always a pair of vertices of odd degree. Thus, the minimum degree of a vertex is denoted as $\delta(G)$, and the maximum one is denoted by $\Delta(G)$.
- **Connectivity:** Is the ratio between the link of the vertices $v \epsilon V$ and the edges $e \epsilon E$ in a graph G and is denoted as

$$c = \frac{|e|}{|v|} \tag{1}$$

where $|e|$ is the number of edges and $|v|$ is the number of nodes in G.

- **Density:** The density of a graph G measures the high or low connectivity of a network. For a non-directed graph, the density is calculated with the following equation

$$D = \frac{2e}{v(v-1)} \tag{2}$$

and for a directed graph:

$$D = \frac{e}{v(v-1)} \tag{3}$$

- **Mesh Graph:** The mesh M of a graph is used to measure its structure. It is important to note that a plain graph is a graph where none of its edges intersects another. Besides, a region (or face) of a graph is defined as an area bounded by edges and could not continue to be divided into sub-areas. Taking into account the number of faces F of a graph G and taking the formula of Euler (Buh et al., 2006), the mesh would be represented by the following equations

$$F = e - v + 1 \tag{4}$$

$$M = \frac{F}{2v-5} \tag{5}$$

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where F is the number of faces of a graph *G* y *(v, e) ϵ (V, E)*, then *M* is the mesh of *G* as a function of *F. M = 0* (zero) if the plain graph is a tree type (self-organized). When *M = 1*, the plain graph is a complete (planned) graph.

- **Organic Indicator:** This measure is used to determine if a network has been planned or not thanks to the calculation of the number of vertices of degree 1 and grade 3. In our context, the former represents the dead ends and the latter, the number of intersections without finishing. The organic indicator detailed in (Courtat et al., 2011) is given by the equation

$$O = \frac{v\left(1\right) + v\left(3\right)}{\sum_{j\neq 2} v\left(j\right)} \tag{6}$$

where, *V(1)* represents the sum of all the vertices of degree 1, *V (3)* represents the sum of all the vertices of degree 3 and *V(j)*, represents the sum of all the vertices except for the vertices of grade 2.

- **Betweenness Centrality BC:** Given a graph *G=(V,E)*, the betweenness centrality measures the importance of a vertex *v ϵ V* to connect two edges *p, q ϵ E* considering the shortest routes. The betweenness Centrality is given by the equation

$$B_i = \sum_{j\neq g\in G} \frac{B_{jg}\left(i\right)}{B_{jg}} \tag{7}$$

where $B_{jg}\left(i\right)$, is the number of shortest routes between the two vertices *j* and *g* that pass through the vertex *i*; B_{jg} is the number of shortest paths between them.

- **Closeness Centrality:** Given a graph *G = (V, E)*, the closeness centrality CC is a measure that represents the average distance of all the shortest routes from a vertex *v ϵ V* to any other vertex *v' ϵ V* accessible within the network (Russell, 2013). The closeness centrality indicates how well a node is connected in a graph. This measure is calculated for each of the vertices and is normalized by adding all the possible minimum distances. The closeness centrality is given by the following equation

$$C_i = \frac{\left|v\right| - 1}{\sum_{i\neq v\in G} d_{iv}} \tag{8}$$

where d_{iv} is the shortest distance between vertex *i* ϵ *V* and vertex *v* ϵ *V* in a graph *G*. The vertices that have a small average length towards the rest of the vertices, are said to have a high centrality nearby.

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Measuring Resilience Based on Attacks on the Network

To measure the resilience of the road networks of San Juan de Lurigancho and San Borja districts in Lima-Peru; and Quito Norte, Quito Sur in Quito-Ecuador, we have simulated attacks in important points surrounding health attention areas.

A network attack is a process in which the elimination (*e.g.*, interruption, disabling) of one, several or all the vertices of a graph or network is simulated. These vertices can be interrupted by the impact of a disturbing event. There are of four attack types.

- **Random Attack:** Evaluates the resilience of the network after eliminating the vertices one by one in a random way. This means that all vertices have the same probability of being deleted in the attack. Then we calculate and evaluate the connectivity after each elimination until the network falls completely, that is until it has zero connectivity (Shao et al., 2015).
- **Directed Attack:** Evaluates the network resilience by eliminating all the vertices, starting with the vertex that has the highest betweenness centrality (BC), in descending order. Then, we calculate, after erasing a vertex, the new connectivity of the graph to evaluate the relationship between the eliminated node and the general connectivity of the network (Shao et al, 2015).
- **Localized Attack:** Evaluates the resilience of a network by interrupting the vertices located in a specific sector. In this process, a fraction of 1-n vertices of a larger network component are eliminated, and the new connectivity is computed. This process serves to show how the interruption of this fraction of vertices affects the largest component in terms of resilience. For example, around hospital roads are interrupted by an extreme climatic event such as a flood.
- **Localized Attack With Replacement:** Calculates the resilience by eliminating a fraction 1-n vertices of the whole network, similar to the localized attack. The variant in this method is that the eliminated node is being replaced in each interaction. The purpose of this attack is to measure how much the removed node affects the connectivity of the largest component and to determine which node of the eliminated fraction is the most important. It worth noting that this attack is costly from a computational point of view.

METHODOLOGY

The proposal was developed in steps. The first step comprises the extraction and representation of the study areas by graphs or networks, as shown in Figure 1 and Figure 2. A spatial hierarchy was raised to analyze the networks thanks to the three attacks reported in the earlier section. In this hierarchy the network is divided into three components: 1) large component (Figure 1-a); 2) medium component (Figure 1-b), which is a part of the large component; and, 3) small component (Figure 1-c), which is part of the median component. The geo-referenced data was collected from the Open Street Map platform, addressing four strategies: 1) using the name of a place; 2) applying a bounding box; 3) using Lambert coordinates (latitude, longitude) and a radius; and, 4) drawing a polygon.

It is noteworthy to notice that networks are representing San Borja Lima-Peru and Quito Sur, were built employing the same strategy depicted in Figure 1 and Figure 2.

In the next subsection, the application of the measures outlined above on the urban areas obtained was described. To achieve this aim, a comparison of the results was performed to capture and contrast

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Figure 1. Components of the network: (a) large component belonging the district of San Juan de Lurigancho; (b) medium component formed by a kilometer radius around a Lambert coordinates; (c) small component around "La Solidaridad" Hospital.

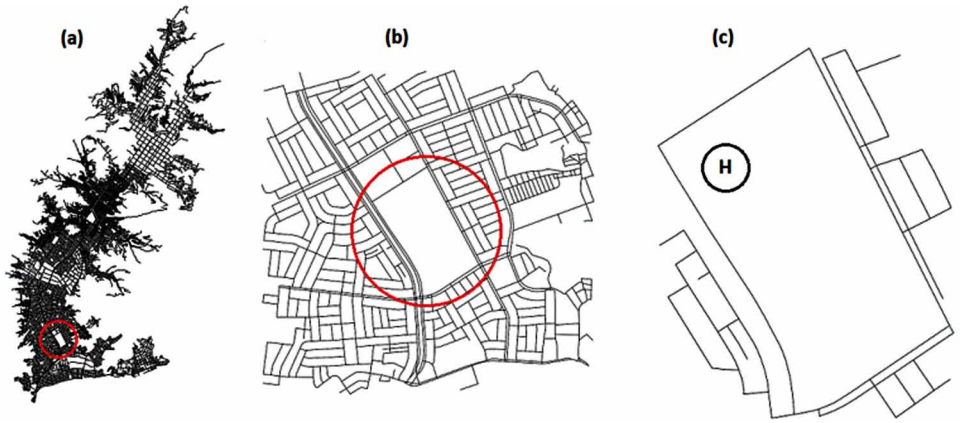
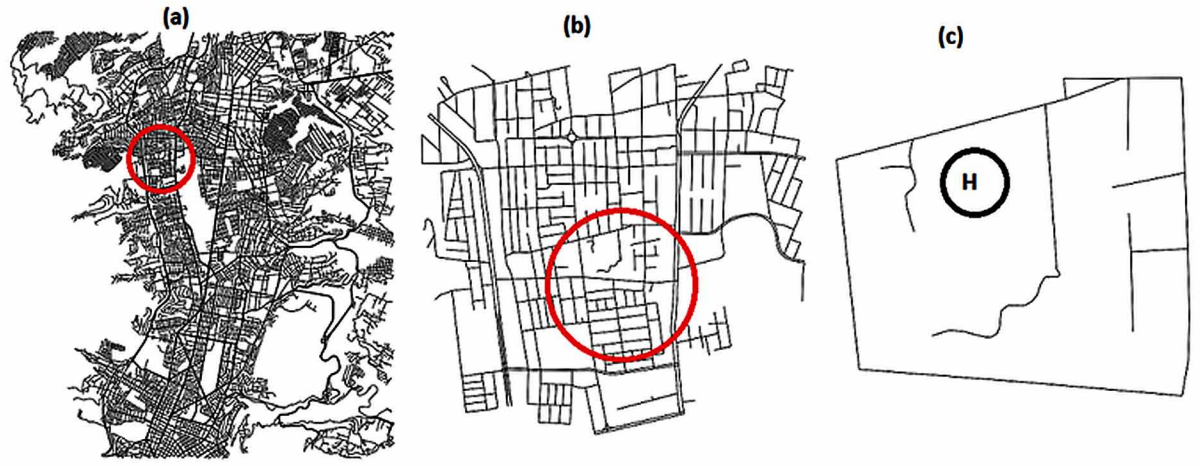


Figure 2. Components of the network: (a) large component belonging the northern area of Quito, (b) medium component formed by a kilometer radius around a Lambert coordinate, (c) small component around the "Pablo A. Suarez" Hospital.



the degree of resilience of each network component. Two contexts were considered: first, in the normal state (without alterations or attacks); and, after being impacted by an abnormal event.

CASE STUDY: LIMA, PERU VS QUITO ECUADOR

For each study cases, the shape, and appearance were evaluated. It is worth noting that the networks representing San Juan de Lurigancho, Quito Norte, and Quito Sur have a linear shape and an irregular appearance. On the contrary, San Borja's shape seems circular, and its appearance is regular or planned.

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Table 1 summarizes the measurements obtained for mesh, organic, density, connectivity, and the intermediate centrality measures of the collected networks.

The predominant appearance for San Juan de Lurigancho and Quito Sur, is mesh, while for San Borja and Quito Norteis organic. Regarding the measure of connectivity and density, San Borja has the best results and San Juan de Lurigancho the worst one.

Betweenness Centrality (BC) and Close Centrality (CC) Analysis

In this part, the Betweenness Centrality CB was computed for the four urban communities at our disposal. The purpose is for identifying the crossroads with the highest volume of traffic (see Figure 3). This measure determines the traffic distribution in urban areas. The shiny yellow dots illustrate the intersections with higher BC, and the green dots depict the intersections within lower BC. This analysis helps to better understand how the crossroads with greater interconnection are distributed.

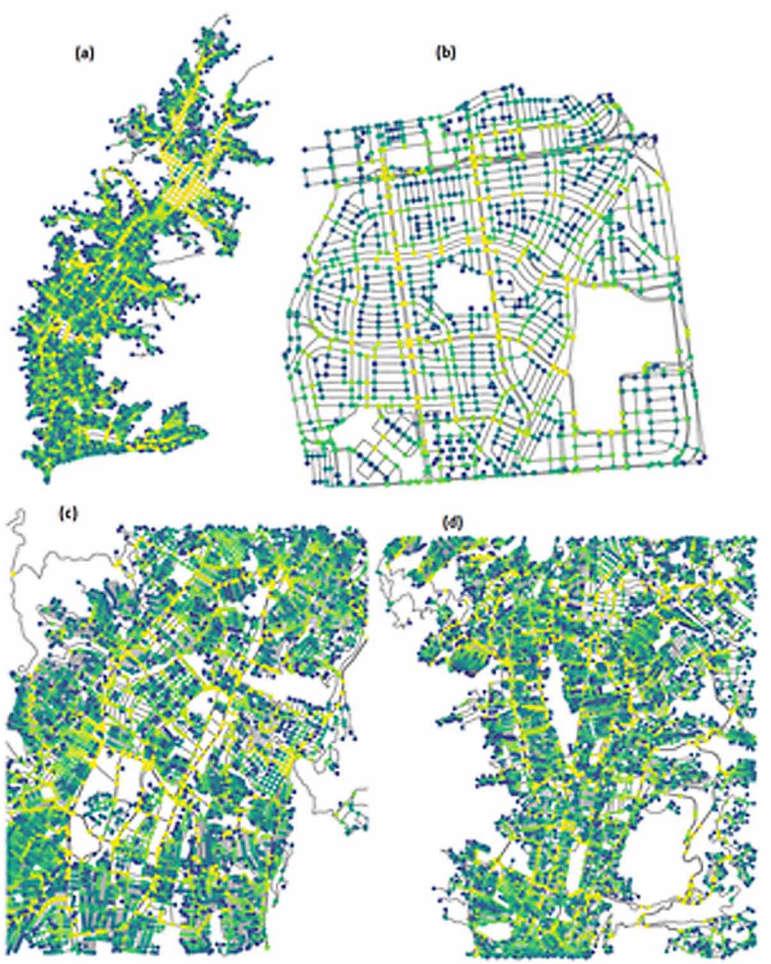
The following analysis focus on the analysis of the Close Centrality CC measure. As illustrated in Figure 4, the intersections with higher CC are the yellow vertices. These results provide another view of the network structure. This measure evaluates the central crossroads that have less proximity (distance) with the rest of the intersections of the large component. Therefore, these intersections are will support a higher volume of traffic than the rest of the intersections. As can be seen, the crossroads with higher

Table 1. Network characteristics of the large, medium, and small components of the urban communities evaluated

Urban District	Hospital	Mesh	Organic	Density	Conectivity	BC	BCs	%
San Juan de Lurigancho	SJL Hospital Solidaridad	0.8718	0.7904	0.0003	1.4930	53.6600 53.6600	0.1047 0.5629	0.20 1.05
Medium component 1km/rad	SJL H. Solidaridad	0.8276 0.8199	0.8542 0.8049	0.0025 0.0039	1.4925 1.5081	18.9080 14.2808	2.0782 2.7182	10.99 19.03
San Borja	Clínica Internacional Niño y Adolescentes	0.6962	0.7215	0.0018	1.5704	17.6022 17.6022	0.1252 0.0767	0.7113 0.4356
Medium component 1km/rad	Clínica Internacional Niño y Adolescentes	0.6993 0.6178	0.6949 0.7373	0.0043 0.0039	1.5108 1.5393	13.1420 12.6420	1.8090 0.6672	13.77 5.28
Quito Sur	Padre Carollo Enrique Garcés	0.8499	0.7568	0.0002	1.4565	48.1593 48.1593	1.0272 0.0159	2.1328 0.0330
Medium component 1km/rad	Padre Carollo Enrique Garcés	0.6740 0.7190	0.7360 0.7700	0.0047 0.0054	1.4364 1.3532	13.6046 13.1918	4.0462 0.9107	29.74 6.90
Quito Norte	Pablo A. Suarez H. SOLCA	0.7323	0.7894	0.002	1.4379	43.6766 43.6766	0.0462 0.1267	0.1058 0.2901
Medium component 1km/rad	Pablo A. Suarez H. SOLCA	0.7314 0.7340	0.7596 0.7800	0.0047 0.0045	1.4481 1.3672	12.2986 12.1598	0.9222 2.1190	7.50 17.43
Mean BC medium component Mean BC giant component							13.83% 0.62%	

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Figure 3. Betweenness Centrality BC for the large components: (a) San Juan de Lurigancho, Lima, Peru; (b) San Borja, Lima, Peru; (c) Quito Sur, Quito, Ecuador; (d) Quito Norte, Quito, Ecuador.



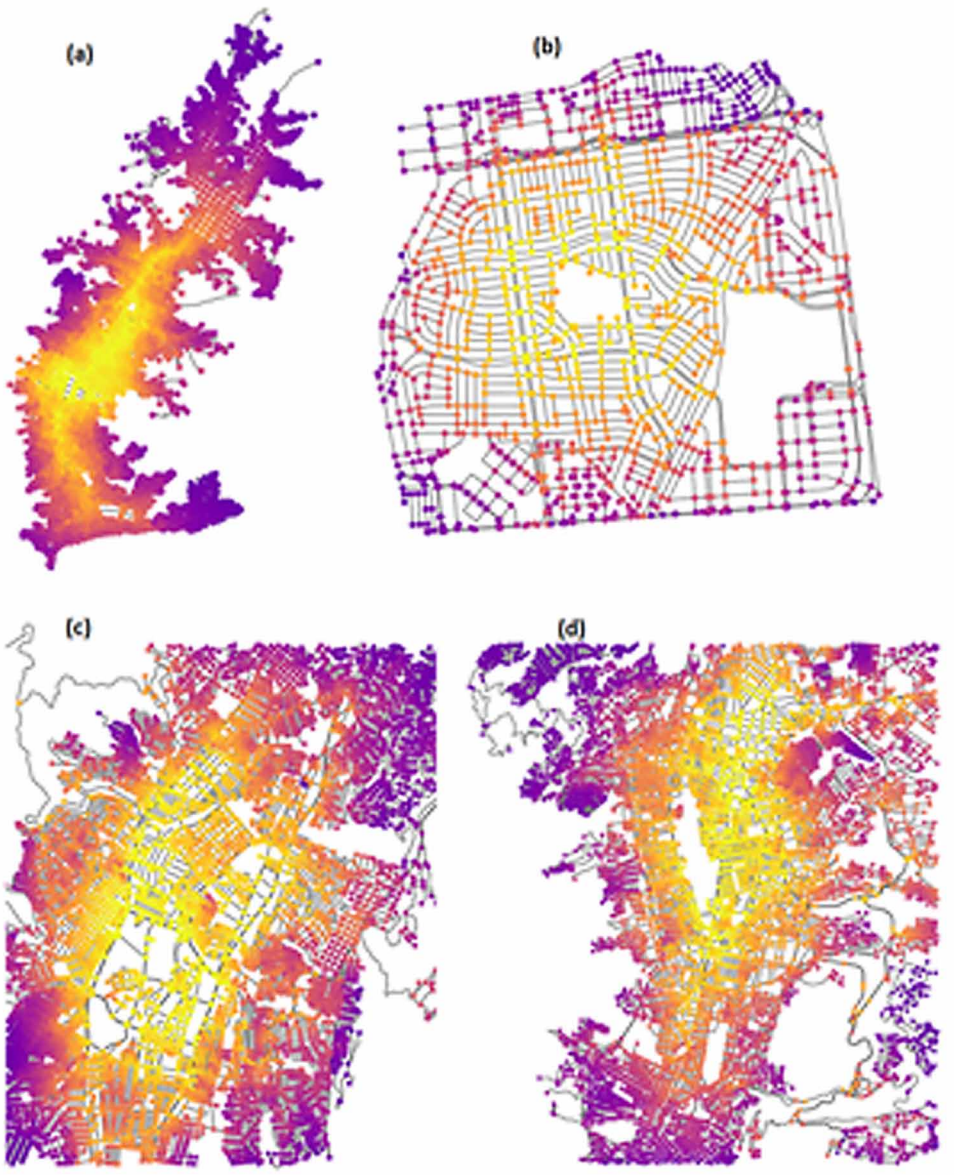
CC are concentrated in the centre of the network (*c.f.*, Figure 4). On the contrary, the BC shows that the most significant intersections are distributed throughout the graph of the large component.

