

DISTRIBUTION AND SUPPLY LOGISTICS

MARTIN STRAKA

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Distribution and Supply Logistics

By

Martin Straka

Cambridge Scholars Publishing



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Distribution and Supply Logistics

By Martin Straka

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Any meaningful activity or work that is a product of a mental or physical nature requires long-term effort and a large amount of time, not only from those directly involved, but the people around them must also give further, not less important support too.

That is why I would like to thank my family, my friends and all those who helped with the design and production of this book, especially my wife, my daughter and my son for their patience and mental support while I was writing this book.

This publication is dedicated to my family.

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“I do the very best I know how – the very best I can; I mean to keep going. If the end brings me out all right, what's said against me won't matter.”

Abraham Lincoln

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FOREWORD

Just as a company progressively undergoes various stages of development, development equally affects the spheres of trade, industry, transport, tourism and so on. At each stage of development, a company searches for the means to enhance and improve particular processes and activities to ensure they are implemented optimally. Whether it is the invention of the wheel, the engine, the telephone or their greater implementation in the lives of people, companies and businesses, it is all closely related to arranging the transport of people as well as goods, animals and things.

This monograph, *"Distribution and Supply Logistics",* seeks to draw attention to areas that form part of distribution logistics. It shows a number of methods that can be used in this area to solve specific problems and it points to the possibility of optimizing the cost, time, distance, use of vehicles and other criteria.

The impulse for the creation of this publication has come from a definite need for solutions to problems in distribution and supply. Since the field of distribution logistics is a broad science it is not possible to solve all the problems in a few pages of text, nor is it possible to offer a universal and comprehensive solution to eliminate the shortcomings identified.

What is logistics? What is distribution and supply? What is supply chain management? Which elements create the distribution and supply space? What rules need to be followed when designing distribution and supply systems? Which aspects affect storage design? Which information technologies are suitable for distribution and supply systems? What costs affect distribution and supply systems? How to manage inventories in warehouses? How to select a suitable location for building a warehouse? How to design efficient systems of distribution and supply? How to design logistics systems? How to use various methods to solve the problems of distribution and supply in practice?

These are just some of the questions explored in this book. In addition to providing theoretical analysis of the problems of distribution and supply, it practically demonstrates the many ways of using heuristics to solve specific tasks. It brings together eight case studies to investigate facets such as designing distribution systems, solving location problems,

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solving problems for the distribution and collection of goods, and inventory management solutions in particular companies. As such, it will appeal to students in the field of logistics, as well as logistics managers, designers and planners.

There are several rules about distribution and supply which illustrate the importance of them:

- Without distribution and supply, goods cannot exist on the market!
- Distribution and supply costs can comprise up to one third of the total cost of the goods!
- Distribution and supply form an integral whole!
- Distribution and supply exist throughout the world in various forms!

The ambition of this monograph is to show the most common problems addressed by distribution and supply logistics, to encapsulate them with concrete examples and to highlight the methods by which it is possible to achieve a solution to them. Definitions, terms, names and expressions used in the following text are the author's perspective on the particular subject matter from his long experience of work in science, education and practice in this area and they will probably, or certainly, provoke heated discussion by some interested readers. If the publication stimulates readers, whether in the positive or negative sense, I will be satisfied that it has met my expectations. As the whole world develops rapidly, so do the fields of logistics, supply and distribution and it is not possible to accept definitions, concepts and views in this area from a few decades ago or even from a few years ago as something fixed and stable. For this reason, I bring my own perspective into this area, which may be contrary in some cases to traditional views.

I hope that this monograph will contribute to the increased knowledge of workers, researchers and students from different disciplines or professional branches and it will be a guide to help them solve their specific problems and tasks in the field of distribution and supply logistics.

I wish you a pleasant journey through the field of logistics of distribution and supply.

The Author

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INTRODUCTION

Economic changes, alternation of periods of crisis (economic, social, moral) and periods of prosperity, the rapid development of technology, industry, business, rising energy costs and increased demands on products, product quality and services lead and force a company to continuously improve the quality and efficiency of production, the efficiency of distribution and of the activities related to it in order to optimize costs and profit with the maximum satisfaction of customer requirements. The goal is to find at least a 'minor' saving or savings that might mean survival for the company in difficult times and provide some competitive advantage relative to other competitors. Several years of experience in the practical solution of many problems in distribution logistics have been decisive in leading me to create an integrated work of logistics with a focus on distribution logistics.

Distribution and supply logistics, with its range of solutions, is focused on the following tasks:

- design of distribution and supply systems for industrial concerns and other companies,
- location and placement of companies, warehouses and distribution centres,
- storage and technical equipment,
- improving the efficiency and dimensioning the elements of distribution and supply systems,
- improving the efficiency of and the development of distribution plans and inventory management,
- selection and improving the efficiency of modern information and expert systems in the area of distribution and supply,
- defining distribution and supply routes.

Distribution, as a part of distribution logistics and supply, and as a part of supply logistics, makes contact with the real market; in other words it connects the end of the manufacturing process with the beginning of fulfilling consumer needs. Distribution additionally enables the needs of customers to be fulfilled. It is also a kind of link between the different

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parts of the world and it enables the connection of regions with a different culture.

For each solution area, distribution and supply logistics suitably combines and uses the necessary methodology, methods, processes and tools specific to the field of logistics but also methods from other fields. The variation of certain solutions in distribution and supply logistics clearly predetermines the use of methods based on the principle of a multi-criteria decision-making process and heuristic principles that are close to human behaviour.

The monograph is divided into four thematic parts:

- The first thematic area is dedicated to the methodological basis of distribution and supply logistics.
- The second thematic area is focused on support processes in distribution and supply logistics.
- The third thematic area introduces methods, models and tools of distribution and supply logistics.
- The final thematic area of the monograph is dedicated to specific applications of the method of logistics to solutions of problems, projects and reviews from the areas of distribution and supply logistics.

The case studies are records of an appropriate combination of creativity, logical thinking, experience and methods to reduce deficiencies and to achieve the defined objectives of tasks in distribution and supply logistics. For reasons of confidentiality, in some cases I have fictionalised the names of businesses where problems were solved and where approaches and methods of logistics were applied, however the approaches used in their solutions remain original.

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I.

THE METHODOLOGICAL BASIS OF DISTRIBUTION AND SUPPLY LOGISTICS

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CHAPTER ONE

THE POSITION OF DISTRIBUTION AND SUPPLY LOGISTICS IN THE LOGISTICS SYSTEM OF A COMPANY

What you will learn: In order to solve problems from the area of logistics, it is necessary to become familiar with the basic terms, classification and levels of logistics. This chapter addresses definitions and concepts in logistics in general, with a focus on distribution logistics. It refers to the elements which create distribution logistics. It defines flow, distribution function and distribution policy. It highlights the importance of storage, packaging and preparation of goods for loading and transport and it defines the basic chain which forms the distribution channel.

Basic terms: logistics, distribution, distribution channel, distribution system.

During the reign of the Byzantine Emperor Leontos VI (886 – 911) the term "logistics" began to be used for the first time. The Swiss General H. Jomini (1799 – 1869) used the term "logistics" as specific military terminology. He understood logistics as the science of moving and accommodating soldiers. At the beginning of the twentieth century, the term logistics entered use in the field of economics and in economic literature. At the beginning of the seventies, experts started to apply the theory of logistics in practical use. According to some authors, logistics can be understood as the branch of science which deals with comprehensive planning, management, implementation and control of material flows, creating the necessary material flows and information systems for material processing. Logistics is a summary of all activities for the comprehensive management and implementation of material flow in manufacturing processes and the circulation of goods (Viestova 1993, Straka 2004).

To achieve the highest performance while maximizing production efficiency, logistics defines or proposes actions on the strategic, tactical

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and operational levels that lead to achieving the required results using all the available means of science and technology, economics and computer science. Businesses try to reduce and minimize costs by applying a logistical approach to secure their competitiveness in the market.

The aim of logistics is to create a united, integrated, optimized material flow, which arises from different part0ts of the system in such a way as to ensure a continuous exchange of goods and services. Logistics has developed gradually and many definitions were also developed together with it (Table 1), at the same time, new perspectives on its scope and its level of activity are still being formed.

Table 1 – Definitions of logistics from the different points of view of many authors

Author	Year	Views of logistics
Council of Logistics Management[1]	1963	**Logistics** is the process of planning, management and implementation of the effective and powerful flow and storage of goods and related information from the point of origin to the point of consumption, the aim of which is to satisfy customer requirements.
J.L. Hesket, N.A. Glaskowsky, R.M. Ivie[2]	1973	**Logistics** is the management of all activities that facilitate the movement and coordination of supply and demand to create benefits of time and place.
Ch. Schulte[3]	1991	**Logistics** is the integrated, market-oriented planning, creation, implementation and control of flows of material, goods and information from suppliers to businesses, within businesses and from businesses to clients with optimal costs.
I. Gross[4]	1995	**Logistics** is the organization, planning, management and execution of flows of goods, starting with development and purchasing

[1] Council of Logistics Management, 1963
[2] Hesket, J.L., Glaskowsky, N.A., Ivie, R.M.: Business Logistics, 2nd edition, The Ronald Press Company, 1973
[3] Schulte, Ch.: Logistik, München, 1991
[4] Gros, I.: Logistics yes or not?, Logistika, Mesicnik Hospodarskych novin, No. 3, p. 58, 1995

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		through production and distribution depending on the final customer so that all market requirements are fulfilled at minimum cost and minimum capital expenditures.
D. Malindzak[5]	1996	**Logistics** is the means and philosophy of flow (material, information and financial) management, to which there are applied: a systematic approach, methods of planning, algorithmic thinking and coordination in order to achieve global optimization.
P. Pernica[6]	1998	**Logistics** is the discipline that addresses the overall optimization, coordination and synchronization of all activities in self-organizing systems, their combination is essential to achieve a flexible and cost-effective final (synergistic) effect.
Council of Supply Chain Management Professionals[7]	2005	**Logistics** is the process of planning, implementing and monitoring the efficiency and effectiveness of the direct and reverse flow and storage of raw materials, materials in processes, products and services, and related information between the point of origin and point of consumption in order to satisfy customer requirements.
R. Lenort[8]	2012	**Logistics** deals with the management of the entire supply chain, i.e. the chain with the initial link being primary suppliers of raw materials and the final link being the final consumers.
M. Straka[9]	2013	**Logistics** is a system in which there is an effect on elements in order to set up coordinated material, information and financial flows, resulting in, or aiming to,

[5] Malindzak, D.: Production logistics I, 1st ed., Stroffek, Kosice, 1996
[6] Pernica, P.: Logistický management, Radix Praha, Praha, 1998
[7] Council of Supply Chain Management Professionals (CSCMP), http://cscmp.org/aboutcscmp/definitions.asp, 2005
[8] Lenort, R.: Industrial logistics, 1st ed., p. 98, VSB-Technical university of Ostrava, Ostrava, 2012
[9] Straka, M.: Distribution logistics, 1st ed., p. 400, EPOS Bratislava, Bratislava, 2013

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		satisfy customer requirements, and the related economic effect.
Council of Supply Chain Management Professionals[10]	2013	**Logistics** is the process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements. This definition includes inbound, outbound, internal, and external movement.
APICS, © *APICS, Inc. All rights reserved* – the association for supply chain management[11]	2016	**Logistics –** 1) In the context of supply chain management this is the subset of supply chain management that controls the forward and reverse movement, handling, and storage of goods between the origin and distribution points. 2) In an industrial context, the art and science of obtaining, producing and distributing material and products in the proper place and in the proper quantities. 3) In a military sense (where it has greater usage), its meaning can also include the movement of personnel. © *APICS, Inc. All rights reserved.*

1.1 Logistics Divisions

In terms of the development of logistics over time, various streams have been and are still being created that understand Supply Chain Management (SCM) from their point of view (Larson et al. 2007).

From the *"traditionalist"* point of view (Figure 1a) logistics is considered to be a system of which a part or a special function is Supply

[10] Council of Supply Chain Management Professionals, Vitasek, K.: CSCMP Glossary, cscmp-glossary.pdf, Definitions compiled by Vitasek K, Available online: http://cscmp.org/imis0/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms.aspx?hkey=60879588–f65f–4ab5–8c4b–6878815ef921 (accessed on 05.jan.2018), 2013.

[11] Pittman, P.H., Atwater, J.B.: APICS Dictionary, © *APICS, Inc. All rights reserved*, The essential supply chain reference, 15th ed., p. 204, APICS Chicago, 2016

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Chain Management. SCM provides the link between suppliers and customers to ensure a business performance.

From the *"identicalist"* point of view (Figure 1b) logistics is identical to SCM. This direction perceives SCM as equivalent to logistics and it tends to cancel the term of logistics and fully replaces it with SCM.

From the *"unionist"* point of view (Figure 1c) logistics is part of Supply Chain Management. SCM arranges the purchase of raw materials for a company, logistics activities in the manufacturing process, sales, which includes marketing and advertising, product development and order fulfilment.

For protagonists of the philosophy of "conjunction", (Figure 1d) logistics and SCM are understood as two separate units which complement each other and they have separate as well as common parts.

All these philosophies have some common elements. All the philosophies work with flows (material, financial, monetary, etc.) and manage them in relation to the elements that make up the system.

Among the main organizations that also deal with terminology of SCM and logistics can be included APICS, CSCMP and ELA.

The American Production and Inventory Control Society[12] (APICS) is the association for supply chain management founded in 1952 by 20 production control managers.

The Council of Supply Chain Management Professionals[13] (CSCMP) is an association which has been covering logistics and SCM since 1963.

The European Logistics Association[14] (ELA) is a federation of 30 national organisations, covering almost every country in Central and Western Europe. ELA was founded in 1984.

In terms of market and enterprise it can be said that it does not matter what philosophy is applied, what is important is helping businesses gain a competitive advantage in the market, reducing costs, securing resources for running various businesses, securing consumers and correspondingly increasing profits.

[12] http://www.apics.org
[13] http://cscmp.org
[14] http://www.elalog.eu

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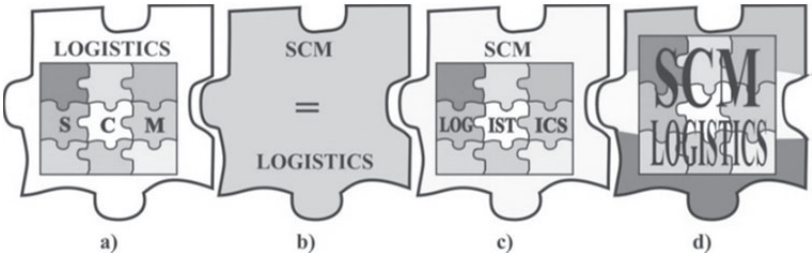


Figure 1 – The perception of "philosophical currents" of logistics and SCM

In terms of hierarchical levels and systems theory, logistics can be classified as (Figure 2):

- macrologistics (a business is an item in the logistics network, logistics chain),
- metalogistics (logistics at the level of a region),
- micrologistics (logistics of a business).

Under the term **macrologistics** it is possible to understand distinctive logistics at the supply chain level, where the elements are industrial concerns, other companies and the government, and the links between them represent materials, information and financial flows (Figure 2).

Under the term **metalogistics** it is possible to understand cooperation at different levels among micrologistics systems and regional specialized entities.

Under the term **micrologistics** it is possible to understand distinctive logistics at the level of an industrial concern or another company, the elements of which are the basic and supporting subsystems of the business (Figure 3).

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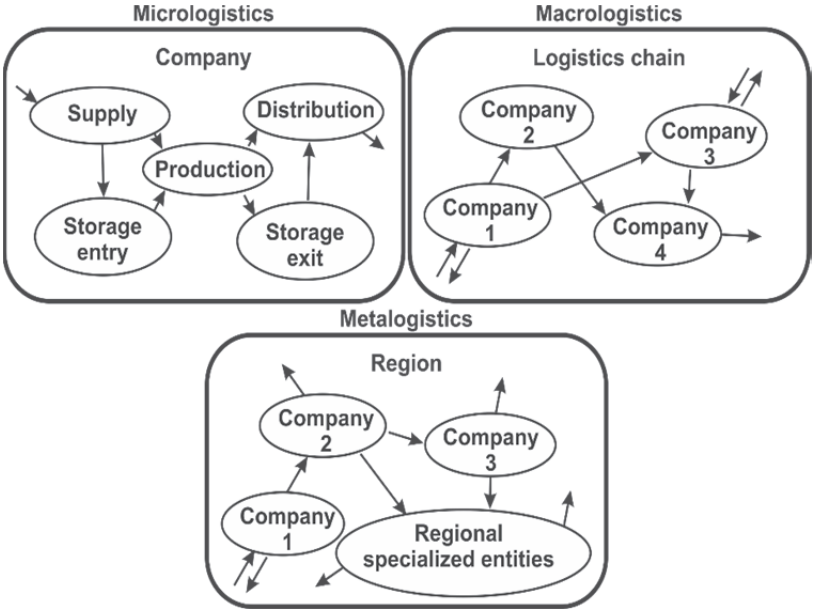


Figure 2 – Hierarchical levels of logistics

If we assume the micrologistics model of an industrial concern and consider a systemic approach, the logistics of a company can be divided in terms of sub-processes (Figure 3) (Straka 2012):

- purchase logistics,
- supply logistics,
- logistics of manufacturing,
- sales logistics,
- distribution logistics,
- strategy logistics,
- reverse logistics.
- logistics of service processes,
- logistics of orders,
- information logistics,
- logistics of finance,
- personnel logistics,
- business service,

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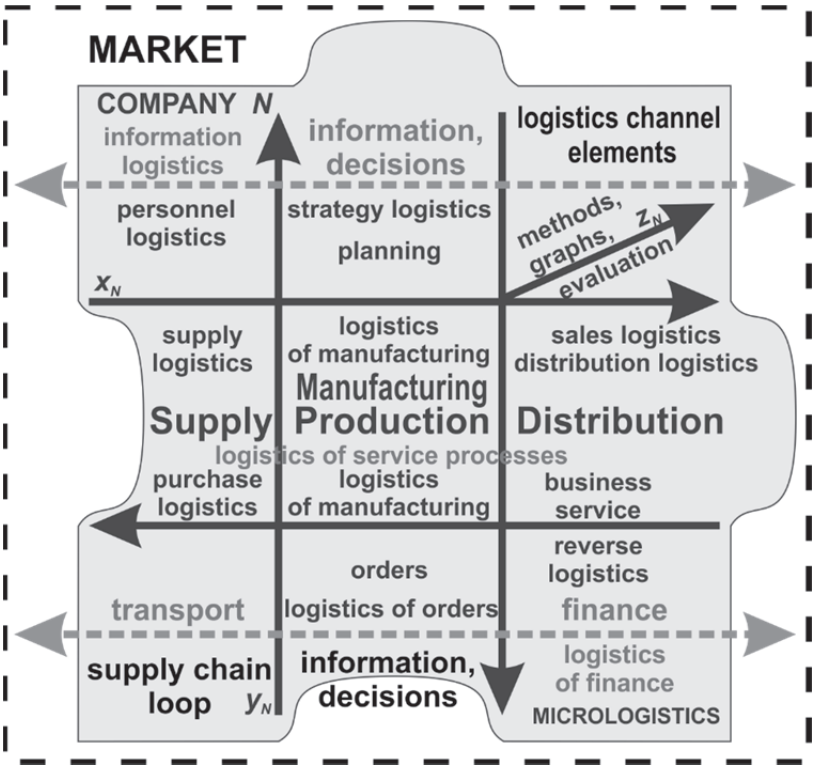


Figure 3 – Basic and supporting parts of the micrologistics model of a company

1.2 Distribution and Supply Logistics

Distribution logistics provides physical, organizational and informational links between the source (the output warehouse of a manufacturing enterprise) and consumers, the input warehouse or point of acceptance (Straka 2007).

Distribution logistics (Table 2) can be understood as the subsystem of logistics, where elements are the means of storing and packaging, the product, the service personnel and the links among the elements providing management of means of transport, information and financial flows related to distribution.

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Table 2 – Definitions of distribution logistics from the different points of view from many authors

Author	Year	Views of distribution logistics
G.B. Ihde[15]	1978	**Distribution logistics** deals with problems relating to time and spatial bridged transfers of real goods and among the systems of division of labour.
Ch. Schulte[16]	1991	**Distribution logistics** is responsible for all storing and transport movements of goods to consumers and related information, management and control activities.
M. Straka[17]	2004	**Distribution logistics** has to ensure the most appropriate manner, selection and analysis of transport most suitable for transfer of products manufactured by producers to achieve the failure-free operation of the market.
DHL Logbook[18]	2008	**Distribution logistics** includes all activities related to the provision of finished goods and products to the customer. These products may be shipped directly from the manufacturing process or dispatch warehouse to a space for further processing or, where appropriate, through other regional distribution warehouses.
M. Straka[19]	2013	**Distribution logistics** has to ensure the most appropriate manner of analysis, selection and implementation of all activities and strategic and other decisions related to the provision of products to a customer so as to achieve the failure-free operation of the market.

[15] Ihde, G.B.: Distributions Logistik, Gustav Fisher Verlag Stuttgart, New York, 1978
[16] Schulte, Ch.: Logistik, München, 1991
[17] Straka, M.: Contribution to the modelling of problems in distribution logistics, TU of Kosice, 2004
[18] DHL Logbook: http://www.dhldiscoverlogistics.com/cms/en/course/processes/distribution_logistics/definition.jsp, 2012
[19] Straka, M.: Distribution logistics, 1st ed., p. 400, EPOS Bratislava, Bratislava, 2013

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Supply logistics exists in synergy and direct connection with distribution logistics. The distribution logistics of a company exist in direct connection with the supply logistics of a company; supply logistics is viewed from the side of the recipient. **Supply logistics** aims to ensure the most appropriate method of analysis, selection and implementation of all activities, strategic and other decisions related to the provision of materials, and intermediate products to the recipient so as to achieve the failure-free operation of the subsequent production, sales and marketing activities.

Distribution and supply logistics provides a summary of logistical tasks and steps related to the preparation and implementation of distribution and supply. The use of distribution and supply logistics in an industrial concern depends on factors such as the manufacturing program, the spatial distribution of production, the positions and elements with the highest demand, the positions and elements with the highest supply, the structure of the distribution centres, the transport available (the transport fleet, the quality of the transport network) and the time of distribution and supply.

Distribution and supply logistics addresses the solution of problems in the following areas:

- the choice of the location of warehouses (storage location),
- the storage of goods,
- managing the packaging of products,
- issuing goods and provisions for loading,
- the transportation of goods.

At the strategic level, distribution logistics (Figure 4) addresses how to define the topology of the distribution system of a business, the system of distribution networks, selection of the location of the distribution elements, design of the distribution region, topology of the distribution system, proposal for distribution policy. These decisions have long-term effects and are of high importance. At the strategic level, decisions are made about the composition of the entire distribution system. Here there are decisions about the location of warehouses, the choice of means of transport and the definitions of how to process orders. The strategic level gives form to the entire distribution system.

At the tactical level, decisions are implemented about the use of resources, the construction of warehouses, the equipment, the necessary equipment for handling materials, and the specific type of vehicles. This level determines the effective use of the facilities that are available.

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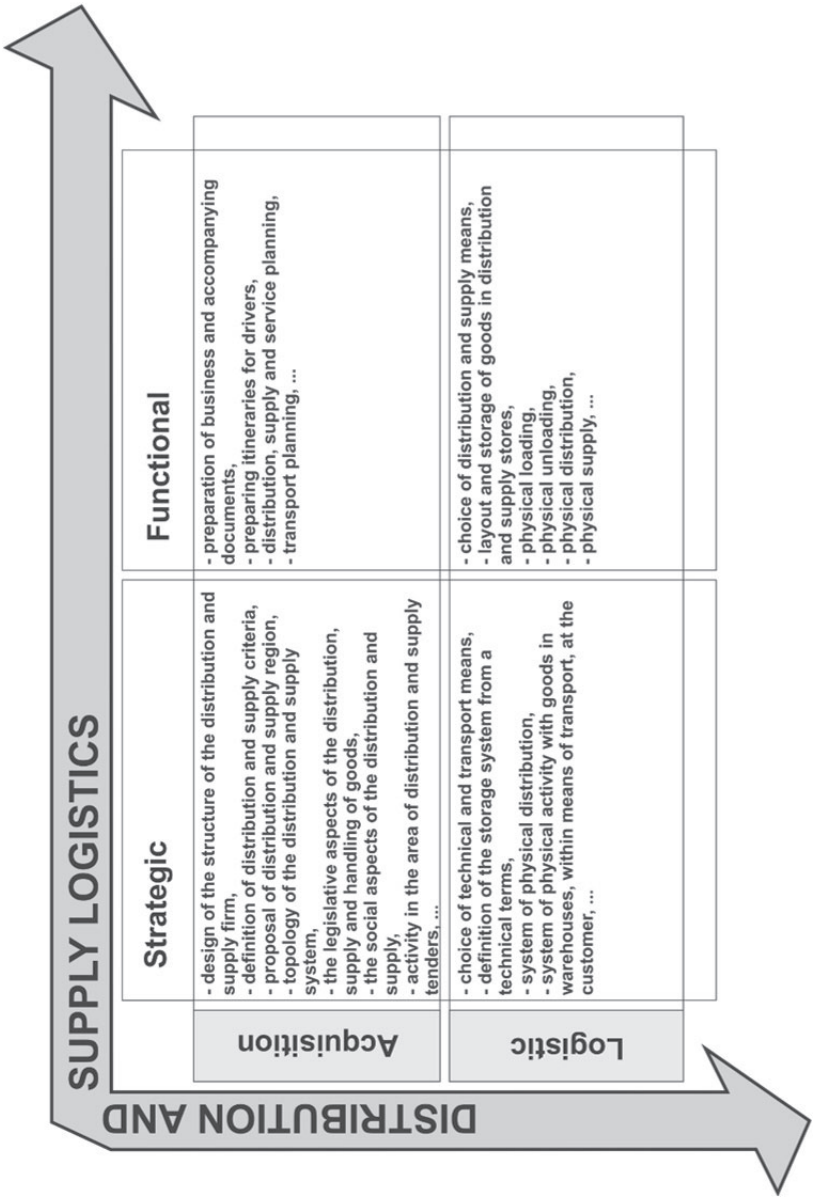


Figure 4 – Distribution and supply logistics and its targets

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At the functional, operational level, implementation of distribution is arranged in a defined distribution network in a distribution region, with distribution management, storage, management of packaging, the output and loading of goods, transportation.

Distribution logistics, in terms of macrologistics, ensures physical links between subjects of the logistics network and logistics chains.

Distribution logistics answers the following questions (Straka, Malindzak et al. 2005):

Where are the resources? Where are the customers? Where are the warehouses and what kinds of them are there? What kinds of warehousing and distribution systems will be used? What means of transport should be used for distribution? What will the criteria for the evaluation of distribution be? Where are stocks and what kinds of them are there? Where should the distribution centres, site, plant be located? Etc.

1.2.1 Connections and Relations between the Concepts of Distribution and Supply Logistics

In the following chapters and sub-chapters, the reader will come across a number of terms and that is why the most frequent terms are described with their definitions and there is clear identification of the position in which they are structurally placed in terms of the clear inclusion of individual parts within distribution logistics (Figure 5).

The terms that are defined and used in this monograph (see Table 3) result from the scientific literature, from the established views of experts on the entity described, from the terms that are used by workers and operators in practice and from the own experience of the author when completing a number of projects in the field of distribution and supply logistics. Conceptually, distribution logistics, distribution and physical distribution and physical supply are totally different terms from this area, however a reader can get the impression that they are synonyms.

Distribution logistics is responsible for all the aspects related to the distribution and transport of goods, from the reception of goods at an output warehouse, through the preparation of documents, loading, arranging transport, warehouse location, selection of personnel in the area of distribution, route planning for distribution, etc.

Distribution provides a coordinated flow that may include items of a non-material character. Distribution does not address the location of warehouses, distribution and logistics centres. The location of warehouses, distribution and logistics centres is addressed by distribution logistics at the strategic level.

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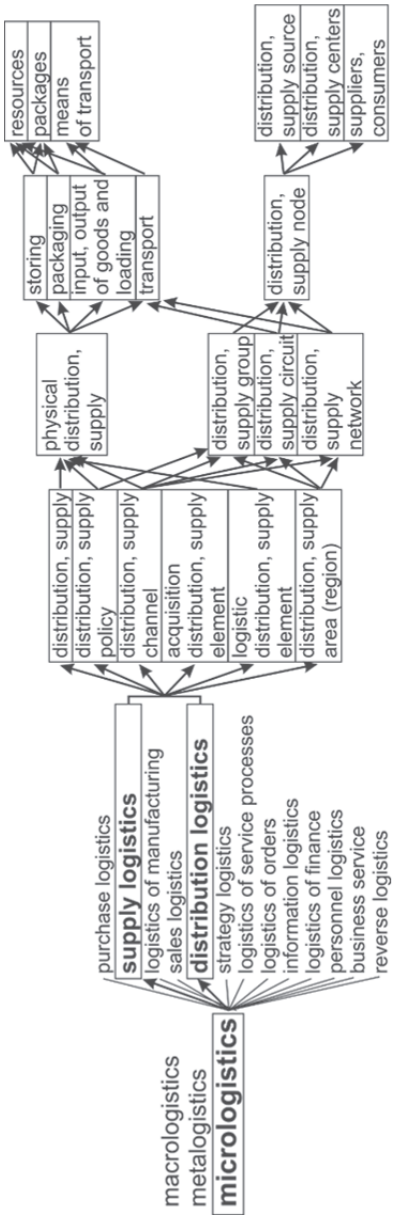


Figure 5 – Terms in distribution logistics, supply logistics and their interconnection

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According to the APICS Dictionary[20] **distribution** means *"1) The activities associated with the movement of material, usually finished goods or service parts, from the manufacturer to the customer. These activities encompass the functions of transportation, warehousing, inventory control, material handling, order administration, site and location analysis, industrial packaging, data processing, and the communications network necessary for effective management. It includes all activities related to physical distribution, as well as the return of goods to the manufacturer. In many cases, this movement is made through one or more levels of field warehouses. Syn: physical distribution. 2) The systematic division of a whole into discrete parts having distinctive characteristics."* *© APICS, Inc. All rights reserved.*

Physical distribution and physical supply tackle the question of the physical movement of particular goods, materials and products, their storage and order fulfilment.

Table 3 – The terms and their definitions, which occur most frequently in distribution and supply logistics

Term	Definition
Acquisition distribution item	**An acquisition distribution subsystem** is responsible for creating legal, economic, information and social relations among the participants of distribution, among whom there is movement of goods.
Consumer	**A consumer** is an element of the distribution network, where there is accumulation and subsequent consumption of goods. The consumer can generate material, raw materials and waste which is the subject of reverse logistics.
Distribution	**Distribution** is the process whereby goods and products of a different nature and character are arranged in such a way that there becomes a coordinated flow with the aim to satisfy the requirements of customers, consumers and users.

[20] Pittman, P.H., Atwater, J.B.: APICS Dictionary, *© APICS, Inc. All rights reserved*, The essential supply chain reference, 15th ed., p. 204, APICS Chicago, 2016

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Distribution area (region)	**A distribution area** consists of a finite number of elements affecting the specific functionality of distribution and which influence each other. **A distribution area** is a limited distribution space – a region which includes all the distribution places, means of transport, the distribution network and their mutual relations.
Distribution centre	**A distribution centre** is an element of the distribution network where an accumulation of goods takes place and subsequently controlled distribution is carried out from this place to consumer markets.
Distribution channel	**A distribution channel** is a set of items which create flows of real, material and information products.
Distribution circuit	**A distribution circuit** is a connection of such distribution nodes which are operated by means of distribution from a single distribution point or distribution source, where a vehicle is capable (in terms of quantity of goods, maximum distribution range, maximum distribution time, capacity of the vehicle) to serve them in one trip.
Distribution group	**A distribution group** is an aggregation of distribution nodes which are created on the basis of defined criteria for the purpose of division of a distribution region into the smaller parts and sites of a structured distribution network.
Distribution logistics	**Distribution logistics** is about providing the best manner, analysis, choice and realisation of activities, strategy and other decisions related to supplying products to customers in order to achieve the failure-free functioning of the market. Distribution logistics is understood as a system.
Distribution network	**A distribution network** is the interconnection of elements of a distribution space by means of transport to meet customers' requirements.
Distribution node	**A distribution node** is a general term for distribution place, distribution source or distribution warehouse, involving the storage of goods, sorting, packaging, assortment, records and subsequent distribution.
Distribution policy	**Distribution policy** is the process of all strategic decisions, which have to be made in context with the route of a product or action from producers to final consumers or processors.

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Distribution source	**A distribution source** is the central element of a distribution network, in which the production of goods takes place and from where they are subsequently distributed to distribution centres or distribution points (a type of consumer).
Distribution system	**The distribution system** consists of particular selected modes of transport, service staff and the points that form the particular distribution network.
Logistics channel (logistics chain)	**The logistics chain or channel** is a set of items, arranged in such a way as to arrange the flow of material, information and finance required in terms of a specific aim.
Logistics distribution subsystem	**The logistics distribution subsystem** is focused on the spatial and time transmission of real goods through transportation and storage.
Means of transport	**Means of transport** are particular transport devices that are used for the actual performance of the given type of transport assigned to a particular type of goods.
Micrologistics	Under the term **micrologistics** it is possible to understand logistics at the distinguishing level of an industrial concern or a firm. Its elements are the basic and supporting subsystems of the enterprise.
Output of goods, loading	**Output of goods and loading** is the process, by which goods or services from production are physically issued and loaded onto a particular vehicle in compliance with all safety arrangements (internal and external) for personnel, equipment and loaded goods in order to deliver the goods to the customer in the correct type, number, location, quality and time.
Package	**A package** represents a product that is used to store, preserve and secure another product, in order to ensure the requirements of the user and to protect the product itself that is stored in it.
Packaging	**Packaging** is responsible for the preparation and completion of batches of goods based on orders into the required shipping units. **Packaging** is defined as the process in which there is physical placement of goods, products, objects, even animals and plants in containers made for that purpose, while maintaining the technical and safety arrangements for packaged goods.

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Physical distribution and physical supply	This involves the movement of goods and materials, storage and order fulfilment under **physical distribution and physical supply**.
Shared logistics	**Shared logistics** is a way of efficiently using logistics chain resources for several entities together. Supply, production and distribution facilities as well as services can be shared by several entities together in order to reduce overall costs.
Shared services	**Shared services** means consolidation of a company's back-office processes to form a spinout (or a separate "shared services" unit, to be run like a separate business), providing services to the parent company and, sometimes, to external customers. Shared services typically lower overall costs due to consolidation and may improve support as a result of better focus.[21]
Stocks	**Stocks** are materials, raw materials, semi-finished products or things and goods in a place that is precisely designed for this purpose and for a precisely specified purpose of use.
Storage	**Storage** is a process, the main task of which is to keep material, goods, products, raw materials over time with preparation of transport units according to customer requirements, production, possibilities of means of transport in order to ensure the continuity of material flows, to satisfy the demands of the market and the effectiveness of follow-up activities such as loading, unloading, transport, managing the distribution and preparation of accompanying documents.
Supply	**Supply** is the process of acquiring materials, goods, products and produce of a varying nature and character for the purpose of securing the functioning of production, trade or consumption.

[21] Council of Supply Chain Management Professionals, Vitasek, K.: CSCMP Glossary, cscmp-glossary.pdf, Definitions compiled by Vitasek K, Available online: http://cscmp.org/imis0/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms.aspx?hkey=60879588–f65f–4ab5–8c4b–6878815ef921 (accessed on 05.jan.2018), 2013.

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Supply logistics	**Supply logistics** has to ensure the most appropriate means of analysis, selection and implementation of all activities and strategic and other decisions related to the provision of materials, semi-finished products and products to the customer in a way to achieve failure-free operation of subsequent production, sales and marketing.
Transport	**Transport** means overcoming distance or changing the location of transported goods using a means of transport.

1.3 Distribution, Supply and its Functions

The term distribution is etymologically derived from the Latin word *distribuo, distribus, distribuni,* which means to distribute, to assign, to decompose, to sort, to integrate, but also from the word *distributis*, which means distributing or sorting goods.

The term supply is etymologically derived from the Latin word *supplere,* which means to fill up, to make full, to complete, but also from the French word *soupplier* or *suppléer*, which means to help, to fill up, to make full.

Distribution on one side of the chain forms a connection with supply on the other side of the chain. Distribution and supply are inseparable parts of a single chain. For this reason, if we are talking about distribution, we also talking about supply in the other part of the chain too.

In scientific spheres, one of the definitions of **distribution** which is very popular is *"the set of operations, by which goods or services, from production are given to the consumer or user with the right quantity, quality, price, place and time."* (Viestova 1993)

In terms of solving projects from the field of distribution, it is possible to define **distribution** as *"the process in which there are influences on goods and products of varying nature and character, in a manner so as to ensure coordinated flow with the aim of satisfying the requirements of customers, consumers and users."* (Straka 2013)

From an economic point of view, distribution performs two basic tasks:

- the role of value creation,
- the task of creating a balance between supply and demand (implementation of a flow between source and consumer).

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From these tasks there follow the basic, classical functions of distribution:

- purchasing products from a manufacturer, shipping and transporting goods from the point of manufacture to the point of consumption
- fractionation of products, the customer receives goods, which must meet his requirements,
- regrouping products, consisting of regrouping scattered parts of manufactured products.
- storing products in all parts of transitional distribution from the point of sale to customers.
- products offered at the point of sale,
- sales to consumers,
- additional activities and services such as delivery service of products, installation, product service, ensuring the customer is informed.

In terms of the flow implemented in space and time (Straka 2013), distribution functions can be divided as shown (Figure 6).

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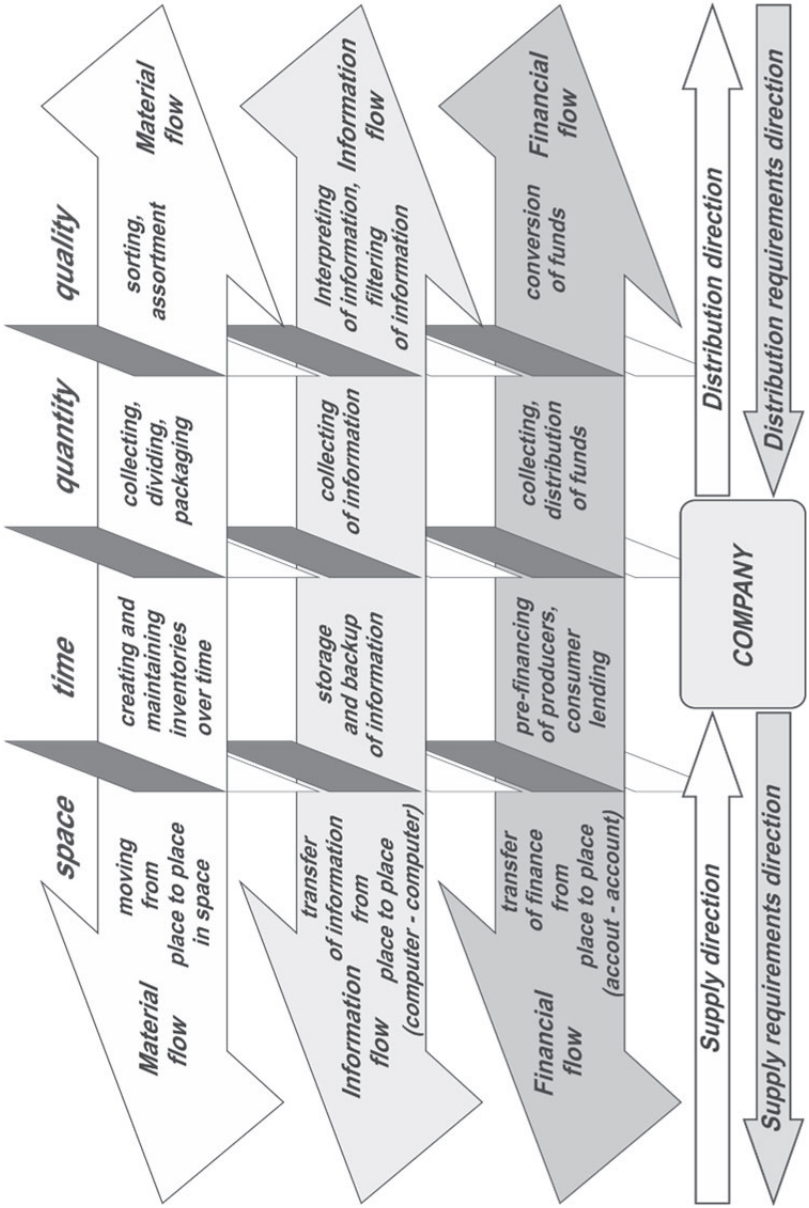


Figure 6 – Basic distribution and supply functions in terms of flows of products, information and finances

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Distribution entities, without which the implementation of distribution functions could not exist, are involved in a particular distribution of products. The basic distribution entities are the manufacturer and the consumer of products (Figure 7). Optional, facultative distribution subjects are distributive procurers and distribution assistants, who serve various supporting functions in the distribution process.

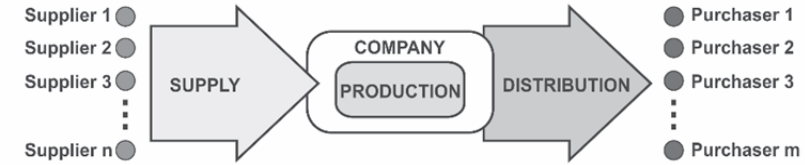


Figure 7 – The flow of raw materials – supply, products flow – distribution

Implementation of these basic distribution functions is performed by various manufacturing companies, trading companies, advertising agencies, banks, and other distribution companies.

The aim of the distribution is to arrange the transport of goods and services so that transportation is fast, reliable and efficient and it leads to an increase of profits. For the distribution to be at all justified there has to be a flow of raw materials, semi-products, products, equipment, etc.

> *"**Flow** is a moving and changing entity that alters its parameters in space and time. Flow arises as a potential difference."* (Malindzak, Takala 2005)

The cause of flow is potential difference (Figure 8) in our case the existence of a market of supply and demand ensures it. The existence of a potential difference of supply and demand causes a consequence, the need to satisfy the demands of the market through product distribution.

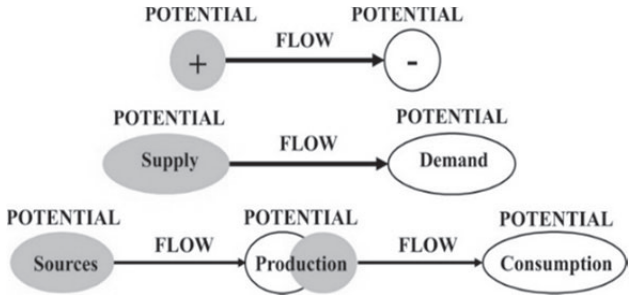


Figure 8 – The formation of flow as potential difference

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1.4 Distribution Policy

*"**Distribution policy** can be defined as the process of all the strategic decisions that must be made regarding the route of a product or action from producers to final consumers or processors."* (Weiss 1987)

Distribution policy is the foundation of the strategic part of distribution logistics. The aim of distribution policy is to correctly decide about how to make the product succeed in the market and to define the objective of achieving, maintaining, or increasing the market position of the company.

The task of distribution policy is to create optimal synergy between production and consumption. Strategic decisions in distribution policy are concerned with the choice of distribution channels, the various forms of wholesale and retail activities, purchasing organizations and service providers. Operational decisions in distribution policy are related to the solutions for the physical movement of goods, information and financial flows.

Distribution policy includes decisions on how to implement activities related to overcoming spatial, temporal, quantitative and qualitative differences that emerge between production and consumption.

1.5 Further Elements of Distribution Logistics

Other, no less important items of distribution logistics are distribution channels, acquisition and the logistics part of the system.

1.5.1 Distribution Channels

Characteristics of the distribution channels or chain (Figure 9) and their perception evolve over time and they can be described using several different views.

According to the APICS Dictionary[22] ***distribution channel*** means

"The distribution route, from raw materials through consumption, along which products travel." © APICS, Inc. All rights reserved.

According to the traditional view a

[22] Pittman, P.H., Atwater, J.B.: APICS Dictionary, © *APICS, Inc. All rights reserved*, The essential supply chain reference, 15th ed., p. 204, APICS Chicago, 2016

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*"**distribution channel** is a connection of producers, procurers and consumers, without the inclusion of institutions, which carries some specific features, such as market research, advertising etc. in a market economy."* (Viestova 1993)

These activities do not therefore directly perform the transfer of a product or ownership from a manufacturer to a customer, but they help to make the distribution process more fluent as ancillary activities.

*"The systemic view understands the **distribution channel** as a set of items which create flows of real, material and information products."*

In all cases it is conspicuous that the distribution channel cannot be created without the existence of items that make up the logistics chain and are involved, by their operation, in its creation.

According to the Council of Supply Chain Management Professionals the

***"logistics channel** is the network of supply chain participants engaged in storage, handling, transfer, transportation, and communications functions that contribute to the efficient flow of goods."* (CSCMP Glossary 2013)

According to the Council of Supply Chain Management Professionals the

*"**supply chain is:** 1) starting with unprocessed raw materials and ending with the final customer using the finished goods, the supply chain links many companies together. 2) the material and informational interchanges in the logistical process stretching from acquisition of raw materials to delivery of finished products to the end user. All vendors, service providers and customers are links in the supply chain."* (CSCMP Glossary 2018)

Another variant of the supply chain is the demand chain.

*"**Demand chain** is another name for the supply chain, with emphasis on customer or end-user demand pulling materials and product through the chain. Demand chain management is the proactive compilation of requirements information regarding demand (i.e., customers, sales, marketing, finance) and the firm's capabilities from the supply side (i.e., operations and logistics management); the development of a consensus regarding the ability to match the requirements and capabilities; and the agreement upon a synthesized plan that can most effectively meet the customer requirements within the constraints imposed by supply chain capabilities. Demand planning systems are the systems that assist in the process of identifying, aggregating, and prioritizing, all sources of demand for the integrated supply chain of a product or service at the appropriate level, horizon and interval."* (CSCMP Glossary 2018)

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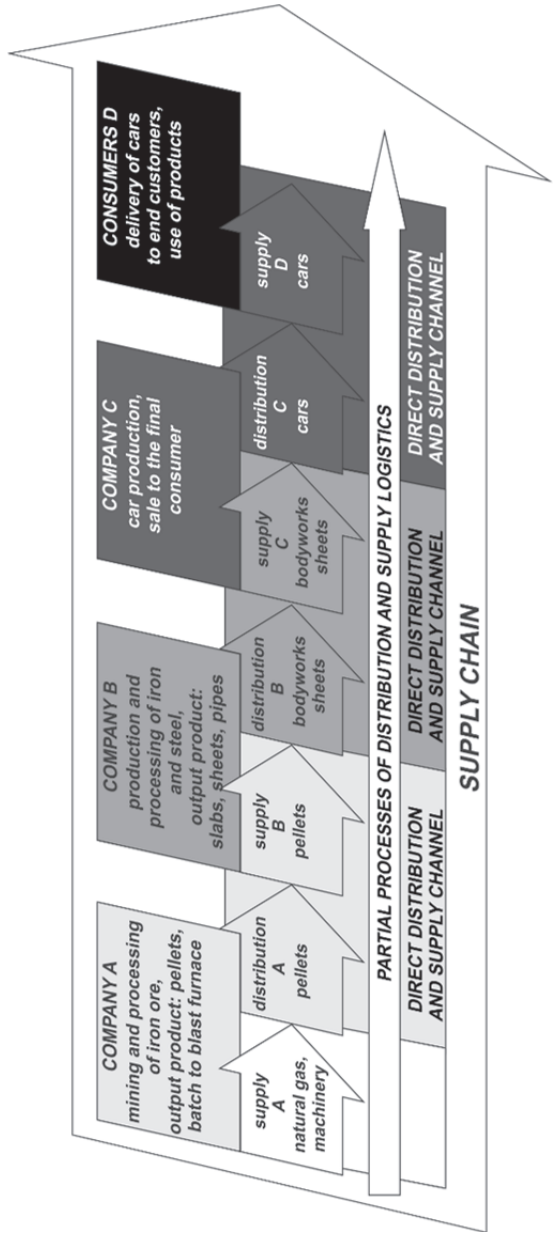


Figure 9 – A supply chain, partial processes, a distribution channel

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According to the APICS Dictionary[23] ***demand chain*** means,

"1) A demand chain is composed of the enterprises that sell a business's goods or services. 2) The supply chain as seen from the viewpoint of the customer, the entity who chooses among competing products and services and thus controls the demand."

Supply chain means,

"The global network used to deliver products and services from raw materials to end customers through an engineered flow of information, physical distribution, and cash." © APICS, Inc. All rights reserved.

Any decision at individual levels can cause improvement or deterioration of system operation. The impacts of decisions can have local effects on the overall operation of logistics systems, but may also seriously affect the whole system, positively or negatively. Many experts and scientific literature define and argue that ***"logistics is only one"*** and it is associated with securing the chain:

"purchase – production – sales", or *"supply – production – distribution"* (Straka et al. 2015).

All other activities are only for securing the activities of the main supply chain. Of course, without the support activities, the main supply chain would be unable to function effectively (Coyle et al. 2008). The impact of the elements of the micrologistics model of a business ensures the effective operation of the logistics channel (Figure 10).

Together with the development of technical equipment of distribution, gradually there is the development of logistics itself and distribution logistics and its parts. The perception of distribution only through the distribution channel is obsolete. In terms of the supply chain one has to perceive not only the distribution channel but also the other connections of suppliers and their customers at lower levels of the supply chain. Within these lower portions processes which are also parts of distribution logistics are implemented. It is possible to ensure the production of finished products and get them to the final customer only by interconnecting them. The supply chain is composed of sub-processes of distribution and supply, while ensuring the connection from suppliers of raw materials, through producers to final consumers.

[23] Pittman, P.H., Atwater, J.B.: APICS Dictionary, © *APICS, Inc. All rights reserved*, The essential supply chain reference, 15th ed., p. 204, APICS Chicago, 2016

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The functions of the distribution channel (Figure 11) can be divided into preparatory and implementation functions.

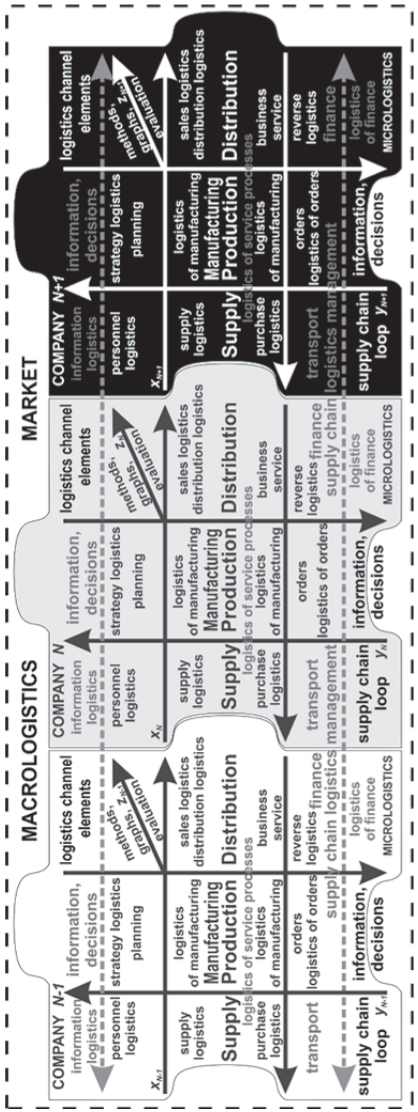


Figure 10 – System of micrologistics enterprise models – logistics channel – supply chain logistics management

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Preparatory functions have no direct impact on changing the owner of the goods, but without them implementation functions, market research, demand support, getting contacts, transformation, negotiation could not exist.

Implementation functions result in a change of owner of the specific products and enable the products to take part in the market, physical distribution, financing and risk-taking.

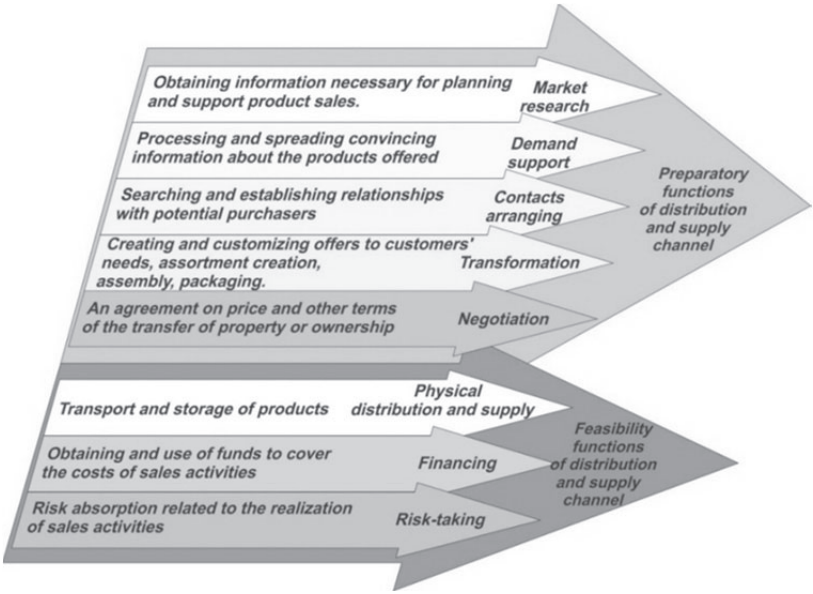


Figure 11 – Functions of the distribution channel

1.5.2 Acquisition and Logistics Distribution Subsystem

The implementation of distribution tasks includes:

a) producers with particular distribution functions,
b) distribution procurer, trade companies,
c) distribution assistants, transportation and storage companies, other supporting companies,
d) particular customers.

Depending on the interconnections among individual participants in distribution, there are two major functional subsystems of distribution:

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- the acquisition distribution subsystem,
- the logistics distribution subsystem.

The acquisition distribution subsystem is responsible for the creation of juridical, economic, information and social relations among the participants of distribution, between whom there is movement of goods. In this distribution subsystem there are ongoing decisions about the routes and the structure of distribution channels.

The logistics distribution subsystem is oriented towards the transmission in space and time of real goods including transport and storage.

Rather than running independently and separately, both systems run together and they have many common distribution parts. The entire distribution system reaches its maximum effectiveness only when both subsystems are synchronized, acting in concert in the distribution process.

1.6 Physical Distribution and Physical Supply

Physical distribution originally comprised only the distribution or movement of finished goods, semi-products, materials and everything that was destined for the market (Figure 12).

Physical distribution and physical supply include movement of goods and materials, storage and order fulfilment. Management of physical distribution and physical supply, in terms of implementation, is executed at the operational level.

Physical distribution and physical supply address tasks that are defined in terms of the daily performance of distribution and supply. This level ensures the execution of defined tasks that have been assigned for the successful performance of distribution and supply. For example, choosing the right product, packing, loading, the actual transport of the goods, loading and unloading (Straka 2007).

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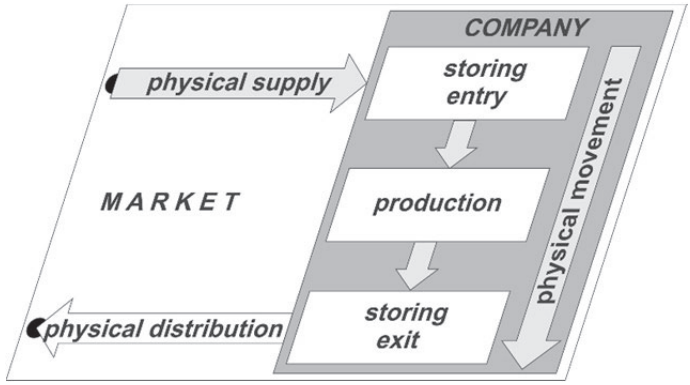


Figure 12 – Arrangement of physical distribution and physical supply

1.6.1 Storage

To run correctly, distribution needs to have on time, accurate and precisely prepared goods for distribution. The actual preparation of specific goods in the correct number is carried out in a warehouse. Storage gives answers to questions about inventory amount, storage cycle, warehouse equipment, warehouse size and the spatial arrangement of a warehouse, sorting goods in a warehouse and administrative organization (Straka 2004). Warehouse activities are defined in terms of a number of storage operations, which can be divided into three main parts, namely – input, receiving goods into the warehouse itself and issuing goods from the warehouse (Figure 13).

The input part – receipt of goods is responsible for the receipt of goods from suppliers and the preparation of goods for storage. This includes activities related to the unloading, identification and marking of goods, delivery inspection and preparation of goods for storage or possible transfer to storage containers or repackaging. Receipt has to be fast and accurate for the goods to be there in the shortest possible time.

Storage is the part responsible for the safe and economical keeping and sorting of goods received. In this section time passes for the stored goods. The handling of goods is of only secondary importance here from the time-based point of view.

The item preparation part is responsible for preparing the shipped quantities of goods as per the customer's order batches. If a product is delivered in small quantities and a customer demands bigger batches, it is necessary to prepare the needed quantity of goods and vice versa. If there

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is a request for a smaller quantity, it is necessary to perform the removal of the appropriate type of goods from the quantity stored.

The packaging section is responsible for collecting and assembling batches of goods according to prepared orders as per the required shipping units. The goods must be in packages that fulfil the protection requirements of the transported goods.

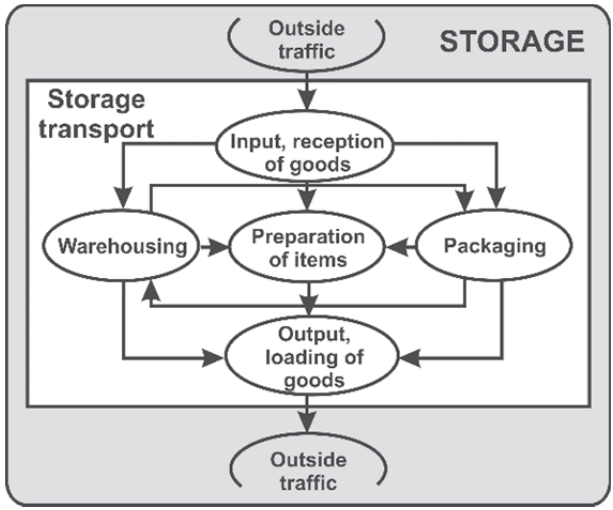


Figure 13 – Basic structure of storage

The output of goods section is responsible for getting the prepared goods to customers. Activities include receiving goods from the packing dept., correctly assigning goods to the proper recipient according to the goods identification and the specific loading of goods to the appropriate means of transport.

Warehouse management is responsible for managing storage and handling operations in the warehouse, it must know where and what kind of goods there are and, of course, what storage capacities are free or occupied.

The in-house transport part covers transport within the factory and transport processes within the warehouse as well as the transport processes on the production shop floors. In-house transport uses different means of transporting goods compared to external transport because of the short transport distances. Goods leaving the factory production line are usually

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placed in a warehouse of finished products, usually at the end of the production process.

1.6.2 Packaging

Packaging is defined as a process in which there is physical placement of goods, products, objects, even animals and plants into packages made for that purpose, maintaining technical and safety requirements for the packaged goods.

Before a customer comes into contact with the goods, he has to remove the package in which the goods are packaged. The **package** represents a product that is used to store, keep and safeguard another product by meeting the requirements determined based on the product itself which is stored in it.

Packaging can reveal a lot about the goods. If packaging is damaged, it is possible to determine whether the goods have been somehow inappropriately manipulated. Packaging fulfils the following functions (Spisak 2005):

- manufacturing functions,
- marketing functions,
- functions of multiple usages,
- logistics functions.

The manufacturing functions of packaging enable, based on the size of appropriate packaging, the production of appropriate quantities of goods directly into the packaging. This also can be applied vice versa, according to the size of packaged products it is possible to produce other products directly from the packing.

The marketing functions of packaging are related to the manufacturing policy of the company. It is possible to distinguish producers of goods depending on the types of packaging. Product packaging carries information about the product and the producer, it enables the use of packaging for promotional purposes.

The functions of multiple usages include the ability to recycle packaging or for it to be used again or with small adjustments. The possibility of using packaging for purposes other than those it was manufactured for is also included here, for example, large containers can be used, apart from in transportation, as replacement accommodation – an example from Africa. Plastic packing can be used to replace seals or insulation if appropriate.

Logistics functions include:

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- functions of protection,
- storage functions,
- transport functions,
- handling functions,
- information functions.

The most important logistics functions for packaging are the **functions of protection** of products. Packaging protects goods against damages, so that the intact goods reach their recipient. The protective function of packaging is that a product which has been placed in such packaging, does not cause damage to handling equipment, so packaging protects handling equipment too. Packaging should protect the goods against theft and also it should not cause damage to goods that are transported along with it.

The proper selection of packaging enables easier storage of goods and thereby fulfils the **storage functions**. Packaging must ensure that the contents remain inside, i.e. goods stored in the packaging. The dimensions of one package should be designed to occupy the smallest place for storage in warehouses. Packaging must be resistant to certain physicochemical and mechanical influences.

Packing must be designed so as to enable handling of goods in order to transfer goods from point A to point B. Packing should perform a **transport function** in its form and dimensions, so as to maximise the usage of space in the particular means of transport.

Products can be packed in such a way that they can be handled using standard equipment for handling, e.g. high-low fork-lift trucks, shelf stackers and others. Packaging must fulfil the **handling function**. With manual handling of goods, packaging must have certain properties that are useful for this kind of handling, for example: roughness of the packaging surface, use of a handle or handling holes.

The **information function** of packing is important to enable goods to be located and classified quickly. Packing should therefore be colour differentiated, should be marked with a sign giving information on how to handle a given product. Information on the packing should also give information about what should not be done with the given product inside the packaging or guidance about what to do in the event of damage to the packaging when a dangerous type of goods is inside. Barcodes on the packaging enable information about products to be obtained quickly upon the receipt of goods and also enable goods to be classified quickly.

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1.6.3 Output of Goods, Loading

Output and loading of goods are regularly repeating activities for a properly functioning company. **The output and loading of goods** are the processes by which goods or a service from the area of manufacturing is physically loaded onto a specific means of transport in compliance with all safety/security procedures (internal and external) for personnel, equipment and loaded goods in order to deliver the goods to the customer with the right type (assortment), quantity, place, quality and time.

The following factors can influence the output of goods, shipping of goods and loading:

- the particular goods,
- the location of the output zone,
- hardware,
- organisation.

The properties of the particular goods influence their output and loading as follows:

- their quality and state of completion,
- their shape, size, dimensions and weight,
- their sensitivity to transport (transporting a high explosive material is different to transporting milk),
- the quantity of the shipment,
- the time schedule of the shipment,
- the possibility of handling the goods,
- the performance of their output quality control,
- their packaging.

The output of goods and loading is influenced in terms of location by:

- the required floor space, space for loading,
- alignment of the loading zone,
- security structures in the output zone.

Hardware (technical equipment) influences the output of goods and loading in terms of:

- storage equipment,
- transport equipment and transport systems,
- controlling and measuring equipment.

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The organization in which the output of goods and loading is carried out influences it in terms of:

- the level of inclusion into its structure (different attitude from external company and internal employees),
- the definition of the exact procedure for output and loading,
- documenting the goods,
- the time needed or defined in organizational rules, determined by the standards for the correct performance of output and loading.

The final method for choosing loading operations is influenced by the specific requirements and properties of the goods and the quantity and type of available equipment that can be used for this activity.

1.6.4 Transport

Transport is one of the most important items in a logistics system. Transport has a major impact on the increase and decrease of logistics costs. The aim of transport is to overcome distances (Viestova 1993). More precisely defined – **transport is understood** as overcoming space or changing of the location of transported goods by means of transport. In terms of an industrial concern, transport can be divided into in-house and off-site.

In-house transport is transport within one particular industrial concern, from one place of manufacturing to another, which serves the continuous manufacturing process or also transport within a warehouse location.

Off-site transport is transport between companies or between different warehouses, or transport between the producer and customer.

The role of transport from the logistical point of view (Straka 2004):

- the choice of the most appropriate means of transport,
- the choice of the most appropriate transport process.

The means of transport is a transport device that is used for a specific transport process, designed for a particular type of goods. The choice of means of transport is affected mainly by the length of the journey the goods must travel, the type or kind of goods that are being carried and the space through which the goods together with the means of transport will move.

When implementing the distribution of goods in the market, it is necessary to distinguish manufacturing, distribution, freight forwarding and transportation companies (Kiss 2001).

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The manufacturing company (the manufacturer) is a company that manufactures products that is trying to succeed in the market through its own or other means of transport. The company is the owner in relation to the shipped goods; it does not need to own the means of transport.

The distribution company (the distributer) is a company that does not manufacture products or goods; it mainly arranges the purchase of goods from other companies that the distributer represents on the market and it is trying to succeed in the market through its own or other means of transport. The company can be owner in relation to the shipped goods, it does not need to own the means of transport.

The freight forwarding company (the forwarder) is a company that does not need to have its own transport fleet but from its database of transportation companies it selects the most suitable carriers to provide transport as well as the most appropriate method and combination. The forwarder dispatches a number of documents such as the customs declaration and prepares cover letters, delivery notes, etc. The company is not the owner of the shipped goods but it takes on the risks associated with the transport of goods and it is responsible for the selection of reliable transportation, it does not own the transported goods or the means of transport.

The transportation company (the carrier) has its own transport fleet which it uses to provide carriage of goods. The company as standard offers and provides one mode of transport. The company is not the owner of the shipped goods but it takes on the risks associated with the transport of goods, i.e. damage or loss of goods. It does not own the transported goods but it is owner of the means of transport.

The transport process is linked to the organization and management of transport operations.

The specific term in logistics is the logistics channel or chain. The logistics chain or channel (Straka 2004; Malindzak et al. 2007) is a set of items, arranged in such a way as to arrange the flow of material, information and finance required in terms of a specific aim. The logistics chain represents the flow of products from a particular raw material to a particular output within the company itself.

In terms of transport, the logistics chain can be characterized as **the transport chain**, i.e. as a sequence of interrelated technical and organizational actions carrying people or goods from one source to the destination (Lambert et al. 2000). The transport chain (TC) can be dissected into single and multi-element chains. A single-element chain means that the link from producer to consumer is without interruption of transport or is an instance of transport using a single means of transport. A

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multi-element chain means that the link from producer to consumer includes a change in the means of transport.

The transport chain:

- Single-element transport chain,
  - uninterrupted transport,
  - direct transport, without change of the means of transport.
- Multi-element transport chain,
  - interrupted transport,
  - combined transport, a change of the means of transport without a change of its content.

When choosing a suitable means of transport, we start from the applicable types of freight transport, which can be divided into five basic types (Bazala et al. 2006) road, rail, air, water and pipe-conveying (Figure 14).

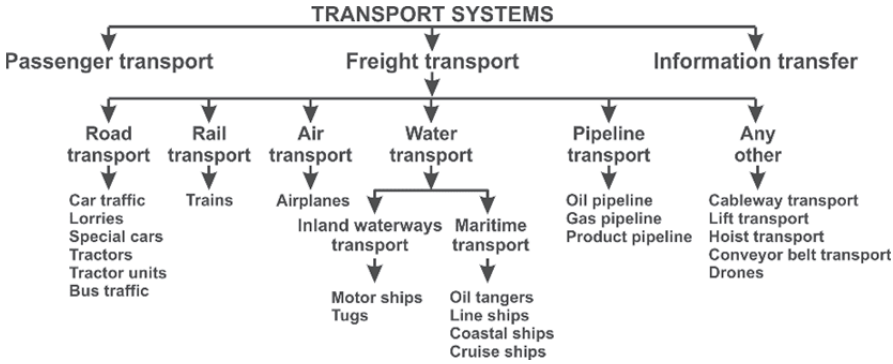


Figure 14 – Basic division of transport

Road transport is important for short-distance transport in comparison with rail, water and air transport. Road transport is advantageous in terms of flexibility and operability.

Advantages of road transport (Boroska, Saderova 2001):

- a dense network of roads has been built,
- possibility of home-delivery,
- high flexibility of transport,
- time saving,
- transport of special shipments,
- high universality.

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Disadvantages of road transport:

- it produces large amounts of exhaust gases,
- limited amount of goods for one vehicle,
- the impact of bad weather on transport,
- limited ability for loading,
- limited transport of oversized and dangerous goods.

Rail transport is a basic type of transport. It substantially contributed to the form of the technological revolution in the field of transport.

Advantages of rail transport:

- transport of heavier freight shipments compared to road transport,
- independent of the roads and traffic density,
- possibility of transport of dangerous goods,
- low failure rate.

Disadvantages of rail transport:

- confined by railways, limited manoeuvrability,
- confined by timetables,
- inability to deliver to home,
- low flexibility.

Air transport is suitable for the transportation of goods over long distances in a relatively short time. The actual time taken to cover the distance between two points is a fraction of the time needed for loading and unloading aircraft and particularly for arranging inspection and customs clearance.

Air freight transport is currently composed of the world fleet of cargo planes mostly Boeing B747, Airbus A330, 400 and Antonov and versions thereof (Straka 2013). These aeroplanes are used to transport cargo over a long distance (intercontinental transport).

More than 50% of goods are transported by dedicated cargo aircraft and the rest is done using mixed versions or utilizing free space in passenger aircraft.

Aircraft carrying air cargo are marked with one or two letters behind their version number to provide information about whether the aircraft is intended for mixed traffic passengers and goods, or just for cargo (up to which size it may be used). The mark of each version means:

F – Freighter (cargo);

AF – All freighters (whole cargo);

CF – Convertible freighter (convertible freight);

C – Convertible;

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QC – Quick change (full convertible);
QT – Quiet trader (full trader).

Advantages of air transport:
- high speed,
- the shortest time to cover distance compared to other modes of transport,
- relatively accurate departures and arrivals.

Disadvantages of air transport:
- high transport costs,
- long time to inspect goods at airports and long customs clearance,
- limits to the quantity and the types of goods transported.

Water transport is the main way of transporting mass bulk materials, which are not demanding in terms of transport time, but they are dependent on transport costs, e.g. the transportation of oil in large super tankers. Using containers in water transport increases cargo space, because it is possible economically to put containers on top of each other; they reduce the possibility of theft of goods, reduce the possibility of damage to goods and reduce the requirement for manpower.

Advantages of water transport:
- high load capacity,
- possibility to transport large quantities and oversized goods,
- acceptable transport costs,
- possibilities of using special ships.

Disadvantages of water transport:
- for inland transport, it is dependent on water flow, water quantity and direction,
- for marine transport, it is dependent on appropriate ports,
- impact of bad weather, storms, fogs,
- low speed of goods transport.

Pipe-conveying is transport, the trajectory of which is defined by the placement of the transport vessel. The transport vessel, in pipe-conveying, constitutes a route and a means of transport in one. It is used to transport liquid and gaseous products, crude oil, natural gas, water, chemicals.

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Advantages of pipe-conveying:

- used for continuous transport,
- high reliability,
- ecologically safe transport,
- self-protection against theft and damage to goods,
- when located under the ground it does not prevent other construction,
- low noise.

Disadvantages of pipe-conveying:

- high investment costs, return only after prolonged use,
- limited use for different types of goods.

Combined transport consists of all the available modes of transport. It can be possible to get a cheaper, faster and more affordable way of transporting goods by combining the modes, rather than by using only one type of transport. Combined transport combines all the characteristics and enables the transport of goods to any place on earth. The most common form of combined transport consists of a combination of road, rail, air and water in one transport chain.