The information provided by the BC and CC measures does not allow define which specific places in these cities are the most critical in terms of use and access of networks and access to particular areas in a component. The idea is to use a finer spatial granularity to find the intersections and streets having the most traffic. For this reason, an evaluation of the intersections with the highest values of BC were performed to compare them with intersections having the highest amounts of CC. This evaluation allows verifying exactly which places in the city have the most considerable traffic.

For this evaluation, 1% of the intersections with the highest values of BC from each network were extracted. For instance, Figure 5 shows the existing relationship of traffic distribution between the districts San Juan de Lurigancho and San Borja in Lima, Peru. On the one hand, the first district has an exclusive one-way dependency (Av. Próceres de la Independencia) since the most inter-connected streets crossings in this district are located here (Figure 5-a). On the other hand, the second district has a better

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Figure 4. The Close Centrality CC for the large components: (a) San Juan de Lurigancho, Lima, Peru; (b) San Borja, Lima, Peru; (c) Quito Sur, Quito, Ecuador; (d) Quito Norte, Quito, Ecuador.

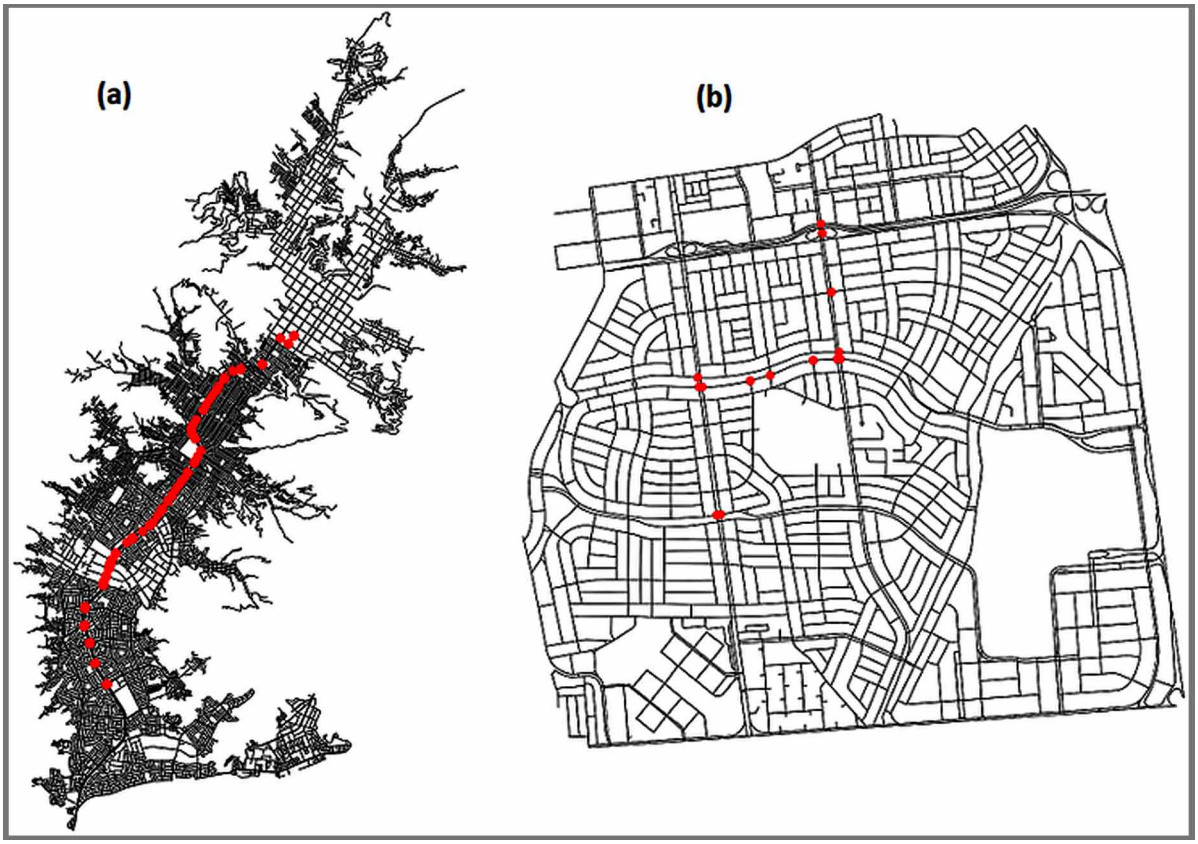


distribution of street crossings with greater interconnectivity, spread over several roads. This information reveals that San Borja is more resilient in terms of the network interconnectivity since it distributes the traffic better over its road network (see Figure 5-a).

Later, the same analysis was performed for intersections with the highest value of CC. These intersections are located in the centre of the urban network. For instance, intersections with the highest values of CC belonging San Juan de Lurigancho are located in the central avenue (see Figure 6-a). In contrast, intersections belonging San Borja with highest CC are better distributed (see Figure 6-b).

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Figure 5. Crossroads of the higher BC represented by red points (a) San Juan de Lurigancho and (b) San Borja Lima-Peru.



From the two previous studies (BC and CC) it is possible to infer which are the critical intersections with a high volume of traffic. These intersections have higher interconnectivity and higher proximity regarding all attainable points belonging to the same large component (Jayasinghe et al., 2015) and (Wang, 2015). This result can be interpreted in the following way: if an extreme event (*e.g.*, a fire) appears and destroys or disables one of these vertices, vehicular traffic could collapse. This fact represents a danger for the mobilization of first aid units (firefighters) sent to support. To strengthen this analysis, the street connecting the intersection of higher BC with the intersection of greater CC was located. The connection is made using the shortest route principle between the vertices x and y; as seen in Figure 7.

Attacks to the Network

Finally, to measure the resilience, three types of attack were performed on the network. The idea behind these attacks is to neutralize a vertex to estimate how much this action affects access to a hospital. To accomplish this aim, three types of attacks were performed: random, directed and localized, for each of the four networks. The purpose of these attacks is to determine the stability of the large component face to an abnormal event. The process consists of neutralizing the intersections one by one and measuring the new BC for the overall network. Results are shown in Figure 7.

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Figure 6. Crossroads of the higher CC represented by red points (a) San Juan de Lurigancho and (b) San Borja Lima-Peru.



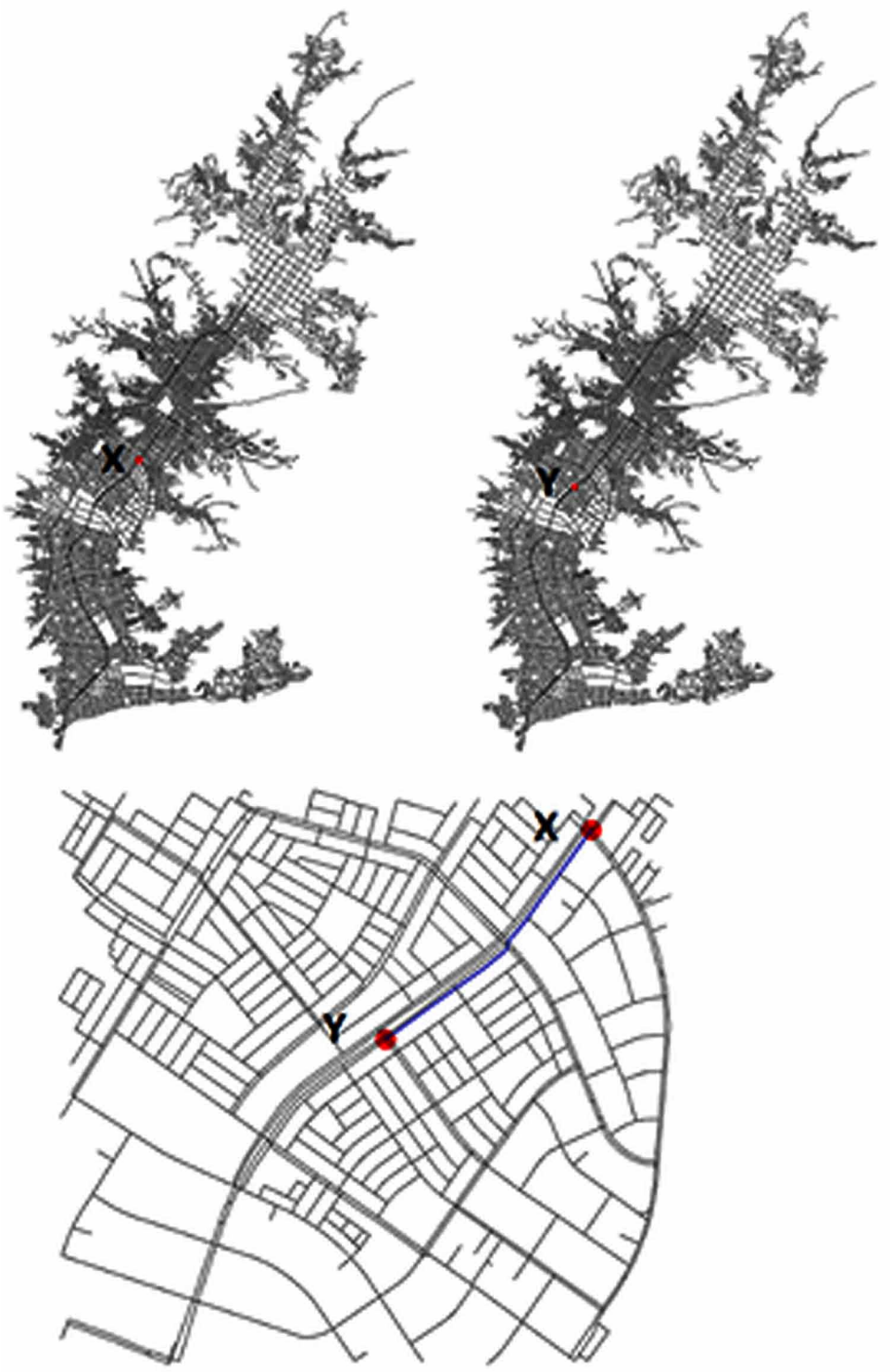
The attack allows us to evaluate how fast the interconnectivity of the intersections falls. As a result, the effect of the localized attack (green line in Figure 8) is not significant for the large component since only vertices of the small component are eliminated. Conversely, the random attack (orange line in Figure 7) substantially affects the connectivity of the large component, and the network becomes inoperative when 50% of the total intersections are shut off. Finally, the directed attack (blue line in Figure 8) is the attack that impacts the most on resilience. This last attack consists of eliminating the vertices of higher BC. Later, the incidence of the directed attack varies according to the resistance of each component according to the BC of each node. In conclusion, if vertices belonging a network have a better distribution of BC, the network resists a direct attack, making it more resilient.

This analysis shows that the most fragile networks are San Juan de Lurigancho and Quito Sur since the connectivity drops drastically when eliminating between 5 and 8% of the vertices (see Figure 7-a and Figure 7-c). On the contrary, San Borja and Quito Norte, are more resistant, because the disintegration of the network is more uniform and falls when 25 to 20% of vertices are eliminated. As a consequence, San Borja and Quito Norte are less fragile networks, therefore, have greater resilience.

Additionally, it is crucial to evaluate the incidence of the localized attack and understand how the interruption of the intersections of the small component affects the activity of the medium and large component. The idea behind this evaluation is to find which vertices of the small component around each hospital are the most important. First, we eliminate the vertices of the small component one at a time and

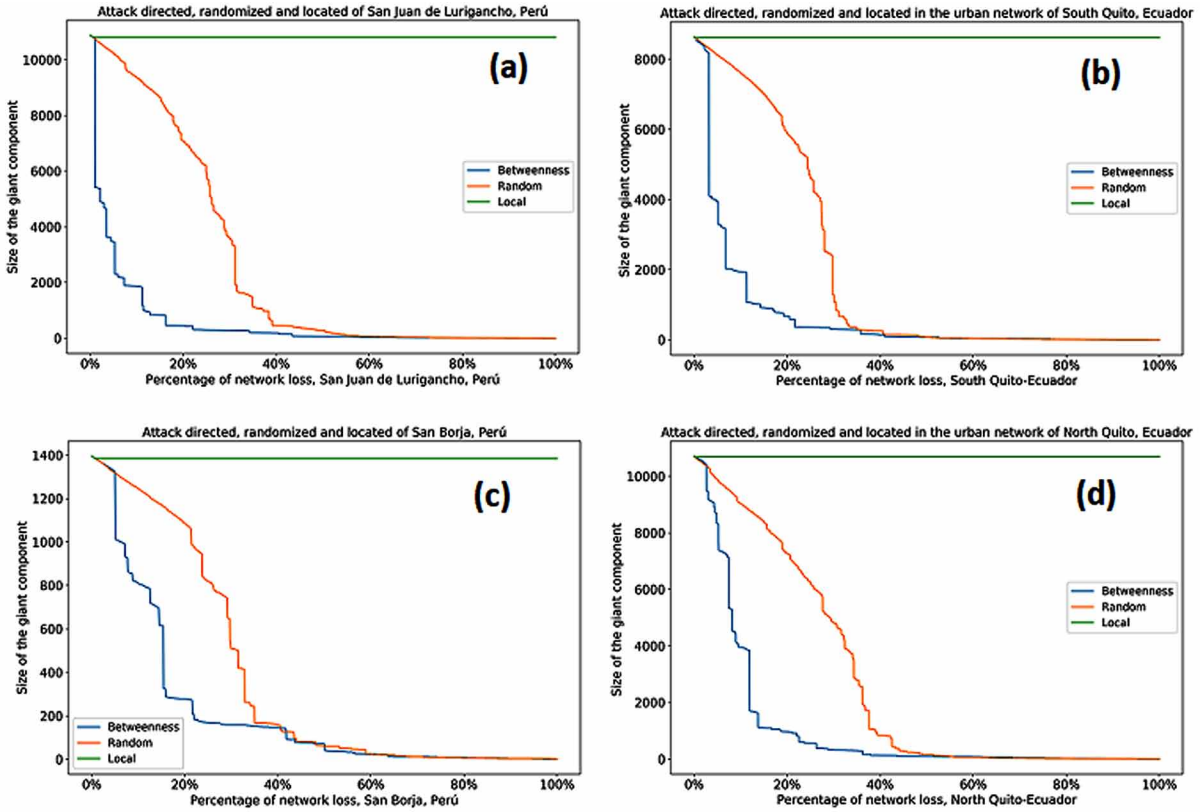
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Figure 7. Intersections and street sections of major BC and CC belonging San Juan de Lurigancho: (a) the intersection of highest BC, (b) the intersection of the highest CC, (c) the street segment (red line) that joins the two intersections x and y.



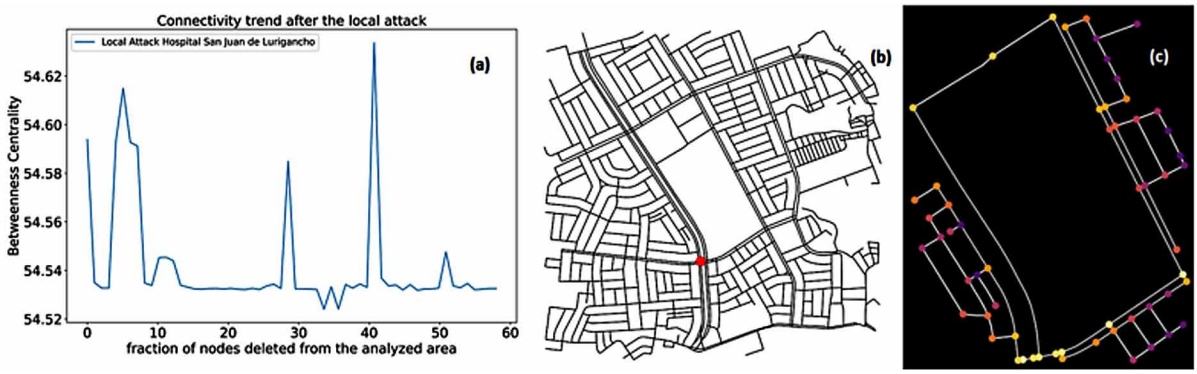
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Figure 8. Description of the random attacks (orange line), directed attack (blue line), and located attack (green line) performed to (a) San Juan de Lurigancho, (b) San Borja, (c) Quito Norte, (d) Quito Sur.



calculate the BC of the large component to see how much it effects the network. This process is repeated for each node with the replacement of the previous node that was eliminated. Later, the obtained values were illustrated in Figure 9. Figure 9-a represents the variation of the BC of the large component by removing each node of the small component. Figure 9-b represents the node of higher BC (red point).

Figure 9. Localized attack: (a) pulsometer of each eliminated intersection, (b) the intersection with a highest BC value found in (a), (c) the intersections ordered by their degree of importance found in (a).



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Figure 9-c shows the heat map with vertices having a higher value of BC (yellow points) and those with lesser values of BC (purple points).

SOLUTIONS AND RECOMMENDATIONS

The hierarchical method of extraction and construction of networks, (*c.f.*, Figure 1 and Figure 2), allows analyzing an urban network in a scalar way. That is, it allowed us to evaluate the large component, the medium component and the small component of each urban area included in this study. In this part, we analyze jointly and individually the measurements of each urban area and relate the incidence that exists between them.

The hierarchical method of extraction and construction of networks allows analyzing an urban network hierarchically, *i.e.*, the large, the medium, and the small components of each urban area included in this study (*c.f.*, Figure 1 and Figure 2). In this part, the measurements of each urban area were computed and compared to capture the incidence existing between them.

The first findings show some characteristics of the networks, such as the mesh, the organic indicator, the density, the connectivity, the BC and the CC. The last two measures were compared, and the results were summarized in Table 1. These results revealed that for high connectivity and density, the network is more resilient to attacks. Since, if there are more interconnected roads, there is a higher probability of remaining connected and maintaining access to the different crossroads.