Advantages of combined transport:

- use of all available modes of transport, depending on the type of transported material,
- an appropriate combination of transport can reduce the total transport costs.

Disadvantages of combined transport:

- increased time needed for reloading,
- tied to timetables for certain modes of traffic,
- waiting for reloading.

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CHAPTER TWO

CLASSIFICATION OF ITEMS OF THE DISTRIBUTION AND SUPPLY SPACE

What you will learn: The distribution space consists of a finite number of items which influence the functional side of distribution and they also influence each other. This chapter deals with the classification of the items of the distribution and supply space, defining types of one-way, basic and multi-level distribution networks and it also indicates the topology (location and relations) among the elements of the distribution space.

Basic terms: distribution network, items of the distribution and supply space, types of distribution networks.

For the explicit identification of the topic addressed it is necessary to define the basic area of distribution and the related subjects and objects of distribution.

2.1 Definition of the Items and Criteria of the Distribution Space

The structure of a distribution network is determined greatly by the items that comprise the distribution network, the distribution factors and well-chosen criteria. Distribution items and distribution factors can be divided into the following groups (Straka 2004):

- items and criteria defining the shape and size of the distribution and supply space,
- items and criteria influencing the topology of the distribution and supply network,
- items and criteria defining the performance (operation) of distribution and supply.

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2.1.1 Items and Criteria Defining the Shape and Size of the Distribution and Supply Space

For the analysis of the distribution space, it is necessary to know the spatial location of items of the distribution network in the distribution space i.e. the defining items, the structure of the distribution network, the structure of the infrastructure and the planning of distribution routes.

The distribution and supply space is a limited distribution area – a region which includes all distribution places, means of transport and distribution networks and their interconnections. The distribution space consists of all the items involved in the distribution process. The boundaries of the distribution space are formed by the boundary items of the distribution network (Straka 2004).

The distribution space is a part of the distribution system. The distribution system consists of specific selected transport modes, operating staff and the points that create a particular distribution network.

The basic items that create the distribution space can be divided into (Figure 15) a distribution source, distribution centres and consumers, which are linked by the means of transport and information transfer (Straka 2004).

The distribution source is the central item of the distribution network where the manufacturing of goods takes place prior to their subsequent distribution to distribution centres or to distribution places of the type: consumer.

The distribution centres are items of the distribution network, distribution hubs, in which goods accumulate and subsequently, controlled distribution to the points of consumption is implemented.

The consumers are items of the distribution network where goods accumulate and are subsequently consumed.

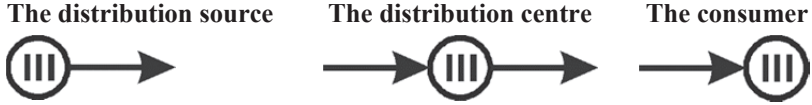


Figure 15 – Symbols of the distribution source, the distribution centre and the consumer

Combining the items of the distribution network creates the conditions for the formation of material, financial and information flows, i.e. operational distribution channels (Figure 16).

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The distribution channel is a set of entities that perform the flows of material and information products.



Figure 16 – Schematic representation of the distribution channel

If the work is limited to work with a map only, without the use of computer technology, it is possible to omit axes of places in the space. However, if it is necessary to analyse the distribution space and to define the optimal distribution network using computer technology, it is appropriate to define the location of distribution places in a form that is understandable for the computer. In this case, it is necessary to determine the axes of places in the space relative to a basic point, which does not have to be part of the distribution space. The values of the axes of distribution places in the x, y Cartesian system best describe positional information about distribution places in the space and they are the most suitable for computer work.

In order to define the image of the distribution space in the computer, the following basic data is required:

- the number of distribution places in the distribution space,
- axis data $[x_i, y_i]$ of distribution places to define their position in the distribution space relative to the origin, which is the starting point of the axis system,
- distances between the distribution places (ideal or real distances).

An ideal distance (Figure 17) is the shortest distance between two points, it is the distribution distance “as the crow flies”, or the shortest possible distance between two points that can be achieved using the selected means of transport. In some literature, the ideal distance is referred to as the optimal distance, which may not be the shortest direct distance “as the crow flies”, but the shortest possible distance given by the road and rail infrastructure.

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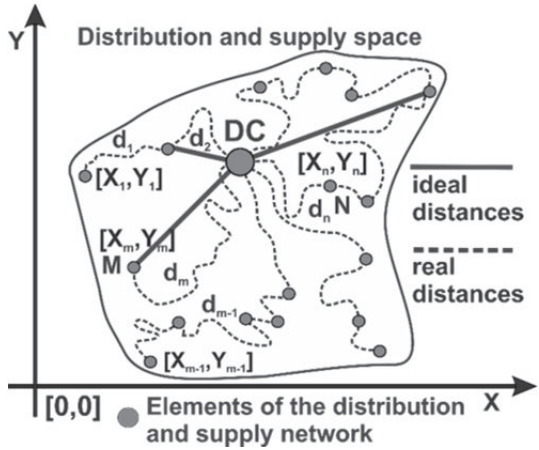


Figure 17 – Distances between distribution places copying the structure of the transport network

A real distance (Figure 17) is the distance between distribution places dependent on the structure of the road, rail, pipeline or waterway network which connects the distribution places. There may be multiple real distances if there are multiple ways to make the connection between the specified points. The real distance can be many times longer than the ideal distance. It is optimal when the lengths of ideal and real distances are the same.

Ideal distances are shorter than the real distances, so it is necessary to decide which distances to work with. The ideal distance between distribution places can be used when the distance between distribution places does not play a crucial role in defining the distribution network, when the real distances are unknown, when distribution between distribution places is done by air, or when the products being distributed are such that the speed of transport is not dependent on the distribution trajectory e.g. electricity.

If the task relates to the distribution of goods and services which are dependent on the distribution trajectory, it is advisable or needed to use data on the real distances between the distribution places. The real distance and velocity of distribution can also be expressed appropriately based on the time needed for distribution.

The logic connecting the distribution items to achieve the defined objectives of distribution using transport and information transfer is defined the basis of the distribution network.

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A distribution network (Figure 18) is a linkage of items of the distribution space through the means of distribution in order to satisfy consumer demand.

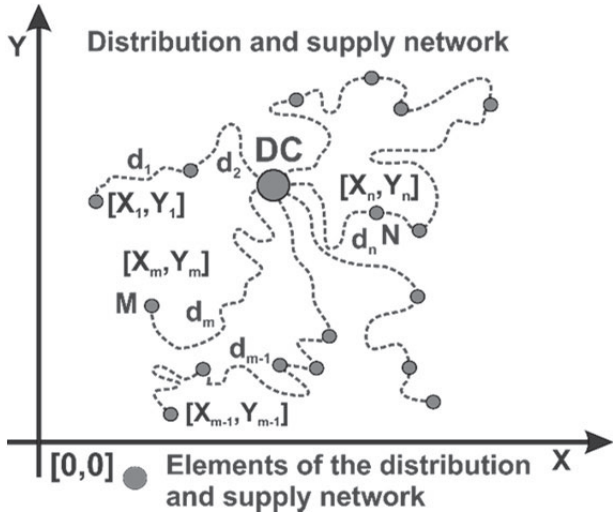


Figure 18 – The distribution and supply network and its items

2.1.2 Items and Criteria influencing the Topology of the Distribution and Supply Network

When defining the topology of the distribution network, it is necessary to know how topology is defined: "the subject of geometry studying the correlation of the position of geometric units".

The topology of the distribution and supply network means exploring the inter-relations and connections of the position of items in the distribution network they compose.

After definition of the distribution space, it is necessary to define the structure of the distribution network.

The shape and structure of the distribution and supply network is determined by the number and placement of distribution places and their inter-relations.

The criteria characterizing the distribution network are carriers of information which affects the shape and size of the distribution network. They can be divided into:

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- criteria which define the basic shape of the distribution network,
- additional criteria which are involved in the determination of the distribution source and the distribution centres, or that affect the performance of some distribution activities.

Proper selection and definition of criteria is the key condition for the proper definition of the distribution network because they affect the shape of the distribution network. The decision-making entity provides criteria selection.

2.1.2.1 Criteria defining the Basic Shape of the Distribution and Supply Network

The criteria that define the basic shape of the distribution network can be classified as:

- the location of the distribution source,
- the locations of distribution centres,
- the maximum time of distribution,
- the maximum length of the distribution trajectory,
- the priority of places in the distribution structure,
- the capacity of the means of transport.

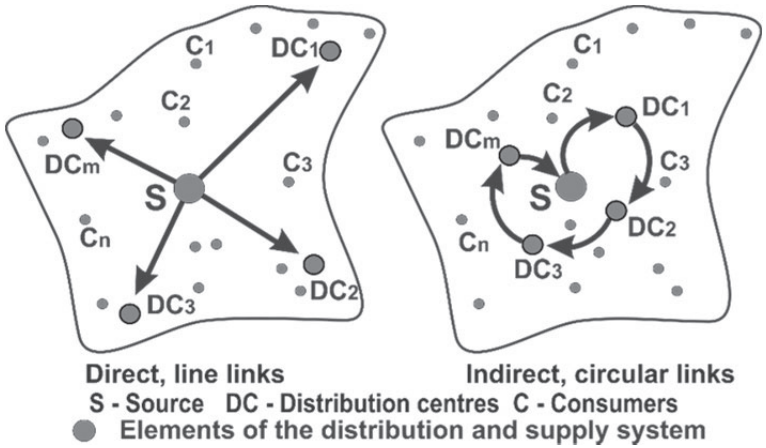


Figure 19 – Possible connections of the distribution source with distribution centres

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The Distribution Source

If the location of the distribution source within the distribution space is known, the first essential point of the distribution network is available, from which further connections to distribution places will be developed. It is assumed that the distribution source is determined by the activities of the distribution company.

The Distribution Centres

The predefined location of distribution centres has an influence on the shape of the distribution network. If the distribution centres are far from the distribution source, it is highly probable that the distribution routes between them will be limited to direct delivery of goods and not circular delivery. If the distribution centres are closer to the distribution source and the character of distribution activity and the capacity of the means of distribution enable it, then it is possible to plan circular delivery (Figure 19).

Maximum Time of Distribution

This limits the number of distribution places in a distribution circuit or in a distribution connection. The distribution source or distribution centres must be located in such a way for it to be possible to perform delivery and collection of goods to/from consumers forming a distribution circuit within the distribution time. If it is not, it is necessary to establish a new distribution centre, an intermediate store, so that distribution connections meet the time limit of distribution.

Maximum Length of the Distribution Route

When distribution is limited by the length of the distribution route, then one distribution circuit connection can include only distribution places, which can be operated within this length.

Priority of Places in the Distribution Structure

When solving distribution tasks, a situation can occur when it is required to prefer some distribution places within the distribution structure when selecting the distribution source, centre, warehouse or performing any operational administration task. This can be done by determining the importance of distribution places within the distribution network.

The Capacity of Means of Transport

The capacity of the means of transport is determined by its carrying-capacity, volume, in relation to the type of a vehicle. The capacity of the

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means of transport influences the shape of the network, due to its ability or inability to serve multiple distribution places in one distribution trip.

2.1.2.2 Additional Criteria that Influence the Choice of Distribution Stations

The criteria that influence the selection and location of the distribution source, the distribution centres and thus which are indirectly involved in the creation of the distribution network can include:

- quantity,
- price,
- time required for loading and unloading goods at the distribution source (S), distribution centres (DC), consumers (C),
- capacity of storage at S, DC, C,
- number of means of transport,
- average velocity of means of transport,
- flexibility of supply,
- equal numbers of distribution places in distribution groups,
- access to distribution places.

Quantity and Price

The criteria of quantity and price influence the definition of the number of distribution circuits and the definition of distribution places in particular distribution circuits and they also influence the selection of the distribution source, centres, warehouses or determine approaches to operational administration tasks (e.g. Cooper's iteration method).

Time required for Loading and Unloading of Goods

This criterion influences the size of distribution circuits, because if distribution is limited to the maximum distribution time it is necessary to subtract the time for loading and unloading goods at various distribution places. The overall distribution circuit will be shorter by the time required for loading and unloading so the criterion of maximum time is still fulfilled.

Capacity of Storage (Warehouses)

Capacity of storage particularly influences the frequency of supply according to the quantity to be brought in or out during a given period of time.

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Number of Means of Transport

The number of vehicles influences the overall distribution time in a distribution region and the frequency of supply.

Average Velocity

The criterion of average velocity of the means of transport shortens or prolongs the time of distribution, reduces or expands the distribution area or space and it acts as a factor in the fulfilment of the criteria of maximum time for distribution.

Flexibility of Supply

The criterion of flexibility of supply influences the determination and definition of the distribution source, centres, storage or operational administration tasks. Flexibility of supply is affected by the capacity of storage, the capacity of the means of transport, the number of means of transport and the amount of material that needs to be brought in or out within a certain time.

Equal Number of Distribution Places

The criterion of equal number of distribution places represented in the distribution circuits influences the total number of distribution circuits, but it does not influence the overall distribution structure or the type of distribution network.

Access to the Distribution Place

This influences the choice of the distribution source or distribution centre but not the type of distribution system or the manner of distribution. It is necessary that the distribution source and distribution centres have the best possible access to the means of distribution.

2.1.3 Items and Criteria defining the Performance (Operation) of Distribution and Supply

The criteria that define the distribution process itself can include (Straka 2007):

- the climatic and geographical character of the region,
- the current climatic conditions, the weather,
- the features and specifications of transported goods,
- the laws of the state or of the European Union.

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The climatic and geographical character of the region influences the choice of the means of distribution and thereby the actual manner of distribution. In mountainous conditions, the means of transport is by horse, mule or man. The distribution of products in Alaska will be performed using different means to the distribution of the same products in equatorial Africa, or Europe and America.

The current climatic conditions and the weather influence the performance of distribution and can prolong the performance of activities related to distribution.

The features and specifications of transported goods define the selection and use of the means of distribution and the method of storing and packing goods. The distribution of eggs, grenades and glass are performed differently, as is the loading of plates, screws and nails.

The laws of the state or of the European Union determine the conditions for the performance of the distribution and transport of goods, define the limits of the individual means of transport used and define the rules and conditions for the people involved in the distribution process. For example: to take regular driving breaks, to substitute drivers on long journeys, to keep the traffic rules and restrictions of distribution.

2.2 Classification of Distribution and Supply Networks

It is possible to get an idea of the distribution network which is characteristic for the distribution company by connecting the items involved in the distribution process in the order of execution of distribution (e.g. activities related to means of transport).

2.2.1 The Basic Types of Distribution and Supply Networks

If distribution of goods takes place in only one direction, either there is one common source, from which there are branches into smaller parts, or there are multiple basic sources which join into one trunk. Such a distribution network is known as a **one-way network** (Figure 20). A one-way network can be in the form of "a tree". One example of this is the distribution of water or gas to households, where a common distribution source branches into smaller branches, and then again to bring the product directly to individual recipients. The example of the opposite type of distribution is a sewer system, which starts with a large number of producers, which join into a large common distribution stream (Straka 2004).

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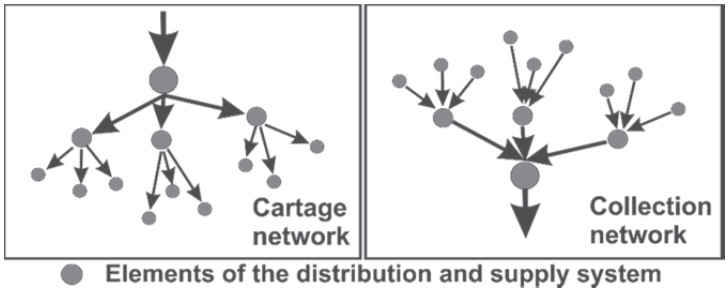


Figure 20 – Tree one-way networks, cartage type and collection type

Other types of distribution networks are dependent mainly on the type of transport and can be divided on that basis (Figure 21) (Straka 2004, Straka 2013):

- point distribution network,
- line – direct distribution network,
- line – indirect distribution network,
- distribution network of the star type,
- distribution network of the ring type,
- distribution network of the flower type.

A point network is specific in that there is no transport of products between producer and consumer, but the manufacture, sale and consumption of products is performed in one place (e.g. services, network of affiliated branches of massage salons, hairdressers, etc.). The distribution network is schematically represented by points without connection.

The line – direct network type is created by direct connections between a producer and a recipient.

The line – indirect network type is created by connections between a producer and few recipients, which are served by the same means of transport in the distribution process in such a way that start and finish of distribution are not in the same place.

The star type network is created by several recipients, or suppliers, which are supplied with (or from whom are collected) products from/to a common distribution centre – most often a warehouse or the operations site is used.

The ring type network is specific in that several distribution places are served in one distribution circuit in such a way that the means of

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transport starts and finishes distribution in the same initial distribution place.

The flower type network is specific in that supply to the distribution places is performed from a common distribution centre in such a way that the means of transport starts and finishes distribution in the same distribution place, but it is not possible to serve all the distribution places because of time, capacity, distance and other factors within one distribution round. There have to be least two distribution places in one distribution connection, otherwise the distribution network is of the star type. This sequential distribution to individual distribution places creates a distribution network of the flower type.

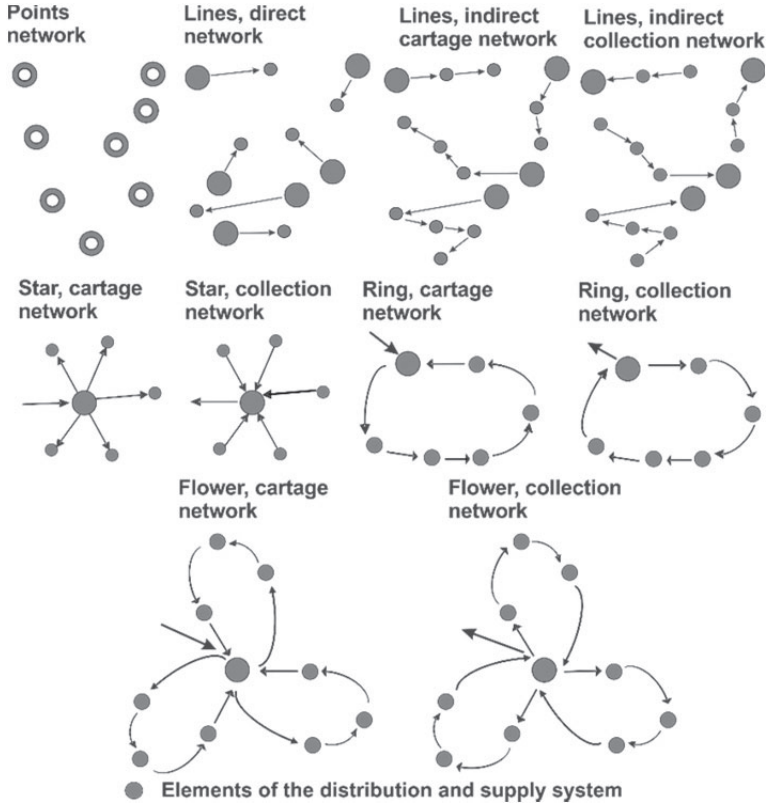


Figure 21 – Basic types of distribution and supply networks

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2.2.2 Complex Structures of Distribution and Supply Networks

If the process of distribution includes distribution places with linkage to distribution warehouses and the distribution centre, it is possible to define other types of distribution networks as a combination of lines, stars, rings and flowers. The particular structure of a distribution network is formed by the combination of the above types of distribution networks in the distribution process. The following types of distribution networks are created by their combinations (Figure 22).

Within these networks, parts can be focused on the distribution of goods, transport of goods or a combination, and on parts of the network that are only one-way. By combining and joining other items it is possible to create multi-level distribution networks (Straka 2004).

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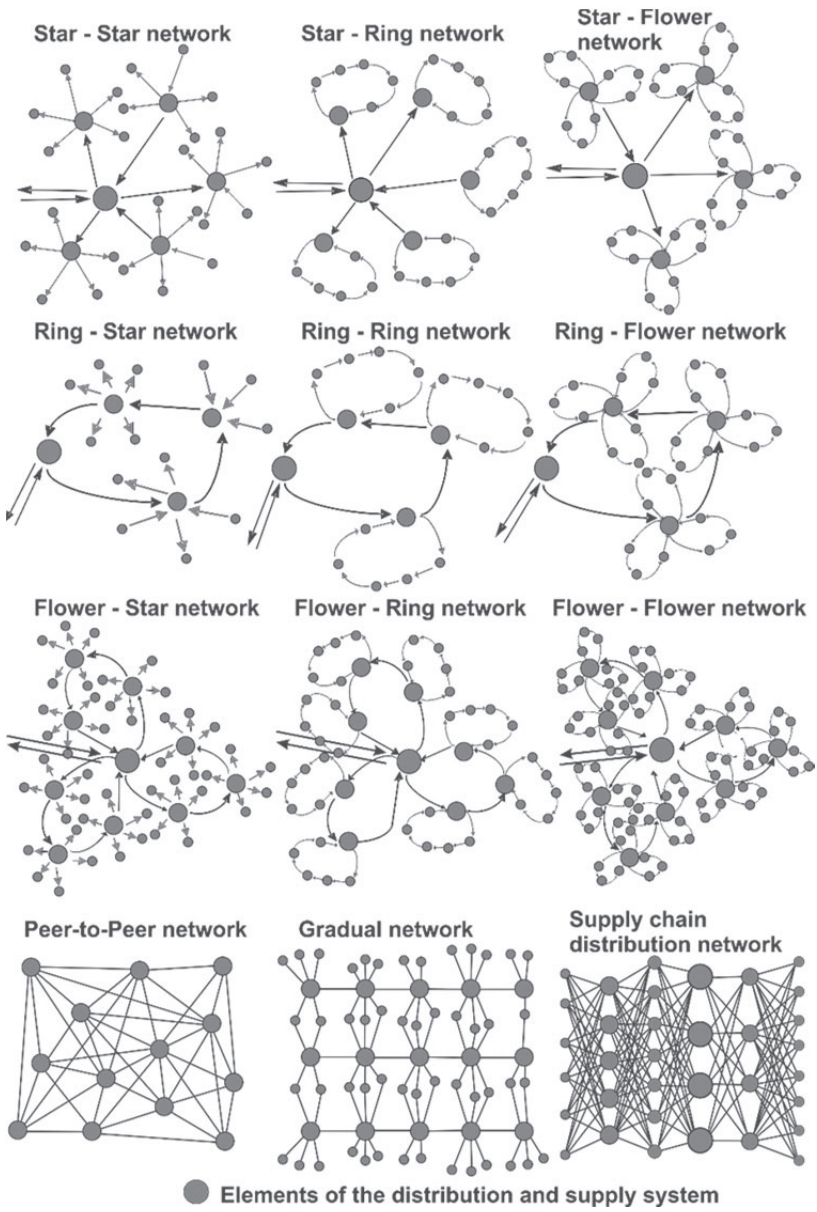


Figure 22 – Complex types of distribution and supply networks

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2.2.3 Linkages between the Items of Distribution and Supply Networks

In the solution of distribution tasks, the aim is to get the best overview of the distribution linkage between the distribution places. The distribution process involves a varying number of distribution places. The following types of linkages are created by their connection and by the provision of a type of distribution (Figure 23) (Straka 2005, Straka 2013):

1 – 1, **1 – 1 – 1**, **1 – 1 – m**, **1 – m**, **m – 1**, **m – n**, **1 – m – 1**, **m – 1 – n**.

The **1 – 1** (from one to one) linkage type means that there is a one-way connection between one distribution place at input and one distribution place at output. The connection can be one-way or cyclical.

The **1 – 1 – 1** (from one to one to one) linkage type means connection of partners in a logistics triad. This connection is typical for shared logistics or shared services. Shared logistics can exist in many variations, e.g. sharing of supply, production, distribution or services.

The **1 – 1 – m** (from one to one to many) linkage type means the connection of partners to logistic triads. This connection is the connection of several logistics triads and is typical for shared logistics too.

The **1 – m** (from one to many) linkage type represents the connection of one distribution place at input with *m* distribution places at output. E.g. the connection of a distribution warehouse with several customers, delivery of goods. The linkage can be one-way or cyclical.

The **m – 1** (from many to one) represents a connection of *m* distribution places at input and one output distribution place. E.g. the connection of several suppliers of semi-products to the place of completion or the collecting of goods at a distribution centre. The linkage can be one-way or cyclical.

The **m – n** (from many to many) linkage type is characteristic of the connection of *m* distribution places at input and *n* distribution places at output. This means the linkage of several terminals to their customers, the consumers. The connection can be one-way from any place to any customer, or cyclical.

The **1 – m – 1** (from one through many to one) linkage type represents the connection of one distribution place at input to one place at exit through multiple different distribution centres. This means the connection of one supplier to one end-user through many distribution places (e.g. water supply to wastewater treatment through individual households). Linkage can be one-way from one distribution source through a number of

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distribution centres to one end consumer, or cyclical connecting one input source and one exit point through common distribution centres.

The **m – 1 – n** (from many through one to many) linkage type represents the linkage of *m* places at input with *n* places at output through one common distribution centre. This could be the connection of many suppliers with their customers through one common distribution warehouse. The linkage can be one-way from each distribution place to a common distribution centre, or cyclical connecting several places at input and many places at output through a common distribution centre.

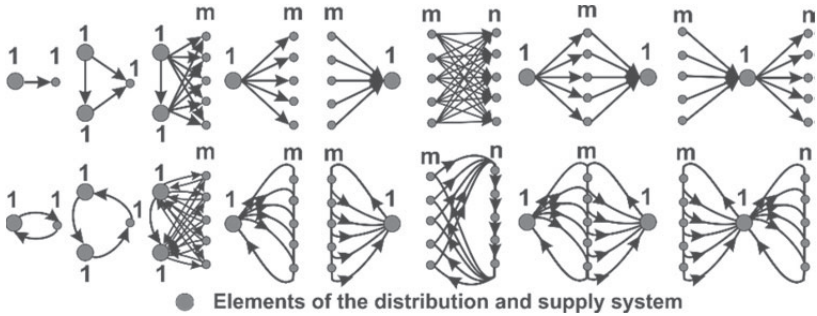


Figure 23 – Relations that arise in the distribution and supply processes

The basic step for the successful solution of distribution tasks and optimization in the distribution process is the proper definition of the linkage between the particular distribution places.

2.2.4 Static and Dynamic Distribution Networks

There are two types of distribution networks based on their dependence on the type of means of transport and the mode of distribution operation in practice:

- static distribution networks,
- dynamic distribution networks.

Static distribution networks are networks where the form of distribution, the mode and the character are not changeable over time. Examples of static distribution networks include oil, gas and water pipelines, gas and electric distribution networks and sewer networks.

Dynamic distribution networks are networks where the form of distribution, the mode and character are changeable over the time.

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Examples of dynamic distribution networks include the cartage of goods to order.

The shape of a static distribution network is determined by the shape of the distribution pipelines of the gas and water mains and the fixed distribution pipes or a static distribution network can also be created by fixed ongoing distribution e.g. regular deliveries of bakery products within a node.

The shape of the dynamic network changes as necessary. In dynamic networks dynamic planning of distribution routes according to needs of cartage of goods is very important. Dynamic networks are typical for courier companies where the route and a type of distribution system can vary from customer to customer.

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CHAPTER THREE

RULES OF DISTRIBUTION SYSTEM NODES

What you will learn: This chapter is devoted to summarizing certain rules that are valid in distribution logistics, starting from the known physical and mathematical laws, supplemented by the rules of logistics.

Basic terms: rules, distribution node, goods, quantity.

Activities in distribution logistics and the creation and behaviour of distribution systems can be defined by certain rules, which are based on basic physical principles and heuristics.

The quantity of goods which is distributed from a distribution source is taken by the gradual distribution from distribution warehouses to distribution points (places) or to an end consumer. Goods that are brought into the warehouse are divided and go to other endpoints. The quantity of goods which are located in different distribution warehouses, distribution hubs or which have been sold in a certain period gives an overview of the total production for that period. Kirchhoff's laws apply to a whole distribution network and the items which comprise it.

3.1 Rules of Keeping Quantities of Goods in Distribution Nodes

Distribution node is a general term for a distribution point, distribution source or distribution warehouse where storage, division, packaging, sorting, registration and subsequent distribution of goods are performed (Straka 2004).

Rule no. 1 (about keeping a quantity of goods at node "J"): The sum of the quantity of goods Mn_I entering distribution node *"J"* and the quantity of goods located at the node (quantity of goods at the node at the beginning Mn_S) is equal to the sum of the goods exiting from node Mn_O and the goods remaining at the distribution node (the quantity of goods at node Mn_E) (3.1) (Figure 24).

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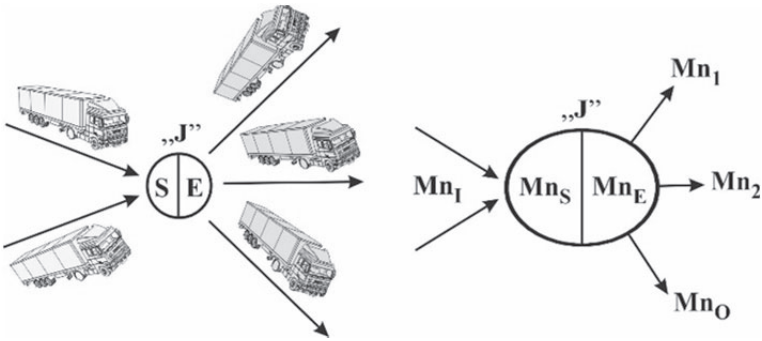


Figure 24 – Diagram representing the first distribution rule

$$\sum_{I=1}^{n} Mn_{I,J}(t) + Mn_{S,J}(t) = \sum_{O=1}^{m} Mn_{O,J}(t) + Mn_{E,J}(t) \quad (3.1)$$

$Mn_{I,J}(t)$ – the quantity of goods entering node *"J"* during period *t*,
$Mn_{O,J}(t)$ – the quantity of goods exiting node *"J"* during period *t*,
$Mn_{S,J}(t)$ – the quantity of goods located at node *"J"* at the beginning of period *t*,
$Mn_{E,J}(t)$ – the quantity of goods located at node *"J"* at the end of period *t*,
n – the number of inputs *I* into node *"J"*,
m – the number of outputs *O* from node *"J"*.

Rule no. 2 (about keeping a quantity of goods in the distribution network): The sum of the volume of goods at the output of the distribution source over a certain period of time Mn_{SOURCE} and the volume of inventories at distribution nodes at the beginning of this time period Mn_{SNODE} is equal to the sum of the volume of stock at the distribution nodes at the end of this time period Mn_{ENODE}, the number of goods sold from distribution nodes in the period of time $Mn_{SALENODE}$ and the quantity of goods located in the means of transport for distribution i.e. "on route" Mn_{WAY} (3.2) (Figure 25).

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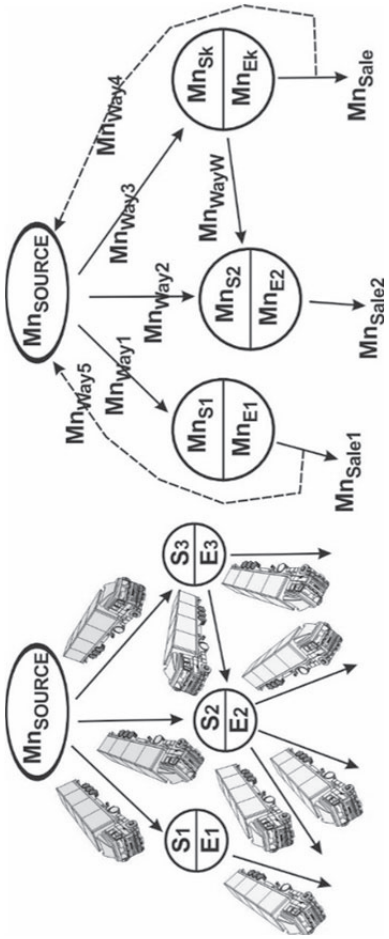


Figure 25 – Diagram representing the second distribution rule

$$Mn_{SOURCE}(t) + \sum_{NODE=1}^{k} Mn_{S_{NODE}}(t) = \sum_{NODE=1}^{k} Mn_{SALE_{NODE}}(t) + \sum_{W=1}^{x} Mn_{WayW}(t) + \sum_{NODE=1}^{k} Mn_{E_{NODE}}(t) \tag{3.2}$$

$Mn_{SOURCE}(t)$ – the quantity of goods exiting the distribution source during period of time t,

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$Mn_{SNODE}(t)$ – the quantity of goods located at nodes at the beginning of period t,
$Mn_{SALENODE}(t)$ – the quantity of sold goods from distribution nodes during period t,
$Mn_{WayW}(t)$ – the quantity of goods located in vehicles on the roads at the end of period t,
$Mn_{ENODE}(t)$ – the quantity of goods located in nodes at the end of period t,
k – the number of nodes in the distribution network except the distribution source,
x – the number of vehicles on the roads at the end of period t.

3.2 Rules for Creation of Distribution Groups and Distribution Circuits

Structuring the distribution region into smaller distribution parts has to be based on criteria that give the ability to create clusters of distribution nodes in **distribution groups** (Straka 2004).

The distribution space is the bordered distribution area – a region which includes all distribution nodes, the means of transport for distribution, the distribution network and their mutual relations. The distribution space consists of all items involved in the process of distribution. The boundaries of the distribution space are formed by the border items of the distribution network.

The distribution group is a cluster of distribution nodes and is created on the basis of defined criteria for the purpose of structuring the distribution region into smaller parts and building a structured distribution network.

Restrictions on distribution include criteria that enable the creation of distribution groups:

- the maximum time of distribution – $maxT_d$,
- the maximum length of a distribution channel – $maxD_d$,
- vehicle capacity – K_T.

Rule no. 3 (about keeping a distribution region as one distribution group):

If distribution or supply is not dependent on the previous criteria or no limiting criteria are defined, then it is not possible to define several distribution groups –all the distribution nodes form one distribution group instead.

If distribution or supply does not depend on limiting criteria, then unlimited time, length and also capacity can be assumed. If there are no

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limiting distribution criteria, then the distribution network can be of the types point, line, star, ring, or flower, i.e. elementary distribution structures (of the 1st hierarchy). Without limiting criteria, it is not possible to define smaller distribution areas which would be the basis for a structured distribution network and the whole region is equal to one distribution group (Figure 26).

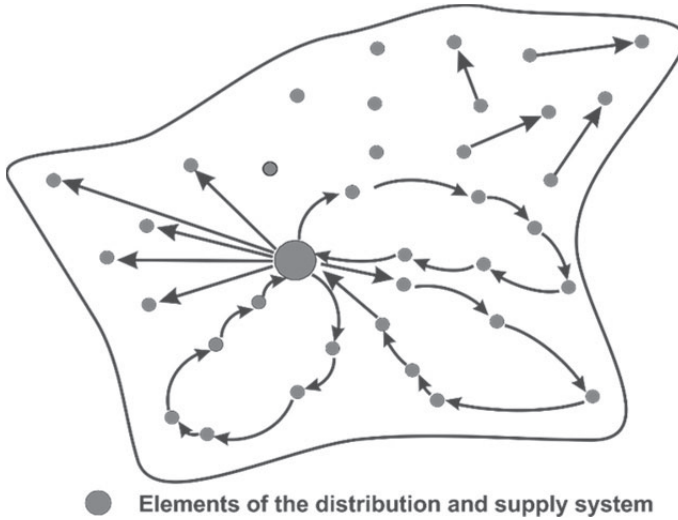


Figure 26 – A distribution region without defined criteria creates one distribution group

Rule no. 4 (about structuring a distribution region into smaller distribution groups) In the case of distribution limited by limiting distribution criteria there is the possibility to create a structured distribution network and all possible types of distribution networks are to be considered (distribution structures of the 1st hierarchy and complex distribution structures) (Figure 27).

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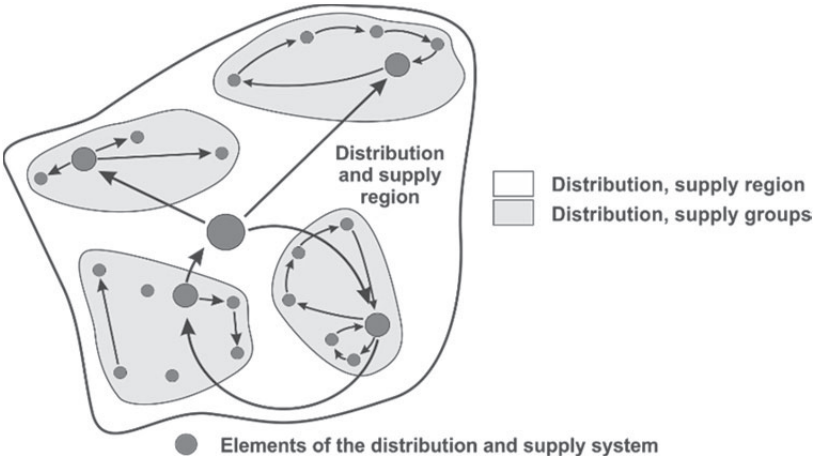


Figure 27 – Distribution region with distribution groups and distribution circuits

A distribution circuit is the connection of distribution nodes that are served by the means of transport from one distribution point or distribution source, within the capabilities of the means of transport (in terms of quantity of goods, the maximum distribution range, maximum distribution time, the capacity of the vehicle) to serve in one trip (Straka 2004).

If criteria are defined to limit the size of the distribution network, then the distribution circuit has to fulfil the stated criteria.

Rule no. 5 (about the maximum distribution time): The time required for the distribution of goods between distribution nodes or consumers forming a distribution circuit must be less than or equal to the time which is the maximum time of distribution, or at least one distribution node from a group must satisfy the condition of the maximum distribution time to all other nodes in the distribution group or distribution circuit (3.3) (3.4) (3.5).

If it is not possible to comply with rule no. 5, i.e. to create such a group of consumers or the maximum time of distribution is less than the distribution times for particular consumers, it is necessary to define a further hierarchical level, a distribution centre which will ensure compliance with the criteria of maximum distribution time.

Taking into account the criteria of maximum distribution time, it is necessary, if required by the distribution plan, to take into account the time needed for loading and unloading the goods at the distribution source, the distribution centres, warehouses and consumers, if they are part of the

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distribution routes and to also take into account the time needed for administrative tasks. The times for loading and unloading of goods and for administrative tasks reduce the total time available for distribution and when considering the maximum distribution time there is a commensurate reduction of the distribution range.

The distribution range can be characterized as the distance or the time in which it is possible to serve the distribution nodes (Figure 28).

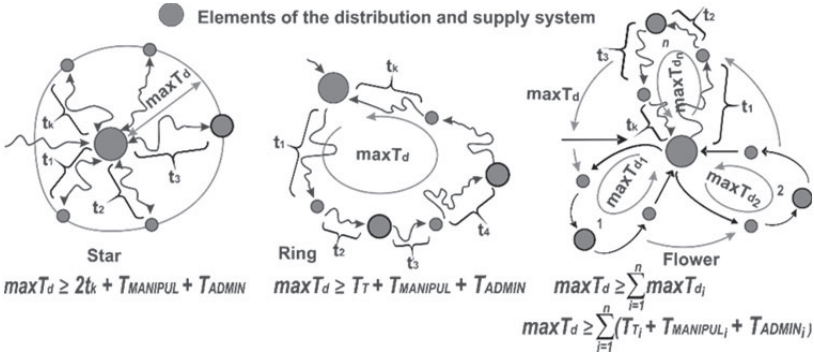


Figure 28 – Definition of distribution circuits while complying with the condition of maximum distribution time

The following is valid for one distribution circuit of a distribution network of the star type:

$$maxT_d \geq 2t_K + T_{MANIPUL} + T_{ADMIN}. \quad (3.3)$$

The following is valid for one distribution circuit of a distribution network of the ring type:

$$maxT_d \geq T_T + T_{MANIPUL} + T_{ADMIN}. \quad (3.4)$$

The following is valid for one distribution circuit of a distribution network of the flower type:

$$maxT_d \geq \sum_{i=1}^{n}(T_{Ti} + T_{MANIPULi} + T_{ADMINi}) \quad (3.5)$$

$maxT_d$ – maximum time of distribution,
$T_{MANIPUL}$ – total time of loading and unloading at the distribution source, distribution centres and consumers,
T_{ADMIN} – total time associated with administrative tasks at the distribution source, distribution centres and consumers,

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T_T – the total time needed to transport materials between locations that form part of the distribution circuit, the sum of times needed to overcome the distance between locations that will be served during distribution (3.6),
t_k – time of distribution, time for transport between locations that are part of the distribution circuit, $k = 1, 2, 3, \ldots$,
n – number of circuits, $i = 1, 2, 3, \ldots$.

$$T_T = \sum_{k=1}^{p} t_k \tag{3.6}$$

p – the number of connections between locations.

Rule no. 6 (about the maximum distribution path): If the maximum length of the distribution path is a limiting criterion for generating distribution circuits, then such groupings of locations are found where it is valid that path lengths of at least one of these locations to all other locations in a distribution circuit are less or equal to the maximum length of the distribution path (Figure 29), (7), (8), (9).

If it is not possible to create such circuits, because the lengths and distances between locations are larger than the maximum length of the distribution circuit, it is necessary to build intermediate stores so that the criterion of the maximum path length of the distribution circuit is fulfilled.

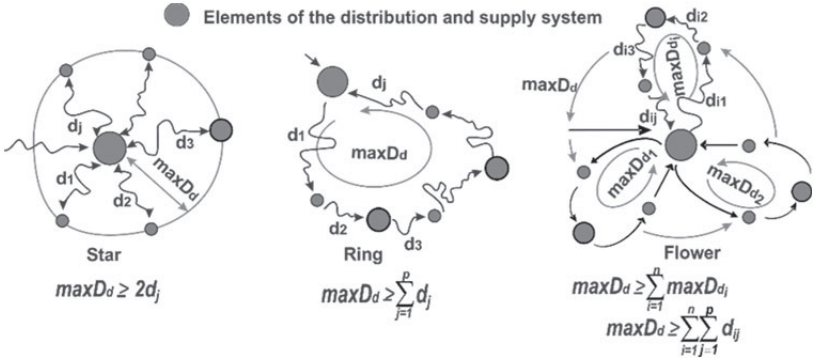


Figure 29 – Definition of distribution circuits so that the condition of maximum distribution path is fulfilled

The following is valid for one distribution circuit of a distribution network of the star type (3.7):

$$maxD_d \geq 2d_j. \tag{3.7}$$

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The following is valid for one distribution circuit of a distribution network of the ring type (3.8):

$$maxD_d \geq \sum_{j=1}^{p} d_j. \tag{3.8}$$

The following is valid for one distribution circuit of a distribution network of the flower type (3.9):

$$maxD_d \geq \sum_{i=1}^{n} \sum_{j=1}^{p} d_{ij} \tag{3.9}$$

p – the number of connections between locations,
n – the number of circuits,
$maxD_d$ – maximum path length of distribution,
d_j – length of the path between the points forming distribution groups, $j = 1, 2, 3, \ldots$,
d_{ij} – the length of the path between the points forming distribution groups and distribution circuits, $i = 1, 2, 3, \ldots$, $j = 1, 2, 3, \ldots$.

By fulfilling these conditions, it is possible to define distribution circuits for places with a given distribution source, distribution centre and distribution warehouse, or alternatively a place can be selected to build a distribution warehouse. Warehouses must be placed so that the previous rules are also fulfilled for the distribution circuit consisting of the distribution source and distribution centres.

3.3 Rules for Choosing a Suitable Method for Locating a Distribution Centre

After defining the distribution groups that must fulfil the distribution criteria, it is possible to select a location for a distribution warehouse. When choosing such a location it is possible to use two basic approaches:

- find a new location for a centre building on a "green field site";
- select an existing distribution centre from the distribution locations within a defined, specified distribution group.

Rule no. 7 (about using multi-criteria methods): If all distribution nodes in a defined distribution group meet the requirement of maximum time range from a distribution centre or the condition of maximum path length from a distribution centre and the criteria (factors) are from different areas of production, trade, social issues or economics, and there are undefined relations among criteria, then it is advisable to use any of the

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following methods of multi-criteria decision-making for defining or selecting a distribution node to be the head node of the distribution group.

- Weighted sum method;
- Multiplication of ratings method;
- Quadratic graph method;
- Analytic Hierarchy Process – AHP method, etc.

If the dominant problem of distribution is transportation, it is possible to transform the task of selecting a distribution node for the transportation task and then to solve the geometric task with a method such as:

- Cooper's iteration method;
- Geometric centroid of the distribution area;
- Location with the smallest sum of distances to other distribution nodes that form the distribution circuit) etc.

The determined or selected distribution centre, service management or service centre must also fulfil the conditions of the maximum time of distribution or the maximum distribution distance (transport capacity limitation) from the head distribution centre if these are specified as limiting criteria. If a given node does not meet the criteria it is necessary to find or determine another centre, warehouse or service management centre in the defined region which meets the criteria or to insert another intermediate warehouse or enough stores so that the condition of the maximum time of distribution or the maximum distribution distance (limited transportation capacity) between the head distribution centre and a given location is fulfilled.

3.4 Rules for Selection of Type of Distribution and Supply Network

After defining the distribution source, the location of distribution centres and the locations related to distribution and after defining distribution circuits in the distribution region, it is necessary to establish a link between the distribution source, distribution centres and consumers to fulfil the defined criteria or corresponding to the character of distribution activities e.g.:

- goods distribution (dispersing goods and haulage) maximizing the number of distribution locations in one distribution circuit,

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- planned distributions (goods dispersing and haulage) maintaining the fastest delivery,
- fast intervention in the event of breakdown,
- saving lives,
- intervention during natural disasters.

If the character of distribution or the function which the distribution network is to fulfil is not known, it is very difficult to define the shape of the distribution network. It could happen that the definition of the distribution network will be incorrect, which can lead to the total collapse of the general "functioning" of distribution. It is very important to know what, in principle, the distribution network has to comply with.

Rule no. 8 (about the characteristics of a distribution network of the star type):

In cases when the basic function of distribution activities is fast intervention in response to local needs, it is appropriate that the network is of the star type, because this type represents the shortest and fastest connection between the distribution source and the place of intervention (Figure 30).

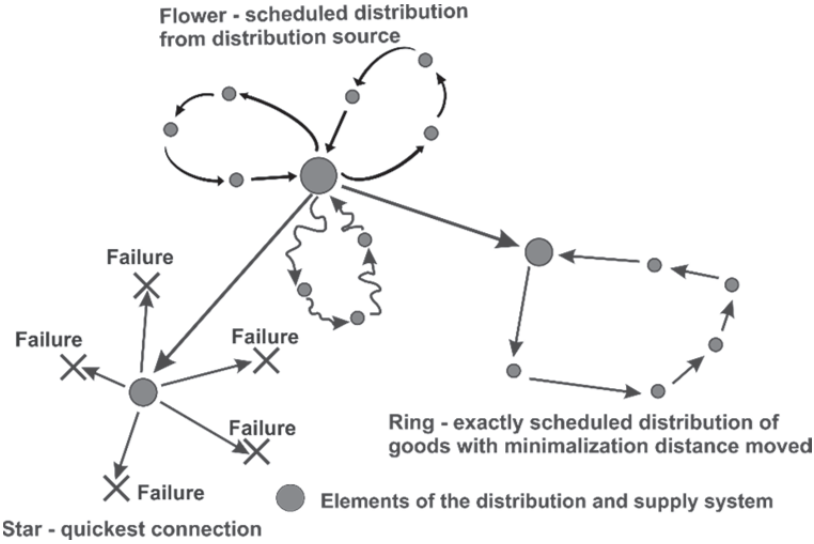


Figure 30 – Connection of distribution locations to possible types of distribution network according to the criteria of distribution

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Rule no. 9 (about the characteristics of a distribution network of the ring or flower type): In the case of goods distribution maximizing the operation of particular locations of distribution in the defined distribution area while minimizing the total distance travelled along the path during a given period, the appropriate type of distribution network is a ring or flower type. The final shape of the distribution network arises by connecting particular locations in the distribution region based on the type of network.

The direct connections of locations are, of course, only idealized paths; it has to be understood that the direct line connection is only a schematic representation of the real shape of the network, which can include paths of various shapes.

Defining and selecting the appropriate type of distribution network is influenced by the defined activities of the distribution company.

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II.

SUPPORT PROCESSES OF DISTRIBUTION AND SUPPLY LOGISTICS

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CHAPTER FOUR

DESIGNING WAREHOUSES AND TECHNICAL FACILITIES

What you will learn: Warehouses are also one of the elements of a distribution channel; their primary function is the storing of different raw materials, other materials, items, goods, etc. over time. In some cases, warehouses are also part of a technological process (ageing of materials, raw materials and goods). In terms of functional, security, economic, informational, technological, technical and social aspects, a properly designed warehouse provides opportunities for its effective use. In many cases not all the aforementioned criteria are covered when designing warehouses. This chapter deals with the aspects which influence the design of warehouses and the technical aspects necessary for effective and proper warehouse operation.

Basic terms: warehouse, designing, PDS warehouse model, warehouse technical facilities.

A logistics system consists of several items; one of them is storage, which has become an integral part of systems. It was once a part of logistics systems which was not given sufficient attention, but it became one of the most important parts later. The storage process has great importance for ensuring the required level of service delivery at the lowest cost, which is one of the basic ideas of logistics. Storage is a process that connects manufacturers with consumers and forms a link between them (Bazala et al. 2006). Material flow in a distribution system is provided by passive and active items.

Passive items are objects (raw materials, basic and auxiliary materials, spare-parts, intermediate and finished products), which are the subject of transport and handling operations, that gradually change their position and orientation in relation to their surroundings. The movement of the subject of transport and handling is understood as passive, because they are moved by handling equipment (industrial robot or induction trolley...) (Pernica 1995, Straka 2005).

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Active items change the position and orientation of the passive items. Active items in the distribution system are technical facilities and equipment for handling, transporting, storing, packing, fixing and other auxiliary equipment and devices that work in conjunction with the particular buildings, storage areas and routes. Technical facilities and equipment that support work with information, information carriers, tools and networks for remote transmission of messages and data together with management workers (decision-making entities) who work on the control elements of the distribution system are also active logistics items (Pernica 1994, Straka 2005).

4.1 Warehousing as Part of Logistics

Warehousing is a process, the main task of which is to store material, goods, products, raw materials over time, while preparing units for transport in accordance with the customer requirements and the means of manufacturing and transport with the aim of ensuring continuity of material flow, so as to satisfy market demand and optimize follow-up activities such as loading, unloading, transport, controlled distribution, and the preparation of shipping documents.

The most important functions of warehousing are receiving the goods (raw materials, materials as part of production, finished products, intermediate products), storing them and retaining their useful value, shipping out supplies and carrying out storage handling, providing information about the status of stocks, conditions and locations of storage products (Straka 2013).

The main purpose of warehousing is to create and collect stock for later continuous delivery or issuing to a customer.

The main reasons for storage of stock are:

- smoothing the difference at input and output of flows of materials,
- merging, accumulation of stock,
- protection against unpredictable risks or predictable situations,
- reducing the total cost of logistics of an enterprise,
- supporting various systems of supply, manufacturing and distribution,
- storage as a part of production technology (maturing, refining, fermenting, drying or assembling products),
- speculation on the development of market prices,
- storage of ecologically hazardous material,
- protection of materials and goods.

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Supply and storage of stock are among the main areas of use of warehouses in industry. Storage fulfils the function of securing the manufacturing activity of an enterprise, mixing different products from different manufacturing equipment of a company for shipment to one customer (Bazala et al. 2006).

4.2 Storage Systems

Three basic technological storage systems (Stehlik 1997; Trosanova, Straka 2011) in the theory of warehouse management can be identified based on the method of storing pallets and various goods and they are classified as follows:

- small (manual, by hand) storage,
- block pallet storage,
- row pallet storage with access to each storage unit.

The small manual storage system is nowadays used only for the storage of small quantities of goods. The use of mechanical technology to store goods in this system is economically disadvantageous. This system is used in two-story warehouses or it is supplementary to other storage systems.

The second system is block pallet storage, which consists of storing pallets in columns in one row. This system has the advantage of utilization of the height and area of the warehouse and its disadvantage is considered to be insufficient access to different types of pallets. It is used for mass goods storage. Technological equipment for storage can also be used.

The third most widely used storage system is the row pallet storage system. The advantages of this system are transparency and the ability to access individual pallets. It can be used for different kinds of goods. Storage can be performed using forklifts or cranes (Stehlik 1997).

4.3 Types of Storage and their Functions

Warehouses can be characterized using a wide range of possibilities. According to their position in the value-creation process they can be divided into:

- input warehouses (designed to maintain stocks of input materials),
- buffer storage (intended for stockpiling between particular stages of the production process),
- distribution warehouses (balancing timing differences between production and marketing).

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The function of **manufacturing stores** is to offer the smooth running of the manufacturing process and at the end to concentrate and prepare finished products for shipment to customers. To ensure the continuity of the manufacturing process, the following are used:

- a stock of raw materials,
- a stock of intermediate products,
- a stock of sub-deliveries,
- buffer storage for in-process manufacturing and assembling,
- a stock of finished products.

The task of warehouses is to reconcile different rates of flows. Depending on the importance of storage it is possible to define the following functions of storage (Straka 2013):

- the smoothing function,
- the collection function,
- the functions of risks and predictable states,
- the economic function,
- the function of support,
- the technological function,
- the speculative function,
- the ecological function,
- the protective and safety function.

The smoothing function of storage is associated with the provision of the necessary raw materials, materials and resources for a system in which supply and consumption are not the same.

The collection function is related to the accumulation of stocks of materials, products and goods for the purposes of supply, manufacturing, distribution and sales.

The function of risks and predictable states of storage are associated with securing the resources necessary for supply, manufacturing, distribution and marketing in the context of unpredictable events (accidents, breakdowns, downtime), or predictable states (planned repairs and maintenance of equipment, campaign lay-offs, planned relocations of manufacture, etc.) in order to reduce or eliminate the effects of risk in the defined states.

The economic function of storage is related to its higher rate of contribution to the cost of system operation such as additional storage costs. Despite the costs of storage required for their operation, materials and supplies, a properly designed, located and operated warehouse saves more than the costs incurred; in some cases, this also relates to reducing the costs of transport of materials.

The function of support is related to direct or indirect support for various systems such as push, pull, just in time, and others.

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The technological function of storage is associated with the direct integration of storage into the technological process as an item which is used for maturing, fermenting, refining, completing, cleaning.

The speculation function of storage is related to storing goods for a certain time until market prices fall or increase, etc.

The ecological function of storage is related to the storage of materials which can cause a serious ecological disaster in the environment. This includes the storage of spent fuel from nuclear power plants, hazardous waste of a chemical or biological character and others.

The protective and safety function of storage is connected with the protection of material against weather conditions and securing goods and raw materials against theft and unauthorized persons.

Warehouses, in terms of their importance, equipment, safety and other aspects, can be subdivided into the following subgroups (Table 4).

Table 4 – Classification of warehouses

Method of classifying warehouses		**Types of warehouses**
1	According to the degree of mechanization	manual warehouses
		mechanized warehouses
		highly mechanized warehouses
		automated warehouses
		fully automated warehouses
2	According to the type of material stored	warehouses for piece material
		warehouses for bulk material
		warehouses for a liquid medium
		warehouses for a gaseous medium
3	According to the storage system	quick response warehouses
		efficient consumer response warehouses
		line picking warehouses
		hub and spoke warehouses
		cross-docking warehouses
4	According to the degree of production completion	warehouses for raw materials
		warehouses for semi-finished products
		warehouses for sub-deliveries
		warehouses for finished products
5	According to the degree of process value creation	entry warehouses
		intermediate warehouses
		outbound warehouses

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6	According to the utilization of the warehouse and the circuit of customers	general business warehouses
		customs warehouses
		frozen and cold warehouses
		special commodity warehouses
		warehouses for bulk substrates
		warehouses for the needs of physical entities (form of business)
7	According to the warehouse management system	warehouses working with a PUSH system (MRP 1, MRP 2, OPT, DBR, BOA, FZ)
		warehouses working with a PULL system (JIT, MRP 3, MRP 4, Kanban, Conwip)
8	According to the structure of the storage system	operational warehouses
		central warehouses
		regional warehouses
		shipping warehouses
		centralized warehouses
		decentralized warehouses
9	Depending on the use of transport	distribution warehouses (one type of transport)
		logistic centres (combined transport)
10	According to the storage method	stationary, immobile
		dynamic, movable
11	According to the ownership relationship toward the warehouse	public warehouses
		private warehouses
		contractual warehouses
12	According to the supply area	central warehouses
		local warehouses
13	According to the construction solution	fixed warehouse buildings
		portable warehouses
		open warehouses
		special warehouses (tanks, silos, bunkers)
14	According to the location of the warehouse	indoor warehouses
		outdoor warehouses
15	According to the utilization of the warehouse space	single-storey
		multi-storey

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4.4 Logistics Systems in Storage

The systemic dependence of processes is named based on the logistics technologies which are used in the storage facility, including:

- Quick Response,
- Efficient Consumer Response,
- Line picking,
- Hub and Spoke,
- Cross-docking,
- Concentration of warehouse network.

Quick Response – QR is focused on consumables from manufacturing through the wholesale and retail network. It improves inventory management and increases efficiency by speeding up the flow of goods. Using QR consists of applying the principles of Just in Time – JIT throughout the supply chain from the supplier of raw materials through to the manufacturer to the final consumer. This technology requires the introduction of automatic identification (QR codes) and electronic data interchange (EDI).

The main advantages of this technology include (Bazala et al. 2006):

- less handling operations with goods,
- easy inventory control, which enables it to be reduced,
- less storage space needed,
- acceleration of the flow of information and reduction of the degree of uncertainty in decision-making,
- profitability – stocks are lower, profits higher.

The technology **Efficient Consumer Response –** ECR is a special variant of QR technology that connects the logistics chain from suppliers through manufacture to final customers. It is divided into the following ECR strategies:

The first strategy is the management of logistics chains, which leads to stabilization of flows with minimal stocks of goods, which also includes chain integration, synchronization with manufacturing, continuous supplementing of goods, automated warehouse orders, reliable operation and cross-docking.

The second strategy is the objective arrangement of the range of products into product groups and corresponding stabilization of the logistical infrastructure and management of processes. The third strategy is the introduction of new products onto the market.

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The final strategy is promotion. Promotions are performed only when and where they will bring the desired benefits (Trosanova, Straka 2011).

Cross-docking is a storage alternative, where an immediate product transfer system is used where the stores are primarily used as mixing distribution centres (Figure 31). The products arrive in large quantities and are then divided in amounts that a customer requires, combined with other products in the shipment intended for the same customer. Goods do not stop to be stored in the stock zone; they are only regrouped. This system is mainly used by retail businesses so that they can order goods in full truckload shipments, then the items are divided and immediately shipped to individual stores.

Firms store goods somewhere between the manufacturing company and the customer. There are two storage options to choose between for local storage. The first option is to rent warehouse space – a public store or related services; or to arrange one's own storage space – private storage (Trosanova, Straka 2009).

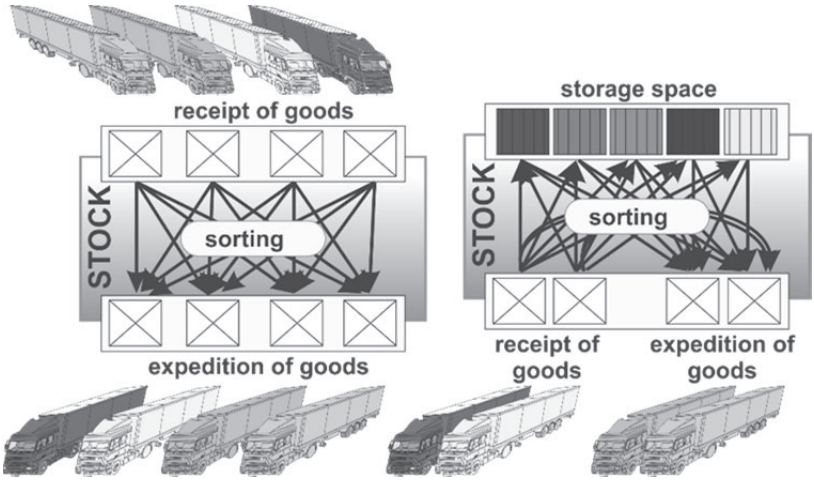


Figure 31 – Cross-docking in a warehouse

Line picking technology (Bazala et al. 2006) is used throughout shipments to the distribution centre. The composition of goods consists of one type of goods in palletized units in a quantity and assortment without relation to recipient orders. The quantity supplied does not correspond to

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the dispatched quantity. Line picking operations in the warehouse can be defined as:

- unloading a palletized unit,
- receipt,
- dismantling a palletized unit,
- completing (the remaining quantities of goods remain until the next delivery),
- packing (fixation with PE films),
- loading a palletized unit.

Hubs & spokes is the technology of logistics services (Bazala et al. 2006). This technology brings together (groups) smaller consignments of goods into larger units which are then ungrouped after transport by high capacity means of transport and systems. It uses logistic centres (hubs) and general road collection and delivery. It eliminates the negative effects of Just in Time for transport and the environment. The hubs & spokes technology has more frequent but smaller deliveries than JIT. The technology is more cost-effective for long distance shipments using high-capacity means of transport than for smaller shipments over a short distance.

Advantages of hubs & spokes:

- low transport costs,
- environmental friendliness,
- relief of traffic routes.

Disadvantages:

- investment demands,
- preferred for use only over longer transport distances.

Concentration of the warehouse network is associated with centralizing storage (Bazala et al. 2006). It is an alternative technology to JIT. It involves concentrating scattered warehouses into one or several large automated warehouses using suitable warehouse technology. Concentration of the warehouse network helps to reduce overall logistics costs. The basic characteristic feature of the concentration of the warehouse network is that the costs of financing inventory and warehouse transport services fall, but the costs of delivery of goods to customers rise.

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4.5 Warehouse Design

At the beginning of a warehouse design it is necessary to follow the basic procedure set out in the following rules which must be addressed before designing the warehouse (Trosanova, Straka 2011):

1. It is necessary to realise that the design of a warehouse must begin "inside out", it means that it is necessary to become familiar with the **material flow and warehousing technologies** that will be used in the particular type of warehouse. After getting familiar with the material, it is necessary to adapt the internal warehouse structure so that it best suits it.

2. The second phase of design is the inclusion of the **warehouse facility**, where the designer should design and plan looking to the future, for example:
   - increased turnover of stock material,
   - what changes to the range of stock we can expect,
   - whether and how the number of stored items will grow,
   - whether a change in the size of packing is possible, etc.

   The equipment designed into the warehouse should be variable in order to adapt quickly and dynamically to any changes.

3. The third phase, **the material flow,** is the decisive factor. It is therefore necessary to think through the route of material through the warehouse and already reflect it in the organizational form and in the competences of workers at the time of design and planning the warehouse.

The organization must be configured to secure the three basic functions of warehouses in all cases:
- reception of goods,
- storage,
- issuing and shipment.

The warehouse design has to take care that reception and issuing of goods do not interfere with each other. Also, specific types of storage in the warehouse have to be designed and considered properly.

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4. In fourth phase of the design activities of the organization of a warehouse it is necessary to choose an appropriate **information system** for the specific type of storage.

5. In the fifth phase, the creation of **handling units** should be well established in order to create summary measures for the most efficient use of manpower and equipment. The type and size of handling and storage units are important for the overall equipping of the warehouse. The depth and height of shelves, floor carrying capacity, lift height and width of lanes for the means of handling need to be determined from the type, weight, dimensions and centre of the gravity of all handling units.

6. In the design phase, aspects that create good working conditions in a warehouse should be taken into account:
   - quality and characteristics of the floor,
   - ventilation of the warehouse,
   - heating and lighting.

7. When designing and planning a warehouse it is necessary to ensure the perfect use of space, because construction is always a costly matter.

4.6 The Top Requirements for Building Warehouses

The top requirements for building warehouses are based on two fundamental questions, namely (Trosanova, Straka 2011):

- What material will be stored?
- What equipment and storage systems will be used?

Regarding the material stored, the requirements are diverse and characterized by the specific type of material. On the one hand there are materials that can be stored in free open-air areas so there are no specific requirements, because the character of the materials does not require it; and on the other hand, the storage requirements can be very demanding (e.g. dust-free, air conditioning, etc.). Such specific requirements must be resolved in time and each addressed separately.

Requirements, from the side of mechanization used, are general and hard to specify. Requirements are different for open-air spaces and different for enclosed spaces. The reason is that heavy machinery is used for handling in an open-air space. Regarding mechanization the most important warehouse requirements are the carrying capacity and surface quality of the floors.

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The carrying capacity of floors is one of the major requirements for the construction of the warehouse. Carrying capacity depends on the type and size of handling units and the type of handling equipment that will be used. For example, when specifying for fork lift trucks it is necessary to consider the fact that the front wheels of the truck support more weight than merely half the weight of the truck with the load while used. In determining the carrying capacity of storage areas it is necessary to take into account the total weight of handling units, but also how a handling unit comes into contact with the ground (whether the handling unit will touch the floor completely, or only at some points or positions).

When determining the carrying capacity of floors, it is not possible to rely only on static force and weight. The dynamic effects must be taken into account.

If the above rules are not followed, it could lead to the distortion or destruction of floors.

Another important requirement is the **surface quality of floors**. Floors should have a perfectly flat surface made of a suitable material (Trosanova, Straka 2009):

- cement daub (for light and medium trucks using tires),
- bituminous carpet (characterized by its good adhesion coefficient),
- asphalt concrete (for all types of handling equipment),
- cast and abrasive cast asphalt (for all types of handling equipment),
- metal tiles (heavy and hot loads).

Materials that are not suitable for quality flooring include: wood, tile, soft materials and worn concrete. An important element of quality flooring is the quality of the layers below it. In a storage room there must be easily visible signs showing the maximum permissible floor load. In warehouses where bulk materials are stored, the storage height above the floor must be colour-marked on the walls and supporting pillars, and where applicable on supporting rods.[1]

The storage areas (warehouse floors) should correspond to the following composition (from top to bottom):

- concrete slab 240 mm,
- gravel sand packing 120 mm,
- crushed gravel 250 mm,
- gravel sand 350 mm.

[1] Decree 59 / 1982 of the Slovak National Labour Inspectorate, section 11, setting out the basic requirements for ensuring safety and technical equipment.

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Areas designated for the movement of handling equipment and vehicles should have the following composition (from top to bottom):

- asphalt-concrete 120 mm,
- gravel sand 350 mm,
- gravel sand packing 150 mm,
- crushed gravel 250 mm.

4.7 Aspects affecting Storage Projects

In the past, little attention was paid to the design of stores. Today, developed industrialized regions emphasize their demands especially on the safety of employees at work, the ecological significance of the project, the social and economic benefits to the industry and to people. Storage is one of the most developed sectors in industry, where strict standards and rules must be kept. In the past, stores did not completely meet the requirements for their function. Violations of safety rules occurred. In the late 20th century, theory was enriched with new information that has been applied and developed in practice. At present, the designers establish the objective to create a warehouse project where the work of staff is as efficient as possible or the human factor is minimized in warehouses. Minimizing the human factor in a warehouse leads to the reduction of damages caused by incorrect and often faulty inventory records (Trosanova, Straka 2011).

There are high investments associated with storage and therefore, when designing warehouses, corners are cut in construction and equipment for warehouse buildings, leading to warehouses built with an insufficient range of services and facilities. This action affects the profitability of products. Such warehouses are unsuitable for workers and for the goods stored and waiting for shipment. It occurs that goods are kept in nonconforming conditions, e.g. with no shelters or roofs. The floors of buildings, in the case of a multi-level warehouse, are often overloaded (Figure 32). The danger of injuries is increased when storage racks are overloaded with goods and it may cause a collapse.

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Figure 32 – Example of incorrect storage[2]

4.7.1 Questions that Influence Warehouse Design, "what?, when?, why?, how many?, where?, how?, how much money?, what with?, for whom?"

One of the most important things in warehouse management is designing a warehouse or projecting a model for the design of a warehouse. In the solution, many more questions can ensue relating to the design and the construction of warehouse buildings, as well as different types of storage and storage materials. It is necessary already to think about future development and innovation during design and project preparation.

In designing the project for a warehouse, it is necessary to answer a few basic questions which influence the particular construction of the warehouse (Figure 33).

[2] http://englishrussia.com/index.php/2007/09/21/the-real-mess-at-russian-super-mart/

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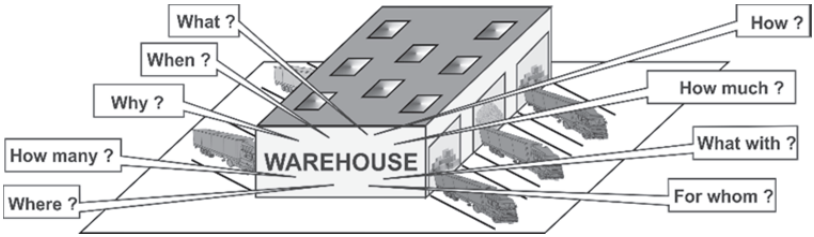


Figure 33 – Questions that influence a warehouse design

"WHAT?"

This question deals with what kinds of materials in terms of their quantity, shape, physical state, will be stored, transported and how they will be handled. It is the question of the material (concerning the type, characteristics, handling and transport units) that affects the further development of the warehouse project. From this point, everything gradually unfolds in terms of the types of buildings, warehouse equipment, in-house transport and transport of goods.

The is where the question is answered of whether the company wants to store solid, bulk or liquid material. If the company decides to store solid material, the design for the warehouse may include a double-floor warehouse. However, it must pay attention to the floor's load carrying capacity. This solution also includes elevators, rules and laws associated with their operation. Shelves, pallets, consoles or block racks, height Man-up trucks or special storage structures for solid goods are used.

Large single-floor buildings are chosen for bulk materials. Warehouse equipment for bulk materials is different than for solid storage and also in-house transport is designed differently. Bulk materials can be stocked in two different ways: in level stores or in containers.

"WHEN?"

This question needs to be asked in relation to a draft timetable and the process of further development and construction of warehouse buildings. The timetable is created in accordance with the due-dates for submission and approval of project documentation. This question is about the construction terms and the necessity of performing detailed surveys before beginning work on the project. If the company decides to build the warehouse it must respect the timeline of selected activities to build a warehouse. Submission of applications for planning permission to the

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building office, including filing applications at the specialized office, the state rail office, the state water management office, the road transport office and other specialized construction offices takes about 60 days. Before issuing a building permit the building office also examines local surveys and research. If the building office considers the surveys and observations and authorities' reports to be positive, the company obtains the building permit. Upon expiry of the 15–day period for concerned parties to submit an appeal, the building permit becomes final and construction work can begin.

"WHY?"

This question seeks an answer to whether there are any better solutions than building or renting a warehouse. A company which aims to gather all its goods in one place usually decides to build a distribution warehouse. For a company that buys or produces in high volumes, uniform distribution should result in further savings. The need to succeed in global competition and the need to reduce costs lead companies to examine the methods of storage and distribution of their products. Some companies move away from years of using strategic options, either the warehouse or distribution to new solutions. Today, distribution warehouses bring more economic benefits for a company which takes into account their future development.

"HOW MANY?"

This question deals with the number and turnover of goods to be stored, handled and transported. From the perspective of a warehouse project, it is a question of determining the size of the warehouse and storage areas. The principal factors that determine the size of a warehouse include the number and the size of stored products and the level of customer service. With the growth of customer service levels there are increased requirements for a warehouse, storage space, so that more and more goods are placed in a warehouse. If there is greater diversity of products, more storage space is needed. It is also true, when handling units are of a larger size, that the requirements for the size of the warehouse are higher.