To evaluate the traffic in populated areas, the betweenness and close centrality were calculated for each network representing the four studied areas. Figure 2 shows how the most and least significant intersections having the highest value of BC. Later, the same strategy was used to compute the CC measure, as shown in Figure 3. The intersections of streets of high CC distributed in the center of the graph were visualized. The two previous analysis allows determining that extracted vertices have higher traffic.

Nevertheless, these two measures evaluated separately to lose reliability. For this reason, two centralities measures were analyzed in parallel, as shown in Figure 4 and Figure 5. For this, 1% of vertices having higher BC and CC were selected to analyze graphically if these vertices are distributed in common areas.

After these analyzes, the study is still weak to accurately determine the intersections and stretches of streets with the highest traffic. Therefore, an analyze were performed with a finer granularity. Besides, intersections with higher BC and CC were connected through the shortest route (*c.f.*, Figure 7). This fact is allowing to define the set of intersections between these two points, which implies that these street elements are those that have the highest volume of traffic within a city.

With these pieces of evidence, it is possible to identify which area of a city is the most sensitive to be affected by the appearance of a disturbing incident. Therefore, it is appropriate to take preventive measures that strengthen resilience by prioritizing the street components of this identified area.

The following analysis allowed to evaluate the resilience of the studied areas due to the simulation of randomized and directed attacks (see Figure 8). Thanks to these attacks it is possible to identify which networks are more resistant to the systematic attacks. As a result of this process, the networks of San Borja and Quito Norte are more resilient, and the networks of San Juan de Lurigancho and Quito Sur are the weakest ones.

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The earlier results only evaluate the entire network, but it does not explain what goes on in specific places. To answer this question, the BC of intersections of each small component was measured. This process was performed measuring what happens if an intersection is removing simulating a localized attack. In Figure 8 describe this process.

With these evaluations, it is possible to reach the following conclusions: On one hand, in San Juan de Lurigancho district, the hospital called "La Solidaridad" has more significant connections than the "San Juan de Lurigancho" hospital. Conversely, in San Borja district, the interconnections of the "International" hospital have greater interconnectivity than the "Hospital of Children's and Adolescents". On the other hand, in Quito Sur, the intersections of the "Hospital Padre Carollo" show greater interconnectivity than the "Enrique Garcés" hospital, showing values above the general average. Finally, in Quito Norte, the interconnections of the "SOLCA" hospital are further significant than in the "Pablo A. Suarez" hospital.

FUTURE RESEARCH DIRECTIONS

This paper presents an instrument to assess the resilience of densely populated cities. Some techniques associated with graph theory and data science were presented in this chapter. The goal of the present effort is to measure the resilience of four regions in two different countries: Peru and Ecuador. One technique was performed to identify the most significant vertices and edges (intersections and sections of streets), due to values of Betweenness Centrality and the Close Centrality measures.

Also, two types of network attacks were simulated: random and targeted, aimed at assessing the resilience of urban infrastructure.

Later, localized attacks were simulated on a small network around major hospitals in each city; to understand which intersections of streets the most important face to an adverse event are.

The study shows that proactive decisions can be taken based on evidence from the analysis presented in this document. Indeed, our findings can be used to enhance the management of humanitarian aid in urban areas.

In future works, it is expected to improve the results by adding other variables to the analysis, for instance, time, address, the distance between points of interest (*e.g.*, firefighters), among others. Besides, it could be interesting to perform the same study to other cities and compare them with the results shown in this work.

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Chapter 20
Tool for Decision Making in Humanitarian Logistics Chains

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ABSTRACT

This chapter develops a decision support tool with a focus on the humanitarian logistic chain in a crisis environment considering process drivers' constraints such as costs, capacity, and throughput time. For instance, elements to reduce the suffering of the affected families, by using an adequate supply support for the first 72 critical hours. The authors will focus on minimizing the risks of shortages in the first response supplies in a high flood probability zone in Peru. This research presents different scenarios and it analyzes the representative variables (demand, civil defense warehouses, points of distribution, distance and logistics resources), the humanitarian chain value, and the effective distribution of the aid in the affected areas with efficient operations that balance between the economic and operative resources in this recurrent logistical problem. The results present three crisis situations with a distribution plan and a base of a public policy to prevent a crisis.

INTRODUCTION

Cities are artificial environments created by humans where several inhabitants and their activities concentrate. These activities have different functions related with political, economical, cultural, social, technological, ecological and other human functions (David, 2011). These functions generate flows such as products, people, money and information between their entities (Liu & Savy, 2012) (Heckmann,

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Shorten, & Engel, 2003) (Sunil, 2019). The value of this complex network is to satisfy humans´ resource requirements (Hesse & Hall, 2013) (Dablanc & Frémont, 2015) and basic services as infrastructure, housing, transportation, among others (Kilroy, Mukim, & Negri, 2015).

This human delighting environment generates the urbanization process ; the urban population has grown exponentially and is projected to be 6,50 billion by 2050 or 68% of the world's population (United Nations, Department of Economic and Social Affairs, Population Division, 2018). These cities have different characteristics and challenges, the most populated city is Tokyo with 38,80 millions of inhabitants in 2 188 km^2 or 17 733,09 inhabitants/km^2 (United Nations, Department of Economic and Social Affairs, Population Division, 2018). Currently, Tokyo and other 37 cities are considered as megacities, cities with more than 10 million of inhabitants (MIT, 2014). Japan, with a GDP of US$ 41 418,25 (International Monetary Fund, 2019), had four of the fifteen tectonic plates in the world, 20% of the earthquakes with a magnitude of six or more occur there also 7% or 110 of the active volcanoes. (Disaster Management Cabinet Office, 2018) (Japan Meteorological Agency, 2019) (Centre for Research on the Epidemiology of Disasters - CRED, 2019).

On April 14th and 16th, 2016, the Kumamoto Earthquakes occurred with a maximum seismic intensity of 7 and caused 228 fatalities, 200 000 houses were affected (totally and partially); and all the infrastructure services were in operation in a month (Disaster Management Cabinet Office, 2017). This case and other catastrophes such as the earthquake in Haiti in 2010, the earthquake and tsunami in Tohoku in 2011 or the earthquake in Azerbaijan in 2012, are one of the reasons why the world's attention is focused on humanitarian logistics. Those disasters illustrate the unforeseen of the nature, the consequences in the population and the lack of trained professionals to manage the response and attend the affected population (Carter, 2008) with its fundamental objective, which is to reduce human suffering (Holguín-Veras, Pérez, Jaller, Van Wassenhove, & Aros-Vera, 2013) as well as the socio-economic wellbeing principles, considering logistic and deprivation costs when a natural or anthropogenic disaster occurs (Leiras, De Brito Junior, Peres, Rejane, & Yoshizaki, 2014). Natural disasters are explained as a low frequency phenomena over time, but with high impacts in a concentrated population; for instance the *"Niño Costero"* phenomena back in 2017, the earthquake in Puebla, the three strong hurricanes in North America (Harvey, Irma and Maria) and the tsunami in Greenland (Venkateswaran, MacClune, & Enríquez, 2017) (Centre for Research on the Epidemiology of Disasters - CRED, 2019), while the anthropogenic disasters or caused by man will increase drastically (Centre for Research on the Epidemiology of Disasters - CRED, 2019) with a complex relation between actors, phases and processes (Kovács & Spens, 2007), and unknown demand, uncertain supply and disrupted flow which belong to business logistics and humanitarian logistics factors, such as complicated operation, infinitive challenges and unfamiliar issues (Apte, Khawam, Regnier, Simon, & Nussbaum, 2013); reflected on 366 humanitarian missions from the US Army between 1979 to 2000, twenty of them in combat situations. In 2019, we had a global humanitarian crisis caused by Venezuela, Honduras, Nicaragua, Afghanistan and Syria's migration against their neighbor countries, which rises from internal conflicts, disaster, poverty, ideological alignment and the lack of food and public services as water, electricity, healthcare, among others (Winkler Osorio, 2019), with consequences in their health system, demographic composition and unequal opportunities.

The disaster management cycle has four phases after the emergency: response, recovery, preparedness and mitigation (Emergency Management Institute, 2012). The response phase occurs before the disaster and focuses on saving lives and reducing human suffering, with emergency aid and adequate food. The recovery phase is based on activities with the purpose of returning to the original scenarios. The preparation phase focuses on early warning activities, such as plans, training and tools before the

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event, and the objective of the mitigation phase is to interrupt the chain of disasters and vulnerabilities, prevent causes, reduce the impacts and their consequences (Thomas & Kopczak, 2005) (Santos Lima, de Oliveira, Buss Gonçalves and Marcondes Altimari Samed, 2014) (Harvard Humanitarian Initiative, 2014). This research proposes a plan that considers the four civil defense warehouses of Peru (INDECI), five evacuation zones, three distribution centers (DC) and ten distribution points (POD) as the first recovery capacity of the community in case of emergency, in an area of high risk of flooding and the immunity of Lurigancho-Chosica to improve the response to a disaster and reduce human suffering. We define "Inmegacidad" as a city within a Megacity.

The district of Lurigancho Chosica was created on August 4, 1821; In the 1826 Census it had 1,248 inhabitants, most of them dedicated to agriculture. Currently, it has 236.47 km^2, 240 814 inhabitants and a density of 1 018.37 inhabitants / km^2 (Municipality of Lurigancho-Chosica, 2019). The risk of natural disasters and the concentration of urban dwellers are critical variables in the organizational process during the response to the crisis, in order to address the challenges in the three phases: incubation (time before the disaster), response (time immediately once the event has occurred) and recovery (return to incubation) (Silveira dos Santos, Bandeira-de-Mello, and Almeida Cunha, 2016).

The aim of this chapter is to propose a decision support tool which is focused on the humanitarian logistic chain in a flood crisis situation. The proposed tool is applied to Lurigancho-Chosica area, due to the seasoning of "*El Niño"* phenomenon and its climatic consequences. We considered the coordination between Civil Defense warehouse, Lurigancho-Chosica center of distributions and the community point of distributions for medicines, non-perishable food and emergency suppliers in the first 72 hours after a possible emergency, considering the geographical environment, public and private personal as well as equipment restrictions. The paper is organized, with the main background including a brief description of the *"El Niño"* phenomena of 2017 and its consequences in Lurigancho - Chosica. Secondly, the methodological framework with operation research tools. Thirdly, the results and discussion section. Finally, as a conclusion, practical implications.

BACKGROUND

The "El Niño" phenomena in Peru is originated by the weakening of the trade winds and unusual increase of the winds coming from the west of Peru from Australia, there is a displacement of warm waters (Kelvin waves) in The Pacific Ocean and influxes the cold current of Humboldt (Servicio Nacional de Meteorología e Hidrología del Perú, 2014). This phenomenon has a minimum duration of three months with anomalies in the sea surface temperature, a change in maritime currents and the direction of the winds, affecting Ecuador, Peru and Chile north coast. (Instituto Nacional de Defensa Civil, 2017). The consequences are heavy rains on the north coast, an increase in temperature in the coast and drought in the southern highlands. The negative consequences are the movement of anchovies (one of the principal fishery species in Peru); moving to the south, agricultural land losses by floods, glacial retreats, destroyed communication routes, floods, landslides and an increase in diseases such as cholera, dengue and malaria (Servicio Nacional de Meteorología e Hidrología del Perú, 2014). Its consequences can even be fatal (United Nations, 2009). Also the positive consequences are aquifers recharge,-dry forest regeneration in the north coast, new marine species presence and the reduction of frost intensity.

The frequency of this natural phenomenon has been increasing over the years, being 2012 the most critical due to intense rain. From January through May 2017, over 4 336 events occurred in Peru due to

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floods and landslides generated by *El Niño Costero* Phenomenon, which represents a 93% increase of events in comparison to the impact of 2012 (Instituto Nacional de Defensa Civil, 2017). The number of victims has increased as well, starting at less than 500 000 victims in 2003 and reaching over 3 million people in 2017 that had been impacted in any way by this phenomenon (Instituto Nacional de Defensa Civil, 2017). The main regions impacted in 2017 were: Piura, Lambayeque and Lima due to the rainfall intensity that generated floods and landslides causing human losses as well as transport infrastructure, destruction of houses and farming areas (Sistema Nacional ante Emergencias y respuestas, 2017) (Instituto Nacional de Defensa Civil, 2017).

The district of Lurigacho-Chosica is located in Lima, Peru. This district is crossed by the Rimac river and is surrounded by hills which along with the presence of its urban development, make it one of the most vulnerable areas in Lima to face the *El Niño* phenomenon. In order to assist disaster victims in Lurigacho-Chosica, the district enables a coliseum as an intermediate central warehouse with an inventory to help 50 families. However, the government estimated the victims can rise up to over 1 000 families (Instituto Nacional de Defensa Civil, 2017) (Sistema Nacional ante Emergencias y respuestas, 2017) (Municipalidad de Lurigancho-Chosica, 2019).

Under this scenario managing and delivering the donations become a critical part of the response phase, with multiple ways in the distribution network of Lurigacho-Chosica in order to attend the victims in the most effective manner. In order to understand the opportunities in Lurigacho-Chosica, the humanitarian supply chain is defined as a network of multiple interactions among the stakeholders; eliminating the redundancy as well as maximizing efficiency along the chain (Cozzolino, 2012). The main difference between a commercial and humanitarian chain is while the commercial supply chain is focused on quality and profitability, the humanitarian focuses on eliminating suffering and mitigating human losses with the lead-time of 72 hours after an event occurs (Leeuw & Mok, 2016). In this scenario, the distribution process is a key to guarantee the success, with the interaction of the suppliers and donors as the first entities, the Civil Defense as distribution centers, the municipality of Lurigacho-Chosica as an intermediate distribution center and the community as the final point of distribution of the community (Balcik, Beamon, Krejci, Muramatsu, & Ramirez, 2010)

After a crisis or disaster (and mostly after the first aid phase) people do not have a normal life condition and lack some basic goods. It also depends on the people; some are physically, mentally and emotionally affected by this traumatic event, but others are able to recover and go on with their lives quickly (Destro & Holguin-Veras, 2011) (Holguin-Veras, Jaller, Van Wassenhove, Perez, & Wachtendorf, 2014). On the other hand, humanitarian will (national or international) increases the act of donation. However, those donations are not always the good products sent to the good destinations (Holguin-Veras, Jaller, Van Wassenhove, Perez, & Wachtendorf, 2014). Material convergence is the flow of supplies, general donations (solicited or unsolicited), and equipment that travels to the site of the disaster (Fritz & Mathewson, 1957) (Destro & Holguin-Veras, 2011). After a disaster or catastrophe, larger quantities of supplies are sent to the affected area by donors of all kinds (individuals, faith-based groups, non-profit organizations, companies, governments), but the main problem is that the materials and supplies delivered to the affected areas include a large proportion of useless goods that create chaos in the disaster response (Holguin-Veras, Jaller, Van Wassenhove, Perez, & Wachtendorf, 2014) (Osorio Ramírez, 2016).

A new episode of "El Niño" was seen at the beginning of 2019. Although some advances have been made, population and authorities are not yet sufficiently prepared to respond to those crises, mainly in terms of primary aid and material convergence management. For those reasons, this research aims to

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analyze the implementation of an intermediate warehouse that protects non-perishable food and will serve an area including Lurigancho-Chosica and its neighborhoods. Moreover, the warehouse must supply the necessary products in less than 72 hours of a disaster as a first response measure to reduce the lack of first necessity materials and support a larger strategy of supplying populations in a quick manner in the first recovery phase of such disaster.

METHODOLOGY

Model Formulation

The case of Lurigancho-Chosica defines three categories of problems: warehouse location, warehouse management and transportation management; with three important dysfunctions: correspondence between needs and products, inbound and outbound transportation and knowledge of humanitarian logistics. Considering the drivers of supply chain performances: facilities, inventory, transportation, information, sourcing and pricing (Chopra & Meindl, 2008) and the logistics drivers: installation and location.

We evaluate three cost-effective decision criteria as a first phase to address the research: The cost reduction by facility location and transportation mode; the capital adequacy by inventory level distribution center and ownership of the warehouse; and finally the service improvement by customer satisfaction (LOGYCA, 2017). The first phase proposed a facility location as the first priory and distribution center as the second.

The second phase proposes the network facility location problem with its fundamental basis in the pre-positioning of emergency warehouses (de Brito et al., 2014; Noyan, 2012; Rawls & Turnquist, 2010) considering the model formulation. The sets are the entities warehouse (W), distribution centers (DC) and point of distribution (POD). The variables are the weight in tons of aid materials transported from the warehouse to the distribution center (QWD), the weight from the distribution center to the point of distribution (QDP) and the state of the distribution center (open or closed) with a binary variable (BinCD). The parameters primary parameters of the warehouse are: capacity (qW) and transportation cost (cW); the primary parameters of the distribution center is fixed cost (fDC) and handling cost (cDC); the unique primary parameter of the point of distribution is the demand (d). The secondary parameters are the distance in kilometers from the warehouse to the distribution center (dWD), the distance from the distribution center to the point of distribution (dDP), the capacity of the distribution center in tons (qDC), the numbers of available distribution centers (maxDC, minDC), the demand in the point of distribution (D) and the number of available point of distribution (maxPOD, minPOD). The constraints families are capacity of the distribution center, demand per point of distribution, quantity of distribution centers, quantity of point of distributions, conservation flow between distribution centers and point of distribution and the binary relations. The objective is to minimize the cost.

Data Description

The primary data of the sets warehouse (W – Civil defense), distribution center (DC – Municipality of Lurigancho-Chosica) and the point of distribution (POD – Community) are presented in the table 1, table 2 and table 3.

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Table 1. Warehouse primary data

Warehouse (W)	Address	Transportation cost (cW) $/kg-km	Capacity (qW) kg
1	Av. Argentina S/N 3017, Callao – Central warehouse	0,00078	47 000
2	Av. Elmer Faucett 3970, Callao – Warehouse 1	0,00078	47 000
3	Av. Elmer Faucett cuadra 39, Callao – Warehouse 2	0,00078	47 000
4	Ex Mercado del Pueblo "San Isidro" intersección del Jr. Abelardo Quiñonez y Psje. Leoncio Prado, Huancayo	0,00120	47 000

Source: Instituto Nacional de Defensa Civil. (2019).

Table 2. Distribution center primary data

Distribution Center (CD)	Address	Installation cost $	Annual rent $	Fixed cost (fDC) $	Transportation cost (cDC) $/kg-km
1	Corner of Av. Hipólito Hunanue with Ayacucho	8 500	12 000	20 500	0,00060
2	Compañia de bomberos Lurigancho-Chosica	13 500		13 500	0,00050
3	Hospital José Agurto Tello	15 800		15 800	0,00055

Source: Municipalidad de Lurigancho-Chosica. (2019).