The calculations require the volume of stored material and the method of storage to determine the storage space. The volume of stored material is given in handling units for solid goods, but tonnes for bulk material.

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"WHERE?"

This question has a strategic importance and it addresses the warehouse's location in space and its geographic position relative to suppliers and customers. It is necessary to develop an analysis of potential customers, their position and their access to the future warehouse. One important factor in the design of a warehouse is the availability of infrastructure. If rail transport is located near a warehouse, there is the possibility to connect rails like one type of in-house transport tracks in an industrial concern.

"HOW?"

This question involves the handling of goods and the manner in which the goods will be stored or transported. Some companies deliver their products directly to retail customers (direct delivery to shops) without using distribution warehouses. Large producers have a large number of storage options and it makes it difficult to choose the most appropriate one while taking into account a reasonable rate of investment and a reasonable investment return period. One alternative, the most widely used recently, is the immediate transfer product system called Cross-docking. After the goods are received they are immediately split and combined with other goods in a consignment to the same customer. Products never stay in the stock zone, they are just regrouped. The advantage of Cross-docking is that the storage space is not cluttered with goods.

The second option is contract storage. A company should consider whether it is to operate storage on its own or ask another company to do this as a service. In deciding whether to use its own or external storage, the company needs to consider: whether there is enough investment to build a warehouse, what the degree of dependence is, the need for personnel, the general operating costs of the warehouse. Building one's own warehouse requires high investment costs, but it provides a higher level of service in relation to customer service. The personnel are more familiar with the goods of their employer. The costs of a public warehouse operation are higher, because when a company rents out warehouse space it wants to make a profit. The advantage is that any unused storage capacity is suffered by the company that owns a warehouse.

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“WHAT WITH?”

This question deals with the techniques by which the goods in a warehouse will be stored, handled and transported. It's a problem of technical means and equipment. It is necessary to consider the use of equipment for the transport of solid materials and equipment for transport of bulk materials, or other special types of devices. The answer to this question depends on the type of material stored, i.e. the answer to the question "WHAT?" The design of a warehouse includes listing the means of transport used for storing and handling of goods in order to take into account the different width of lanes for specified types of transport trucks.

Now it is decided about the selection of technical equipment for storing goods in this step. Nowadays there are many types of equipment for transport of goods, it is just a question of financial possibilities of the company. A designer has to keep in mind the rapid growth of technology and he has to design a warehouse to be as flexible as possible for future development.

“HOW MUCH MONEY?”

This is a question that influences all that mentioned above. Investment costs in the project study are determined by a comparative analysis of price comparison with similar previously-designed or implemented structures. Furthermore, they are based on the price information and offers from sellers, expert estimations, a system of technical-economic indicators etc.

Investment costs for the project study are compiled by financial calculation and they are classified identically to the classification of the aggregate project budget. They must have a transparent structure to meet the sufficient condition for verification of the overall efficiency of investment and to be comparable with the financial costs of the project.

Budget documentation means budgets processed as part of the project. They reflect the budgetary costs of construction, which become, after a discussion, the budgetary costs of the building or part of one[3].

[3] General assessment for documentation of buildings (Ordinance 107/66 State. Commission for Technology) further specifies the types of financial costs and selling prices.

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"FOR WHOM?"

This question deals with the consideration of whom the warehouse is to serve, whether it is intended only for private use or as part of a public warehouse with leased space. Depending on this fact the designer has to take into account the internal layout of the warehouse and possible equipment.

4.7.2 Warehouse Assortment

As part of designing a warehouse, it is necessary to consider the kinds of material being stored or transported, their amount, shape, state, and in what handling unit they will be placed or transported to the warehouse. The nature, properties of handling and transport units have an impact on the further development of a warehouse project. Everything progresses from this point, from the type of construction, equipment, in-plant transport to the transport of goods in and out of a warehouse.

The main part of material side is that distribution systems are **passive logistics items** e.g. raw materials, basic and auxiliary materials (packages), spare-parts, semi-finished and finished products. Within distribution systems, passive items take the form of handled, transported or stored objects (pieces, units, shipments), the movement of which is ensured by **active logistics items** from the place and time of their creation through various production and distribution chains to the place and time of their production or final consumption. They have an exclusively non-technological character, the amount or nature of raw materials and finished products is not changed i.e. their physical, chemical, and other properties.

Classification of passive logistics items forms the basis for the management of a distribution logistics chain to provide information to a supplier for the selection of the appropriate means of handling and transport by assessment of the structure, passive items, transported volumes, procedures for arranging handling, structure of active equipment at work with passive elements, structure of the starting and end points of the distribution chain, structure of time-consumption (frequency, seasonal fluctuations). The structure of a passive item may have a gaseous, liquid or solid state. It can be moved as bulk freight, in pieces, as handling and transport units (Pernica 1995; Straka et al. 2005).

Material analysis enables improvement of the overall warehouse design and flexibility and preparation of the warehouse for innovations in future. It addresses whether a company will store items in pieces, bulk material or liquid material.

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The basic **handling units** (Figure 34) include:

- cardboard boxes,
- boxes (plastic, metal),
- containers (plastic, metal).

The basic tools of handling include:

- pallets,
- roltainers,
- carrying cases.

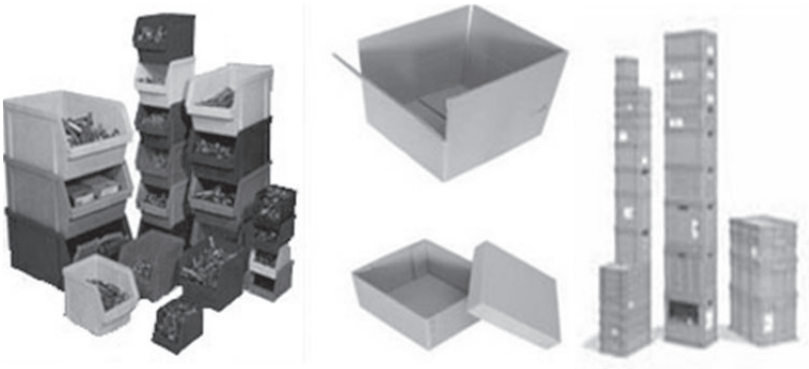


Figure 34 – Handling units[4]

Pallets – the most commonly used handling devices for storage. These are special platforms of different sizes and structures, most often made of wood, plastic and light metals.

Simple pallets (Figure 35) – are used for all kinds of suitable packaged materials.

[4] http://www.342.vsb.cz/hra42/TLSO_2.pdf

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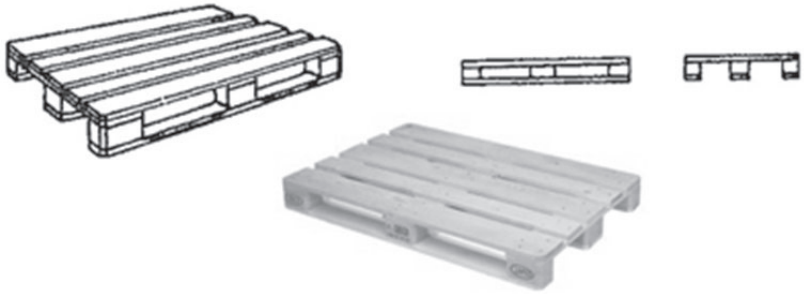


Figure 35 – Simple pallet[5]

Stackable pallets (Figure 36, A) are designed for bar materials, **box pallets** (Figure 36, B) are designed for smaller, non-packaged products (screws, bearings, etc.), **box pallets** (Figure 36, C) are intended for bulk materials.



Figure 36 – A: Stackable pallet, B: Box pallet, C: Box pallet[6]

Roltainers (Figure 37) – are designed for movement and storage of special types of materials.

[5] Straka, M., Malindzak, D. a kol.: Distribution logistics, Expres Publicit Kosice, 2005

[6] http://www.342.vsb.cz/hra42/TLSO_2.pdf

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Figure 37 – A roltainer

Types of **transport units** are:
- containers,
- swap bodies,
- trailers,
- mobile sets and others.

Containers. There are containers for ordinary loads (sealed container with natural or forced ventilation, open top containers, platform container) and for special goods (thermal container, tank container, container for dry bulk material).

Thermal container (Figure 38, A) – a container that has insulated walls, door, floor and roof to slow down the exchange of heat. This includes: a refrigerated container, a heated container.

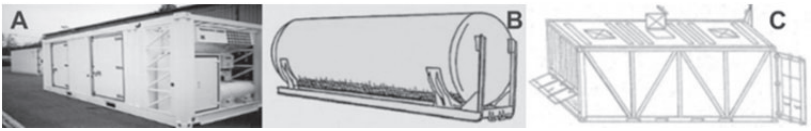


Figure 38 – A: Thermal container, B: tank container, C: container for dry bulk material[7]

Tank container. (Figure 38, B) This involves two basic items – a tank or a tank with a framework.

Container for dry bulk material (Figure 38, C) – for transport of dry bulk unpackaged materials.

[7] http://www.342.vsb.cz/hra42/TLSO_2.pdf

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4.7.3 Packages

Packaging is one of the subsystems in a distribution chain. This subsystem includes packaging, the packaged product, packaging equipment, transport and handling equipment, and workers who work with these things.

The main purpose of packaging is to protect a product from adverse effects in order to keep its utility value and to facilitate handling processes and operations of a commercial nature. The product resulting from the packaging subsystem is a package or packaged product. The packaging issue has to be resolved with consideration of its economic efficiency as well as considering the requirements of the user or consumer.

The packages must meet the following requirements:

- facilitate fixation during handling and transportation,
- suitability based on the weight of contents,
- suitability with respect to single or multiple use,
- dimensions in relation to the uniform dimensions of packages,
- suitability for stacking,
- needs of loading, unloading and reloading,
- space requirements.

In terms of economy, it is advantageous to introduce returnable packages, thereby reducing the cost of purchasing new packages.

It is necessary to come up with a sales plan for determining the required number of packages. The consumption of non-returnable packages is calculated as (4.1):

$$P_n = \frac{Q}{q} \text{ [pcs]} \tag{4.1}$$

Q – planned sales of packaged material (*kg, t*),
q – the amount of material packed into a single package (*kg, t*).

To calculate the consumption of returnable containers (2) the following formula (Straka et al. 2005) is used:

$$P_v = \frac{P_n}{q_s \times m} \text{ [pcs]} \tag{4.2}$$

q_s – the number of internal packages filled into the outer packages,
m – planned number of rotations.

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What kind of package is suitable for use (4.3) can be assessed from the inequality (Straka et al. 2005):

$$N_n \times Q \geq N_v + O(r-u)(c-d) \tag{4.3}$$

N_n – acquisition costs of non-returnable packaging,
N_v – the cost of acquiring returnable packaging,
O – the number of rotations of packaging,
r – the costs for maintenance and repair, cleaning, handling, sorting and registration,
u – compensation granted to customers (if agreed),
c – the cost of packaging disposal,
d – the salvage value of the packaging material.

4.7.4 Means of Transport

The manner of transport of goods into warehouses is one of the first and essential pieces of information that a designer should know in order to tailor the reception and dispatching the goods to a certain type of transport. From the building perspective, the most frequent types (modes) of transport that occur in Central Europe and their construction requirements for a warehouse are described.

The means of transport are among the active items of logistics. All the means for loading and unloading, packaging and storage are considered technical means of distribution, however distribution is carried out by the means of transport, causing the material to be transported in single loads (except pipe transportation) where the size is limited by the capacity of individual means of transport (Pernica 1994).

It is necessary to consider the functional properties expressed by the technical-economic and environmental parameters of handling, transport, auxiliary machinery and equipment when choosing active items. The classification of active items is as follows:

- means of transport,
- tools of handling,
- auxiliary equipment,
- information technology,
- operators.

Freight road transport is used to transport goods to the warehouse. It is one of the most frequently used modes of transport that are used for the receipt and dispatch of goods. If the warehouse project includes road

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freight transport, the conditions are the loading and unloading ramps to be installed. The ramps should be about 1.2 metres below the level of the warehouse facility. Loading and unloading ramps are included in decree 59/1982 (individual numbering depends on the country), whereas the basic requirements to ensure the safety of work and technical equipment are defined in Slovak law no. 454/1990. According to these rules, the ramp width must allow for the safe movement of people and for goods handling (Trosanova, Straka 2009). The sides of loading and unloading ramps including stairways must have safety markings. Ramps used as pathways for pedestrians, must be equipped with removable handrails from the open side. The ramp must have at least one safe exit.

Loading ramps that minimize the height differences between the vehicle ramp and the loading ramp are very important technical aids. These ramps are called adjustable bridges. Transhipments are performed by front ramp, side ramp or a combination of both ramps.

In-plant railway sidings can be built for **railway connection** directly to storage facilities. They are arranged in warehouses where the frequency of rail wagons entering and exiting implies economical use of the freight equipment. Building a siding assumes a minimum frequency of transferred wagons per working day, which is calculated on the basis of the average freight load. Weigh-scale sidings are installed only at big warehouses or where the siding is used by multiple users. Specific standards apply to the clearance gauge and the profile of wagons. No part of the buildings and equipment or other obstacles can infringe on the transit of the wagons. This is especially relevant when goods are unloaded or prepared for loading on ramps.

At some modern warehouses the siding space is paved, so if there are not wagons on the siding near the ramps, this place can be used for handling goods on trucks (Straka 2013). Railway loading and unloading ramps are divided into:

- covered ramps protected from the weather, for short-term storage of goods,
- open ramps not protected from the weather, for short-term storage of goods.

Based on the position in relation to the railway, they can be divided into:

- side,
- front,
- side-front (handling is possible form the side and from the front, at the end of a track).

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The position of the warehouse towards rails is predestined by the geographical nature of the area and the details are defined by standards and the building act. In general, it is possible to orientate the warehouse towards rails using four basic types of warehouses (Figure 39) (Straka 2013):

- *Rectangular type of warehouse* – this is the simplest and the most used type of warehouse. The disadvantage of this type of warehouse is that all wagons to be loaded or unloaded are on the same rails and that creates time losses.
- *Terraced type of warehouse* – eliminates the disadvantage of rectangular type of warehouse. Wagons are independent of one rail track. Time losses do not occur. The only disadvantage of this type is the difficult use of transport vehicles.
- *Warehouse with sloped ramps* – is more favourable than the two previous types of warehouses. This arrangement eliminates the disadvantages of both warehouses.
- *Warehouse with internal track* – the roof of warehouse also covers the rails and the wagon. This type best suits the requirements of a warehouse. The disadvantage is the high investment required.

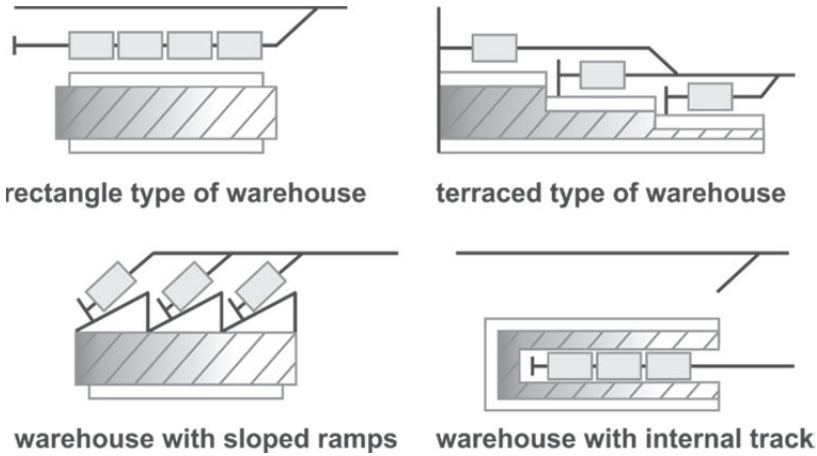


Figure 39 – The position of a warehouse in relation to the railway[8]

[8] Straka, M.: Distribution logistics, 1st ed., p. 400, EPOS Bratislava, Bratislava, 2013

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For positioning the warehouse in relation to the railway it is necessary to calculate the total area of the warehouse. It is necessary to know what kind of goods will be stored in the warehouse, the form of storage and what types of handling equipment will be used for storing the goods.

Water and air transport are limited in terms of their direct interaction with the requirements of warehouses and they mainly serve as items of combined transport. More of these types of services are described in chapter 1.6.4.

4.7.5 Storage Technologies

If the output of the company's activities is piece-goods, the warehouse project may include a two-storey solution. It has to respect the floor load (e.g. on the upper floor only textile goods are placed, as they are lighter). This solution also includes lifts and considers rules and statutes related to their operation. Shelving, pallet racks, cantilever storey racks, high pallet stacking devices, special warehouse constructions, etc. are used for all kinds of piece-goods.

4.7.5.1 Storage Technologies for Piece-goods

Nowadays, in this technologically developed time, there are many kinds of differential storage technologies.

Shelving racks (Figure 40), this kind of storage technology is not designed for storage of palletized goods freely, in boxes, in plastic or metal crates. They are meant for manual operation with direct access of operators. Storage of goods in shelving racks is forbidden for forklift trucks. Structurally, with this type of shelving racks, multi-level galleries or platforms can be created which replace the multi-floor warehouse buildings and they are less expensive (Bazala et al. 2006).

Multi-level warehouses – galleries are warehouses that use the full height of the storage space and have an additional storage platform at a particular transition level. The multi-level warehouse is a perfect solution to increase the capacity of the racks or to utilize the height of the storage hall to the maximum without any structural modifications. This technology is typically used for spare parts warehouses and for fast-moving material, but also for archives or libraries (Bazala et al. 2006).

Multi-level galleries generally can be divided into:

- multi-level warehouses of shelving racks,
- multi-level warehouses of pallet racking,
- multi-level warehouses of a steel structure,

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- multi-level warehouses with building modifications,
- combined multi-level warehouses.

Also, **mobile shelving racks** are included in this category; they are used for manual loading with direct access of people to shelves. The usage of mobile shelving racks is primarily in archives, handy warehouses, for issuing tools and spare parts, depository warehouses and where non-pallet goods need to be stored (Bazala et al. 2006).

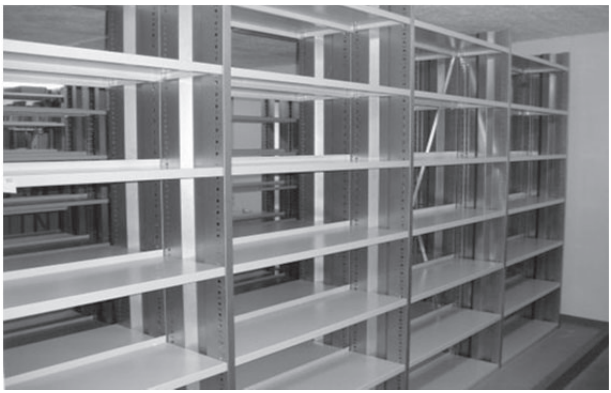


Figure 40 – Shelving racks[9]

Pallet racks (Figure 41) are used for storage of all types of pallets, crates and boxes of all sizes and for piece-goods stored freely. Loading operations are possible with various types of forklifts, rack stackers and manual operation with direct access or using complete systems.

The storage height of rack systems is up to 10 000 mm, with the maximum width of the rack column up to 4 000 mm. The maximum permissible load of a pallet rack column, according to type of construction, is about 32 000 kg (Bazala et al. 2006).

[9] http://www.dirp.cz/sk/policove-regaly

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Figure 41 – Pallet racks[10]

Entrance (tunnel) racks of a DRIVE-IN type (Figure 42) are without serving corridors. The entrance racks are designed for loading pallets of the same dimensions in one tunnel. The negative aspect is unavailability of pallets loaded inside the warehouse system and there are limited application possibilities for accessories. The positive aspect is the high utilization of the warehouse space (Bazala et al. 2006).

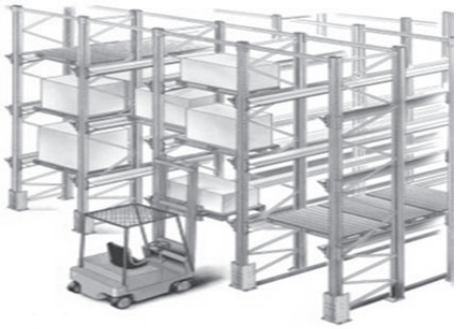


Figure 42 – Rack of a Drive-In type[11]

Gravity racks (Figure 43) are the same type of structure as entrance racks, in particular, tunnels are not occupied by runners for static storage pallets, but by a roller track on particular loading levels. The disadvantages of gravity racks include unavailability of pallets during

[10] http://www.mecalux.sk/paletove-regaly/standardni-paletovy-regal
[11] http://www.kredit.cz/vyrobky/sklady/paletove-regaly/vjezdove-regaly-drive-in

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storage and the high investment costs. The advantage is the utilisation of the storage area and compliance with the FIFO system without any significant requirement for an inventory system of units (Bazala et al. 2006).



Figure 43 – The gravity rack[12]

Mobile pallet racks (Figure 44) are suitable for conventional standard storage. They are suitable for environments with a low temperature (refrigerators, freezers). The advantage of these racks is, if the mobile units are set into a block with a single service corridor, it is possible to achieve: an increase in capacity of current storage space, the maximum possible capacity in the considered area for designing the new warehouse with FIFO operations, reduction of investment for the construction of a building of the defined capacity, significant energy savings in the operation of the warehouse (Bazala et al. 2006).



Figure 44 – Mobile pallet rack[13]

[12] http://www.primus.sk/sk/kategorie/167/SPADOVY-A–VLECKOVY-REGAL.html
[13]http://www.regaz.cz/sk/page/2648.pojizdne-regaly-archivni

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Console racks are suitable for the storage of metallic and plastic profiles with some greater lengths, pipes, timbers, rod intermediate products, plate goods such as metal plates, etc. Storage of these products in racks can be performed using various types of forklifts, cranes and manual operation with direct access or with the use of completing trucks. The rack can be adjusted according to the load, height and nature of the stored goods. The construction of console racks can be single-sided, stationary or mobile (Bazala et al. 2006).

4.7.5.2 Storage Technologies for Storage of Bulk Material

Large single-floor buildings are chosen for bulk materials. The equipment of a warehouse for bulk materials is different from the equipment for a piece-goods warehouse, and internal transport is also managed differently. Floor storage with an aeration mechanism are used for storage of cereals. Steel warehouses, bunker storages that are fully mechanized with active aeration or no aeration are other possible means for storage of cereals. Bulk materials are an important part of the material flows in logistics chains, as well as in supply. Bulk materials can be stored in two different ways:

- in stockpiles,
- in tanks.

Stockpiles are suitable for long-term storage of bulk materials in smaller quantities and for materials which are not influenced by the weather. These materials are: building materials (sand, gravel, stones, etc.), coal, coke, etc. The design side of stockpiles is generally solved as hard surfaced areas (concrete, metal or coated grit) with sufficient load capacity for the machinery used. Important parameters include the floor loading capacity and suitable and sufficient drainage of the storage space. These areas provide mass storage (building materials), freely accessed by handling equipment (cranes, conveyors) or road vehicles, or in layers generally served by bulldozers (Danek, Pavliska 2002).

Tanks are used for short term storage of bulk, or lump materials. The volume of stockpile capacity can be thousands of cubic meters. Tank volume ranges are in ordinal units, principally not more than a few dozen m^3. Tank capacity is mainly dependent on the required size of storage and also on the irregularity of supply of a material. Tanks are components of technological and transport operations. The aim of this storage technology is to fully provide the needed supplies for the smooth running of technological lines or transport facilities. The task of tanks is to

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synchronize supplies of goods between a customer and the material (Danek, Pavliska 2002).

As determined by the type of stored material, tanks are divided into:

- containers for piece-materials, containers for bulk materials,
- containers for liquid materials, containers for gaseous media,
- special containers (for nuclear waste, chemical material, etc.).

Structurally, the most diverse types of tank containers are for bulk materials, because bulk materials are the most widespread raw materials in transportation and handling. Very often in practice it is possible to see two types of tank containers for bulk materials:

- Bunkers – low tank containers;
- Silos – tank containers.

Bunkers are low tank containers. Their shape is based on the purpose and nature of the stored materials. Emptying and filling bunkers is carried out from the top and from the bottom. They are made of different materials (usually steel). They have various shapes depending on the transport conditions and the type of stored material (Danek, Pavliska 2002).

Silos (Figure 45), their horizontal dimensions are generally much less than their vertical dimensions. Silos are almost always closed from the top, which differentiates them from bunkers. They are filled from the top. They are emptied from the bottom or even on different levels from the side. They are designed mainly for storing predominantly fine-grained and powdered materials (fine sand, cement, cereals, bulk feed) or raw materials for food (flour). Silo are usually filled pneumatically, they are emptied by gravity or also pneumatically, when emptying is performed from the side (Danek, Pavliska 2002).



Figure 45 – Tank containers for bulk materials[14]

[14] http://www.spaim.sk/images/sila_4.jpg

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4.7.6 Handling Tools in a Warehouse

This part relates to technical tools and equipment. Equipment is divided in equipment for handling piece-goods and equipment for handling bulk materials. With developed technology, it is just a question of the financial means of the company which handling tools it chooses for the storage of goods in a warehouse. When choosing the handling equipment which will be used in storage operations in a warehouse, the designer has to take into account the rapid growth of technology and he has to design the warehouse to be as flexible as possible for future development.

4.7.6.1 Handling Equipment for Piece-goods in a Warehouse

Handling equipment moves the handled material from the point of origin to its destination in batches, in closed working cycles, which may vary depending on the batch size, speed of movement, track and time intervals between batches (Boroska, Saderova 2001).

The machinery can be divided into:

- transport trolleys,
- cranes,
- shovel excavators and bulldozers,
- lifts (elevators),
- scraper mechanical shovels and rope dozers.

The most commonly used technical tools of storage operations are transport trolleys. They carry material horizontally and vertically. They are used for loading and unloading directly into the vehicle from ramps and bridges.

Trailers have heavier construction. They are four-wheel or multi-wheel, trackless or rail-borne vehicles with a drawbar or a truck with drawbar that can be harnessed behind a vehicle to pull it.

The towing instrument of trailers is a chain (or a rope). Trailers are arranged to circulate continuously at a working place. They do not have a driving engine.

Hand carts (hand pallet truck) are used for loading piece-goods, boxes and parcels for short distances (Figure 46). These carts are without their own drive power; they are towed or pushed by human power (Boroska, Saderova 2001).

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Figure 46 – Hand pallet truck[15]

According to their working purpose, powered vehicles are divided into five basic groups (Boroska, Saderova 2001):

a) towing vehicles,
b) trucks with a fixed or hinged bay,
c) low-lifting trucks,
d) high-lifting trucks,
e) cranes.

These basic groups contain more detailed classifications, which are included in STN 26 8802 – Powered trucks – marking types and STN ISO 5053 (26 8810) – Powered industrial trucks – terminology.

a) Towing vehicles are divided into (Boroska, Saderova 2001):
   - Double axel towing vehicle – powered truck designed to tow or to push other vehicles or loads.
   - Saddle towing vehicle – towing vehicle designed for transporting a semi-trailer.
   - Automatic towing vehicle – towing vehicle with automatic or programmatic control.

b) Trucks with a fixed or hinged bay are divided into:
   - Platform truck – trolley without a height-adjustable carrier, designed to carry loads.
   - Platform truck with a solid body.
   - Special truck.
   - Truck with a tipping body.

[15] http://www.rokotep.sk/webimages/vozik-rucny.jpg

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c) Low-lifting trucks are divided into:
   - Flat low-lifting truck – truck with a low-lifting platform designed for the horizontal movement of storage platforms.
   - Fork low-lifting truck – truck with a low-lifting fork designed for the horizontal movement of pallets.
   - Gantry low-lifting truck – designed for moving loads.

d) High-lifting trucks are divided into:
   - **Trucks with lifting platform – forklifts** (Figure 47) are used for storage of piece-goods, mainly pallets and stacked crates. According to their design, they are divided into low-lift and high-lift forklifts. Low-lift forklifts can lift up to 200 mm, high-lift forklifts can range from 1500–6000 mm, according to the manufacturer. These may be operated manually, with a sitting or standing operator (Boroska, Saderova 2001).

The structure of forklifts comprises a fork (front, side, telescopic forks) or other tentacles, which are used for loading and unloading various rolls, discs, etc.

Types of forklifts (Stuart 2008):

- **Forklifts with forward forks –** most often used in practice. They are used in wide corridors, because they have a wide angle of turning. On the rear side is a counterweight.
- **Forklifts with protruding forks –** used for manual pallet rack servicing. They are used in narrow corridors. They are only produced as battery driven.
- **Forklifts for narrow corridors –** Their work is in very narrow corridors. They are divided into two basic types. Trucks with turnable forks up to 90 degrees are similar to standard forklifts with protruding forks. The second type is a forklift with turnable forks up to 180 degrees.
- **Man-up forklifts –** They are designed for manual picking in various narrow corridors. They are divided into two basic types. Truck with turnable forks up to 90 degrees are similar to standard forklifts with protruding forks. The second type is a forklift with turnable forks up to 180 degrees.
- **Forklifts with hinged forks –** They can move inside a warehouse, but also on external transport journeys. They are preferred because they are multifunctional. Companies do not have to purchase two devices for internal and external transport.

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Figure 47 – Classic forklift[16]

Lifting devices are also used – **cranes** (bridge, gantry, turnable cranes) of various loading capacities which can be equipped with interchangeable types of girders, grabs and other non-tie tools to move more products, for storage of piece-goods of a large size and weight (sheets, coils, wood, etc.) (Boroska, Saderova 2001; Saderova 2010).

4.7.6.2 Handling Equipment for Bulk Material in a Warehouse

Known equipment for bulk materials and handling them include (Boroska, Saderova 2001):

- cyclically operating reloaders – universal front loaders, excavators, grab cranes, mechanical shovels, wagon tippler;
- continuously operating reloaders – conveyors – transporters: belt, steel belt, screw, redler, aeromechanical.

Known equipment for bulk materials and handling them include (Boroska, Saderova 2001):

Selection of these types of this equipment for reloading depends on the type of bulk material and the situation in the building where the reloading will take place. This equipment is described in the text below.

Cyclically operating reloaders for bulk material include (Boroska, Saderova 2001):

- **Universal front loaders** – their use is mainly for loading freely stockpiled materials (stone, ore, sand, etc.) using shovels.

[16] http://www.rokotep.sk/webimages/vozik2.jpg

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- **Excavators** (Figure 48) – are equipped with a grab sampler, designed to transfer freely stockpiled materials.
- **Grab cranes** – used for transferring bulk materials.



Figure 48 – Excavator[17]

- **Mechanical shovels** – rake out the bulk material through the door opening of rail cars to elevators (cereals, etc.).
- **Wagon tipplers** – used for unloading materials from rail cars.
- There are various types of conveyors and pneumatic equipment which are classed as **continuously operated reloaders**.

Pneumatic conveying equipment (Boroska, Saderova 2001) for material reloading:

- **Suction kits** are suitable for transportation of bulk, easy-flowing materials. Granularity of materials can be from a fine dust to pieces as large as 100 mm. Basically, it is a large high-performance industrial vacuum cleaner and suction conveyor at once.
- **Telescopic filling nozzles** are used for ecological handling (filling, transport, and unloading) of dry, loose and non-adhesive materials. They are suitable mainly for flour, bran, cereals, animal feed, sugar, salt, cement, gypsum, fertilizers and powder-paint.

[17] https://www.whonnockrentals.com/wp-content/uploads/2017/03/cat–303–5e2–cr–01.jpg

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4.7.7 The Degree of Warehouse Mechanization

This subchapter deals with selecting the appropriate degree of warehouse mechanization. It is about the mechanization tools in a warehouse and the degree of mechanization and how they depend on the type of material stored. It has to be noted that there are two factors in opposition in choosing an appropriate level of mechanization. When a warehouse is constructed with a low degree of mechanization, generally it results in high labour costs and low cost of operation of devices. Conversely, when there is a high degree of mechanization or automation, labour costs fall, but costs for procuring and operating equipment per handled unit rise after the calculation. It is necessary to assess whether it is appropriate to go the way of increasing the number of manual workers or improving the performance of the warehouse through full mechanization or automation (Kovac 1984).

The index of the degree of mechanization and automation in a warehouse *Km* (4):

$$Km = \frac{zr - za}{zr} \times 100\ [\%] \tag{4.4}$$

zr – expresses the number of workers in a warehouse before the introduction of mechanization,
za – expresses the number of workers in a warehouse after the introduction of mechanization.

Automation and mechanization simplify storage, reduce costs, relieve workers from physical tedious work, or work in harmful or hazardous environments. They improve the quality of storage.

Depending on the degree of mechanization and warehouse technology, warehouses are divided into (Starzyczna 2013):

- **A manual warehouse** is a warehouse, where goods are handled manually by the hands of workers.
- **A mechanized warehouse** is a warehouse, where various tools of mechanization for goods handling are applied. This is not addressed as a whole, but this mechanization deals with only partial movements of goods in the warehouse.
- **A highly mechanized warehouse** contains advanced technology, certain items of automation, but the reception, storage and release of stock are performed by workers.
- **An automated warehouse** (Figure 49) includes part of the movement of goods arranged automatically.

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- **A fully automated warehouse** is a warehouse that has all handling processes fully automated.

The degree of mechanization of a warehouse is based on the nature of the stock (it can be piece or bulk), on the number of type of goods, the number of customers, the speed of the system, the investment costs and operating costs, the assortment (goods turnover), and the size of the goods (Starzyczna 2013).

Off-line warehouse management is not an interconnected system. This means that there is no direct link between the flow of information and the flow of goods. Difficult decisions and commands are executed by humans (the majority of high-rise warehouses). If a device for information processing is connected directly to the physical flow of goods, it is an interconnected on-line system. Humans perform only control. These warehouses are technically feasible, but their operation is quite expensive (Starzyczna 2013).

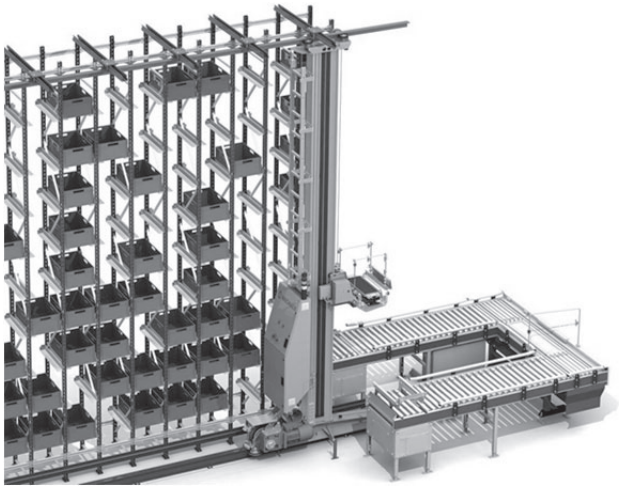


Figure 49 – Automated rack warehouse[18]

In the process of goods storage there is an average of two to six handling operations. *"The costs of goods handling consist of about 35% of the total costs of the process"* (Straka 2013). The area of warehouse

[18] https://mecaluxsk.cdnwm.com/automaticky-sklad-krabice/zakladace/img1.1.2.jpg?imageThumbnail=3

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automation requires maximum attention and there is a need to effectively enforce the most progressive methods and technical tools.

Automated warehouses provide functions of: reception, storage, registration and release.

The rack storage system is the most widely used variant of the automated warehouse. The volume and dimensions of the warehouse are defined by the typical material in stock. A rack storage system with automatic vertical collators occupies a small volume with a high capacity, it has high mobility and is easy to automate. An automated rack warehouse consists of the following basic items (Straka 2013):

- a racking structure,
- an automatic stacker,
- a device to transfer pallets (full and empty) from the stacker to the buffer,
- a device for transporting pallets from the buffer to the transport system,
- hardware and software system of automatic control.