Table 3. Point of distribution primary data

Point of distribution (POD)	Demand (d) kg
1	1 125
2	3 555
3	3 461
4	1 683
5	8 591
6	5 369
7	1 863
8	1 449
9	12 303
10	450
11	1 931
12	1 584
13	2 538

Source: Municipalidad de Lurigancho-Chosica. (2019).

The secondary data of distance (dWD) in kilometer from the warehouse (W) to the distribution center and the distance (dDP) from distribution center (DC) to the point of distribution (POD) are presented in the tables 4 and 5.

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Table 4. Distance from the warehouse (W) to the distribution center (DC)

	Distance in kilometers (dWD) from the warehouse (W) to the distribution center (DC)		
Warehouse (W) / Distribution center (DC)	**1. Corner**	**2. Firefighter company**	**3. Hospital**
1. Central warehouse	52	51	52
2. Warehouse 1	53	53	53
3. Warehouse 2	53	53	53
4. Warehouse Huancayo	259	260	259

Source: Instituto Nacional de Defensa Civil. (2019). Municipalidad de Lurigancho-Chosica. (2019).

Table 5. Distance from the distribution center (DC) to the point of distribution (POD)

	Distance in kilometers (dDP) from the point of distribution (POD) to the Distribution Center (DC)		
Point of distribution (POD) / Distribution Center (DC)	**Corner**	**Firefighter company**	**Hospital**
1	6,0	4,2	3,8
2	3,7	1,8	1,4
3	2,5	0,6	0,1
4	1,9	0,5	0,6
5	1,8	1,7	1,8
6	1,2	1,1	1,3
7	0,5	2,2	2,2
8	0,9	1,8	2,0
9	0,6	2,9	2,8
10	0,5	2,0	2,2
11	1,9	0,6	0,9
12	1,5	0,7	1,0
13	1,9	2,0	1,0

Source: Instituto Nacional de Defensa Civil. (2019). Municipalidad de Lurigancho-Chosica. (2019).

Objective Function

The objective function is a minimization of three groups, the transportation cost from the warehouse (W) to the distribution center (DC), the transportation cost from the distribution center (DC) to the point of distribution (POD) and the fixed cost of the distribution center installation

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$$Min = \sum_{i \in W} \sum_{j \in DC} QWD\left(i,j\right) * cW\left(i\right) * dWD\left(i,j\right) +$$
$$\sum_{j \in DC} \sum_{k \in POD} QDP\left(j,k\right) * cP\left(j\right) * dDP\left(j,k\right) +$$
$$\sum_{j \in DC} fDC\left(j\right) * BinDC\left(j\right)$$

Constraints

The first group of constraints are auxiliary variables for each set: warehouse (W), distribution center (CD) and point of distribution (POD).

$$\sum_{j \in DC} QWD\left(i,j\right) \leq qW\left(i\right) \forall i \in W$$

$$\sum_{i \in W} QWD\left(i,j\right) = qDC\left(j\right) \forall j \in DC$$

$$\sum_{j \in DC} QDP\left(j,k\right) = qP\left(k\right) \forall\, k \in POD$$

The second group of constraints are the binary restriction in the primary and secondary sets.

$$qP\left(k\right) = demanda\left(k\right) \forall k \in POD$$

$$\sum_{j \in DC} BinDC\left(j\right) \leq MaxDC$$

$$\sum_{j \in DC} BinDC\left(j\right) \geq MinDC$$

$$\sum_{k \in POD} BinPOD\left(k\right) \leq MaxPOD$$

$$\sum_{k \in POD} BinPOD\left(k\right) \geq MinPOD$$

$$BinDC\left(j\right) * M \leq QDC \forall j \in DC$$

$$BinPOD\left(k\right) * M \leq QPOD \forall\, k \in POD$$

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The third group of constraints is the balance of materials.

$$\sum_{i \in W} qW\left(i\right) = \sum_{j \in DC} qDC\left(j\right)$$

$$\sum_{k \in POD} qP\left(k\right) = \sum_{j \in DC} qDC\left(j\right)$$

RESULTS

In this section, an analysis of scenarios is presented, which consists in the opening of warehouses considering the proximity to the evacuation areas, that is, determining if more or less warehouses should be opened taking into account the need to have warehouses closest to the evacuation areas. For this, the different scenarios vary the minimum amount of (Pmin) and maximum (Pmax) of the POD.

The first scenario considers Pmin = 1 and Pmax = 1, the second scenario considers Pmin = 2 and Pmax = 2 and the third scenario considers Pmin = 2 and Pmax = 3. Table 6 shows the total costs obtained for each of the scenarios, the scenario that presents the lowest cost is the first, while the third presents the higher cost. Therefore, the analysis will focus on the first scenario.

Table 7 shows the cost structure of the first scenario. The highest cost, in this scenario is to implement the warehouse, however this cost will decrease over time, since it is only necessary to maintain the asset. The other costs together represent only 15% of the total cost.

Figure 1 shows the location of the zones of the evacuation areas in red tones and the location of the PODs, it should be noted that the less reddish tones represent the areas with less demand for help (measured in kilograms), while the red tones represent the areas with the greatest demand for aid. In total, 7 evacuation zones and 2 POD were determined.

Table 6. Total costs for each scenario

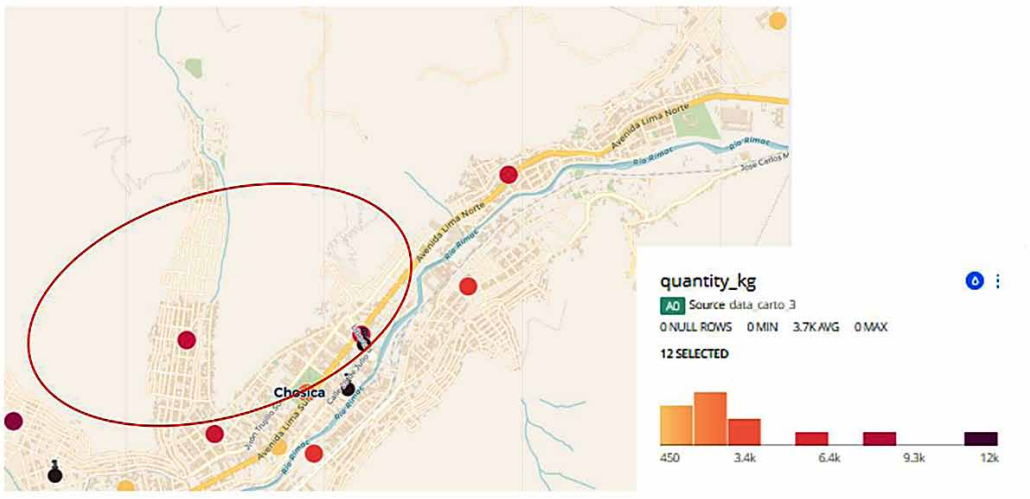
Escenarios	Corner of Av. Hipolito Huanue with Ayacucho (POD 1)	Chosica Fire Company (POD 2)	Chosica General Hospital (POD 3)	Cost (USD)
Simulation Open 1 WH		X		$ 16,022
Simulation Open 2 WH		X	X	$ 31,790
Simulation Open 3 WH	X	X	X	$ 52,123

Table 7. Structure Cost of 1st Scenario

TOTAL COST	$ 16,021
DC fixed cost	$ 13,500
Outbound Transport	$ 432
Inbound Transport	$ 1,837
DC Handling	$ 252

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Figure 1. Points Localization



DISCUSSION

To improve the response in a humanitarian supply chain with the characteristics of the proposed case, not only should the optimal solution be sought, it is also necessary to identify the factors that influence the cost, as was done in the results section. This allows requesting an integral support of the entities in charge of providing support in the response to disasters.

The implementation of public policies related to disaster risk management will be a great contribution to lessen the impact of a possible catastrophe and promote a culture of risk management.

The estimation of budgets for warehouses is aligned with the requirements of the entities involved in the response to disasters. The generation of solutions with different budgets as those being proposed contribute to the identification of different options for the implementation of public policies in the field of humanitarian logistics, since these policies have a main focus on monetary budgets, in addition to feasibility of the solution to be implemented.

A practical implication to take into account is the need to consider the geography and the form of access to the areas at risk of danger so that optimal locations can be established for the facilities, so that solutions that take into account the monetary cost but also the time for attention; seeking to maximize the number of people who are served, can be established. The solutions that have been identified as potential are located on the river, which mainly serve the areas with the highest population density; to reduce the attention and social risk, you should also have a solution under the river.

CONCLUSION

The tool proposed in this study helps decision making within the humanitarian logistics chain to supply those affected after a disaster considering the lower investment. So that the suffering and the risks of scarcity of first response supplies can be reduced.

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The greatest contribution of this study is that it allows the determination of the most beneficial solution in economic terms, which provides the entities involved in the disaster response with relevant information for the implementation of economically viable public policies. Another important contribution of the proposed tool is that it evaluates multiple scenarios, facilitating decision making.

The tool was applied in the city of Lurigancho-Chosica, Peru. The quantity and location of facilities in a distribution system in the humanitarian logistics chain was determined. The Lurigancho-Chosica area was selected for its high levels of geographical vulnerability and population growth, being exposed to constant crisis situations. The results show that the solution with the lowest cost establishes a warehouse, 7 evacuation zones and 2 POD.

The addition of more reliable concentration points based on the Km2 methodology would make more accurate decision making with the proposed tool. For this, it is important to improve data collection problems related to field surveys and improve collaboration among research teams. As future research, the routing is proposed in phases that allow the distribution of humanitarian aid supplies at the lowest possible cost and in the shortest time, seeking to serve as many people as possible.

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Chapter 21
Comparison of Multi-Criteria Decision-Making Techniques for the Location of Multi-Modal Terminals in an Integrated Public Urban Transport System

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ABSTRACT

Multiple actors from both private and public sectors are currently involved in the design and operation of urban passenger transport systems seeking at optimizing their own objectives. Multi-criteria decision-making (MCDM) techniques actually aid this process. In this chapter, the authors consider the problem of locating multimodal terminals of an integrated public passenger transport system (IPPTS). A case study for the city of Bogota, Colombia is evaluated. Majority of works in MCDM does not explicitly justify the choice of the applied technique. This chapter applies three different techniques, AHP (analytic hierarchy technique), ELECTRE II (elimination and choice expressing the reality), and CRITIC (criteria importance through intercriteria correlation), to solve problem. A feature of this study is that traditional economic and logistic criteria are evaluated together with environmental and social criteria not previously evaluated in the literature. Numerical results show that each multi-criteria approach may prefer a different alternative, depending on the intrinsic behavior of each technique.

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INTRODUCTION

Decision-making problems in business and management very often require the participation of different actors (decision-makers) commonly having diverse interest. However, traditionally decision-making processes have been single-criterion oriented (with cost minimization or productivity or profit maximization as main objectives), while more recent approaches have required the consideration of multiple criteria simultaneously (Radnor and Barnes 2007, Subramanian and Ramanathan 2012). This has required the use of Multi-Criteria Decision-Making (MCDM) methods for making effective decisions that satisfy all the relevant criteria at various levels.

In urban transport, the variety of stakeholders and their not always coinciding goals and objectives make decision support a complex task (Gonzalez-Feliu et al., 2018a). Moreover, in a context of collaboration where both passenger and freight transport flows need to be considered, it is important to propose suitable decision support methods that feed consensus search and support reaching agreements (Gonzalez-Feliu et al., 2018b).

In that context, the deployment and organization of public transport terminals can be of particular interest for two reasons. The first is that, although related to passenger transport, those platforms have, in their organization and operational management a set of flows that are considered as a part of urban management flows or internal logistics flows (as on the definition of Gonzalez-Feliu, 2018b). Those logistics flows (workforce, material, vehicles, fuel, etc.), which are part of urban logistics, are dependent on the strategic choices related to the design, location and deployment of the terminal (mainly in terms of location and network design, Crainic and Laporte, 1997, 2012). Consequently, it is important to study the location and design issues of public transport hubs. Moreover, in Latin American cities, a lower information level, the complexity of the involved stakeholders and their interactions, and the lack of systematic land planning issues (Gonzalez-Feliu, 2018a) make the holistic analysis of public transport terminals a challenge.

Decision-making for designing and planning of transport systems is typically a complex task because decision-makers have to take into account a wide range of benefits and negative externalities regarding social costs and serious impact on the environment (e.g., emission of several gases, such as CO_2, NOx, and others) (Browne and Ryan 2011). Classical single-objective optimization models based on economic metrics are a generally acknowledged methodological approach providing an optimal solution. However, in urban passenger transportation systems, an assessment only based on economic impacts can be too narrow as other impacts besides the monetary can have influence on the final decision (Salling et al. 2007, Barfod et al. 2011, Ambrasaite et al. 2011, Camargo-Pérez et al. 2013, Camargo Pérez et al. 2015). Actually, the final decision will in many cases involve multiple criteria related to economic, environmental and socio-political aspects, as already pointed out in this paper. In this context, multi-criteria decision making (MCDM) can be seen as an applicable methodology to assess such problems arising in the analysis of urban transportation systems (Tsamboulas et al. 1999, Tsamboulas 2007; Macharis et al., 2012; Gonzalez-Feliu et al., 2018).

In that context, urban transport stakeholders need decision support methods and tools to support they choices, at all strategic, tactical and operational levels. We can define a decision support method as a procedure that shows different paths (and their suitability) for decision making, or a set of suitable solutions, but the decision maker has always the final solution. The aim of decision support is not to take the decision instead of the decision maker but to help him to make the decision he or she considers as the rightest one. In other words, decision support is not an evaluation tool or an expert system, but

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a support that allows final decision makers to have a global knowledge in order to make a final choice (Tudela et al., 2006). In that context, MCDM techniques have a particular interest and suitability (Barfod et al., 2011; Macharis and Bernardini, 2015).

Applications of MCDM techniques for the design and planning of urban passenger transportation systems exist since 1982. Camargo Pérez et al. (2015) provide a comprehensive review of research papers published between 1982 and 2014 applying MCDM models of urban passenger transport systems projects. These authors noted that publications regarding this transportation systems are mainly in the areas of transportation management and engineering, operational research / decision sciences, and engineering projects, so reviewed papers were classified according to the type of transportation project and decision level (strategic, tactical, operational), the multi-criteria approaches / technique, and the decision criteria. One of the main outputs of the cited survey is the use of about 58 different MCDM techniques, where the analytical hierarchy process (AHP) and the technique for order performance by similarity to ideal solution (TOPSIS) are the most employed. With lower proportion, authors employed techniques such as Electre, Promethee or Macbeth, in addition to tailored and dedicated techniques and tools based on hybridized classical techniques with meta-heuristics. When analyzing published literature on MCDM for transport systems, a clear observation is that authors chose a technique to solve the problem, and without a clear justification of this choice.

Under such a context, the aim of this chapter is to compare the performance of different MCDM techniques when solving a particular problem. As case study, the design of an urban passenger transportation system is considered. Among the different decisions to be made to design such a system, we must decide the location of multi-modal terminals. To this end, Section 2 presents a description of the transport system under study as well as the definition and role of multi-modal terminals. Section 3 justifies in detail the choice of implementing three different MCDM techniques to solve this problem, as well as their application. Section 4 gives a rigorous comparison of solutions obtained based on both numerical evaluation and practical issues. This paper ends in Section 5 by presenting some concluding remarks and drawing some opportunities for future research.

THE TRANSPORT SYSTEM UNDER ANALYSIS AND SELECTED DECISION CRITERIA

As outlined previously, public and private stakeholders take part on both the design and the operation of passenger transportation systems and hence economic, productive, social, technical, environmental and urban planning issues are of the highest importance (Ferrari 2003, Zhu and Liu 2004, Banister 2011). In that sense, the analysis of such systems does require the evaluation of multiple decision criteria in order to minimize negative impact to society in general due to the selection of physical infrastructure, vehicle technology, location of terminals, route design, etc.

In addition, the last decades have witnessed, all around the word, more and more the implementation in big cities of integrated transport systems composed of buses, metro, trains, tranways, BRTs (bus rapid transit) systems, and other modes (Hensher 2007, Tirachini et al. 2010). This is mainly due to the fact demand of trips has highly increased, together with the increase in size of cities. As a consequence, local authorities are more and more looking to offer diversification of transportation modes. Under such a context, multimodal exchange facilities are of highest importance when designing integrated transport systems. In this paper, a modal interchange facility or multimodal terminal is defined as the place (i.e.,

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station) in which a set of different transportation modes converge, such as buses, metro lines, trains, tramways, taxis, etc. The objective of local authorities is to find the "best" location of such infrastructures in order to minimize their negative impacts.

The Location Problem is one of the most ancient problems in the Operations Research literature, mainly analyzing only one optimization criterion (Farahani Zanjirani et al. 2010, Daskin 2013). However, recent academic works have considered the inclusion of multiple optimization criteria, leading to the so-named Multicriteria Location Problems (Farahani Zanjirani et al. 2010). Regarding the application in public passenger transport systems, the first known published work is due to Roy (1982) who proposed a ranking of the different alternatives for the design of metro lines in Paris, France. According to the rigorous review of literature carried out by Camargo Pérez et al. (2015), multi-criteria decision making models were applied to many other design and planning problems passenger transport systems, but it was only until years 2000 that location problems are documented in the academic literature. Mateus et al. (2008) employed Macbeth technique to solve the problem of locating stations of a rail system. A similar problem was studied by Mohajeri and Amin (2010) who proposed a hybrid procedure coupling the Analytical Hierarchical Process (AHP) with Data Envelopment Analysis (DEA). Wang et al. (2012) proposed the use of meta-heuristic procedures for the design of metro lines. Finally, Camargo-Pérez et al. (2013) employed AHP to solve a hypothetical problem of locating multimodal transfer nodes in passenger transport system. In addition, social and environmental impacts of urban passenger transportation systems are regarded as a menace for the global ecology and the society. The concept of sustainable transport systems has appeared (Intikhab and Lu 2007) and all private and public stakeholders involved in the process, especially local authorities, must take into account non-economic criteria when designing such systems. The current paper extends our last work (see Camargo-Pérez et al. 2013) by evaluating other MCDM techniques and considering a complete set of economical and non-economical criteria (Rodrigues da Silva et al. 2008).