Robots and Handlers in a Warehouse

The most important factors at the design of a robotic warehouse are the properties of goods. Goods classification determines what degree of automation of handling operations may be used in a warehouse. Consideration must be given to:

- handling units (pallets, containers, etc.),
- bulk materials,
- size, weight, shape of goods (geometric shape, regular shape, irregular shape),
- the risk of damage (fragility, corrosiveness, etc.),
- the condition of the goods (temperature, humidity, pollution, etc.).

Piece-goods with regular geometric shape without specifying limits are the best suited for robotic simplicity of workplace, because they enable group handling. The main goods handling operations suitable for robotics are (Buda, Kovac 1990):

- transport of material ensuring the link between inputs and outputs of technological workplaces and warehouses,
- palletizing and de-palletizing of goods,
- combining transport flow (with the same or different types),
- handling operations during storage,
- handling operations in support activities (packaging, cleaning, etc.).

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Robots can transport goods directly and transport is the most often provided by mobile (hanging, or ground) types of industrial robots. These robots are capable of transporting pallets or containers. Other variations of such robots in transportation include automatically guided trolleys, rack stackers, etc.

Automatic handling equipment is divided into (Boroska, Saderova 2001):

Single-purpose handlers provide only one or a few simple movements and are often a part of the machine and adapted to the type of machine for which they are intended. Combining several single-purpose manipulators can create more complex handling actions.

Universal handlers have a higher number of handling options, range of motion, accuracy and load. They are constructed to be independent of machine operation; they are individual and often mobile.

Synchronous handlers (teleoperators) are managed remotely by a person either by signals or by special equipment copying the movements of their hands.

Handlers with fixed programs work automatically without direct human intervention.

Handlers with changeable programs are customizable by changing the program and have greater mobility possibilities.

Cognitive robots are able to identify and analyse the situation and adjust their behaviour based on that. They are able to orientate themselves in space, to recognize the handled object, to evaluate their position.

All known kinds of robotic equipment are used in a warehouse with inter-operative transportation. The most preferable variants are belt and roller conveyors. In addition to the standard conveyor solutions there are flexible conveyor stations that enable the movement of goods in both directions, the separation of goods into multiple traffic flows and program control.

Conveyors

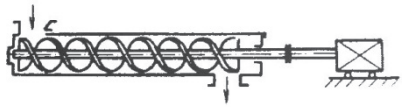
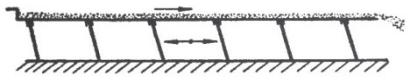
They are used to transport bulk goods, but also small piece-goods materials at distances from a few metres to a few kilometres. It is one of the simplest, most reliable and cheapest ways to transport bulk material. Typical materials for a conveyor are: cereal grain, malt, groats, small coal, sugar, cement, sand, clay, coke breeze, stones, mineral ores, salt and others.

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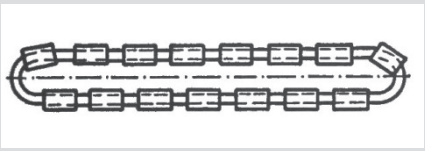
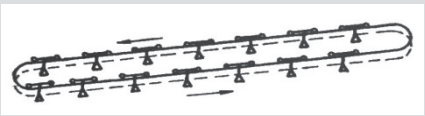
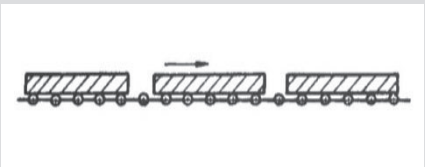
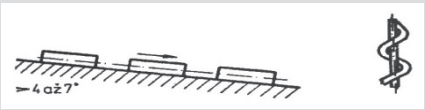
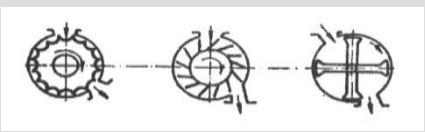
The main principles for the design and operation of belt conveyors:

There has to be access permission along the route of a conveyor construction. Transfer from one conveyor to another conveyor must be designed in such a way that the material does not fall from a great height and especially not at right angles to the next belt. The material should be fed in the direction of belt motion. Inter-structure conveyors are best placed in closed steel or concrete troughs. It is necessary to maintain the cleanliness of the belt to prevent material dropping below the lower side of the reversible drum on the bottom roller bench. In practice, there are usually metal conduits that prevent loss of materials. Belts must follow a straight line, otherwise they wear down quickly (Buda, Kovac 1990). Choosing the right conveyor (Table 5) is based on the properties of the bulk material (moisture content, flowability, grain size, etc.). The following types of conveyors – transporters are the most frequently used:

Table 5 – Types of conveyors (Trosanova, Straka 2011)

Conveyors – transporters	belt		Most often used for bulk material and in specific cases for piece-goods.
	chain		Used with a wide variety of bulk materials (fine to boulder) and mass piece-goods.
	screw		Used for the transfer of granular materials such as corn, rice, flour.
	vibrating		Bulk material moved based on vibrations.

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	elevator		Vertical transport of granular materials.
	trolley		Transportation of bulk materials and piece-goods by connected trolleys.
	hanging		Transportation of individual handling units, mainly piece-goods.
Loading tracks	roller		Inter operation transport of: cartons, parcels, materials and products stored on solid supports (pallets, crates, boxes).
	gravity		Equipment for loading piece goods onto a conveyor.
Feeders	redler		Transportation of bulk non-abrasive materials.
	tourniquet		Volumetric batching of bulk granular material from buffers.

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4.8 The PDS Model – Project for Distribution Stock

The PDS model is an instrument for efficiently and quickly determining a conceptual warehouse design. The final version of the conceptual design of the warehouse is obtained through algorithmic processing. The PDS model was created as a tool for a conceptual warehouse, respecting the high investment costs required to build a warehouse. It is necessary to take into account items whose meanings are important for building a warehouse, when creating the model.

Real processes involving warehousing can be captured in the form of the analytical model. The output of the model can get answers to questions of what goods will be stored, what means of transport will supply and deliver the goods, what means of handling will be used in the warehouse, what degree of mechanization will be used, what warehouse technology will be installed and others.

The practical purpose of creating the PDS model is the solution of variant situations that may arise during the design and construction of the warehouse. The basis of the model is system analysis further depicting the parameters and constraints of all items that influence the building of a warehouse and it is important to follow the certain sequence of the procedure. The content of the model specifies distribution-logistics warehouses and their conceptual design, not special types of warehouses, which are the subject to fixed standards and existing laws.

The PDS model (4.5) consists of a set of items that influence the design of a warehouse. The basic model, the equation for the distribution warehouse project can be created from a finite number of variables (Trosanova, Straka 2011).

$$PDS = \{T, R, D, M, S, P, I, L\} \tag{4.5}$$

Acting as input to the PDS model and their properties:
T – variable representing the type of goods to be stored.
R – variable representing warehouse size, area and volume data of the warehouse and warehouse floors.
D – variable representing the type of means of transport by which the goods will be loaded and unloaded.
M – variable representing the degree of mechanization and automation for warehouse stock, which determines the type of warehouse receipt, storage and dispatching.
S – variable representing the technology used in the warehouse.

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P – variable representing the handling equipment that will perform storing operations on goods.
I – variable representing the use of information technology and the information systems to be used in the warehouse.
L – variable representing the people, the number of workers in the warehouse.

4.8.1 Characteristics of PDS Model Variables

The content of variable *T* is the type of goods that will be stored in the warehouse, taking into account their physical and chemical properties. The variable *T* is relevant as a variable which influences other variables in the proposed model of a warehouse.

This particular variable can take the following values (Trosanova, Straka 2011):

- *K* – piece-goods, which can be measured in:
  - *pcs* – quantity in pieces,
  - *hu* – handling units,
  - *pu* – pallet units.
- *S* –bulk material, which is in mass units:
  - *g* – gram,
  - *kg* – kilogram,
  - *t* – tonne.
- *LS* – liquid substrate, which is in volume units:
  - *ml* – millilitre,
  - *cl* – centilitre,
  - *dl* – decilitre,
  - *l* – litre,
  - *hl* – hectolitre.

The values of this variable influence the warehouse project and the warehouse devices used for the storage of goods.

Variable *R* represents data on the surface and volume of the warehouse. Warehouse size can be expressed in two ways. The first is to determine the storage surface, which is interpreted in square metres. This method does not reflect the vertical storage of goods. The second option is to determine the storage space in cubic metres, which refers to the total volume of space. Calculations for the warehouse space apply the existing formula for piece-goods and bulk material. This variable has the values:

- *sl* – the storage length of the warehouse,
- *sw* – the storage width of the warehouse,

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- *sh* – the storage height of the warehouse,
- *sf* – number of floors of the warehouse.

R_K (Warehouse for piece-goods)

The variable R_K represents a piece-goods warehouse. It is necessary to make the necessary calculations for its construction. The calculations should be based on the logistical and project requirements for the type of warehouse. The amount of material is given in pieces or in number of handling units. The type of handling units depends on the stored material, for most piece-goods warehouses this is pallets. It is possible to use the following formula for a piece-goods warehouse:

$$R_K => R_p \tag{4.6}$$

The importance of formula (4.6) lies in the connection of variables which implies, if a warehouse is for piece-goods, the model can include a multi-floor warehouse.

$R_{K, sf}$ (Size of a warehouse for piece-goods, number of floors)

This variable is the basis for the structure of the warehouse building, where the possibility of multi-floor solutions is limited only to piece-goods. This variable has a numeric value.

Floor load levels have to be respected (e.g. on the second floor of a warehouse only lighter goods like textile products are placed). Standards show that each floor of a warehouse must be equipped with sanitary facilities for warehouse workers. This set of variables includes elevators, regulations and statutes related to their operation.

R_S (Dimensions of a warehouse for bulk material)

For the construction of the bulk material warehouse, different calculations need to be performed than for a warehouse for piece-goods. The volume of stored material is measured in the number of tonnes or in number of handling units. The number of tonnes of stored material is generally indicated for freely stored bulk material with floor storage, while the number of handling units is generally characteristic for storage of piece-goods.

The means of goods receipt depend on the type of means of transport. The variable *D* represents the means of transport from which the goods are unloaded and dispatched. The designer should take into account the construction and building requirements for ramps of the warehouse and he must know whether the receipt or dispatch of goods will be carried out

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by rail or road transport. The best way is when a vehicle arrives at the destination and goods are unloaded to the desired location by handling tools which do not have to deviate from their trajectory of handling and storing operations.

In this variable, it is necessary to know what kind of means of transport will be connected to the warehouse building. The variable has the values:

- D_Z – direct connection of railway wagons to a warehouse, to which the goods are imported and then dispatched.
  This variable has a value in terms of method receiving and dispatching goods:
  - v – siding, which connects a warehouse with the railway line.
- D_C – this variable shows road freight transport, which includes trucks, which are used in the supply and shipment of goods.

Mechanization and automation are essential to the model of a warehouse and they are included in the variable M. This is a tool to improve the performance and competitiveness of the warehouse. The variable has the values:

- M_m – mechanized warehouse,
- M_a – automated warehouse.

The group of mechanized warehouses M_m (4.7), where a human activity in handling operations is required, includes:

$$M_m \{r, p_m, f_m\} \tag{4.7}$$

- r – manual,
- p_m – partly mechanized,
- f_m – fully mechanized.

The group of partly and fully automated warehouses M_m (4.8), where human activity in handling operations with goods is not required, includes:

$$M_a \{p_a, f_a\} \tag{4.8}$$

- p_a – partly automated,
- f_a – fully automated.

If a company requires the highest performance of a warehouse, which requires high investment costs, then the level of mechanization in the warehouse will be fully and partially automated without any help from

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humans. People will be replaced by robots and handlers. Reception, storage and dispatching will be fully automated.

The contents of variable *S* are storage technologies; the type of which depends on goods storage. The storage equipment is a part of the project from the beginning. The aim of the correct choice of technology is for the storage area to be used most efficiently, flexibly and without bottlenecks. The storage technology variable S, has the values:

- k – storage technology for piece-goods,
- s – storage technology for bulk material.

S_k (Storage technology for piece-goods)

This variable is used in the piece-goods warehouse; the following formula applies:

$$T_k => S_k \tag{4.9}$$

The importance of the formula (4.9) lies in the relationship of the variables. The choice of storage technology depends on the type of stored goods. In this relation it holds that if the warehouse is for the storage of piece-goods T_k, then the storage technology will be chosen for piece goods S_k. The variable has the values:

- pr – pallet racks warehouses,
- pr_i – shelving racks warehouses,
- v_j – entrance shelves warehouses,
- s_r – gravity racks warehouses,
- p_o – mobile racks warehouses.

***S_s* (Storage technology for bulk material)**

Part of this variable is the storage technology for bulk material, where the following formula holds:

$$T_S => S_s \tag{4.10}$$

Bulk storage technologies are used for the storage of bulk materials T_S (4.10). They are different from the storage technologies used for piece-goods. The variable has the values:

- ps – platform storage of bulk material, which has the values:
  - p_v – open air bulk storage,
  - p_z – covered storage,
  - p_u – closed storage.

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- z – containers for the storage of bulk materials, which have the values:
  - z_b – bunkers,
  - z_s – silos.

The variable P represents handling equipment intended for handling goods in a warehouse, for reloading onto carriers and for transfer between vehicles. Nowadays the perfect handling equipment varies. Handling equipment depends on the nature of the goods and the environment (4.11) in which handling is carried out. The implication can be defined as:

$$T => M => P. \tag{4.11}$$

The variable P is dependent on the variable T (type of goods). The handling equipment which is used for storage of goods will be based on the construction the warehouse for piece-goods. Handling equipment is also dependent on variable M (**degree of mechanization and automation in a warehouse**), whether a warehouse will be fully automated, semi-automated or mechanized. Variable P can be elaborated as:

- k – the handling equipment for piece-goods,
- s – the handling equipment for bulk material.

P_K (The handling equipment for storage of piece-goods)

Handling equipment is used for easy transport of piece-goods from a vehicle to a destination in a warehouse. The variable depends on the type of goods and the mechanization of the warehouse, which is described by the above relationship. The variable has the values:

- t_v – towing vehicles,
- t_f – trucks with fixed or hinged bays,
- t_l – low-lifting trucks,
- t_h – high-lifting trucks,
- t_c – crane trolleys.

P_S (Handling equipment for storage of bulk materials)

The task of handling equipment for bulk materials is to store bulk material. This variable also depends on variable T. The choice of handling equipment used for bulk material storage will be based on the type of material to be stored in the warehouse. Handling equipment for bulk material is also dependent on the variable M, i.e. whether a warehouse will be fully automated, semi-automated or mechanized. The variable has the values:

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- f_l – universal front loaders,
- e_r – excavators,
- g_c – grab cranes,
- m_s – mechanical shovels,
- w_t – wagon tipplers.
- X_c – conveyors, which are:
  - b_c – belt conveyors,
  - ch_c – chain conveyors,
  - s_c – screw conveyors,
  - v_c – vibrating conveyors,
  - e_c – elevator conveyors,
  - h_c – hanging conveyors.

In a warehouse where the predominant use of handling equipment is for bulk material, an alternative is also to use handling equipment for piece-goods, and vice versa.

If a bulk material is stored in a warehouse it can be freely stockpiled, where conveyors, mechanical shovels and other equipment for the storage of bulk materials are used for handling. On the other hand, it can also be stored in bags and handling equipment can be used such as forklifts and equipment for storage of piece-goods. This means that the parameter in the algorithm will have a common basis of choice, the customer's equipment selection is not limited and the condition of flexibility of the model is fulfilled.

The variable *I* represents the state of information technology and systems applied for the needs of the functional side of a warehouse. It contains the part of *IT* focused on specific information technology and the *IS* part, which is focused on storage information systems. The *IT* parameter for piece-goods has the values:

- *AIS* – Automatic Identification Systems, which further includes:
  - b_c – bar code,
  - *OCR* – OCR technology,
  - v_t – visual technology,
  - *RFID* – Radio-frequency technologies,
  - i_t – inductive technologies,
  - v_{is} – voice identification system.
- K_s – communication standards:
  - *EDI* – Electronic Data Interchange,
  - *XML* – format for the transmission of general documents.
- S_n – Satellite navigation:
  - *GPS, Glonas, Galileo.*

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The *IT* parameter for bulk material:

- *Sa* – scales, which are divided into:
  - *rs* – rail scales,
  - *ts* – truck road scales,
  - *cs* – crane scales,
  - *bs* – conveyor scales (built-in belt conveyors),
  - *ts* – scales in tanks.

The specific use of the information system within the parameter *IS* of the IT system should be taken into account:

- SAP,
- KARAT,
- Exact Globe,
- MFG/PRO,
- POHODA,
- Money S3,
- OR – SYSTEM and others.

In variable *L*, it is necessary to pay attention to the structural and design requirements for human health in a warehouse. This variable has numeric values; this means the number of people in a warehouse. After getting information about the number of people meant to be in a warehouse, the designer has to include sanitary facilities for employees. The variable depends on the degree of mechanization in the warehouse. Its meaning is defined and supported by laws and regulations that form an integral part of occupational safety and health (OSH) for workers in a warehouse. The variable *L* must consider working areas for employees, such as:

- free floor space for one employee (min. 2 m^2),
- headroom for permanent workplaces,
- headroom for transitional workplaces,
- width of corridors and other construction and spatial conditions.

Another factor which must be taken into account is workplace safety and security of storage areas. Marked and controlled emergency walkways must be permanently unobstructed in the case of evacuation for warehouse employees. It is also necessary to take into account the height of the stacks, their stability and compliance with permissible amounts so that stacking pressures are not exceeded. Racks and as well as other storage technologies must be operated, maintained and repaired in accordance

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with the requirements of the valid applicable regulations, which must be defined in the storage and handling procedures of the warehouse.

4.9 Calculation of Warehouse Capacity

Dimensioning a warehouse as one of the items of the distribution network is dependent on the determination of its capacity, which takes into account external and internal criteria. The size of the warehouse space has a direct impact on the capacity of a warehouse. The degree of utilization of warehouse space is expressed in terms of the capacity of the warehouse, which is expressed in units (tonnes – mainly for bulk materials, m^3, m^2, and warehouse capacity can also be expressed in terms of the number of trucks, wagons etc. whose contents can be stored in a warehouse or the number of handling units – the most common are pallets).

The calculation of warehouse capacity indicates how much material, raw materials, intermediate-products and goods can be stored in a warehouse, taking into account the equipment of the warehouse (rack stackers, shelves, storage shelves ...). Storage capacity within the distribution system can be determined from the quantity of goods, the materials to be stored in a warehouse. Improper storage capacity, wrong sizing of a warehouse as a distribution network item results in it being undersized or oversized. From a functional point of view this may lead to unsatisfied customer demands.

If there is the warehouse is undersized it leads to storage of goods and materials outside the defined storage area in traffic lanes and passages, reducing the handling of goods in the warehouse and increasing the risk of damage to goods and the occurrence of potential accidents. If a warehouse is oversized, storage areas are not used, which increases the costs per unit of stored goods.

In determining the calculation of warehouse size, spaces in the warehouse are considered; these can be divided in terms of their use into (Straka 2007):

- operational space,
- auxiliary spaces,
- administrative and sanitary spaces.

The operational areas consist of space for the storage of materials, intermediate products and goods for transport.

Auxiliary spaces are spaces for quality control of materials, spaces for treatment and packaging of materials, preparation and shipment of material.

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The administrative and sanitary spaces are offices and spaces for the employees of the warehouse.

Warehouse capacity can be calculated according to the formula (4.12):

$$K_S = S_{OC} \times \bar{h} \text{ [m}^3\text{]} \tag{4.12}$$

K_S – warehouse capacity [m^3],
S_{OC} – area of real operational space, i.e. area without crossings and traffic lanes [m^2],
$\bar{h}$ – the average height to which it is possible to store goods – influenced by the type of material, the height of a warehouse and the technical equipment of the warehouse [m].

The real area of operational space can be calculated according the formula (4.13):

$$S_{OC} = S_O - S_D \text{ [m}^2\text{]} \tag{4.13}$$

S_O – total area of operational space (storage space, traffic lanes, crossings...) [m^2],
S_D – area (4.14) of traffic lanes and crossings [m^2].

$$S_O = S_S + S_P + S_V + S_D + S_M \text{ [m}^2\text{]} \tag{4.14}$$

S_S – storage area [m^2],
S_P – area for goods receipt [m^2],
S_V – area for issuing material [m^2],
S_M – area for handling spaces [m^2].

The storage area depends on the type of material to be stored. Different areas can be used for bulk materials and others for general material. Based on the type of stored material, two approaches to the calculation of the storage area for bulk material S_S and S_S for solid material are considered.

The storage space area for bulk materials is calculated according to the formula (4.15):

$$S_S = \frac{Q}{\rho \times n \times \eta} = \frac{V}{n \times \eta} \text{ [m}^2\text{]} \tag{4.15}$$

S_S – the storage area for bulk material [m^2],
Q – the amount of the stored material [t],

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ρ – the specific density [t. m^3],
n – the medium height of the filling material [m],
η – the coefficient of utilization of the storage area (0.4 – 0.6),
V – the volume of the stored material [m^3].

The storage space area for solid materials is calculated according to the formula (4.16):

$$S_S = \frac{N_S \times V_S}{M_S \times h_S \times \eta} = \frac{R_S \times f_S}{\eta} \text{ [m}^2\text{]} \tag{4.16}$$

S_S – the storage area for solid material [m^2],
N_S – the number of handling unit stored s [pcs],
V_S – the storage volume of one handling unit [m^3],
M_S – the number handling units stored [pcs],
h_S – the storage height [m],
R_S – the number of stacks [pcs],
f_S – the storage area of one handling unit [m^2].

The area for goods receipt S_P depends on the measured value of the received material. Normally 1 m^2 per 1 ton of material received daily is used. If standard material is received into a warehouse with a high specific density, then a lower area can be sufficient for goods receipt and vice versa for materials with lower specific density – a larger surface is needed for goods receipt.

The area for issuing stock S_V also depends on the density of the material issued but normally 1.6 to 2.4 m^2 per 1 ton of daily stock issued is used.

The area for transport lanes and passageways S_D is given by the sum of all areas of transport lanes and passageways by (4.17).

$$S_D = \sum_{i=1}^{n} s_i \times l_i \text{ [m}^2\text{]} \tag{4.17}$$

n – the number of transport lanes and passageways,
i – the index of a lane, a passageway ($1,2,3,\ldots,n$),
s_i – the i^{th} lane width,
l_i – the i^{th} lane length.

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The width of traffic lanes and passageways is dependent on the type of handling equipment used and the manner of organizing the movement of handling equipment, i.e. whether there is one-way or two-way transport operation, or if the lanes are single or multi flow.

The area of handling spaces S_M is dependent on the type of storage and the handling equipment used. The manufacturer of each type of handling equipment specifies the required width for the safe transport and handling space (lane), in which the equipment has to be safely turned around and moved.

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CHAPTER FIVE

INFORMATION AND COMMUNICATION TECHNOLOGIES IN DISTRIBUTION AND SUPPLY LOGISTICS

What you will learn: Nowadays, a modern company cannot imagine a operating without the use of a quality information system and information technology. Within distribution logistics it is also necessary to transfer, record and edit a large quantity of information. For this purpose, there are various systems that enable quick identification of inventory items, enable the fast exchange of various formal and informal documents, enable the management, monitoring and control of distribution and transport and enable communication between partners without their direct physical presence. This chapter is devoted to information technologies and systems that raise the function of distribution to a level that reduces the risk of errors many times and speeds up activities related to administration, implementation and identification.

Basic terms: information systems, technologies, AIS, EDI, GPS.

5.1 Information Technology Items

Logistics systems supported by information technology items are strongly connected to the distribution of goods and raw materials. They are an integral part of the work of managers in distribution logistics, production scheduling, and in finding the optimal location of warehouses, shops, production lines, machinery, distribution and technical centres. The use of available quantitative methods speeds up, clarifies and improves the overall decision making of managers. Distribution and quality proposals and fast decisions by managers in this area are crucial for the activities of producers, distributors and the consumers themselves.

Distribution connects production with the market or it connects the end of the production process with the start of the satisfaction of the customers' needs. Additionally, distribution enables the satisfaction of the

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needs of customers and it is also a link between different parts of the world and it establishes a connection between regions with a different culture.

The use of information technology in distribution logistics and the construction and location of structures brings excellent results in terms of saving time, transport costs and the total effective work, which covers all activities relating directly or indirectly to distribution. Working with these methods and using their potential for efficiency requires basic preparation and expert knowledge as to when and how a variety of applications can be used with regard to the goal of obtaining maximum performance and minimum distribution costs. Support software and object models of distribution logistics provide invaluable help (Balog, Straka 2005).

Nowadays there are ever increasing pressures, not only in distribution, to streamline all activities within companies that want to remain or break into the domestic, European or world market. Restructuring, changing outdated thinking and old habits and business processes is closely linked with the use of information technology, modern approaches and modern logistical methods to increase efficiency, rationalization and optimization of material, financial and information flows within companies.

Management and introducing flexible global logistics networks with their high communication and coordination demands creates conditions for further intensive growth.

The most important information technology items involved in distribution logistics in terms of their impact on the quality of decision-making include:

- automatic identification systems (AIS),
- communication standards (EDI, XML),
- satellite navigation systems (GPS, GLONAS, Galileo),
- providing network communication (Internet, Intranet, Extranet).

5.2 Automatic Identification Systems (AIS)

Automatic identification systems are of great importance in improving the response capacity of a company, with the related increase in quality and reduction in costs. AIS systems can be seen in different sectors of human activity from the food industry through production, transportation, warehouses, libraries, retail, services – simply everywhere where it is necessary to bring some degree of order and flexibility. The use of AIS systems as a part of information systems is forced by the need to improve logistics information systems.

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AIS systems are systems that are used for the creation, collection and acceleration of information processing, increasing accuracy and automation of data processing.

With the development of information technology, the use and development of AIS systems is increasing. AIS systems can process significantly more information and that is why they can save time by eliminating the manual data processing – especially when entering data, they reduce the (fallible) human factor.

In general, an AIS system consists of the following items (Balog, Straka 2005):

- a sensor,
- a carrier of a code,
- a programming unit,
- an evaluation unit.

The sensor – ensures the loading of identification codes and their subsequent conversion into the desired form suitable for further processing.

The carrier of a code - ensures the preservation of the code and enables it to be read. The carrier of the code may be the product itself, a tag, a tape or an electromagnetic card. Carriers of codes are dependent on the identification technology used.

The programming unit - ensures the storage of the identification code on a data carrier.

The evaluation unit – ensures the code is converted to a form suitable for the user, or a form suitable for automatic evaluation.

The technology used in AIS systems can be divided into:

- optical, radio-frequency,
- inductive, magnetic,
- biometric.

Optical technologies – use the principle of reflection and absorption of light that reaches the code carrier and this light is decoded by sensitive devices. Technologies based on this principle are for example:

- barcodes,
- the OCR system (Optical Character Recognition – recognition of fonts / characters),
- visual technology.

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Barcodes *work on the principle of light reflection of bright areas and light absorption of dark areas. The data items in barcodes are encoded with light and dark stripes of different thicknesses in a logical order. A barcode is a graphical representation (Figure 50) of the identification number of goods, products, shipping containers, etc.*

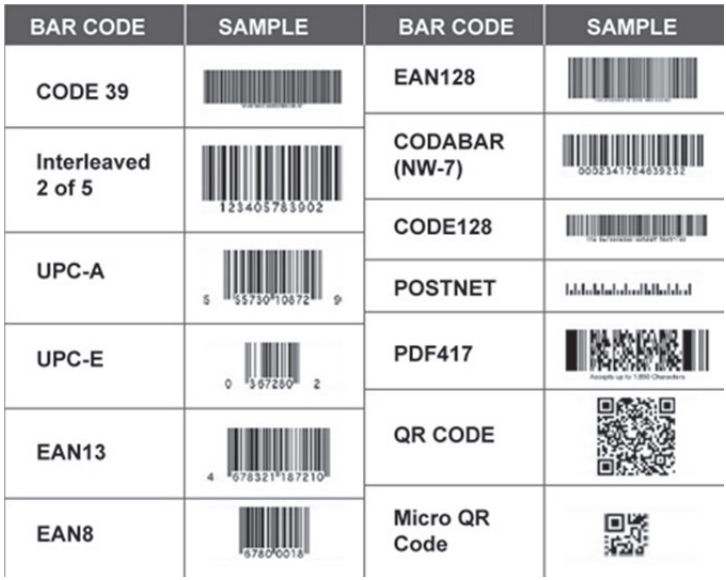


Figure 50 – Different types of barcodes[1]

Stationary barcode scanners (Figure 51), unlike portable ones, are not used for data collection, but for scanning bar codes and the immediate transmission of data for processing to a computer to which they are connected by a cable through either a serial or a keyboard interface. These are single-line or multi-line depending on the construction of the laser beam distribution, and they are hand-held or fixed depending on whether they are for retail or industry use (Balog, Straka 2005).

A separate category contains the GS1 DataBar barcode type that can, within its code, carry much more information than conventional barcodes. Their implementation is mainly in fields where, in addition to basic information, it is necessary to place information e.g. about the composition of the product, its dimensions, date and time of consumption, etc.

[1] https://blogs.sap.com/wp-content/uploads/2013/10/bar_code_304856.jpg

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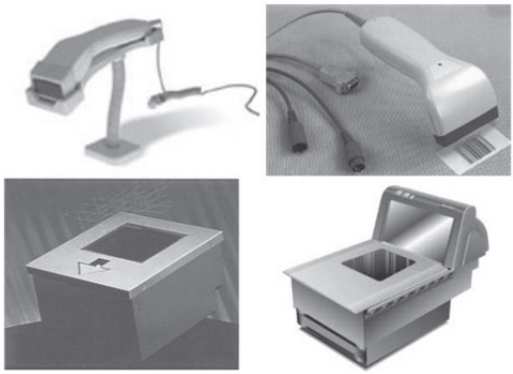


Figure 51 – Stationary types of barcode scanners

OCR technology is used to read and recognize written and printed characters (Figure 52). These characters are converted into digital format by a sensor, enabling their further processing for example by computer.



Figure 52 – Optical character recognition is a useful technology to convert an image into machine-readable text[2]

[2] http://cdn.techpp.com/wp-content/uploads/2011/11/ea6a5_nokia-multiscanner.jpg

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Visual technologies convert, using their sensors, various patterns and dot codes into a digital form for further use in information systems.

Radio frequency technologies - use the principle of transmitting a radio signal, which stimulates a comprehensible response in the signal receiver in the identification tag (Figure 53). These technologies are suitable for dusty or dirty conditions and are suitable for automatic monitoring and recording goods, products or people.



Figure 53 – Different types of RFID tags[3]

Inductive technologies - work in a similar manner to radio frequency, but the data transfer uses the principle of electromagnetic induction. They are suitable for inspection, identifying the contents of pallets and containers, and for the automation of the management of vehicles in the manufacturing process or warehouses.

[3] https://image.slidesharecdn.com/radio-frequencyidentification-151220141348/95/radio-frequency-identification-6-638.jpg?cb=1458881990

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Magnetic technologies - work on the principle of magnetically encoded data in a coating or strips on cards that are read by the sensor heads (Figure 54). They are the most widely used technology for automatic identification. They are most often used in the banking sector to identify user accounts, which enable an account to be accessed through a cash point or to enable cashless payments. Magnetic cards with a magnetic strip are used in services, healthcare, ID checks, in libraries and for other secure systems outside the banking sector, etc. (Balog, Straka 2007).



Figure 54 – Magnetic strip cards[4]

Biometric technologies – work on the principle of scanning the physiological features of a human using computer technology (Figure 55). The main identification patterns used are the fingerprints, voice, retina of the eye or a signature. Most often, biometric technology uses voice recognition.

Voice technologies work on the principle of comparison of words, or the "colour" of the voice, with a sample that is stored in memory.

[4] https://3.imimg.com/data3/NK/SB/MY-8724629/magnetic-card-500x500.jpg

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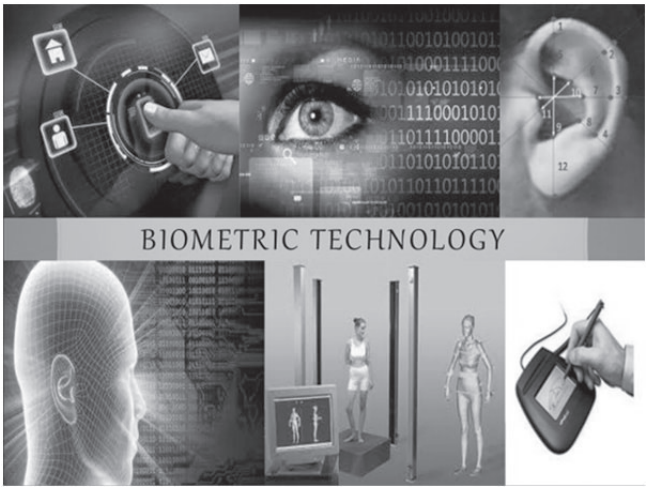


Figure 55 – Types of Biometric technology[5]

AIS systems have a wide range of applications, but generally they are applied for:

- recording information,
- identifying and finding information,
- identifying and finding objects, products and people,
- management and control,
- transmitting information.

The largest use of AIS systems (Balog, Straka 2005) or ADC systems (Automated Data Capture) is in business, specifically in the operation of cash desks. Such a large quantity of goods passes through them during the day that must be registered by cash registers for a receipt to be issued. Barcodes are used on the packaging to accelerate, refine and simplify the work with the goods. Using barcode scanners, information about the goods very quickly enters the cash registers. In practice, all activities with goods at cash desks are limited so that a product with a barcode must pass through a laser code scanner at a cash desk. The goods are recorded and the receipt is generated in automatic mode.

In the area of goods **storage** as an item of distribution logistics, products can be received into stock directly from production or from other

[5] https://image.slidesharecdn.com/biometrictechnology-161213155142/95/biometric-technology-1-638.jpg?cb=1500737506

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departments and operations. After the goods are received and the barcode of the pallet on which the goods are located is scanned, the system automatically suggests where this pallet should be placed. The whole process of administrative activities associated with the process of receiving goods into a warehouse and issuing goods from a warehouse runs in parallel.

In **air transport**, baggage is quite often lost and a reliable solution is to introduce AIS, e.g. by using a barcode. A label is placed on the item of baggage with information about the name of the owner and the destination airport. All the information is stored in a central computer. Barcode scanners are located around the transport track. Sensors transmit data from barcodes to a central computer that controls the cross switches on the transfer belt. The baggage item is directed to the correct aircraft in this way. If a passenger cancels the trip, it is no problem to remove the baggage from the conveyor because the sensors always know the position of the baggage.

A similar system also helps companies that handle several million parcels weekly. Implementation of AIS removes many unpleasant situations between companies and customers as it is always clear where a particular item of baggage is at any time. Ultimately, there is a major saving of the finances which would be needed to pay for lost baggage or to pay fines for incorrectly directed baggage.

Automatic identification systems are often used **to check on people**, monitoring their movements and behaviour. The basic activity of people is their work. People move around during work and that is why it is important to properly evaluate their work activities. When people are being checked, an AIS system is the best for checking their arrival and departure from work. Personal ID cards are very often used for checking people; the cards are based on a barcode that is hidden beneath a protective film. The film improves copy protection. These barcodes are scanned with infrared sensors. All information obtained by the sensor is sent to a central computer. The computer evaluates the real working time and it can be checked on the monitor. Interruption of working time can be entered using the keypad, or with the identification cards.

The system enables the attendance of employees to be automatically analysed each day at the same time. They can make up for missing time in the case of a shorter than required working time. Some mines use radio frequency technology to **accurately identify their employees**, the miners, to increase the safety of their work. A miner is equipped with a radio frequency identification tag on which is encoded his identification number.

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The tag is resistant against shocks and the dusty environment (Balog, Straka 2005).