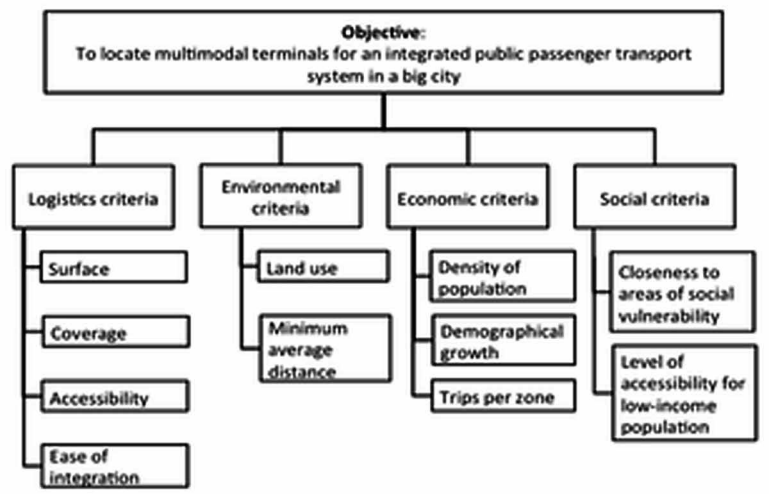
In order to define the criteria to evaluate when applying the MCDM techniques, our review of literature (see Camargo Pérez et al. 2015) allowed us to classify key performance metrics into four families of criteria that consider: economic, logistics, environmental and social issues. Then, following the guidelines proposed by Choi and Sirakaya (2005) for the design of metrics in multi-criteria decision making, we considered the following issues:

- That information about selected attributes is easy to obtain or measure in an integrated passenger transportation system,
- That such attributes are easy to use,
- That their use is universal, which means that the attributes are not city-dependent and can be applied anywhere else, and
- That costs associated to both their use and data collection are low.

Figure 1 presents the hierarchy of selected metrics as criteria to evaluate when applying the different MCDM techniques. Logistic criteria, respectively, refers to the surface of the area in which the multimodal terminals will be located, the demand that is covered by selected location, the ease of access by pedestrians or by using other transport modes such as bicycles, and the ease of integration into the local environment. Environmental criteria are related to the land use and the distance required to reach the terminal. Economic criteria look at the demand to be actually covered in terms of current density and demographical growth on the medium and long term, as well as the number of trips at the selected

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Figure 1. Criteria to evaluate



location site since this metric is of interest of vehicle operators. Finally, social criteria look to provide transport to low-income population, so selected sites of multimodal terminals must be as close as possible of the actual transport demand and must be easy to access.

From this process of analysis, a system of indicators has been developed that are the basis for evaluating the alternatives that will be identified, for the consequent application of the multi-criteria technique that will be selected. Indeed, to implement and compare MCDM techniques in a unified way, it is important to define an application framework basis. To do that, Criteria need to be defined in a homogeneous way and independently of the considered MCDM technique. To do that, the application field that was chosen is that of the location and implementation of public transport terminals in Bogotá, Colombia, according to Camargo-Pérez's (2018) considerations. Criteria analyzed in this chapter were therefore selected following a two-step approach in which firstly an analysis of literature was carried out so metrics can be identified to characterize each criterion, followed in a second stage by a focus group in which experts were asked to validate the choice of this criteria and the way they were measured.

The literature review (Camargo-Pérez, 2018) resulted in the identification of the definition of four categories of criteria, which follow a similar orientation than that of urban logistics dashboards (Gonzalez-Feliu and Morana, 2014): logistic, economic, environmental and social. Each category of criteria is then subdivided into attributes. On each of the attributes a methodological sheet was constructed that defines its justification, relevance of the indicator, measurement characteristics and sources of information that support its importance and supporting literature. The methodological sheets have been widely used in the definition of sectoral indicators by international entities such as the United Nations (UN) and its area divisions such as the Economic Commission for Latin America and the Caribbean (CELAC) (Quiroga Martínez, 2007). In this methodological sheet the measured indicator is defined, its justification and importance for the analysis of the problem, macro-theme to which it belongs, weighted weight that has within the macro-theme, the updating periodicity (which refers to how many times it is necessary update it according to the nature of the information required), the calculation methodology, the formula for measuring it, the observations (if any) and the bibliography used to create the indicator.

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Box 1. Canvas of the methodological sheets to define each criterion

1. Denomination: a sentence that defines and identifies of the criterion (see appendix 1 for the definition of each selected criterion.
2. Criterion significance: explanation of the criterion's interest and way of observing it.
3. Justification and importance of the indicator: motivation and justification of the chosen indicator, according to literature.
4. Topic to which the indicator belongs.
5. Relative weight within the system: both for the topic and for the indicator.
6. Updating period: with which frequency the indicator needs to be updated.
7. Calculation methodology: needed data, retrieval methods and indicator formulation.
8. Observations, if needed.
9. Indicators used to its calculation, if needed: with both origin (references) and indicators' names and definitions.

It is important to note that technical indicators could be considered within the group of economic indicators, if the classical classification of sustainable development is followed (Gonzalez-Feliu, 2018b). However, given the nature of this research, it has been decided to maintain two separate categories (logistic indicators and economic indicators) in order to distinguish between the aspects of logistics decision and the macroeconomic aspects related to the population.

Evaluation by Experts' Focus Groups

Based on the 3S system framework of Cloquell (2003) and Gutierrez-Fernández et al. (2012) for the validation of indicators based on field feedback, the *sui Validatio* and *scienciatis Validatio* steps are applied. Taking into account the internal evaluation carried out with the macro criteria and attributes obtained, already described in the previous step, a methodology for evaluating the proposed criteria was developed, based on the 3S system that uses the evaluation of third party experts. The steps used in this framework (Cloquell, 2003) are the following:

Level 1: *sui Validatio*: self-validation must be done by the study writing team itself. Its purpose is to carry out an internal reflection of what is proposed.

Level 2: *Scienciatis Validatio*: scientific validation aims to provide rigor and objectivity to those that have been designed by the writing team by integrating the judgments of independent experts.

Level 3: *Societatis Validatio*: social validation, related to the incorporation of public participation, which allows to overcome barriers that classical management issues have. Moreover, it gives the process greater transparency and a greater possibility of success.

The third step of the system proposed by Gutierrez-Fernandez et al. (2012) is not used. It is a Validatio society that consists in the validation of the attributes through public consultation of the citizenship, since this research work is not of a social nature and the validation of the attributes requires of specific technical knowledge with which the community in general does not count.

This is how the methodological sheets presented in the previous section were developed, an open and anonymous survey was built in a web tool based on the information requested by the methodological sheets. This was presented to four experts in the areas of logistics, roads and transport, in a focus group, in order to validate criteria and define precisely the indicators used and their respective weights. More detail on that process can be found in Camargo-Perez (2018).

MCDM techniques were applied to solve the transport selection mode in the city of Bogotá, Colombia. It is located in the center of the country and is its capital. There are over 8 millions inhabitants and

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about 87% of frequent users of public urban transport have lower incomes. They use the urban transport system very frequently and mainly to travel from home to workplace and vice versa. Passenger transport system in Bogotá is mainly based on a bus rapid transit (BRT) system: rapid buses with dedicated lanes and interconnections with other vehicles. A BRT can be defined as a "flexible, rubber-tired form of rapid transit that combines stations, vehicles, services, running ways and information technologies into an integrated system with strong identity" (Levinson et al. 203). In Europe, researchers and practitioners prefer to use the term Buses of High Level of Service or BHLS (28). Around the world, the existing bus corridors comprise about 280 corridors, 4300 km, 6700 stations and use 30,000 buses, serving about 28 million passengers per day (29). As shown in the study of Hidalgo and Gutiérrez (2013), "in the period 2010-2011, 19 cities completed new systems (16 in the developing world) and seven cities expanded their current systems. By late 2011, about 49 new cities were building systems, 16 cities were expanding their corridors, and 31 cities were in initial planning". This impressive growth may be attributed in part to the successes of Curitiba, Bogotá, México City, Istanbul, Ahmedabad and Guangzhou where the systems have shown low cost, rapid implementation and high performance BRTs, with significant positive externalities. In Latin America, there are 32 cities with BRT or buses corridors, servicing 17.6 millions of passengers per weekday (EMBARQ 2013). For the case of Bogota, Colombia, about 1.7 millions passengers are serviced per weekday. It has 87 km of main dedicated busways plus 663 km of corridors for secondary buses (TransMilenio 2013a). In the medium term, the city development plan aims at having in operation an integrated public passenger transport system (called SITP for its name in Spanish) in which metro lines, a tramway, and classic buses will operate in an integrated manner (TransMilenio (2013b). The network has also to be able to integrate other transportation modes such as bicycles in the city center and shared vehicles in external areas. The configuration of the network is still under study, while preliminary designs have been already presented to the City Council and the community. Our work hence intends to contribute to the solution of such a problem, by proposing the best possible location of transfer points between transportation modes. In order to simply the analysis, a set of 10 possible transfer points were randomly selected; however, selected criteria and their weight are already part of the final decision-making process.

SELECTION OF MCDM TECHNIQUES AND IMPLEMENTATION

As stated in precedent sections, our previous literature review (Camargo Perez et al. 2015) showed the evolution on the use of multi-criteria decision techniques to solve design and planning problems in passenger transport systems. One of the conclusions of this review is that most of the time authors select a MCDM technique without comparing it with others and hence objectively justifying their choice. So, in order to enable a non-biased selection of MCDM technique to solve the problem under study, we now present a detailed comparison of characteristics, advantages and drawbacks of AHP (Analytical Hierarchical Process), ANP (Analytical Network Process), Bayesian Analysis, Multi-attribute value theory, Weighted Sum, Electre, and CRITIC. This comparison is our own elaboration, based on the works of Cho (2003), Aragonés et al. (2010), and Zopounidis (2012). According to the outcomes of this comparison, Bayesian Analysis and Multi-attribute Value Theory are not useful for the case under study in this paper. The former is eliminated since our problem is not probabilistic (instead a strategic decision is to be made), while the latter is not used because we do not have any knowledge about the probability of occurrence of the outcomes once the decisions are made. Finally, we did not used in this

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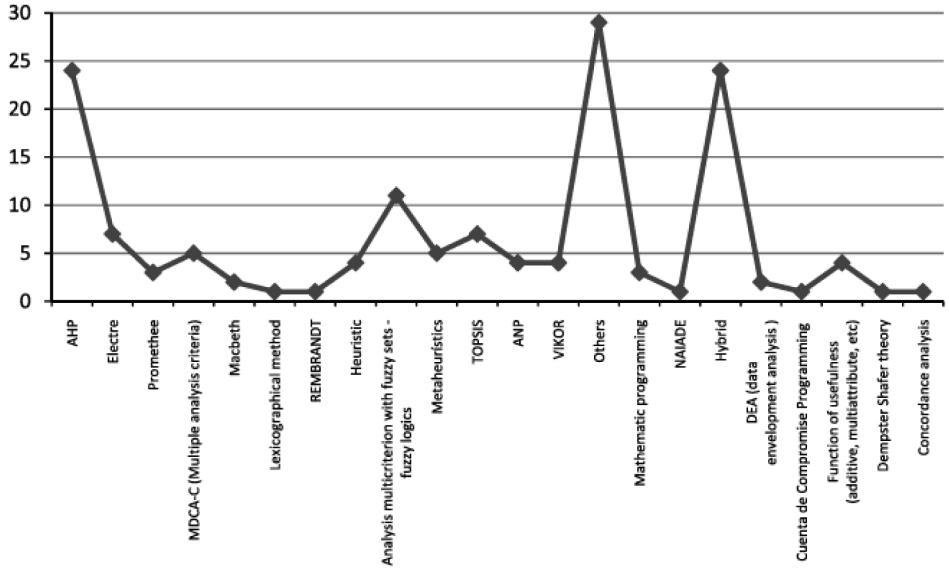
paper Weighted Sum, although easy to implement, because the weights of criteria can be determined subjectively, and hence obtain some bias in the final decision. Instead, CRITIC is implement to avoid this bias. Besides, AHP and Electre are also selected because they are the commonly employed techniques in MCDM literature, as shown in Figure 2.

Application of AHP

The Analytical Hierarchy Process (AHP) was first proposed by Saaty (1977, 1991, 1999, 2003). It is a MCDM method allowing prioritizing alternatives. The AHP is based on the use of pair-wise comparisons, which lead to the elaboration of a ratio scale. Moreover, the AHP permits to refine the decision-making process while examining the global coherence of the user's preferences, as it can include the calculation of an overall consistency ratio. The AHP is based on a four-level hierarchy linking eth main goal or objective, criteria, sub-criteria and alternatives. Pair-wise comparison is based on a 1 to 9 scale used to rate the relative preferences. These pair-wise comparisons finally constitute square matrices where the diagonal elements are equal to 1 and the others verify the fact that, for i different from j, the i-j element of the matrix is equal to the inverse of the j-i element. Priorities are then determined using these matrices and a global consistency test can be performed to judge of the coherence of the user's judgements.

When applying AHP to the case under study, alternative number nine (9) is the best alternative since it obtained the highest value of the weighted sum of the priority vector. It is to note however that the consistency index was 0.19 which is a little higher than the accepted upper limit for the consistency ratio. This could be explained by the fact that the selection of possible locations of multimodal terminals was done at random. For improvement, a Geographical Information System (GIS) can be integrated into the decision-making tool (see Camargo Perez 2015). Once the possible locations have been defined, the next step consists on carrying out a rigorous study with experts to assess the actual hierarchical structure of

Figure 2. Main MCDM and number of times they are used for urban transport systems planning (Camargo Pérez et al., 2015)



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the model. This can be done by applying well-known techniques such as Expert Judgement or Delphi approach (Dalkey and Helmer 1963). The former uses of structured or unstructured inputs from different individuals who have specialist knowledge of a particular domain, while the latter is a widely used and accepted method for gathering data from respondents within their domain of expertise (passenger transportation, for our case). Delphi technique is designed as a group communication process which aims to achieve a convergence of opinion.

Application of ELECTRE II

ELECTRE II method was originally developed by Roy (1982). The acronym ELECTRE stands for ELimination and Choice Expressing the Reality (originally in French: *ELimination Et Choix Traduisant la REalité*). At the time it seemed adequate and served well to promote the new tool. Nevertheless, the developments in ELECTRE methods over the last three decades, the way in which we consider the tool today and the methodological foundations of multiple criteria decision aiding have made the meaning of the acronym unsatisfactory (Figueira et al. 2005). This is a method for dealing with the problem of ranking actions from the best option to the worst (Smith et al., 2000).

In order to apply ELECTRE II method, we first proceeded to normalize the variables not holding proportionality, so variables became homogeneous. Numerical computation of this method found the best alternative to be the number three (3), which is the only one non dominated when executing the algorithm for the strong classification.

Application of CRITIC

The CRITIC method was also applied to the case under study. CRITIC stands for "Criteria Importance Through Intercriteria Correlation". The method was proposed by Dialulaki et al. (1995, cited by Aznar Bellver and Guijarro Martínez 2012). It is based on weighting the criteria according to data obtained for the different alternatives. This weighting idea is similar to the one employed in the Weighted Sum technique; however, weight given the latter are (subjectively) assigned by the decision-maker or by a pool of experts, while weights employed in the CRITIC method are obtained from data which add objectivity into the procedure. The weight w_j of criterion j is given by the expression $w_j = s_j * S(1 - r_{jk})$, where s_j is the standard deviation of criterion j and r_{jk} is the correlation coefficient between criteria j and k.

In order to apply the CRITIC method, values of variables where normalized in order to allow a fair comparison so that they have values between 0 and 1. Deviation between criteria was computed as:

$$\mathrm{S_j} = \sqrt{\frac{\sum_{\mathrm{j=1}}^{\mathrm{n}} \left(\mathrm{X_j} - \overline{\mathrm{X}}\right)^2}{\mathrm{n} - 1}},$$

while the correlation between criteria was calculated using the Pearson correlation coefficient as:

$$\mathrm{r_{jk}} = \frac{\mathrm{cov}\left(\mathrm{j,k}\right)}{\mathrm{s_j} * \mathrm{s_k}}.$$

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These two mathematical expressions give the information required to compute weights of criteria. After applying this method to data on the case under study, the best alternative was number five (5).

COMPARISON OF TECHNIQUES

As observed, the application of three different MCDM techniques gave different alternatives as final solution for the location of a multi-model terminal. In order to aid the decision maker to assess these results, a comparison between these solutions is carried out using Manhattan distance method (Aznar Bellver and Guijarro Martínez 2012). The concept behind this procedure is taken from Zeleny's Axiom, which states that, given two possible solutions on the space of objectives, f1 and f2, the preferred solution is the one that is closer to the ideal solution (Aznar Bellver and Guijarro Martínez 2012). The Manhattan distance, *Lp*, is computed as:

$$L_p = \left[\sum_{j=1}^{n} \left| x_{ij} - x_{kj} \right|^p \right]^{\frac{1}{p}},$$

where x_{ij} is the ideal value of alternative *i* for criterion *j*, x_{kj} is the value obtained by alternative *k* for criterion *j*. Absolute values are employed in order to avoid bias due to positive or negative values.

Table 1 presents a summary of data required to compute the comparison, as well as the final results. In quantitative terms, alternative number five (5) obtained the lowest distance to the ideal value. Just recall that this alternative was also obtained by the CRITIC method.

Table 1. Data and results of the Manhattan distance method

Criteria	Ideal alternative	Alternative 5 – CRITIC (Absolute distance)	Alternative 3 – ELECTRE II (Absolute distance)	Alternative 3 – AHP (Absolute distance)
Surface	126029.7977	126029.7977 (0)	10878.87283 (115150.9249)	12260.0479 (113769.7498)
Coverage	284.9757	201.6517 (83.32)	284.9757 (0)	194.2304 (90.7453)
Accessibility	5	4 (1)	5 (0)	3 (2)
Ease of integration	4	3 (1)	3 (1)	3 (1)
Demand	180008.804	69817.147 (110191.66)	97546.099 (82462.7053)	18008.80 (0)
Demographical growth	8067	3633 (4434)	2633 (5434)	5553 (2514)
Social accessibility	5	5 (0)	5 (0)	5 (0)
TOTAL		114712.98	203048.63	116377.50

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CONCLUDING REMARKS AND FURTHER RESEARCH

After a conceptual comparison of different multi-criteria decision-making (MCDM) techniques, this paper evaluated the application of three different techniques to evaluate the possible location of a multi-modal terminals in integrated public urban transport system. The case studied was the city of Bogotá, Colombia, where a simplification of the problem was necessary in order to avoid high data processing cost and time. This results provide decision-makers with formalized information to make a more accurate decisions regarding the location of multimodal terminals in a complex passenger transport network based on a bus rapid transit (BRT) system servicing about 1.7 millions of passengers per weekday. The data sets considered in this paper included both real life data and a set of random selected possible locations for the multimodal terminals. Our objective was to illustrate how a multi-criteria decision making (MCDM) approach could be employed to solve this kind of problem when complex multiple criteria are included in order to evaluate sustainability (e.g., logistical, economic, environmental and social). The proposed methodology and results have direct implications in research and practice, mainly relating them to the field of collaborative transport policy and planning (Macharis et al., 2012; Gonzalez-Feliu et al., 2018). Indeed, the proposed methodology can be a first step of supporting consensus search via the methodology to obtain and validate indicators, then via the comparison of techniques for multi-criteria assessment.

A lot of possible lines for further research are still open. For example, as possible locations were randomly selected, it is necessary to include in our approach a first step that aids the designer to find the best possible locations in the city. This can be done by integrating a Geographical Information System (GIS) into the decision-making tool. The tool can be interactive, allowing the decision-maker to change the location of transfer points and then automatically obtaining the values of the evaluation of the different criteria, as well as the ranking of alternatives. Once the possible locations have been defined, the next step consists on carrying out a rigorous study with experts to assess the actual hierarchical structure of the model.

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Chapter 22
SMS as a Tool to Improve Information Flow on Humanitarian Logistics:
Case Study – Quebrada Quirio in Chosica

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ABSTRACT

This chapter assesses the suitability of mobile phone technology, an established technology (humanitarian), to support humanitarian operations, create an inventory of support donations, and track the needs of people throughout humanitarian logistics after the disaster. The main objective is to reduce the exposure to the consequences of disasters by reducing the time of information flow through SMS interaction technology. Quebrada Quirio was used as a prototype. The process consists of using the INDECI rapid assessment visit to collect basic data, including a telephone number, of the people affected by the disaster, and based on this information, multiple initiatives aligned with the optimization of the flow of information were created.

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INTRODUCTION

The ONU stated that more than 60% of the Peruvian population is vulnerable in case of natural disasters (La Prensa, 2015). In the period between December of 2016 and April of 2017, Peru was hit by a series of strong rains, due to El Niño phenomenon, in the north and east of the capital. According to the Center of Operations of National Emergency (COEN), by March 15th, there where 552,866 people affected by this disaster and 62 642 victims (Perú21, 2017). Additionally, it caused a total of 66,093 homes destroyed and another 371 370 homes affected. It is also worth mentioning that educational institutions were also damaged: 354 where destroyed, and a total of 3 266 where affected, while 64 health establishments stayed unfit, and another 1,044 where affected. INDECI stated, on the Statistical Digest of 2017, that in Lima, El Niño phenomenon lead to 18 775 victims, 40 176 people affected, 16 deceased, 76 wounded and 1 missing person (INDECI, 2017).From this department, Chosica was one of the most damaged districts with more than 4 thousand people affected, with hundreds of homes collapsed and roads destroyed (El Comercio, 2017).

All the above, bring as a consequence a big group of people needing help after the disasters. Nevertheless, post-disaster process in Perú is treat as a push process, that starts with an estimated demand, this causes longer response time to these people. In Perú, demand estimation begin with the information gathering process which is already established by INDECI, this process consists legally of three phases, two of them for gathering data and a third one to summarize the information collected in the first two phases (INDECI, Manual EDAN Perú, 2016). This makes this process prone to eventualities that, as a consequence, cause delays on donations distribution. The INDECI statistic report of July 2017 confirm the damage on transport and communication of 218 089 road kilometers and how this transport limitations bring the necesity of local governments cooperation to measure damages and necessities (Dirección de Políticas, 2017). According with Cozzolino et al, in HL time lost means lives lost (Cozzolino, 2012). Thus, is highly relevant to optimize information flow and reduce eventualities probabilities that cause bottlenecks in the Humanitarian Logistics (HL) process. All these in order to minimize and calibrate human suffering.

On the other hand, the probabilities of transporting non-necessary or low priority donations increases without real data. As in the case of the city of Tahoku, where these irrelevant donations represent around 50 - 70% of the total charges increasing transportation cost, taking warehouse capacity from critical resources and abstaining other communities of these resources (Holguín-Veras, 2012). Prioritize donations also partially solves distribution problems, because it reduces the need for coordination between agents (Buzogany, Prioritization models in humanitarian operations: systematic review of the literature, 2015). Nonetheless, it is still important coordination between the different agents to assign the scarce resources and saves efforts, resources and time. On Osh earthquake in 2015 there was families which receive 50 bags of flour whereas others did not receive anything (OCHA, 2016). In Peru's case, stakeholders are divided in two main groups: the public sector, represented by INDECI, and the private sector; represented by companies, NGO´s and civils. These groups are not aligned and one of the factors collected in interviews was the accessibility to quality information to know where their help was required.

This paper describes a case of study of SMS interaction technology implementation to reduce information flow time and increase quality of data in post disaster humanitarian logistics process, using the Quebrada Quirio as a prototype. The main objective is to create a work flow capable of reducing the

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information gathering cost and, as a consequence, the response time. And to build a prototype to prove one of the initiatives. Since the first visit of INDECI is mandatory, it is proposed to use it to collect base needs and contact information of people affected by the disaster and, based on that information, create multiple initiatives align to information flow optimization.

SMS technology was chosen because of its low cost, facility to use and accessibility worldwide, including emerging and developing countries (La Prensa, 2015) (DEVELOPMENT, 2005). Peru has 36.99 million lines and 72.5% districts with mobile phone service (INDECI, Estadísticas de las Tecnologías de Información y Comunicación en los Hogares, 2017). This stadistic is divided in an average presence of mobile phones for urban areas of 92.8% and in rural areas of 72.3%. Furthermore, the report statistics information technology and communications in home stated that metropolitan Lima has the largest number of mobile lines in Perú with 97% (OSPITEL, 2017). Is worth to mention that when a disaster strikes, the existing connectivity level is challenged, but there is a higher scope for SMS technology than for internet connection in these scenarios. (Mendoza Riofrío, 2017)

For the terms of this chapter, the zone of the Quebrada Quirio was selected as the location where the pilot would be developed. This zone was chosen because it conglomerates around of 5000 homes, that are occupied by around 20,000 people. As mentioned by Antonio Peña Jumpa, Quebrada Quirio is one of the riskiest ravines of the district of Chosica, with a high geological and hydrological risk, as well as being consider one of the most strongly affected during the El Niño phenomenon with about 1000 homes are at risk because of floods (JUMPA, 2017). Asking Quirio's habitants, they estimated a media of 2 disasters on the area per year. Likewise, Quebrada Quirio is considered one of the districts with better connectivity in Lima, this area did not have any troubles with connectivity during El Nino phenomenon (Redacción EC, 2015) which makes it perfect to prove of prototype. This chapter is organized as follows. First, the background is presented. Then the objectives are described. After that, the methodology for each objective is detailed. Following, the results and discussion are presented. Finally, conclusion and some prospects for future work are proposed.

BACKGROUND

Many methods for improve information flow have been developed. An article in the Online Journal of Public Health Informatics published in 2014, describes an Electronic Disease Early Warning System (eDEWS) that has the objective to minimize mortality due to communicable diseases by detecting potential outbreaks at an early stage. This system was introduced in 2013 in Yemen as a pilot, in 100 health establishments and 4 governorates, the eDEWS platform captured data electronically in real time about prioritized epidemic diseases. This information was delivered immediately to the government hubs for its validation using mobile based and internet-based interfaces. If the information about the outbreak is validated, SMS alerts are generated automatically. The central database of eDEWS generated 906 SMS alerts, 745 of these were verified as true alerts and over 82% were investigated and responded within 24 hours. The results showed that the system, along with the prompt public response, were effective and efficient with an early containment of outbreaks. (Ahmed, 2014)

Another case in which SMS were used for humanitarian logistics was in the Haiti Earthquake in January 2010. A crisis management system was incorporate to evacuate victims. Civils and entities notify

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possible places of search using social media and SMS. This information was processed and uploaded to an information system called SAHANA, which proved information to find and rescue people. Although, this system safe a lot of people; it has information overload problems, variable speed of information delivery and the high risk of receiving inaccurate or incorrect information because of its lack of user trackability (Dugdale, 2012). In this disaster was also implement an SMS-based emergency reporting and response system, to provide a tool to report emergency needs. It basically translates, geolocate and categorize messages as they arrived. It was used to prioritize needs on the zone and give general instructions to the Haitian population, by outgoing messages and emergency responses (Meier, 2010).

Africa has also implemented multiple initiatives to use of IoT technologies in humanitarian logistics. Schumann-Bölsche study the possibilities and challenges of humanitarian logistics in sub-Saharan Africa have addressed and the possible application of single-board computers – such as the Raspberry Pi – in combination with sensor networking with the main objective of create a service to enhance food and medicines distribution in disasters (Abushaikha, 2016). Furthermore, SMS was used in humanitarian logistics in the case of Somalia, here mobile phones was a tool to control and prevention of Polio, through SMS as an effective mechanism for transmitting information and alert a large amount of people. This system was also used as a mean to send vouchers to people, so they can redeem them for water and sanitation items (Höflich, 2002). Likewise, Abushaikhaa et al concentrates on the use of mobile phone technology, as a simple and established technology, for delivery "mobile cash & vouchers" to refugees in sub-Saharan, Jordanian and Germany camps, submitting deeper analysis of its utility on operations. (Union International Telecommunication, 2015).

Multi-Platform technology is use in HL process too. Cinnamon et al shows how call detail records (CDR) and both-side interaction via text messaging (SMS) could help to understand Ebola and Zika affected people. The authors made a decision tree for the use of mobile data including SMS and CDR to map the different uses and its derivated benefits. As a result, it was found that CDR help to have a big picture of risk and the number of possible affected people, its density and distribution. Likewise, both-side SMS help to understand deeper information as the degree at which the population has been affected, resource needs and symptoms. As a result, it is usefull in prevention, preparedness, response and recovery. Likewise, Cinnamon propose that there are gaps to shorten in order to ensure secure widespread acceptance and access to informed about use of mobile phone data in disease outbreaks and disaster management. (Cinnamon, 2016)

Yuanrong Hea et al built a mobile-based disaster management system (MDMS) to collect, share and determine the damage caused by disasters, combining native technologies, web and open source software like GeoServer, Openlayers, Cordova and jQuery Mobile. This solution qualifies where multi-platform capabilities. The results show that offline work and the portability of the system are the most valuable features considered to facilitate subsequent disaster management. Therefore, it was concluded that a MDMS based on free and open source software is an affordable, portable and cross-platform management post-disaster tool. (Tagliacozzo S., 2018)

In each case presented, the innovative character is not concentrated on the technology itself but on innovative ways to use it in logistics and supply chain management. Each of these have shown an increased interest in the role of logistics function in supporting humanitarian relief operations and the importance of an efficient process to reduce people suffering.

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METHODOLOGY

1. Create a Work Flow to Improve Information Process

As Holguín-Veras et al sustains, the biggest difficulty in a great magnitude disaster is donation management and the importance of material convergence, flow of supplies and equipment that is sent to the disaster area by donors (Holguín-Veras J. J., 2012). Thus, based on the experience present before and interviews to INDECI experts we will propose three different initiatives to improve distribution management on disaster scenarios by improving information flow. Martinez Olvera et al propose a tool to develop an efficient supply chain strategy call Customer - Product - Process - Resource (Martinez-Olvera, 2006). The study proposes three initiatives related to affected people (customer), donation and information management (product), distribution process (process) and donation and people suffering (resource).

Constant Update of Inventory of Donations

According to R. Perez-franco, to define a strategy of supply chain is necessary match supplies and demand (Perez-Franco, 2016). Because of the lack of internet in affected areas there are

some clearances at the moment of update inventory and also there are not enough information to check if a person had received a kit previously, this generates an inequality distribution of donation as in the case of Osh earthquake (OCHA, 2016) . As a response of this statement, the interactive SMS system will enable the uploading of all donations movements in real time. The process consists in 4 interactive steps. (1) The start point is the first survey of INDECI, this survey gives the risk statement base to prioritized affected people needs. With this information the first kits necessity is upload to the database with "available" status. (2) While the kits are available their status is uploaded to "full", (3) when dotation are on the way to the affected area it would change to "on the way" and (4) finally to "deliver" once affected family got it.

Survey to Prioritize Necessities

Rafael Villón, leader of technology in INDECI (Villón, 2018), said that there have been a lot of times when private sector cover donations demand before INDECI arrives. This scenario causes transportation and warehouse resources wasted and the necessity of inverse distribution for unnecessary donations or a double expenditure to transport resources to where they are really need. Nevertheless, is worth to mentions that in most of the cases this private groups; individuals, community groups, churches, and private companies; got the genuine interest in helping but they have a lack awareness about what is really needed and the negative impact that their donations could produce. (Holguín-Veras J. J., 2012) To prevent this kind of situations, we propose to build a web page and link it to the donation inventory and its status. All the above in order to make available affected people needs and synchronized efforts. To keep tracking affected people needs we propose to send surveys asking about the top five donations people needs. To rank the principal needs will reduce unnecessary donations and will improve distribution flow. An example of this is Tanzania, where the out of stock of Malaria medicine was reduce from 79% lo less than 26% with app interaction to send request when medicine was close to minimum stock line (Abushaikha, 2016). Furthermore, survey the affected area can help to understand what resources are already available in the area and which ones are really needed. (Holguín-Veras J. J., 2012)

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SMS Voucher to Pick up Donation Kit

In the case of Somalia (O'Donnell, 2015), distribution of water and health elements through SMS vouchers was success, because every person had a unique voucher assign by the system with that they could ask for the kit. In the case of Chosica, before, during and after disaster, people are informed by SMS about what they must do during and after the event. Villón mentioned that this communication is thought Movistar, a Telecom company in Peru . Movistar check the mobile phones that are active in a specific zone and time and send warning messages for them. Furthermore, communication though SMS has not cost, because is part of the activities that Movistar does when a natural disaster happens (Villón, 2018). The vouchers to pick up a donation kit could be send through this mecanism but this time with contact information given by INDECI.

2. Prototype Creation

The implantation of a prototype of SMS interaction system in the Quebrada of Quirio consist in 4 steps detailed: select IoT technology, prepare interact SMS process, create Arduino circuit and try the prototype on Chosica sample. The principal progress of the main system is measure by the fulfill of each of the 4 steps. Efficiency, costs, effectiveness and scalability criteria would be deepened too.

Select IoT Technology

For the prototype it is used four core elements: Arduino, GSM SIM900, SIM card and a free database. Arduino work as the main controller which creates a connection between hardware and the instructions to be follow by the SIM900 software (Herrador, 2009). GSM SIM900 make possible to communicate with cell phone GSM red and access to services: SMS, MMS and GPRS (Rahman, 2015). Arduino plays instructions through UART using AT commands to send and receive SMS. It also connects with SIM900 and this to the internet over GPRS network. Internet connection plays a central role because it allows to connect with the database and display queries to get information to structure SMSs or receive information and file it on the database. It's worth to mention that to power up the GSM SIM900 is necessary to use 12V and that SIM900 requires an original SIM card size, this SIM must be pin lock off, to enable red communication.

To select Arduino as IoT technology we compare it with other 3 technologies guided by art of literatures, and the straightness and difficulties that each study case have with these technologies. Yuanrong Hea et al emphasize the importance of portability, accessibility, affordability and usability in technologies related to disaster management system fully operational situations (Tagliacozzo S., 2018). From these and base on Somalia study case, efficiency, cost, effectiveness and scalability were choose as measure variables (O'Donnell, 2015). Table 1 describes the 4 technologies comparison results.

Each of these criteria respond to the following questions. Efficiency, were the activities carried out according to the original plan? otherwise they adapt correctly to the changes? How to program the Arduino to make it more interactive with the users? How are the challenges handled? And what kind of support is necessary for the future? Costs are more specific questions regarding total costs and comparison. What is the total cost of the proposal? How does this compare with approaches to promoting traditional disaster programs in Peru? Effectiveness, what was the level of participation from all community segments including vulnerable groups? Did communities face challenges reading/responding to SMS? How did

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Table 1. Compare table

Project\ Variable	Costs	Effectiveness	Scalability	Efficiency
CDR	x	x	✓	✓
Raspberry Pi	x	x	✓	✓
Social media and SMS	✓	x	x	✓
Arduino/SMS	✓	✓	✓	✓

they store the information – is phone memory capacity an issue? Is the quality of telephone coverage a problem in Quebrada Quirio? Scalability, what are the interest levels from communities, program teams, other actors to take this to scale? What changes should be made/incorporated to make the program scalable? (O'Donnell, 2015) (Dugdale, 2012)

There were studies with CDR technology (Cinnamon, 2016), but it was discarded for these project because this technology do not include people status, and resources needs, fundamental data for efficient donation distribution. Furthermore, in Perú is really difficult to access to this data because of the dispersion of users in telephone companies. Also, we validate the use of CDR technology but according to Rafael Villón, use massive methods at the moment of estimate demand will cause not affected people include or affected people not count. For that reason, he considers is indispensable the initial visit with INDECI (Villón, 2018).

Another IoT technology study was Raspberry Pi, a credit-card sized computer. Because even when this device does not include a GSM shield it is compatible with it. Nevertheless, Schumann-Bölsche solution to create a service to enhance food and medicines distribution in disasters based on Raspberry Pi cost around of $30 dollars (Abushaikha, 2016). The prototype proposed is composed by an Arduino Uno Rev 3 ($22) (Arduino, Arduino quotation, 2018), GSM SIM900 shield ($16.91) (Ebay, 2018) and a sim Card ($15) (Movistar, 2018). Raspberry Pi solution is much more expensive than Arduino.

Finally, Social media was discarded because during cadasters internet connection is more prone to get lost but calls and SMS usually are not affected (Mendoza Riofrío, 2017). Furthermore, administrate this data could require text mining or hours of human work because of the amount of information that would be compiled. Likewise, there is a low internet penetration in Perú. According to INEI in 2016 45.5% of Peruvians with 6 years or more got access to internet (INEI, 2018) This represents more than half of the population without internet access.