The principle of the system lies in scanning the numbers upon the arrival of the miners at the mine. The system records the date and time of arrival for each scanned number and it sends the data to the central computer. The system scans the tag again when the miners leave the mine. These two timestamps are sufficient to determine the length of time spent by the miners in the mine.

This system enables the monitoring of the miners in the mine. Each miner is equipped with an active radio frequency identification tag, so it is no problem to determine the location of the miners in real time. The computer shows a map of the mine and where a given miner is currently located. This system is invaluable in emergency situations. Credit cards based on the principle of magnetic technology are an indispensable part of the **banking sector**. Credit cards have simplified and streamlined payment transactions. Traditionally, payments required a paper document which had to be filled in manually by the traders and signed by the customers before the banks performed the transfer of funds. By introducing a new generation of terminals, that time-consuming administrative work has been reduced to a minimum. The terminal can handle different types of payment cards. The application and development of AIS is fastest in the banking sector. In the **automotive industry,** AIS are used to control various manufacturing operations while maintaining manufacturing procedures. Each barcode label contains information about activities that have been performed on a car or activities that are yet to be performed. The use of human labour decreases and the quality of information obtained in the production process increases, so problems associated with production and control are reduced.

5.2.1 Advantages of using AIS and its Significance for Distribution Logistics

The importance of automatic identification systems lies in the fundamentals of their operation. The basic principle of AIS lies in the creation and collection of information in order to provide accurate data and automation of executed activities. The basic benefits of using automatic identification systems can be determined from this definition and its nature:

- the reduction of manual tasks and difficulty of work,
- the reduction of administrative work,
- the reduction of errors caused by the human factor,

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- the increase of reliability of the recorded items,
- the reduction of the number of employees,
- the increase of safety and information security,
- the reduction of time spent,
- the reduction of the costs for transporting goods, sorting goods and information,
- the increase in the level of organization of manufacturing and transport,
- the improvement of customer service.

It can be stated that AIS systems in the distribution processes facilitate the checking of orders and deliveries, facilitate the movements of raw material and goods and ensure customer satisfaction.

While, in the area of financial management and accounting, the problem of entering really current data is handled by electronic transmission within the system as well as from outside (electronic communication between banks), in the sphere of distribution logistics it will be always necessary to identify and monitor real objects (products, goods) and their movement and to ensure that the relevant information flows are transferred as closely and quickly as possible to the IS. AIS integration into ERP systems is the main challenge of information logistics.

5.3 The Importance of Communication Standards for Distribution Logistics – Electronic Data Interchange EDI

To ensure the proper running of a company it is necessary to generate and simultaneously process a large amount of documentation, orders, invoices, delivery notes, payment orders, cover letters, and so on, the final form of which is very often a paper document. The documents mentioned are carriers of important information needed to ensure the smooth running of material, financial and information flows. In order to strengthen the competitiveness of companies and secure their position in the market, it is necessary to ensure the quality of the information flows that are part of these documents. The paper method of transferring information between the manufacturer and the recipient is very susceptible to errors which may lead to a business transaction not being made.

One of the possible solutions to ensure more reliable and faster exchange of relevant documents and information on these matters is the application of the electronic communication tools known as Electronic

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Data Interchange EDI or the XML format for the transfer of general documents (eXtensible Markup Language) (Balog, Straka 2005).

The traditional exchange of business information that is included in trade documents can be summarized by the following list of activities:

- preparing a document on a computer,
- printing a ready-made and completed document,
- sending a business document by regular mail, or via a courier company,
- receipt of a business document,
- conversion by the recipient of the received document into digital form (for archiving or for filling in another document).

From these activities it can be seen that a large number of errors and mistakes may occur that can fundamentally change the meaning of business activities implemented in the process of implementation of the conventional exchange of business documents.

Data exchange using tools of electronic communication enables the elimination of manual processing of business documents and it enables transfer from computer to computer (Figure 56), without influence from other entities.

Electronic data interchange EDI is data exchange in the form of structured messages from the computer of a sender to the computer of a recipient using electronic tools, with a minimum of human intervention.

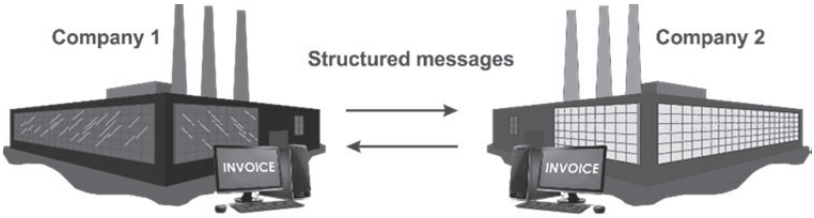


Figure 56 – Electronic data interchange between two cooperating companies

The equipment needed to operate EDI is divided into:

- Software – the application software that supports EDI.
- Hardware – the communication hardware connected to a network (internet).
- Services – the services of communication network operators (communication, telephone, cellular network, etc.).

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The difference between EDI and XML is that XML also enables the transfer of a document structure with the document itself, which really enables the flexible expansion of the possibilities of the system and responds faster to customer needs. There is a precisely set standard for EDI, in which the structure and method of making reports is precisely determined.

5.3.1 Advantages of Communication Standards

The advantages of communication standards (Balog, Straka 2005) are related to the activities that these standards replace and to the speed and accuracy of their operation. The basic benefits can be divided into:

- saving work,
- saving time,
- minimizing errors and increasing the quality of transferred documents,
- increasing the quality of services provided,
- increasing business space,
- rationalization of costs,
- compatibility with other information systems.

Saving Work

The information is entered into a computer on the side of the sender and it is not needed to re-enter it into the computer on the recipient side. Other operations are carried out with received data. In the case of bank transfer, a recipient has software available to automatically process the requirements received from the customer and thus it is possible to automate the performance of activities related to the transfers of finance without human intervention.

Saving a Time

Because the performance of activities related to the exchange of business documents is carried out by tools of the electronic information channel, the exchange of these documents is takes place almost immediately after they are sent.

Minimizing errors and increasing the quality of transferred documents

The possibility of transcription errors is eliminated, while errors, which may be caused by a third party (mail, courier service, etc.) are removed too, so there is no necessity to re-perform the same activity.

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Increasing the Quality of Services Provided

Due to the use of the electronic environment for communication between companies and the reduction of service time, it is possible to respond faster and more flexibly to customer requirements.

Increasing Business Space

Communications standards, through electronic communication, enable the expansion of business space to companies without extending the response time.

Costs Rationalization

The production of goods is connected to the electronic orders received, which means that it is exactly clear what, when, who, where and in what quantities products need to be made. This enables production in a "just in time" system, enables the reduction of inventories and subsequently also the reduction of storage costs.

The costs of expendable supplies are reduced and job performance is streamlined by removing a large number of traditional office documents.

Compatibility with other Information Systems (IS)

Within logistics information systems there can be a direct connection between communication standards and other information systems (automatic identification systems, barcodes), which enables a further increase in the qualitative characteristics of the whole IS.

5.3.2 The use of Communication Standards in Distribution Logistics

The benefits of EDI and XML communication standards for the key areas of operation of a distribution company can be divided into the following areas:

- accounting,
- sales,
- marketing,
- distribution logistics.

In corporate accounting – EDI and XML communication standards enable the direct connection of companies with banks and therefore faster invoicing, faster transfers and payments can be performed, it is possible to provide faster access to check bank transfers performed, to perform a

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quicker check on the status of accounts and more efficient handling of the available finances.

In the field of sales, direct connection reduces the time required for administration and it enables the automatic preparation and issue of transport, shipping and customs documents because of the direct connection with business partners.

In marketing, connection of companies using communication standards can affect markets which cannot be served geographically. It is possible to update the offer and respond to customer feedback directly from the parent company ensuring personnel are trained and qualified fast and accurately.

In distribution logistics, the connection of producers with customers on the basis of communication standards ensures the transparency of the organization of transport, movement of goods, faster handling of transport and accompanying documents.

The communication standard for electronic data interchange UN/EDIFACT – Electronic Data Interchange for Administration, Commerce and Transport is the established global standard worldwide and is included in the ISO 9735 standard. EDI uses barcode technology for its information transfer and the GTIN and GLN unique identification numbers.

> *"GS1 is a subset of the UN / EDIFACT global standards, which have been approved by the United Nations. This standard is the most widely used in supplier - customer relationships between producers, transporters and traders. More than 50 messages, such as purchase orders, invoices, order confirmations, delivery notes, etc. are defined within the GS1 EANCOM."*[6]

The numbering of GS1 EDI brings many benefits, which can be divided into four classes:

- **Identification data** – information exchanged at the beginning of the business relationship, to identify business partners.
- **Commercial transactions** – information related to the entire business process from order to delivery of goods.
- **Reporting and planning messages** – information related to informing business partners about future activities.
- **General reports** – information for transfer tests between partners who are starting to communicate with this system.

[6] http://www.gs1sk.org/gs1-eancom

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5.4 Management of Distribution using Satellite Navigation

Positioning using satellites – sometimes referred to, imprecisely, as satellite navigation, has already found applications in many areas of human activities. Satellite navigation systems in distribution logistics enable the effective management of the transport of valuable loads and of truck routes carrying ordinary goods. The American Chamber of Commerce has described satellite navigation as a branch with rapid development, with a huge increase in revenue and profits. There are already multiple satellite systems (Balog, Straka 2005):

- the GPS system of the US military, sometimes referred to as NAVSTAR,
- the GLONASS system of the Russian military,
- other systems (EGNOS, GALILEO, GNSS, etc.).

For commercial (civilian) purposes it is currently practically possible to use only GPS and GLONASS.

5.4.1 GPS – Global Positioning System

GPS (Global Positioning System) consists of about 27 satellites. They orbit around 20200 km over the Earth's surface with an orbital period of approximately 12 hours. The satellites transmit navigation signals. An electronic terrestrial receiver can receive these signals and compute its current position (latitude and longitude, also altitude).

The basic principle of GPS is based on measurements of transit distances, which has a large range of applications in the field of distribution of goods. GPS satellites transmit a digital signal (Figure 57) containing information about the exact position of the satellite, its velocity and the time of transmission. Simultaneously with the navigation data, the satellite sends a time signal. The GPS receiver generates a copy of the signal and compares the shift of its signal with the signals received from the satellite. The size of this shift should be directly proportional to the distance. But it is not, because of the desynchronization of clock in the satellite and in terrestrial receivers. Therefore, the measured distances are called pseudodistances. This phase difference becomes the fourth unknown in solving the system of equations. The first three are the location coordinates of the receiver. To solve this system of equations it is therefore necessary to determine the distance to at least four satellites. With an increasing number of satellites, there is also an increase in the accuracy of positioning. The position of the satellites relative to each other

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at the moment of measurement and atmospheric influences also affect the accuracy.

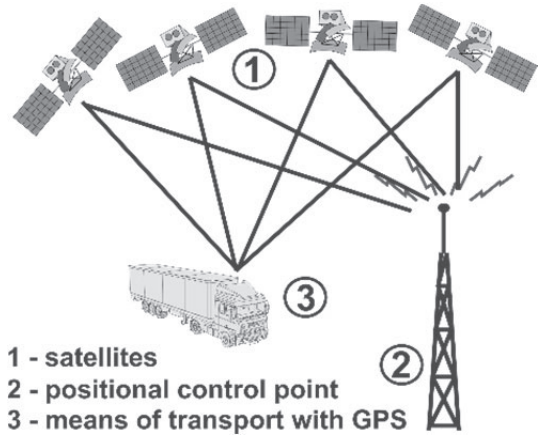


Figure 57 – Diagram of GPS navigation system operation

If GPS is operating in **tracking mode**, the carrier performs his journey using maps and the GPS receiver plots the route. The GPS user is able to mark or stake out the waypoints on complex routes and intersections to be used in navigation later or for further use by other users. After the completion of his journey, he saves the route to a computer by using software and it is ready for further use.

Another utilisation is **navigation mode**, when the route in the GPS device is either prepared in advance by a computer or programmed directly into the GPS device. At the starting point of the route, the driver turns on navigation and drives following the instructions of the device, which shows him when and how often he deviated from the route and what the direction to the nearest waypoint is. If he gets into a confusing or dangerous situation, GPS can bring him back quite safely (in the range of accuracy of the device - about 100 m) by using Trace Back (reverse navigation), after this option is selected, the device takes the recorded points and compares them with the actual position. However, it is necessary to study how the device creates a route for the Trace Back. Usually it has from 100 up to 2 000 Trace Points in memory (points through which the device plots the route travelled and which it records automatically when reaching a certain movement - after about 150 metres). It takes these points and selects 30 to be imported to record as the

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Route (30 Waypoints is the maximum number for one Route although it differs depending on the manufacturer of equipment).

Most manufacturers also build the Man Overboard feature into receivers. When activated, the current location is recorded and then the device navigates just to that point. This name indicates where and when this function is to be used.

Because the precision of the device is predetermined by the technology (the effect of satellites and the atmosphere), comparison between them is more in terms of their design, added features, speed of locating their position at the start and finally in terms of power consumption. This is still significant in many devices and the only exception is the Magellan Pioneer, but there is an exception to everything.

The three largest manufacturers of GPS receivers in the market are currently Garmin, Magellan and Lowrance/Eagle (Figure 58). Most mobile phones have built-in GPS chips with navigation at present. They produce mostly handy tools for general-purpose use, some of them with oriented maps and it is possible to load a map as needed for some of them. The devices from one manufacturer contain mostly the same software and the devices are varied in terms of the convenience of their operation and the possibilities of working with a map.



Figure 58 – Diagram of GPS navigation system operation[7]

[7] https://www.rammount.com/images/personal-navigation.png

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5.4.2 GLONASS – the Global Navigation Satellite System

The Russian navigation system GLONASS (Balog, Straka 2005), which works on a similar principle to the American GPS navigation system, was released for civil use by government decision on March 1995.

In spite of the fact that both systems operate on similar principles, the Russian GLONASS has a few differences. For example, the orbit of satellites is lowered to 19 100 km. This level, in terms of characteristics of the system and the special characteristics of the antenna radiation is more preferable as it ensures that the satellite's trajectory above the Earth surface is the same and this situation is repeated every 17 orbits, which means 8 days.

Today, the GLONASS system plays a role equally important as GPS for the purposes of commercial use.

5.4.3 GALILEO – the European Satellite Navigation System

GALILEO is a navigation system operating on the same principle as GPS and GLONASS.

The fully operational system consists of 30 satellites, which will perform the same functions as GPS and GLONASS. The orbit of Galileo satellites, unlike the previous systems, is at the level of 24 000 kilometres and the whole system is strictly a civilian project. The advantage of the GALILEO system is greater signal range including in areas that are not covered by the GPS and GLONASS signals.

5.4.4 The use of Navigation Systems in Distribution Logistics

In terms of distribution logistics, the use of navigation systems can be divided as follows:

- positioning,
- navigation,
- distribution route planning,
- vehicle and goods monitoring.

Positioning in transport is important for road, air, sea, rail transport. Companies are able to use these systems to determine the location of their vehicles on the map.

Navigation of means of transport enables precise navigation according to the chosen route with a known starting point and destination. Systems optimize the transport route according to selected criteria. In terms of **planning distribution or supply routes**, satellite navigation

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systems are used for preparing and planning optimal connection of places that a vehicle must visit. The route plan is prepared by a dispatcher or by a responsible person in the company and a driver gets it before his journey as a travel order, which is obligatory for him.

Monitoring means of transport and goods, is used to check ongoing distribution and compliance with the planned distribution or supply routes.

5.5 The Internet and its Modifications

An information phenomenon such as the internet enables a variety of processes in terms of the direct integration of customers into the fulfilment process within Electronic Retailing or Electronic Commerce (e-commerce). Software applications of these systems have a strong relationship with distribution logistics, just as distribution logistics creates and manages those business processes. Services related to using the Internet enable the simplification and acceleration of the process of mutual contact with the supplier, customer, carrier and other companies. In the future these services will increase, from elementary communications during transactions to closing a deal. It is evident, that communication between companies over the Internet creates space for advertising, finding partners, presenting one's own results, references, etc.

These possibilities can be divided as follows:

- **Internet presentation**, sale and purchase of products

  Presentation of products and services, offering finished products and services through internet links (virtual department stores and traditional advertising).

  For this reason, manufacturers are forced to seek and use ever newer possibilities to present their products and to reach an increasing range of customers.
- **Internet Data Exchange**

  Ordering, invoicing, and supporting documentation for goods distributed between a buyer and a supplier over the internet.
- **Electronic Banking** - bank communication with clients through modern information technology such as:
  - home-banking,
  - internet telebanking,
  - mail-banking,
  - phone-banking,
  - GSM banking,
  - mobile-banking.

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An intranet is a communication system inside a company, the principle of which is similar to the internet but for a closed corporate network. Working with an intranet is identical to working with the internet, a user just uses web-based applications. In practice, an intranet is used for traditional administrative work, e-mail and various management applications with different levels of access permissions.

An extranet is the communication system of several companies using the principle of mutual disclosure of certain categories of information between trading partners. An extranet increases the effectiveness of mutual communication. Access to the data of partner companies is provided by copyright authorization.

5.6 Other Information Technology Applications in Practice

Information technologies have very wide range of use in practice such as:

- interactive warehouses, e-shops,
- communication support systems,
- voice control systems.

Interactive warehouses, e-shops are a progressive system of automated logistics aimed at cost reduction. The principle of interactive warehouse operation is designed to minimize inventories, it provides an overview of stocks in real time and provides information about order-processing. The benefit of this technology lies in the provision of a comprehensive view of warehousing and distribution.

Distribution logistics support systems can include systems that replace ordinary forms of mail. They are often referred to by their common name as Office Automation Systems (OAS).

The importance of support systems lies in the creation of conditions and in speeding the flow of information needed for distribution planning and implementation.

The current level of information technology offers a variety of OAS systems, among which can be included:

- electronic mail systems (e-mails),
- electronic information boards,
- video conferences,
- multimedia systems.

The aim of distribution logistics support systems is to create the final effect, which is the total reduction of the time needed for supply of goods

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and services. The proper functioning or use of support systems creates the correct business environment and the conditions for achieving the expected results.

The expansion of information technology in recent decades enables unconventional solutions to even the most complex management processes in economic practice. Continuous improvement of information and communication technologies takes managerial work to ever higher levels. Organizing workshops, seminars, videoconferences remotely over Internet, traffic monitoring and control through information systems today is nothing unusual, though such communication was in the realm of science fiction a few years ago.

One use of **voice control systems** is in picking consignments in warehouses and in distribution centres, but they can also be used for example in the management of production and technological processes, logistics, etc. They are joint solutions including hardware and software capability and integration with enterprise resource planning systems (ERP systems). Wireless terminals enable workers to move freely (Figure 59), and to use the biggest benefits of this system: the hands free, eyes free system of voice-controlled operations.



Figure 59 – A voice management system[8]

The advantages of voice-controlled operations (Trosanova, Straka 2009) are:

- quick and easy implementation of voice-controlled applications,
- monitoring warehouse operations and warehouse status in real time,

[8] http://www.irms360.com/sites/default/files/Advanced%20Features%20-%20Voice.jpg?1369346399

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- monitoring stocks below limit at the moment they occur,
- optimization of manual operations and reduction of invoicing errors,
- monitoring the personal performance of operators, lost time and others. If necessary, software can be adjusted depending on the specific user requirements.

5.7 Overview of Information Systems in Distribution Logistics

For the efficient use of warehouse management, various types of management systems are now used in a warehouse. This means software that simplifies the work in a warehouse. It records what goods are in stock, how much needs to be dispatched. It evaluates each process implemented in a warehouse. The development of these systems is very fast with the rapid growth of information technology. The most common information systems used in practice are (Trosanova, Straka 2011):

Exact Globe[9] is an application installed on a workstation. It enables the processing of conventional economic, financial and logistical operations. It is used to optimize inventories in a warehouse.

MFG / PRO[10] is an integrated ERP system for enterprise resource planning. This system is designed for warehouses where high efficiency is required in a warehouse with a large number of stored materials. It is used where warehousing to order is in operation.

KARAT[11] is an information system used in a company which uses Client/Server technology. It is designed to manage **medium and large** manufacturing and trading companies. Its task is to unify **accounting, economic, storage and trading software** into a comprehensive customized solution.

SAP, SAP Business One[12], is based on ERP applications. It is designed for small and medium-sized organizations. It provides quick and easy access to all relevant and necessary information. It consists of 11 modules that extend its capabilities by providing more than basic administrative functions and it simplifies business processes, which also include warehouse management.

[9] https://www.exact.com/uk/technology/exact-globe/
[10] https://www.logisticsonline.com/doc/mfgpro-software-0001
[11] http://www.karatsoftware.sk/
[12] https://www.sap.com/products/erp/small-business-erp.html

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The POHODA system[13] is used in accounting, economics and information systems. It includes multiple variants. POHODA PREMIUM includes wages, stores, hardware support, barcodes and mobile invoicing.

Money S3, S4, S5[14] is an economic system and modern ERP system for small, medium-sized and larger companies. It contains all important modules for accounting, invoicing, warehousing, etc. Money S3 is designed for small companies. Money S4 is designed for medium companies and Money S5 is designed for medium and larger companies. It covers the whole area of sales.

OR-SYSTEM[15] is intended for used by manufacturing and trading companies. It is used in logistics, trade, economics and manufacturing. It includes a warehouse management module. Its special modules include electronic data interchange, barcodes and radio-frequency technologies.

[13] http://www.pohoda.sk/?gclid=Cj0KCQiA7dHSBRDEARIsAJhAHwhCXxohXpkp6Oa5IJ9EH2XNK3UOmfl7rJ7Itkgkto5dWQqHAQIYWAsaAr_pEALw_wcB

[14] http://www.money.sk/

[15] http://www.orcz.cz/en/products/or-system-open

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CHAPTER SIX

LOGISTICS COSTS AND ACTIONS IN DISTRIBUTION AND SUPPLY LOGISTICS

What you will learn: Without identifying costs in the process of distribution, the process cannot operate efficiently. Therefore, it is necessary to know and correctly interpret costs incurred. Some are directly related to the functional aspects of distribution and some are related to legal, economic, social and information security. This chapter is devoted to costs in the process of distribution, concepts that are taken into account in the process of physical distribution, physical supply and identification of logistics costs and indicators.

Basic terms: cost, the view of costs, logistics indicators.

Costs themselves constitute a significant item in enterprise economics, they are one of the factors of business success. The success of an enterprise in the market is increasingly determined by supply readiness - its ability to react quickly to market demands. This is dependent on having a competitive advantage, such as quality logistics. Owning or renting further logistics capacity is based on the presumption of further economic development requiring increasingly high-quality logistics service.

Logistics services will grow in terms of its share of total services, raising an understandable interest in costs related to the provision of quality logistics activities. The prerequisites for rationalization (optimization or minimization) of the costs of logistics services or the costs of their outsourcing are identification, registration and transparency of costs (Baumgarten et al. 1997).

The current state of the theory of logistics, logistics terminology, the heterogeneity of opinions on theory and practice create space for research of logistics costs as well as for evaluating the benefits of logistics and the management of logistics costs in the form of controlling.

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6.1 Costs

In general, costs are defined as something which we have to give up in order to obtain something else in the form of purchase, exchange or production (in the last case it means production costs). In economics, the frequently used term is opportunity cost (cost of an alternative output), which expresses benefit, profit, or the value of something that must be given up to acquire or achieve something else. They usually (not always) correspond to cash payments. Sometimes they are characterized as private costs associated with any product or activity (spent by a consumer or manufacturer) and social costs (spent by society as a whole). Social costs of a certain output mean the amount of money expended to compensate a loss incurred in connection with the production of an output, which is not paid by the company or individual, but by society (e.g. the cost of environmental recovery after disturbance by production activities) (Viestova et al. 2007).

Another reference defines costs as business expenses and they are defined as "monetary amounts which an enterprise incurs with the purpose of achieving *revenues*. The subject of *calculation* of costs is their conversion to the determined unit e.g. a chargeable natural unit (piece, km, litre, ton, etc.). Costing is based on the *calculation formula* or calculation formulae, which reflect the specific conditions of the given business entity. Cost calculation often uses the *dead point*, better known as *breakeven point*. The *breakeven point* is the point when, within the activities of firms and companies, it gets to a state where incomes and costs or revenues and expenditures balance. From this point upwards, the company is in profit. The costs of a company are expressed as the financial sums that a company incurs with the purpose of achieving *revenues*. The actual payment is not important. Real paid amounts are expenses, actual revenues that have been paid are *receipts*. The total costs can be assigned to the cost of the main activity and other activities" (Sibl et al. 2002).

For the needs of analysis and evaluating costs, the whole unit of costs is usually broken down according to certain criteria (Rosova 2011). The results are a variety of different ordered complexes of costs. Therefore, the scientific literature works with a wide range of concepts on the theory of costs - such as absolute costs (A. Smith), comparative costs (D. Ricardo), total costs, unit, fixed, variable, manufacturing explicit, implicit, direct, indirect, average, incremental (marginal), alternative, opportunity costs, loan costs, capital costs, costs of circulation, transaction costs, distribution and logistics costs. There are other terms in literature, such as the costs of

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the commercial venture, costs of future periods, overhead or own costs (Straka et al. 2005).

6.1.1 Cost of Circulation of Goods

Circulation of goods is the second sphere in the general theory of economics, after production. The circulation of goods is characterized as the mutually interacting cycles of all the goods that are exchanged on the market (Viestova 2007).

Trade theory understands trade as the implementer of circulation. The circulation of goods is caused by temporal and spatial differences between the moment of completion of production and exchange. The level of exchange of goods creates circulation. Circulation can be conceived as the mass movement of goods and capital. The movement of goods is the physical movement of goods in space and time. The movement of goods in this context includes all the processes that are concerned with goods and that take place in connection with their storage and sale. Goods are prepared for final consumption during as they are moved.

P. Pernica defined the circulation of goods as

> *"the sum of all pre-production and post production material processes which the material passes through, i.e. raw materials, basic materials, auxiliary materials, parts, work in progress and finished products meant for sale (i.e. the goods); it is concerned with processes of a non-technological character (i.e. unchanging quantity or quality of the material), comprised of operations of packaging, creating handling and transport units, further loading and unloading of vehicles, loading and unloading of means of transport, storage operations, control and receipt and more. It therefore means the physical movement of materials and goods, including accumulation, sorting, identification and protection. In addition to physical processes, circulation also includes non-physical processes that involve the movement of information and its use in decision-making, specifically in the collection, inspection, processing and storage of information necessary for purchase and sale, for management of material circulation processes, for recording and more."* (Pernica 2004)

The authors of the Great economic encyclopaedia defined the costs of circulation as

> *"the consumption of live and materialized work that is incurred in the national economy in connection with the circulation of goods and money. It is conditioned by the purchase and sale, storage, sorting, preparation,*

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treatment, packing of goods, finance, record keeping, administration and maintenance of the necessary buildings and equipment." (Viestova 2007)

6.1.2 The Costs for Distribution (the Distribution Costs)

The distribution costs or the costs for distribution are the expression of all costs associated with the acquisition and implementation of distribution logistics processes, costs associated with the implementation of material, information and nominal flows. These costs are mainly associated with the transportation, storage and sale of goods, finance, insurance, risk and communications (Viestova 2007).

Sometimes they are understood in even more detail – as the costs relating to the distribution of goods, covered by the selling or distributing organization. According to the Polish author A. Czubaly, *"The costs spent by enterprises involved in the supply of products from manufacturers to final customers."*

The costs of distribution include design, operation and control of the distribution channel. The structure of them includes general sales management costs, costs for salaries of staff, internal and external sales services (Lambert et al. 2000).

Distribution as an item as well as a marketing tool comprises two equally important components – acquisition (administrative, transactional, merchandising), and physical (operating).

The role of acquisition in distribution is to market the goods, to contract and to financially and legally arrange the activities related to the preparation for sale of goods and services in the market, to commercialize the product. The costs of these activities are called transaction costs.

The transaction costs are *"all costs that need to be paid (they do not include the value of goods exchanged) in order to achieve the exchange of goods or services; e.g. it is necessary to incur certain costs related to the preparation of contracts, obtaining the necessary legal advice, drafting reports about the situation in the market etc. to achieve the exchange between the companies participating in the market. Savings in these areas could increase business risk and cause associated adverse effects for the entrepreneur."* (Viestova 2007) In connection with transaction costs, alternative or opportunity costs are also incurred.

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6.2 Views of Physical Distribution Costs

The physical distribution costs are defined as the costs in monetary terms - associated with the physical movement of products from their places of creation to the points of sale to the final owners. These include: the cost of order processing, storage costs, the cost of maintaining inventory, and shipping costs (Lambert et al. 2000).

The cost of physical distribution has attracted the interest of experts over the long term. From the known theories, we consider the theory of the full costs of physical distribution to be worth mentioning, as we consider it to be the classic. This method has been published in the American and later in the German literature more or less continuously since the 1960s.

The three most important views of the costs of physical distribution of goods representing the basic idea of managing the physical distribution of goods are presented as follows (Viestova 1993):

- the view of cost trade-offs,
- the view of the total cost,
- the view of the total system.

The view of "cost trade-offs" is the basis for the management of physical distribution. Without it, the management of physical distribution would probably not be implemented in the manner that current economic practice implements it.

The starting point of this view is recognising that the types and characters of the costs of various activities of an enterprise are sometimes expressed by mutual economic conflicts (Straka et al. 2005).

Within this view, three basic logistics activities are affected by defining the number of warehouses in the distribution system. If the number of warehouses increases, the transport costs decrease because of the reduction in the distance between a warehouse and a customer and therefore the volume of transportation reduces. However, the costs of maintaining the inventory system and order processing increase. Thus, a conflict is created between the costs of transportation and the costs of maintaining inventory and order processing. The role of the manager is to take a decision on the number of warehouses. Such a decision could be made by balancing or by "trade-offs" of the costs in conflict.

The "total cost" view and the view of costs "trade-off" are closely related. The starting point for the “total cost” view (Figure 60) is the recognition that all kinds of conflicts of costs should be considered together and balanced as optimum (Straka et al. 2005). The total

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substantial costs for the number of warehouses arise from the sum of the three types of costs that form the overall curve of the total costs. While it should be borne in mind that the lowest point of costs on the curve is not the point of the lowest transport costs, it is also not the point of the lowest costs of maintaining inventory and order processing. The lowest point is located between them. Empirically it is proved that integrated transport management, inventory maintenance and order processing can lead to a substantial reduction in costs. The idea of total costs is a tool for deciding which business activities of an enterprise are to be grouped as physical distribution activities.

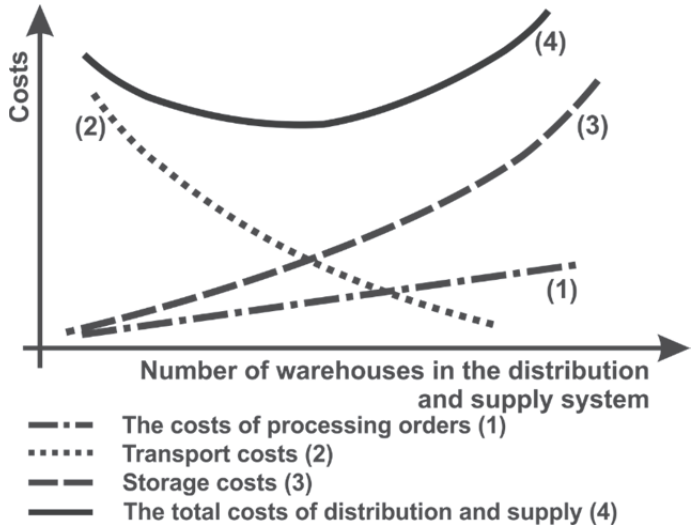


Figure 60 – The "total costs" view

The "total system" view (Figure 61) is a global view of the distribution systems in order to reveal the relationships that can lead to suboptimum decisions if they are unrecognized or neglected (Viestova 1993). The position of physical distribution among the business activities of a company is with other business functions. The activities of physical distribution are strategically integrated into the manufacturing and sales functions of a company. Both functions, production and sale, have an interest in the activities of physical distribution. The organization of the management of both of them influences the level of distribution activities. If physical distribution is fully appreciated in a company, it is not important whether it is a part of production or marketing or a separate

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function of management or an individual function between the production and marketing levels. Effective coordination between various activities is important so that the "trade-off" costs of physical distribution are managed really effectively.

The formula for the total costs of physical distribution is introduced in the Polish lexicon of marketing. The total costs of physical distribution are defined as the sum of the costs of performing all activities (6.1) which are involved in physical distribution, added to the valuation of lost profits from bad operation of the distribution system (Straka et al. 2005).

$$CNFD = NO + NS_s + NZ_z + ND + NA \quad (6.1)$$

CNFD - the total cost of physical distribution,
NO - the costs for order processing,
NS_S - the fixed costs of warehouse maintenance,
NZ_Z - the costs of maintaining inventory,
ND - the transport costs,
NA - the costs associated with the loss of income from delay in delivery, from the loss of customer confidence etc. (opportunity cost).

- The costs associated with the loss of sales opportunities decrease with an increasing number of warehouses.
- The cost of order processing is constant or can slightly increase with an increasing number of warehouses in the system.
- The costs of inventory increase with the number of warehouses because a company usually stores a minimum volume of inventory (buffer stock) of all its types of products in each location. Items with both faster and slower turnover are kept in a warehouse.
- The storage costs generally increase with the number of warehouses. There is a valid equation that more storage means there is more space that a company owns, hires or buys and therefore it needs more resources to secure it. Public and contract warehouses in fact often offer quantity discounts. If a company hires space in several locations, costs begin to decrease.
- Transport costs initially decrease with the number of warehouses and then they increase again because if the distribution system involves a large number of warehouses, the sum of transport costs increases.

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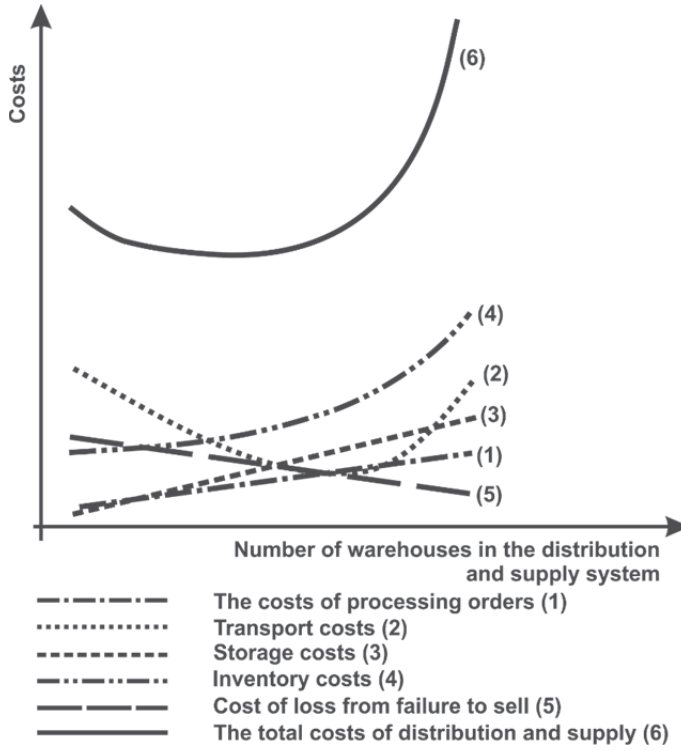


Figure 61 – The physical distribution costs – "total system" view

The amount of *CNFD* is determined by the level of distribution service for customers. The aim of rationalizing *CNFD* is to find solutions enabling *CNFD* to be minimized with the condition of maintaining an acceptable level of customer service. Achieving this goal is not always possible through minimizing individual partial costs. Their integrity (inter-relations) means that a reduction of one type (type of cost) causes a significantly higher increase in other costs, for example transport costs, costs associated with loss of income, and consequently an increase in *CNFD*. Errors of this type of decision are eliminated by an overall limit of *CNFD* and by minimizing *CNFD* for a given level of services (Straka 2013).