Prepare Interact SMS Process

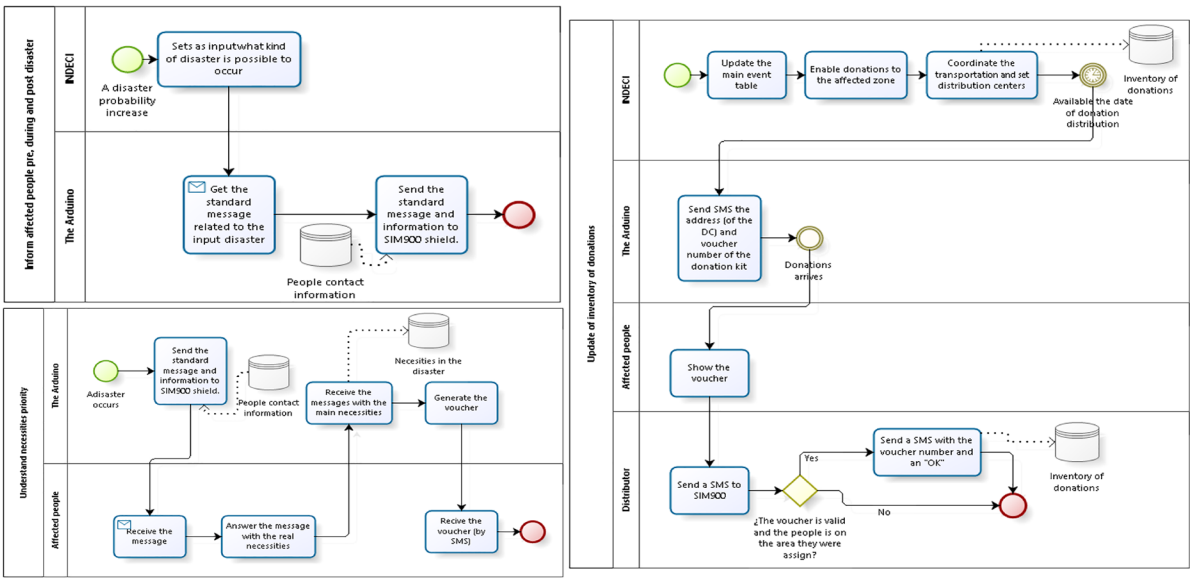
The next step was to identify the sequence of activities that needed to be implemented on the prototype to fulfill each initiative process. Figure 1 describes each objective process.

Constant Update of Inventory of Donations

This process has as input a main database table with each donation event. For the prototype was simulate a database of 50 people associate to 15 families. There are four possible states: available, full, on the way, delivered. The process begin with the update of the main table with all the new donations demands that must be delivered, as a result of the first quick visit and they are set on "available" status. Each time a

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Figure 1. Objectives process diagrams



resource need is upload it is set on the table a new line with six attributes: Voucher number, telephone number, district, number of people inside the family and status. While INDECI enable donations, the status must change to "buyed". This process is thought to be manual as it currently is, nevertheless, technology as bar code reader or RFID can optimized this work. After that, INDECI needs to coordinate the transportation and set distribution centers. Once donations are enroute to affected area, status must change to "On the way".

Finally, when donations arrive to each distribution center, people incharge of deliver donations should send SMS to SIM90 asking about the availability of a kit for the family in question. The response of Arduino should be "yes" if there is one available in the distribution center, "not – distribution center name" if the family got one kit available in other distribution center and "not - the date of the last deliver" if there are not available kits for related to the voucher presented. Thenceforth distributor send a SMS with "the voucher number - OK" to update the event status to "delivered". If distributor made an error, can revert the process by sending "the voucher number - NOT OK". As future work, INDECI could create vouchers in that moment in order to deliver extra kits to family that wasn´t count on the first visit but the objective of this process to reduce the risk of double deliver.

Survey to Prioritize Necessities

To "Understand necessities priority", a survey will be sent to affected people, in order to understand real necessities and avoid obsolete donation on the area. INDECI has 9 principal donations groups: "medicamentos", "techo", "abrigo", "alimentos", "utensilios", "herramientas", "equipos", "agua" y "saneamiento". There was create a standard message asking to prioritize donation necessities. The procedure is similar to "Inform affected people pre, during and post disaster" process that is currently cover by Movistar, but there are two additional activities. First, to receive the response and storage it future statistics and to respond with a confirmation of having received the answer. This information can help to distribute

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limited resources (Holguín-Veras J. T., 2012). It also reduces the risk of deliver unnecessary donations cause by private efforts to cover these needs. Villón told us that there have been scenarios where public donations were distributed and affected people argue they have received private donations and they do not need some items INDECI deliver anymore. (Villón, 2018)

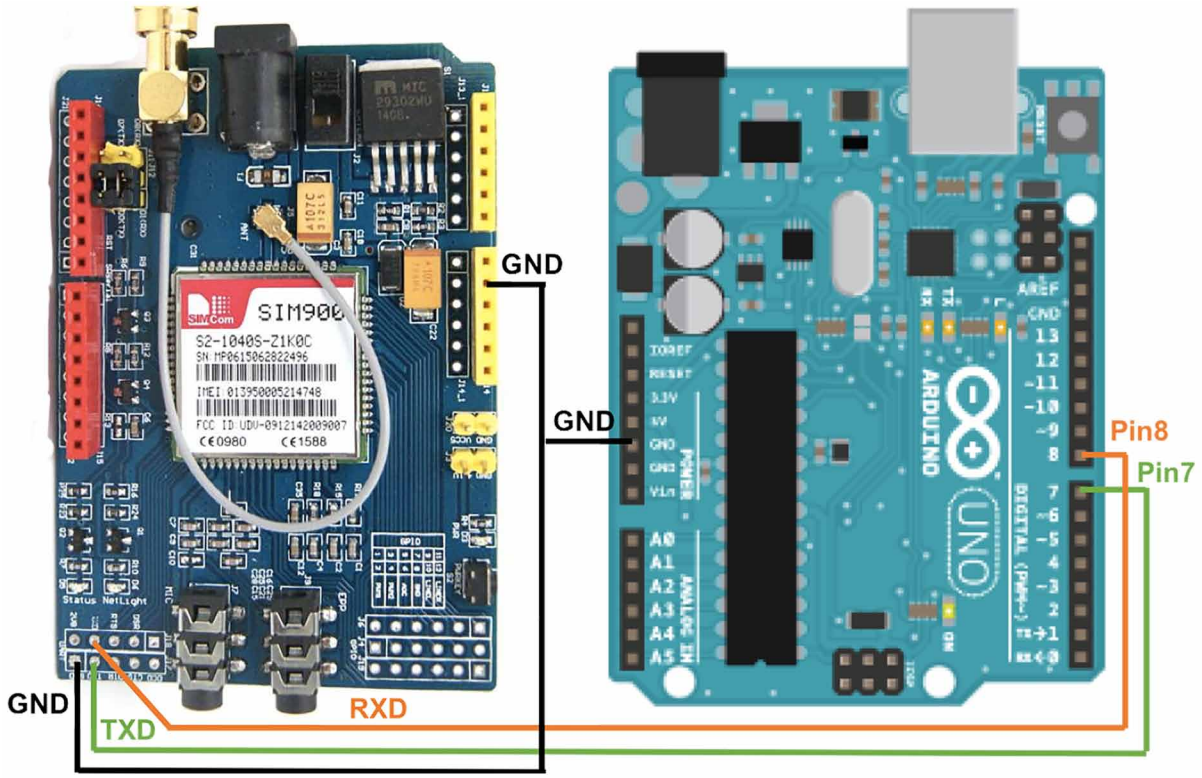
SMS Voucher to Pick up Donation Kit

Voucher initiative can complement phase 3 and 4 of the inventory management initiative. Once INDECI has available distribution center and date of donation distribution, Arduino goes into action and send through SMS with a system generated voucher number, the adress of the distirbution center asign, and the date and hours of deliver. This information help to organize people as in the case of Somalia (O'Donnell, 2015). For the deliver phase, it would be efficient to the distribution process because people can be easily track without the necessity of a identification document. If affected people has any discapacity another person with these voucher number can pick up the kit. Once the kit is deliver the voucher number is disabled.

Create Arduino Circuit

After understanding the process that the circuit should follows, it was needed to create the solution to support all operations. The first test was to connect arduino to SIM900 and recognize signal. Subsequent

Figure 2. Arduino circuit



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to that, it was tested the send message and receive message functionalities. The next step was to integrate both functionalities. With Arduino sending messages SMS to alert population and SMS to give vouchers to pick up donation kits were fullfit, and with arduino receiving messages the survey to prioritize necessities process was complete. However, it was necessary to storage all information. It was possible to export a file with all survey answers but in order to support SMS interaction based on database information, it was necessary to connect arduino to the main database table. A non sql free database, ThingSpeak, was proved but it only has "POST" functionalities. In other words, it only allows to update information to the database but for the update inventory donations process it was needed to have a "GET" and "POST" functionalities. Because of that, a sql database table that allows both operations. Figure 2 shows arduino physical connection with SIM900.

Try the Prototype on Chosica Sample

The next step was to choose a population sample to test the prototype. A test process was implemented with three phases. The first was to test individual functionalities: send, receive and connect to the main database. The second phase was to test send and receive operations and the last one was to test the main prototype. Quebrada de Quirio in Chosica has a population of approximately 15 000 people (Centro de estudios de prevension de desastres, 2006), to test the prototype we choose 15 families conformed by about 5,5 people. These families were also interview about disaster exposure they had had and satisfaction and suggestion to the prototype. We also interview some people who lives around Quirio.

Limitations

The main limitation of using SMS as a tool to improve information flow on humanitarian logistics is the infrastructure´s quality from telecommunication´s companies and their ability to deliver good service during an emergency. Principal factors are the number of antennas installed and the vulnerability of these to be affected by natural disasters, as well as the contingency plans and speed of response of the companies involved. By 2013 the number of antennas per capita in Peru was 1.4 less than Chile in 2012 and 3.2 less than The United States in 2009 (OSIPTEL, 2014). OSIPTEL, communications controller, proposed to install antennas on public buildings to increase the service level and availability, they calculated the need for 14 thousand more antennas for the year 2025 in the whole Peruvian territory. On the other hand, telecommunication companies are investing in their infrastructure in order to improve their service level, according OSIPTEL in 2016 telecommunications operators made investments up to 6.722 million soles (OSPITEL, Inversión por Grupo Económico, 2017).

Results

The results obtained in the test show a response time of INDECI was average of between 4 to 7 days with 20% of the sample with a range greater than 8 days before receiving any type of help. Also, the travel time from downtown Lima to Chosica is approximately 2 hours to more depending on traffic. The proposed prototype took an average of 3 minutes to complete the interaction process between affected and arduino. This reduced the time of the activity to 1.3% of what it was, considering only transport. It should be noted that having a direct interaction with the database, it would not be necessary to transcribe the surveys or the results of the activities, which would lead to further reducing the delivery time. In

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addition, the labor involved in the collection of information after the first visit could be derived to planning and distribution of donations.

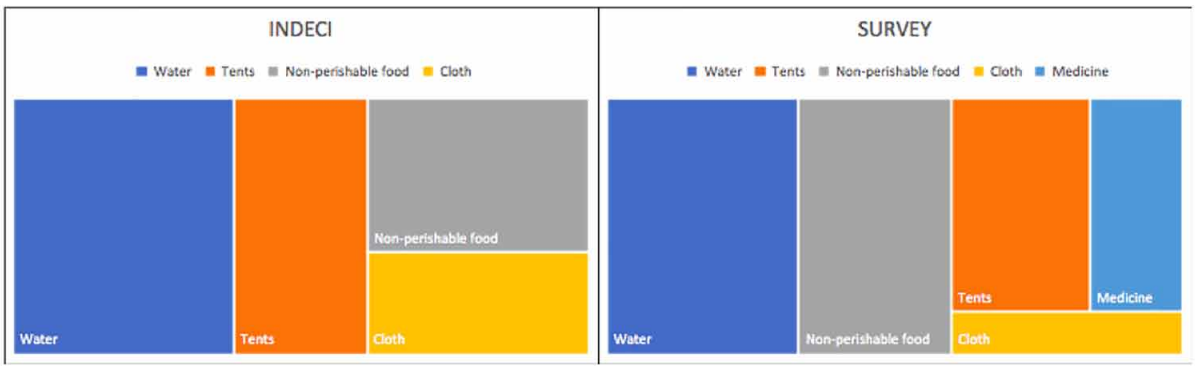
We observe a high capacity to use the proposed model. All the families had at least one person with the knowledge of how to interact via SMS. However, we suggest that if the model is implemented it will educate the most vulnerable areas in the operation of the interaction via SMS. It is worth to mention that apart from being able to participate in the model, all of them had the disposition and considered the device as a promising solution to the lack of communications in case of disaster. In addition to considering it a timely tool for the interaction between public institutions and the affected areas.

Figure 3 shows the result of the test carried out via SMS and the result of the subsequent analysis of INDECI attention and the type of help it provided in the event of a disaster. It can be seen that the respondents consider a different order of priorities. The order of priority of INDECI donations received was first water, followed by tents, non-perishable food and clothing. On the other hand, the result of the survey showed that water was the most requested resource followed by perishable food, shops, medicine and clothing. It should be noted that in the order of priority of INDECI the urgency of the distribution of medicine was not perceived even when the violated consider that this is more important than the shelter. Additionally, donation needs tend to change depending on the affected area environment. As in the case of the tsunami in Japan, where a week after the tsunami when the weather warmed up, the blankets were no longer but the water and medicine was (Holguín-Veras J. J., 2012). For that reason, is important to constantly interact with affected people and track their necessities.

CONCLUSION

The purpose of this chapter was to evaluate the suitability of mobile phone technology to support humanitarian operations, create a support donations inventory, and keep track people needs throughout the post-disaster humanitarian logistics; in order to reduce the exposure to disaster consequences and people's suffering. Mobile phone technology, an established (humanitarian) technology is selected to enhance the performance of humanitarian logistics in disaster relief operations. In Peru, post-disaster actions are treated as an insertion process, the first step is to approach the affected area to collect data and then summarize them and estimate the demand for products that people need after the event. To manage kind information is crucial for the donations distribution since it is at that moment when the type

Figure 3. Comparison between help from INDECI and how affected people prioritize donations



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of donation necessary for the area is known, as well as the exact location of the victims. SMS interaction technology allows information to be gathered, in order to reduce the information flow time and increase its quality and frequency. With the device, people only have to send the information in real time of their state and the competent governmental organizations can have the fast and quality information. INDECI is concerned about the humanity as a supreme purpose of the Risk Disaster Management (INDECI, Instituto Nacional de Defensa Civil, 2018), therefore the system based on share information by SMS is aligned to improve the management of the donations of kits of principal necessities as medicine, food or other implements for survival, after a disaster.

For future work could be interesting to involve private companies. According to Chopra (Chopra, 2008) and R. Perez-Franco (Perez-Franco, 2016) stakeholders' abstinence degrades response capacity and increments the supply chain cost, it is necessary to involve everyone and align their objectives toward the main one: reduce people suffering. To dismiss one stakeholder, like private sector, is a major mistake. In Perú, one way to integrate private sector is to create a public information database, to give enough information about where to direct help. This, in order to include private effort as part of the supply chain strategy and not as an obstacle to it. Now the project is focused in a supply donations tool, but it can also work in the rescue process, like in the Haiti earthquake of 2010, where the text messages sent by trapped people were very important, especially for aid delivery (Abushaikha, 2016).

However, affected areas of Lima did have troubles with internet connection but could maintain line connectivity throughout the disaster (Mendoza Riofrío, 2017). In the case of Quebrada Quirio, located in Chosica, is considered one of the districts with better connectivity in Lima, this area did not have any troubles with connectivity during El Nino phenomenon (Redacción EC, 2015). In addition, OPSITEL established a new regulation quality mobile phone (OSPITEL, El perú tiene 17 millones de celulares y el 72,5% de los distritos tienen servicio móvil, 2008) with three important indicators, two of them being: radio coverage, companies will be evaluated to be certain that they provide service in every area declaring that there is coverage; and, delivery of text messages, where the delay time is evaluated in delivering text messages. This shows mobile phone penetration and efficiency in Peru and even more in Lima.

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KEY TERMS AND DEFINITIONS

INDECI: INDECI is Peru's National Institute of Civil Defense, a public organization that promotes, coordinates and articulates the management of the reaction to the risk of disasters and emergencies. They general objectives include management, disaster response and institutional improvement. The first objective is that the three levels of government will manage the risk, through the development of normative instruments and control mechanisms. The second is to prepare people for have a response and rehabilitation before a disaster, disseminating emergency preparedness techniques. The third objective is to modernize the management of institutions, through an improvement in technology and communication platforms with the modernization of its infrastructure. INDECI has a Research Center that is at the service of the National Disaster Management System. The purpose of this research center is to help people in disaster risk management, for the development of new knowledge and contributions on the subject.

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Chapter 23
Humanitarian Logistics Budget Model:
Case of the North Coast of Peru

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ABSTRACT

In the chapter, the optimal budget was assigned to prevention projects in the northern regions, through an analysis that took into account criteria such as the degree of vulnerability, the level of poverty, the population, and the level of expenditure execution (capacity management of each regional government) in 2015 and 2016. AHP (multicriteria analysis) was used to estimate the degree of vulnerability of each region, since to determine this it is necessary to take into account several criteria and fuzzy logic in order to obtain the budget for each region. The regions to be analyzed were Ica, Lima, Ancash, La Libertad, Lambayeque, Piura, and Tumbes, the most affected by El Niño Costero in 2017.

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INTRODUCTION

Natural disasters are increasing in the Latin American region, both in frequency and intensity, which affects people, infrastructure, agricultural fields, the economy and the development of the countries. In the 1960s, 19 disasters were registered per year, while in the decade of 2000, 68 were registered per year (INDECI, 2018a). In Peru, this trend is also observed, during the year 2017 there were 7 thousand 382 emergencies, 85.9% was caused by natural phenomena and 14.1% by phenomena induced by human action, observing an increase in the number of emergencies nationwide in 42.9% compared to 2016; likewise, an increase of 59.4% in emergencies caused by natural phenomena. The risk of these dangers is intensified by climate change and the processes of high climate variability that cause new types of hazards such as the El Niño Costero Phenomenon (INEI, 2018).

At the beginning of 2017, the phenomenon of El Niño Costero in Peru was presented, mainly affecting the north coast, with the occurrence of heavy rains which caused mudslides, floods, landslides, and storms, as well as other events associated with the emergency such as pests and epidemics; All this caused damage to the life and health of the people who lived in the affected areas as material damages (INDECI, 2018b).

El Niño Costero left a total of 285,955 victims, 1 559 487 people affected, 169 dead people, 500 injured people and 19 people disappeared. Regarding material damage, 37 409 collapsed homes, 28 533 uninhabitable homes and 381 076 affected homes were registered. Regarding road infrastructure, 4 030 kilometers of road were destroyed and 10 251 kilometers of road were affected; there were also 112 748 hectares of affected crops and 51 851 hectares lost (INDECI, 2018b).

Items such as clothing, shelter, cleaning supplies, non-perishable food, water and household goods were donated by the population and national companies to alleviate the suffering of those affected by a total of 2378 tons. Likewise, the international community also made donations for a total of 232.88 tons, which were transferred mainly to the departments of Piura, Lambayeque and La Libertad (INDECI, 2017).

Given the situation generated by the phenomenon, the Peruvian Government declared 14 regions in emergency and a constitutional province to guarantee the welfare of the affected population, deploying immediate response actions directed from the Presidency of the Council of Ministers and the National Emergency Operations Center COEN MINDEF (INDECI, 2018a). The Government mobilized significant financial resources for immediate response and rehabilitation, and others for reconstruction during the following three years. The national government mobilized the Armed Forces, the sectors and the institutions of the State with the purpose of saving lives and evacuating the population in risk areas (INDECI, 2018a). In addition, it provided financial support for around US $ 3 135 million, launching a rescue and evacuation operation, humanitarian aid, operation of pumping systems, implementation of shelters, health, fumigation, education, repair of water systems and roads Communication. Likewise, it established a "Reconstruction with Changes" program with a budget of approximately 6.4 billion dollars for three years following the event (INDECI, 2018a).

Due to its geographical location, Peru is a country that is exposed to natural phenomena such as the Niño Costero (INDECI, 2005), which is why it is necessary for the population to have adequate knowledge and develop prevention and attention capabilities in the face of emergencies and disasters. that may occur as the recent El Niño Costero phenomenon. Given this, the allocation of budget for disaster prevention is a fundamental task of the government, carried out through the Strategy of the Financial Management of Disaster Risk which consists of the set of actions established to ensure an adequate financial management in the processes of disaster risk management and better coverage of the risks that

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arise from the occurrence of disasters (López, 2018). In this sense, regional and local governments have the responsibilities of allocating resources in the formulation of the annual budget to provide assistance to people affected by disasters, execute actions that recover lost basic services and rebuild damaged public infrastructure. as well as prioritizing the allocation of budgetary resources for the development of disaster risk management processes (López, 2018).

This study presents an analysis, using quantitative tools for decision making that take into account important criteria (vulnerability, number of inhabitants, level of poverty and level of expenditure of regional governments) for budget allocation in prevention projects in order to achieve its prioritization. This has the purpose of promoting the correct financing for the development of natural disaster prevention projects for the regions of Ica, Lima, Ancash, La Libertad, Lambayeque, Piura and Tumbes. In this way, the objective of this analysis is to achieve an optimal allocation of the budget that is required for prevention, according to the needs and capacities of each regional government; the amount allocated by the central government for prevention projects for 2018 was considered for that purpose.

BACKGROUND

The El Niño Phenomenon is an oceanic - atmospheric natural event that is characterized by a generalized increase in sea temperature from the center of the ocean to the coasts of South America, causing oceanographic, meteorological and biological variations at a regional and global level. This phenomenon has occurred 44 times in Peru, of which 7 have been of an extraordinary nature (INDECI, 2017).

It is necessary that preventive measures are taken in the country for adequate preparation given the occurrence of both natural and human-induced disasters (INDECI, 2005). An important part for the development of such measures is the financing of prevention projects, which is managed in Peru by the Ministry of Economy and Finance under the Strategy of Financial Management of Disaster Risk (López, 2018). In Peru, the main via of financial administration of the public sector is the National Budget System. This system establishes the political and annual formulation of the public budget, allocation of resources in the country (general budget direction) (Congreso de la República, 2017) with a medium a long-term vision.

An effective method based on criteria and prioritization for decision making is the analytical hierarchy process (AHP). It determines evaluation models, analyzes implementation processes with its possible implications. In fact, the dichotomy between theory and its empirical application is understood (approach based on supplier evaluation: problems and perspectives) (Bruno, Esposito, Genovese & Passaro, 2012).

This technique has many applications in different areas focused in decision-making. First, facing an environment in which there are budget limitations being the aim to keep a road network with more than 2000 bridges in perfect conditions, the allocation of resources must be managed based on priority criteria (risk management in bridge administration with discrete multicriteria decision models). Secondly, there are several reasons for the loss of water in distribution systems, which are pipes, fittings and tanks in poor condition. Usually, the recovery of the leaks has a greater cost than the value of the recovered water. Therefore, with the use of AHP various criteria will be considered in addition to the technical and economic criteria that determine the best decision (application of analytic hierarchy process (AHP) to management of water losses in supply networks) (Delgado Galván, 2011). Finally, Bustince et al. (2016) states that in the face of disasters, the first aid received comes from local governments. Consequently, based on physical, economic, social criteria and the frequency of events in certain areas, the optimal

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actions to be taken to minimize the risk of disasters are determined (priority communes for disaster risk management: a contribution to decision making).

The fuzzy logic, a technique that represents mathematically the uncertainty and facilitates decision-making, is applied in various areas. First, in the finance field, the fuzzy logic establishes the contribution of portfolios of actions with the general objectives of the companies that own them (project portfolio management: a model for improved decision making). Second, in zoology, the impact of climate change on marine species is uncertain and there is little information. Thus, this technique is used considering the acidification of the sea, adaptability, climate hazard and other variables. With that, it's determined which species are vulnerable (using fuzzy logic to determine the vulnerability of marine species to climate change). Finally, this methodology can be used in risk management with inaccurate data and little knowledge unlike traditional models that are based on probabilities in order to make more accurate decisions (applying fuzzy logic to risk assessment and decision making) (Shang & Hossen, 2013).

Budget planning is generated by the Ministry of Economy and Finance. On one hand, AHP suggests that through a variety of criteria and alternatives can be chosen, as evidenced by the supplier evaluation article. Additionally, the second and third articles related to AHP explain how the criteria involved in decision-making are determined and prioritized. The last article generates empathy, because an adequate allocation of the budget makes it possible for affected people to be immediately supported. On the other hand, the three articles of fuzzy logic agree that with little information, accurate or not, solutions for complex situations can be obtained.

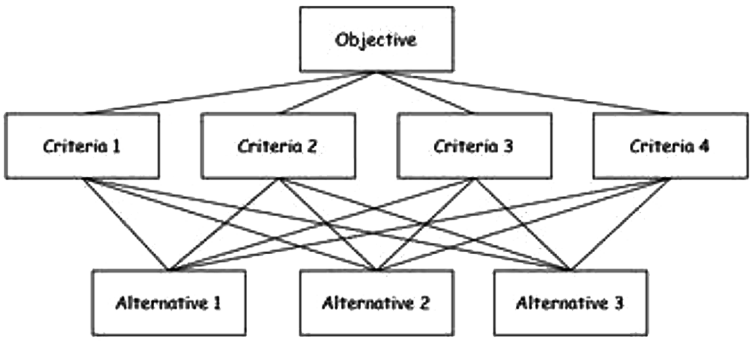
METHODS AND PROCEDURES

The government budget was allocated using the following methods:

1. Analytic Hierarchy Process (AHP)

It is a methodology that allows scientific decision making in complex situations characterized by the consideration of multiple scenarios, actors, and criteria; both tangible and intangible (Saaty, 2014). The decision maker has the capability to choose the criteria that he will use to evaluate the alternatives by his wisdom. Figure 1 shows the components of the method.

Figure 1. AHP methodology
Source: Own elaboration



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The components are the objective, that is the aim the decision maker wants to achieve; the criteria, that are attributes chosen by the decision maker to rate the alternatives; and the alternatives, which are possible solutions for the decision making.

2. Fuzzy Logic

It is a methodology of artificial intelligence that enables the modeling of practical situations in which a description made by natural language includes some grade of uncertainty (Lahoz-Beltrá, 2004). The starting point to develop this method is the fuzzy sets, which are characterized by functions of membership that varies between 0 and 1. Figure 2 shows the fuzzy system.

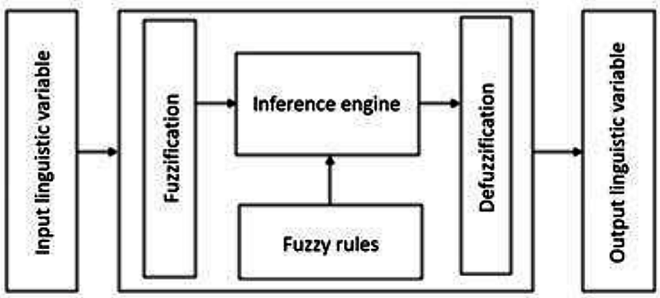
The elements of the diffuse system are the linguistic variables as inputs or outputs, they can take values of the natural language; fuzzification, a process that converts inputs into fuzzy sets; inference engine, which obtains an output based on fuzzy sets and fuzzy rules; fuzzy rules, which are of the if-then type; and defuzzification, that is, the process that converts the diffuse output of the inference engine into numerical information.

The methodology of this research is based on a hybrid model that involves the use of tools for decision making. First of all, the AHP tool can be determined to determine which region is most vulnerable, so that, afterwards, it becomes an entry for the Fuzzy method, which took into account more entries, seeking the allocation of the way efficient. Figure 3 shows the proposed model.

The criteria that were taken into account as entries in the AHP are shown below.

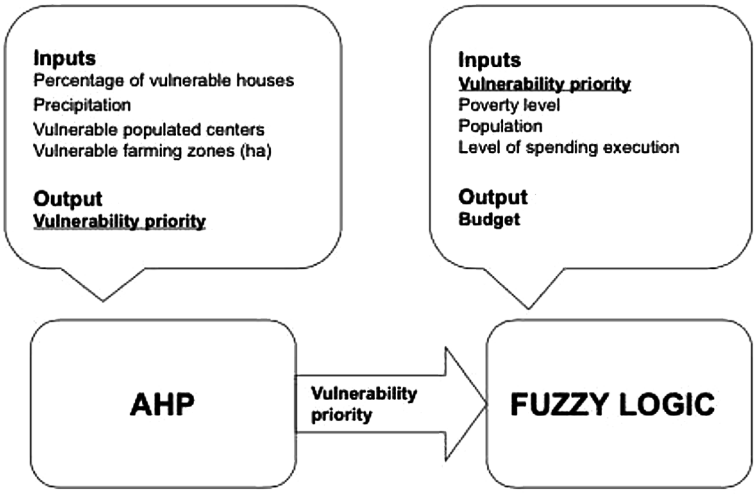
1. Percentage of vulnerable houses: It makes reference to the percentage of non-fine-material houses of each region (INEI,2014).
2. Precipitation: It refers to the quantity of liters of rain per square meter every month (SENAMHI, 2017).
3. Vulnerable populated centers: it is the quantity of vulnerable populated centers due to activation of streams (MINAGRI,2017).
4. Vulnerable farming zones (ha): Defined as the hectares of vulnerable farming zones of each region (Diario El Correo, 2017).

Figure 2. Fuzzy system
Source: Own elaboration



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Figure 3. Hybrid model
Source: Own elaboration



Once the criteria that would be used in the first tool were defined, a pair comparison table was made, in which a numerical score was taken into account to define the importance of each variable. Then, a criteria comparison table was made. Subsequently, the last table was normalized through the vertical sum and the respective divisions. Then, the priority of each criterion was obtained through the average of each row. Table 1 shows the normalization of criteria.

Then, a series of criteria comparison matrices were developed. In this table, each region was compared in terms of priority according to some criteria, such as percentages of vulnerable housing, etc. to identify the most vulnerable region according to its precipitation, population, among other variables and in this way, to make a table of priorities for each region.

Finally, a final priority classification of the vulnerability was obtained through some calculations. As a result, a degree of vulnerability was extracted as an output which was used as an input for fuzzy logic.

Table 1. Normalization of criteria

Normalization Matrix	Percentage of vulnerable houses	Precipitation	Vulnerable populated centers	Vulnerable farming zones (ha)	Priority
Percentage of vulnerable houses	0,11	0,12	0,07	0,19	0,12
Precipitation	0,54	0,60	0,66	0,44	0,56
Vulnerable populated centers	0,32	0,20	0,22	0,31	0,26
Vulnerable farming zones (ha)	0,04	0,09	0,04	0,06	0,06

Source: Own elaboration

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Then, a series of matrices of criteria comparison is done . In this table, each region will be compared in priority terms according to some criteria such as percentages of vulnerable houses, and so on.In this way, the most vulnerable region will be identified according to its precipitation, population, among other variables. Thereby, a priority table for each region will be elaborated (See table 2).

EXPERIMENTAL/NUMERICAL SETTING

Fuzzy

There are four entries that were considered in Fuzzy:

1. Priority of vulnerability, defined as the priority classification obtained from AHP.
2. Population, defined as the number of inhabitants of a region (MIMP, 2015).
3. Expenditure execution level, that is, the average percentage of the budget assigned to each regional government that has been used during 2015 and 2016 (Congreso de la República, 2017).
4. Level of poverty, referred to the percentage of inhabitants of a certain region that is in a situation of poverty or extreme poverty (Diario Gestión, 2014).

Similarly, there is an output which is the budget. It refers to the amount of money that the State has to distribute to each region to execute prevention projects in order to diminish the effects of El Niño Costero.

To obtain a result in Fuzzy it was necessary to establish some logic rules such as the following:

1. If population is low and poverty level is high then budget is high.
2. If population is low, poverty level is low, vulnerability priority is medium and level of spending execution is medium, then budget is medium.
3. If population is low, poverty level is low and vulnerability priority is medium, and level of spending execution is low, then budget is medium.

Table 2. Priority ranking

Region	Priority ranking
Ica	0,08
Lima	0,12
Ancash	0,09
La Libertad	0,13
Lambayeque	0,13
Piura	0,22
Tumbes	0,23

Source: Own elaboration

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4. If population is medium, poverty level is low, vulnerability priority is medium, and level of spending execution is low then budget is medium.
5. If population is low, poverty level is low, vulnerability priority is low, and level of spending execution is low, then budget is low.
6. If population is medium, poverty level is medium, vulnerability priority is medium and level of spending execution is medium, then budget is medium.
7. If population is high, poverty level is high, vulnerability priority is high, and level of spending execution is high, then budget is high.

Based on these rules and the values taken by the inputs for each region, it was possible to obtain the results on Fuzzy. An example of Piura region is shown in the figure 4.

Table 3 reflects the result for each region analyzed and shows the weight that each region must have within the budget of the central government.

Figure 4. Fuzzy results for the Piura region
Source: Own elaboration

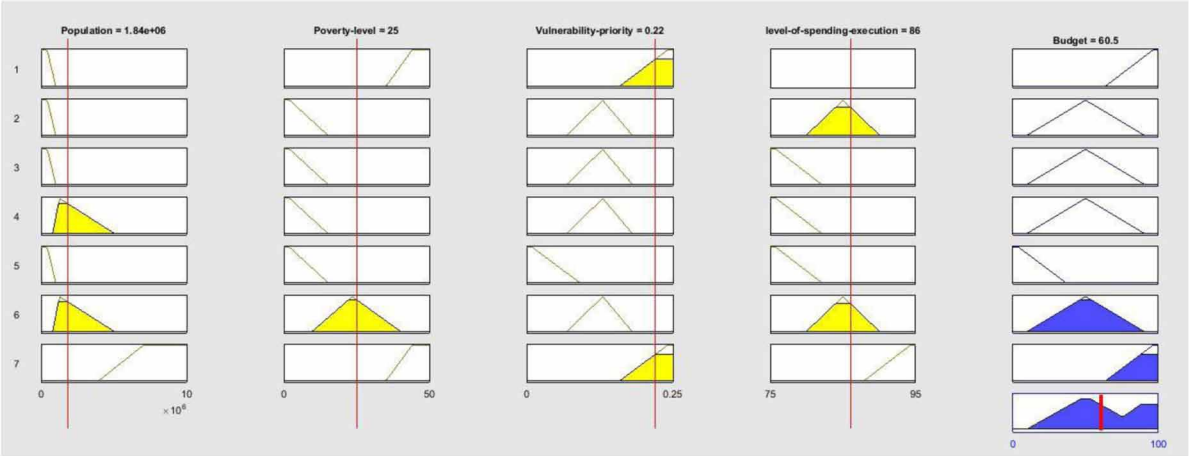


Table 3. Priority ranking

Region	Fuzzy results	Weighting within the budget
Piura	60,6	17.26%
Lima	60	17.08%
La Libertad	50	14.24%
Lambayeque	50	14.24%
Tumbes	49.4	14.07%
Ancash	42	11.96%
Ica	39.2	11.16%

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RESULTS AND DISCUSSION

As a first part of this analysis, through the AHP tool, the degree of vulnerability was obtained for each region. In this way, taking into account the numerical results, which are between 0 and 1, of the ranking given by AHP, it was possible to know that Tumbes is the most vulnerable region with a value of 0.23, followed by Piura (0.22), La Libertad (0.13), Lambayeque (0.13), Lima (0.12), Ancash (0.09) and Ica (0.08). These results were used in the second part of this study to distribute the budget for disaster prevention, which is our ultimate goal.

Then, once the results of the first analysis were obtained, the Fuzzy Logic tool was used considering other criteria necessary for budget allocation in each region, as well as some logical rules that were established. In this way, it was possible to know the percentage that each region should receive from the total budget for disaster prevention projects for 2018, representing an amount of 29,648,998 soles (MEF, 2017). On the other hand, it was determined that this classification was not the same as in the first analysis, because other variables were taken into account that, in some cases, have more weight than the degree of vulnerability. In this way, the results showed that Piura is the region that needs the most budget with a value of 5 115 971.75 soles, followed by Lima (5 065 318.56 soles), La Libertad (4 221 098.80 soles), Lambayeque (4 221 098.80 soles), Tumbes (4 170 445.62 soles), Ancash (3 545 723) and Ica (3 309 341.46). It should be noted that there were increases and decreases in relation to the budgets proposed by the government, which are represented as follows: an increase of 12.69% for the Lima region, 33.02% for the Piura region, 53.05% for Tumbes, a decrease of 11.76% for La Libertad, 7.81% for Lambayeque, 37.78% for Ancash and 6.04% for Ica.

CONCLUSION AND FUTURE RESEARCH

The occurrence of disasters worldwide is on the rise; Peru is no stranger to this situation. Recently, the coastal child showed up in Peru causing serious human and material losses. Given this context, it is necessary that a culture of prevention be accentuated in the population and that the authorities take the appropriate measures in order to be prepared and give a timely response to this type of situation. One aspect to consider for disaster preparedness is financing for prevention projects.

This study presents an analysis for the optimal allocation of the budget to regional prevention projects using AHP and Fuzzy. The structured analysis in this document contributes to better decision making by providing relevant information and can be used by different nations adapting it to their circumstances in this context of climate change and increase of disasters to assign the budget to their projects.

According to the analysis carried out, the regions of Lima, Piura and Tumbes should have received a larger budget (12.69%, 33.02%, 53.05% more, respectively) for the prevention of emergencies than the one granted by the government; they have greater needs, according to their level of poverty, population and vulnerability. Tumbes, despite obtaining the highest degree of vulnerability (0.23) proposed by AHP, decreases its position in the budget ranking, due to its small population of 237685 people and its low level of poverty (12.7%). These results evidenced the need to improve the allocation of budget for prevention projects in the country. Thanks to the proposed model it was possible to redistribute the budget for prevention projects taking into account the needs and capacities of each region, so that each of them receives the appropriate amount.

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