The cost of physical distribution is incidental to (Lambert et al. 2000):

- The costs of missing inventory are the costs arising from the fact that a product is not in stock, such as a missed sale, delayed

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delivery, temporarily lower sales in the future due to loss of reputation, costs arising from the discontinuation of production and all kinds of associated costs.

- The costs of risk or losses are the costs related to obsolescence of goods, petty thefts in retail units, transfers within the inventory system and product deterioration.
- The costs of sales are costs incurred by a trading organization not including the costs of acquiring the goods to be sold.
- The transport costs constitute the sum of all costs to the carrier, incurred in relation to the transportation of goods.
- The storage costs are the costs in monetary terms associated with maintaining own warehouses, rental of warehouse space, performance of associated storage functions ("transformation of assortment"). The structure of storage costs includes:
  - fixed costs for maintaining warehouses - irrespective of the size of stocks maintained or the number of orders (e.g. the costs of depreciation of buildings and equipment, the costs of maintaining buildings and repairs, insurance costs, energy, fixed payments);
  - the variable costs for maintaining warehouses – include the costs related to the use of own warehouses as well as the rental of storage space in warehouses, storage rooms; the amount depends on the size of inventories;
  - the operation of business-related modifications, i.e. the costs of identification of goods, sorting (assortment) packaging, marking, conversion of the produced range into a saleable form.
- The costs of lost sales opportunities.
  - A type of costs called hidden costs that arise as a result of improper operation of physical distribution,
  - the costs of delayed supply,
  - the supply of low-quality goods, not corresponding to product quality, delayed transport.
- The costs of order processing.
  - The costs associated with the reception and implementation of orders. These include costs of information exchange, receiving orders, the costs of administrative processes, documentation necessary to complete the transaction, the costs of verification of client solvency, invoicing, issuing and collection of receivables, the creation and operation of an information system in the process of implementing the order.

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6.3 Costs of Logistics

The costs of logistics are defined variously, as is their internal structure. I would like to state some definitions from several authors so that the reader can get an idea and form their own opinion (Rosova 2011). Generally, the costs of logistics are understood as the costs associated with logistics activities. They are determined as the cost of the logistics chain or the cost of ordering, material handling, warehousing, packing, transporting etc. within the chain, or even a section within the company, both in terms of the absolute amount or relative to a logistics performance unit, a product or order, etc. Against the increasing costs of logistics accompanying an increasing level of logistics services from a company, there are decreasing losses from unimplemented deliveries (i.e. those rejected by dissatisfied customers). According to Schulte (Schulte 1994) the costs of logistics can be divided into five blocks as follows:

- *The costs for management and the system* include the costs of formation, planning and control of material flows and the costs of the sub-functions of production program planning, disposition activities, production management, etc.
- *The costs of inventories* arising due to maintaining stocks and the locked-up of capital costs for financing inventory, various types of insurance, degradation and losses.
- *Storage costs* consist of a fixed component assigned to maintain storage capacities with promptness and a component of pseudo-variable costs for input provided and output processes.
- *Transport costs* include costs for in-plant and out-plant transportation.
- *Handling costs* are understood as all costs of packaging, handling operations and commissioning activity (Cempirek 2004).

J. Prazska and J. Jindra (2002) divide logistics costs into the following groups:

- The costs for management and the system, which includes the costs of forming, planning and control of material and information flows: inventory costs, which are incurred by maintaining inventory and locked-up capital for financing inventories due to insurance, losses, etc.
- The storage costs form a fixed component, which is intended to maintain the storage capacities at readiness (it is not dependent on the current status of stocks – how full the warehouse is) and the components of the variable costs associated with storage processes (operations); the transport costs include the cost of in-plant

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(internal) and out-plant transport. This also includes a part of the fixed costs, which include readiness of transport systems. The costs are then partly dependent on the volume of transported goods. The costs are partly hidden in the price of supplies, i.e. the amount paid by suppliers for the transport of goods to the customer.

- The costs of handling are the costs of packaging, handling operations and assembly operations. Here it is also possible to distinguish the part for emergency costs (always available) and the part for costs that are dependent on the volumes handled (packaging, handling operations, etc.).

The authors D. M. Lambert, J. A. Stock and L. M. Ellram, who dedicated a significant proportion of their publication to the costs of logistics, work with the view of the total cost of logistics activities. They structure the total costs of logistics activities into 6 areas, which consist of 15 main logistics activities (Figure 62) (Lambert et al. 2000).

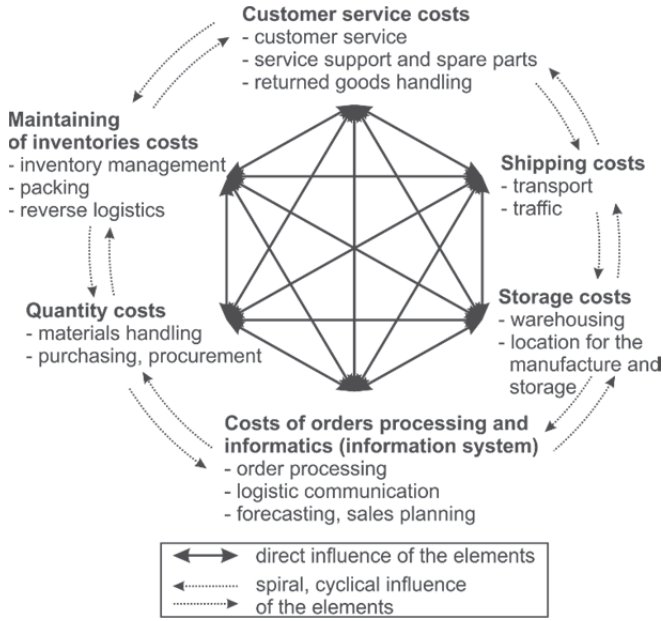


Figure 62 – How logistics activities influence total logistics costs (inspired by[1])

[1] Lambert, D.M., Stock, J.R., Ellram L.M.: Logistics, Computer Press, Prague, 2000

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According to Lambert, it is possible to define six cost items in logistics costs, which cover 14 main logistics activities.

1. *The costs of maintaining inventories* include the costs associated with inventory management, packing goods and the costs of activities associated with the term "reverse logistics".
2. *Quantity costs* have their origin in the amounts that are spent in the process of purchasing / procuring goods and in the production process. These are the costs associated with changes in the purchased quantities. *The shipping costs* are costs for transporting goods. The transport costs can be structured in terms of customers, manufactured products, channel type, etc. The costs vary significantly depending on the volume of supplies, weight of supplies, transport distance, places of origin and destination and the type of transport. *The storage costs* arise in the process of warehousing and storage of goods, and in their essence, they are influenced by the location of the production capacities and warehouses of the company. They include all costs incurred in connection with the change of number or location of warehouses.
3. *The costs of order processing and informatics* include the costs associated with activities such as order processing (receiving orders, entering orders into a system and order processing, advising transporters and customers about sending or preparing supplies, etc.), logistics communication and demand forecasting. *The costs associated with customer service* are the costs that may arise from insufficient levels of customer service; these are the costs associated with the loss of sales opportunities. Also, all the costs associated with supporting customer service (after-sales service, etc.) and handling returned goods (claims) are included (Prazska, Jindra 2002).

The Polish Lexicon of marketing (Altkorn, Kramer 1998) considers logistics costs to be a monetary expression of direct labour, equipment and work items consumed, financial expenses and other expenses that are caused by the movement of products within an enterprise and between enterprises as well as for maintaining inventories. Logistics costs are divided, based on the basic phases of the movement of products, into logistics costs of the 1st phase (procurement), 2nd (production), 3rd (distribution), 4th (consumption = utilization); alternatively based on the basic components of logistic processes, into logistics costs of: 1 the physical movement of products, 2 stocks and 3 information movement; or based on the basic factors of production, into logistics costs of: 1 amortization, 2 the use of materials and energy, 3 extraneous services, 4 work, 5 extraneous capital used, 6 tax assessment; and, based on the

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relation to changes in the size of logistics activities, into logistics costs which are 1 stable or 2 variable.

P. Macurová defines logistics costs as all costs affected by the method of organizing and managing flows in all chains of the logistics network. The terms of flow costs or logistically relevant costs are deemed synonymous with logistics costs (Viestova 2007). Petrbok, for the needs of logistics management in the context of management accounting and controlling, proposes recording logistics costs in the following structure:

- to monitor or summarize logistics costs by type of logistics and in the studied logistics segments (by purpose) according to the place of origin and responsibility, i.e. in the appropriate trade logistics centres,
- by types - calculate i.e. according to the type of production factors entering into an enterprise as well as according to the arrangement of the calculation formulae in the structure of unit costs and the costs overhead,
- by subject i.e. if an order or a logistics performance is defined as a unit of calculation, running costs will also be monitored for this unit.

As a part of accounting and controls management, Petrbok states that it is appropriate to view logistical performance in terms of the types of business logistics as an action in supply logistics (consisting of the implementation of actions related to the receipt and control of goods, with the function of warehouses, in-plant transport from unloading material to arranging manufacturing, with the management, planning and control of information flows from the inputs to production, planning and operations management, the actions of distribution logistics associated with the choice of optimal location of distribution warehouses and storage of finished products so that stocks are the most responsive, performing commissioning activities, including management of packaging, issuing the company's products and implementation of loading and transport of goods to the customer) (Petrbok 1996).

The concept of logistics costs is related to the concepts of logistics action and logistics indicator.

Logistics costs in terms of their substance are associated with the formation of logistics actions provided to a customer in the form of logistics services. The purpose of logistics is to optimize logistics actions i.e. optimization of the logistics services provided to a customer and optimization of logistics costs. Logistics costs can be defined as the sum of all costs associated with the provision of physical distribution. These are

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mainly the costs of transportation, packaging, storage and order processing (Viestova 2007).

6.4 Logistics Actions

Logistics actions arise in the activities of information, handling, storage, transport and other items (chains) in the logistics networks in terms of the supply of goods to customers.

Logistics actions are connected with logistics costs. The relationship between them is purposely influenced by logistics methods and logistics technologies aiming that for a given level of logistics costs the operation of the logistics system is at the highest possible level, (or more often) aiming for the lowest possible costs for a given level of performance of the logistics system (Sibl et al. 2002).

The customer perceives logistics actions as a form of logistics services. Items of logistics services are essentially - delivery time, delivery reliability, delivery flexibility, delivery quality.

Logistics actions involve linking the level of logistics services and productivity in logistics (Lambert et al. 2000). Logistics actions can be monitored on two levels within a company's logistics:

- depending on the type of company logistics, performance in supply logistics consists of the accomplishment of a performance - related to the receipt and control of goods within the function of warehouses, the part of in-plant transport from unloading material to arranging production, to the planning, management and control of information flows from the inputs to production, *the logistics actions of production* are concentrated in two areas - in production planning and in planning operation management, *the logistics actions of distribution* are connected with the choice of optimal location of warehouses, storage of finished products so that inventories are most responsive, performing commissioning activities, including management of packaging, issuing goods from the company and arranging the loading and transport of goods to the customer;
- according to the logistics of transversal sections, logistics actions can include the performance of transport systems, actions of storage and commissioning systems, performance of logistics management, logistics controlling results.

The basis for the analysis of logistics is the creation of the structural and framework indicators that are bound only by the scope of the tasks to

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be fulfilled (volume and a structure of actions), to the number and capacity of task carriers, especially labour and the capacity of material means and also to the time for follow-up of the costs arising. On the basis of this available numerical material, indicators for logistics management can be created, for example productivity indicators which are designed to measure the productivity of labour and productivity of technical equipment in operation. There are also economic indicators, which should accurately reflect the proportion of logistics costs for specific units of outputs and indicators of quality, which should evaluate the degree to which the specified target was achieved (Schulte 1994).

In the scientific literature, logistics indicators are defined in such a way that they consider logistics actions as well as logistics costs (Kubat 2000, Viestova 2007). In detail, these are the following indicators:

- logistics actions,
  - the degree of completeness of deliveries,
  - the flow-through period of an order,
  - the inventory turnover,
- logistics costs,
  - the total logistics costs,
  - the storage costs per quantity unit,
  - the transport costs per quantity unit,
  - the costs of locked-up capital,
  - the labour costs per manipulated quantity unit.

6.5 Logistics Indicators

Logistics indicators are clear indicators used by logistics control signifying the events in individual sections of the logistics chain. They refer to a specific order, to a logistics action or to a product.

The author deals with logistics indicators in detail in the publications Controlling and Logistics of an Industrial Company 1[2] and 2[3].

The logistics indicators for distribution centres with receipt of goods and shipping and with the functions of storage and picking for evaluation of internal logistics within the logistics chain are summarized using four key indicators. These enable sufficient assessment of a distribution centre in terms of costs, time and services. These are *the specific shipping costs* –

[2] Rosova, A.: Controlling and logistics of an industrial enterprise 1, Kosice, ES, F BERG TU of Kosice, p. 83, 2010

[3] Rosova, A.: Controlling and logistics of an industrial enterprise 2, Kosice, ES, F BERG TU v Kosice, p. 96, 2010

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the ratio of the total cost of the dispatch centre to the number of units prepared in shipping for delivery, *the coefficient of dispatched value* – the ratio of the total costs to the total value of goods prepared for dispatch, *the degree of fulfilment of the flow-through period* – the ratio of planned and actual lead time of orders, *the delivery quality* – a function of the promptness of supply and the degree of ready supplies, the promptness of supply coefficient, the ratio of incorrect deliveries and the coefficient of incorrect deliveries, which are joined together, multiplied and added (Kubat 2000).

6.5.1 The Key Indicators of Logistics Actions

A comprehensive but limited set of easily applicable indicators provide feedback for the development of logistics plans for the main functions of the management of product flows (marketing, sales, production and logistics), and determine the need for research or implementation of certain corrections or corrective actions, if necessary.

The high complexity of logistics systems and the rising costs of logistics actions increase the necessity of introducing targeted planning, management, control and coordination of partial segments of logistics. These tasks are performed by → *the controlling of logistics*, which performs continuous control of efficiency by comparing the plan with the reality of costs and actions, and it also supports the acquisition, collection and provision of information needed for the decision-making process (Rosova 2010).

Improving performance and efficiency in a logistics chain depends on:

- the solution of macroeconomic and microeconomic questions related to the distribution of goods,
- the optimization of the complete logistics chain and the benefits resulting from the synergy effect,
- the ability of companies providing logistics services to create an effective integrated logistics infrastructure,
- the ability of a carrier to perform the best integration with companies providing logistics services,
- the ability to form alliances between companies that provide complete logistics services.

The costs of distribution are not the same as logistics costs. Economic practice in particular companies in all sectors is to monitor, record and report total costs, including the costs of distribution and the costs of logistics for the purpose of control at their own discretion. These particular

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companies monitor and report the costs of distribution and the costs of logistics differently. Particular aspects of the records are not addressed by law so the results are not comparable. Comprehensive systematic cost savings for distribution logistics have not been implemented in the required number and structure of companies to produce relevant results (Straka et al. 2005).

The basis for any decision about the costs of logistics is the adoption of common views and strategies for logistics in general and for the company specifically. Until the concept is clarified, the diversity and heterogeneity of opinions is an obstacle to the adoption of any reasonable solutions to the problem.

The basis for the analysis of distribution costs and logistics costs is the creation of a unified database with a set of structural and framework indicators that are related to the scope of tasks to be fulfilled (volume and structure of performance), as well as to the number and capacity of carriers of tasks (especially labour and material capacity), and also to the time period for monitoring costs arising. Based on this available factual material, decisions can be adopted to rationalize costs.

The rationalization of the costs of logistics is limited by the necessary level of customer service in the market.

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III.

METHODS, MODELS AND TOOLS OF DISTRIBUTION AND SUPPLY LOGISTICS

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CHAPTER SEVEN

INVENTORY MANAGEMENT

What you will learn: The entire logistics chain requires quantities of different raw materials, intermediate products, goods and products. Since stocks constitute tied-up capital, it is imperative to manage them efficiently. The balance between flexibility, reliability and the amount of inventory is very important. Effective inventory management is one of the factors ensuring the competitiveness of firms in the market. This chapter deals with the aspects which influence effective inventory management.

Basic terms: inventory, stocks, models, management, inventory strategies.

7.1 Inventory Optimization Options

The creation, accumulation and selection of inventories are natural and logical for any company, industrial concern, warehouse or even consumer (Klepek, Lenort 2011). There are various reasons for companies wishing to accumulate inventory. This may be for the benefit of ensuring the smooth running of production, for the benefit of the market where companies are trying to market their products, or due to the effect of a process where maturation is required or for there to be sufficient seasonal stock. It is important, based on the needs and requirements of the market, to determine the efficient level of stocks, particularly in economic terms, since there is considerable finance tied up in stock as companies try to accumulate material and intermediate products in one or more locations. Therefore, it is necessary to manage inventories very seriously and responsibly and carry out regular analysis and control of them. Stocks can be defined from various points of view (Table 6), whether economic, logistical, physical, legal or technological.

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Table 6 – Definitions of stocks and the view of some authors and sources on stocks

Author	Year	View on stocks
D. Vanecek, D. Kalab[1]	2003	**Stocks** are considered to be raw materials in various stages of utilization or goods stored in a warehouse which are used in the business for production purposes but, they are yet been passed to a customer in their final desired form or consumed in the production process.
According to § 17 accounting procedures[2]	2010	**Stocks** are part of the short-term assets of an accounting entity, which are divided into: • stocks, • short-term financial assets, • short-term receivables. Stocks are: • material, • work in progress, intermediate products of own production, intermediate products, products or animals, • goods.
A. Rosova[3]	2011	**Stock** is any ready economic resource that is not fully used in the current time period, but its quantity is determined to enable coverage of future demand from the economic point of view.
www. euroekonom. sk[4]	2012	In terms of logistics, **stocks** are liabilities. In the extreme case their presence can be interpreted as being due to inability to manage the logistics chain optimally. If the flow of information and goods is more flexible and accelerated, inventory levels drop and tied-up capital decreases as a consequence, reducing overall costs. Japanese managers have raised the question of whether stocks are necessary at all, pre-empting questions

[1] Vanacek, D., Kalab, D.: Logistics, part 1., Introduction, inventory management and warehousing, 1st ed., Southern Czech university in Ceske Budejovice, 2003
[2] § 17 accounting procedures, 2010
[3] Rosova, A.: Logistics of purchase, Dekanat – Edicna stredisko, BERG Faculty, TU of Kosice, 2011
[4] http://www.euroekonom.sk/poradna/ekonomicky-slovnik/?q=zasoby

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		as to where and in what quantities they are to be created, meaning traditional methods of inventory management also lose their meaning.
M. Straka	2018	**Stocks** represent materials, raw materials, intermediate products or things and goods in a place that is precisely designed for this purpose and for a precisely specified purpose of use.

Each of the definitions has its own purpose and justification, some are specifically bound to a particular issue while others are more universal. In terms of economics and minimizing costs, it can be agreed that it would be advantageous to define a system that is able to work efficiently without inventories. But reality is cruel and different, because in most production systems there are items that are not at the same level in terms of capacity, time or in technological terms and in such cases a warehouse with its inventory levels acts as a buffer between them.

7.1.1 Inventory Control Strategies

In the interests of more cost-effective storage and provision of raw materials, stocks, semi-finished products and in general, it is necessary to address their management and optimization. There are a variety of inventory management strategies for this purpose, which in principle can be divided into two basic groups of models:

- deterministic models of inventory management,
- stochastic models of inventory management.

In terms of the inventory management of the company, four main strategies are normally used: *Q,t - Q,r - S,t - S,r* (Table 7) (in the many contributions to the literature there are several different ways of marking them, for example: *t,S,Q - EOQ - S,Q - t,S/t,s,S/t,q - s*,*S* or as per the different considerations of the authors). Since there are many papers[5] and web links[6] that specialize in inventory management from every angle, the following sections will address the conventional models of inventory management (Table 8).

[5] Bazala, J. et al.: Logistics in practice, Verlag Dashofer Praha, Praha, 2006; Vrat, P.: Materials Management, An Integrated Systems Approach, Springer, 2014

[6] http://www.person.vsb.cz/archivcd/FMMI/PL/Prumyslova%20logistika.pdf; https://msu.edu/course/prr/473/oldstuff/Inventory%20Management.htm

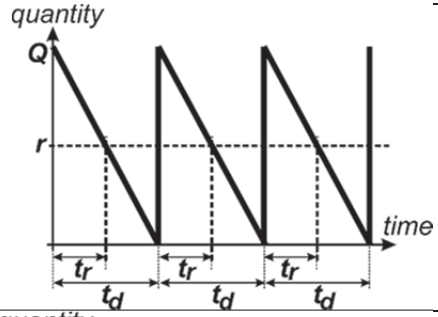
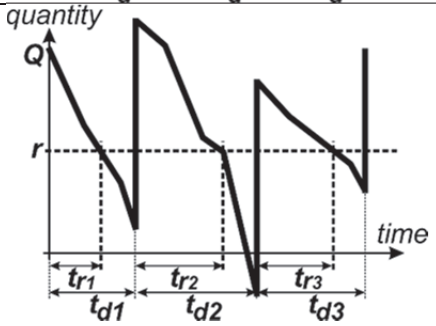
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Table 7 – The basic strategies of inventory management

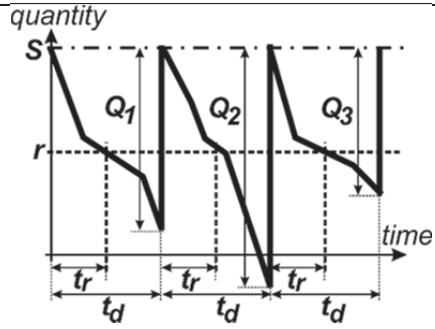
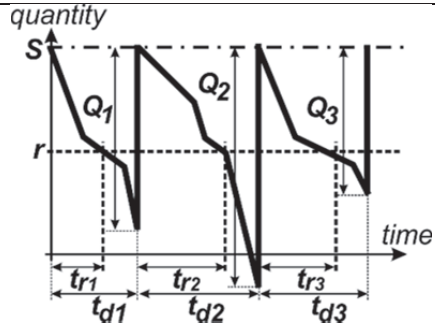
Strategies of inventory management		Ordering interval	
		Fixed	Variable
Delivery amount	Fixed	***Q,t***	***Q,r***
	Variable	***S,t***	***S,r***

Q – ordered quantity,
t – time interval, ordering cycle,
S – planned inventories,
r – level of supplies ordered.

Table 8 –The characteristics and course of the basic strategies of inventory management

Strategy	Characteristics	Course
Q,t	Stock is increased by the same ordered quantity *Q* at regular intervals t_d.	
Q,r	Stock is increased by the same ordered quantity *Q* at irregular intervals t_{di}, depending on the intensity of consumption and reaching signal level *r*.	

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S,t	Stock is increased by a different order quantity Q_i at regular intervals t_d, which depends on the intensity of consumption to reach the planned level of stocks S.	
S,r	Stock is increased by a variable order quantity Q_i, which depends on the intensity of consumption, to achieve the planned level of stocks S, at irregular intervals t_{di}, which depend on the intensity of consumption and reaching signal level r.	

It is important to note that the consumption of materials and raw materials mostly has a step character in reality. The direct line of the progress of consumption and supplies of stock are shown (Figure 63) only as a simplified view to aid their management.

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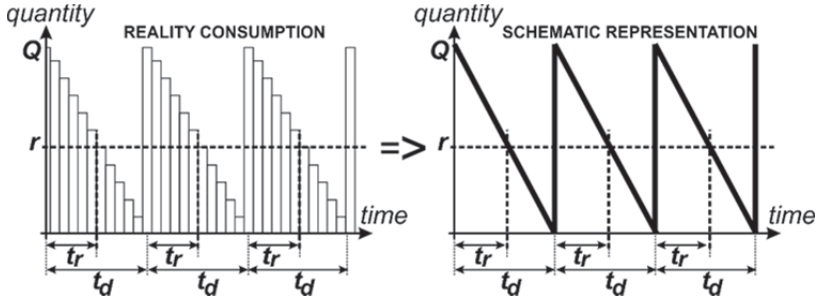


Figure 63 – The consumption of materials in reality and its schematic representation

7.1.1.1 Deterministic Models of Inventory Management

Deterministic models of inventory management are among the oldest and the first models produced dating back to the early 20th century. The basic types of deterministic models include the model with optimally sized delivery of supplies Q_{opt} for continuous consumption of stocks. This model was created by F. W. Harris in about 1913. The model was used and promoted by R. H. Wilson and therefore it is currently termed the Harris-Wilson formula (Erlenkotter 1990, Lenort 2012).

Inventory management with the deterministic type of model is based on certain assumptions:

- a constant level of demand and consumption,
- the optimum size of ordered stocks Q_{opt} is not limited and an ordered delivery occurs immediately,
- delivery time t is the same over the entire planning season,
- the purchase prices and transport costs are the same independent of time and order size,
- a stock represents only one type of product without links of interaction with other types of products,
- the planning horizon is unlimited and there is unrestricted capital,
- it is not possible for there to be a deficit of stocks, since the optimal size of ordered stocks with the stationary model, time of delivery and delivery amount are always constant.

In the case of strategy Q,t there is a deterministic model for the size of orders of supplies. The basis of strategy Q,t is to order exactly the same amount of stocks Q, which are always added in the same delivery cycles (Figure 64).

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From the perspective of management, it is an effort to optimize the ordered quantity Q and to determine the effective level of stocks r to order (Novak et al. 2012). To determine these parameters, it is necessary to know the input variables and their values:

Q – the effective size, the effective amount of stocks, which must be delivered to a warehouse in a delivery cycle, so that the increased level of stocks is above the order level r by a sufficient margin. The order amount ensures the smooth fulfilment of the demands of production, the market and consumption over a certain time.

***r* – the stock order level** is an amount, a level of inventory. If it is reached, the delivery of new stock must be arranged. It is a level which should guarantee that ordered supplies will arrive on time and that production or consumption will continue undisturbed.

t_r – the time of stock ordering is the moment at which inventories reach order level r. At this time, it is necessary to order a new quantity into stock.

***I* – the annual consumption of an inventory item** represents the amount of consumption of that stock per year.

t_d – the delivery cycle (7.1) is the time between arrivals of these stocks at a warehouse. The delivery cycle is dependent on the annual consumption of inventories and the effective size of an order.

$$t_d = \frac{Q}{I} => t_{d_{opt}} = \frac{Q_{opt}}{I}[part\ of\ a\ year] \tag{7.1}$$

***v* – the number of orders per year** (7.2) is the inverse value of the delivery cycle.

$$v = \frac{1}{t_d} = \frac{1}{\frac{Q}{I}} = \frac{I}{Q} \tag{7.2}$$

***t* – the delivery period** is the time between the moment of ordering stocks and the moment of the physical arrival of these stocks at the warehouse for which they have been ordered.

$\bar{Q}$ – the average stock in a single delivery cycle (7.3) is half the optimum amount.

$$\bar{Q} = \frac{Q}{2} = \frac{Q_{opt}}{2} \tag{7.3}$$

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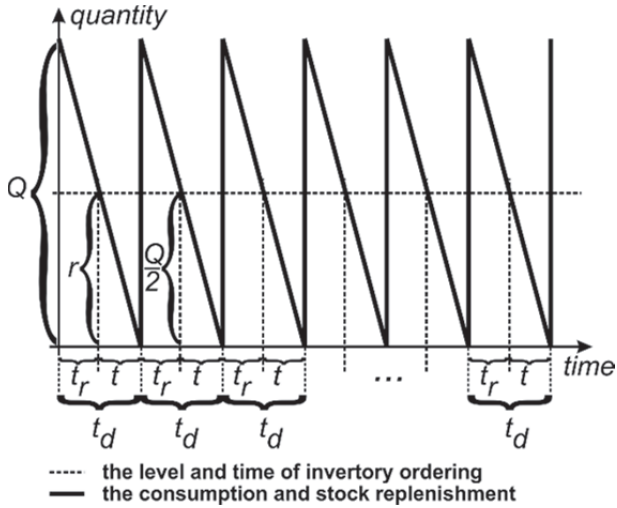


Figure 64 – Graphical illustration of stocking up and consumption of stocks under deterministic models of inventory management

The aim of keeping warehouse operations as efficient as possible is to reduce or minimize the costs of the supply process i.e. to minimize total annual costs (Novak et al. 2012) (7.4) for managing the supply process *Ncr(Q)*.

$$\min z = Ncr(Q) = Nsr + Nor \tag{7.4}$$

***z* – the objective function of the total annual cost**s that must be minimized,

***Ncr(Q)* – the total annual costs** of managing the supply process of the warehouse,

***Nsr* – the annual costs of physically maintaining stocks**, these mainly include the costs of tied-up capital in inventory (size of the profit that the company would have received and invested elsewhere if the capital was not tied-up in inventory), the costs of maintaining a warehouse (costs of warehousing), insurance costs of the warehouse and inventory, the costs of risk (costs associated with the risk of unusable inventories) (Lenort 2012).

***Nor* – the annual cost of ordering**, i.e. administrative costs related to preparing and sending orders and the transport of these raw materials. The costs are total fixed costs related to administratively securing supplies and transport.

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The effective or optimum size of the total annual costs incurred for storage depends on **the optimal level of stocks Q_{opt}** obtained by differentiating the first objective function of total annual costs according to the amount (Domeova, Berakova 2004) (7.5), while the expressed extreme is equal to zero.

$$\frac{dNcr(Q)}{dQ} = 0 \tag{7.5}$$

The annual costs of physical storage *Nsr* (7.6) depend on the average ordered amount of stocks $\bar{Q}$, the delivery cycle t_d, the unit costs of physical storage *Ns*, and the number of orders in a year v.

$$Nsr = \bar{Q} \times t_d \times Ns \times v = \frac{Q}{2} \times \frac{Q}{I} \times Ns \times \frac{I}{Q} = \frac{Q}{2} \times Ns \tag{7.6}$$

The annual costs of preparing and sending orders *Nor* (7.7) depend on the number of orders in a year v and the processing costs of one order *No*.

$$Nor = v \times No = \frac{I}{Q} \times No \tag{7.7}$$

By substitution into the objective function, the total annual costs of supply process management *Ncr (Q)* (7.8) for individual partial costs will form the shape of the objective function, which will become the basis for determination of the extreme of the function.

$$\min z = Ncr(Q) = \frac{Q}{2} \times Ns + \frac{I}{Q} \times No \tag{7.8}$$

The extreme, in this case the minimum, of the expressed objective function is obtained by the first differentiation of it according to the quantity *Q* and it must be equal to zero (7.9).

$$\frac{dNcr(Q)}{dQ} = \frac{\frac{Q}{2} \times Ns + \frac{I}{Q} \times No}{dQ} = \frac{Ns}{2} - \frac{I}{Q^2} \times No = 0 \tag{7.9}$$

From the resulting quadratic equation, quantity *Q* should be expressed representing the optimal order size of a particular stock Q_{opt} (7.10), which can be ordered for the needs of production or consumption.

$$\frac{Ns}{2} - \frac{I}{Q^2} \times No = 0 \Rightarrow -\frac{1}{Q^2} = -\frac{Ns}{2 \times I \times No} \Rightarrow$$

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$$Q_{opt} = \sqrt{\frac{2 \times I \times No}{Ns}} \tag{7.10}$$

The expressed formula is called Harris-Wilson, also known as the Adler formula (Rosova 2011) to calculate the optimal order size of stock Q_{opt}.

Total costs *Ncr (Q)* are reflected in the costs function u (7.11). The calculated Q_{opt} is substituted into the function.

$$\min u = Ncr(Q) = \frac{Q_{opt}}{2} \times Ns + \frac{I}{Q_{opt}} \times No$$

$$= \frac{\sqrt{\frac{2 \times I \times No}{Ns}}}{2} \times Ns + \frac{I}{\sqrt{\frac{2 \times I \times No}{Ns}}} \times No =$$

$$\frac{Ns \times \sqrt{\frac{2 \times I \times No}{Ns}} \times \sqrt{\frac{2 \times I \times No}{Ns}} + I \times No \times 2}{2 \times \sqrt{\frac{2 \times I \times No}{Ns}}}$$

$$= \frac{Ns \times \left(\frac{2 \times I \times No}{Ns}\right) + 2 \times I \times No}{2 \times \sqrt{\frac{2 \times I \times No}{Ns}}} =$$

$$\frac{2 \times I \times No + 2 \times I \times No}{2 \times \sqrt{\frac{2 \times I \times No}{Ns}}} = \frac{2 \times I \times No}{\sqrt{\frac{2 \times I \times No}{Ns}}}$$

$$= (2 \times I \times No) \times \sqrt{Ns} \times (2 \times I \times No)^{-\frac{1}{2}} =$$

$$\sqrt{2 \times I \times No \times Ns} \tag{7.11}$$

***u* – the objective function of total variable costs**, which must be minimized. The costs will be minimized when the order quantity of stock is Q_{opt}, which results from the Harris-Wilson formula.

It is necessary to get the answers to two questions to maintain optimal costs:

1) What is the stock order level (r)?
2) When are supplies of stock ordered (t_r)?

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The stock order level *r* (7.12) can be calculated from:

$$r = I \times \left(t - \left\lfloor \frac{t}{t_d} \right\rfloor t_d\right) = I \times t - \left\lfloor \frac{t}{t_d} \right\rfloor \times Q_{opt}. \quad (7.12)$$

The time to order supplies into stock (7.13) can be calculated from:

$$t_r = t_d - \left(t - \left\lfloor \frac{t}{t_d} \right\rfloor \times t_d\right) = t_d \times \left(\left\lfloor \frac{t}{t_d} \right\rfloor + 1\right) - t \quad (7.13)$$

$\left\lfloor \frac{t}{t_d} \right\rfloor$ – this entry represents the number of deliveries on the road rounded to the nearest lower whole number e.g.: $\left\lfloor \frac{5}{3} \right\rfloor = \lfloor 1.666 \rfloor = 1$.



Task: An international company operating in the food industry sells chocolate products. Stock taking during the day can be considered constant. Interest in chocolate products is high and the annual consumption of primary raw materials represents 18000 kg of cocoa. The company orders 375 kg of cocoa four times per month, i.e. 48 orders per year. The purchase cost is 30 EUR per unit (kilogram) of cocoa. The total annual costs for storage of cocoa as input raw material are 40088 EUR, already including the salaries of warehouse personnel in these costs. The annual costs of salaries of personnel performing order processing are 20560 EUR. The carrier charges 12000 EUR for transporting cocoa during the year. If the company invested funds tied-up in inventory, it would achieve a profit of 12%. What amount of money can this company save if it optimizes the current activities of inventory management using the *S,t* model. The task is to calculate the objective function *Nc (Q)*, the optimal order size for the stock Q_{opt} and the stock order level *r*.

1. The costs of the current inventory management system:

The annual costs of maintaining physical inventories = rent for the warehouse (including staff salaries) + annual costs of capital tied-up in inventory:

$$Nsr = 40\,088 + 30 \times 0.12 \times \frac{375}{2} = 40\,763\ EUR/year.$$

The annual costs of ordering = staff salaries + annual costs of transport:

$$Nor = 20\,560 + 12\,000 = 32\,560\ EUR/year.$$

The total annual cost of supply process management = annual cost of maintaining physical inventory + annual costs for ordering:

$$Ncr(Q) = Nsr + Nor = 40\,763 + 32\,560 = 73\,323\ EUR/year.$$

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2. After a change of system management to use the *Q,t* model, the optimal size of ordering:

I = 18 000 kg/year, *No* = 12 000 / 48 = 250 EUR/transport, *Ns* = 0.12×30 = 3.6 EUR/kg,

$$Q_{opt} = \sqrt{\frac{2 \times I \times N_o}{N_s}} = \sqrt{\frac{2 \times 18\,000 \times 250}{3.6}} = \sqrt{\frac{9\,000\,000}{3.6}} = \sqrt{2\,500\,000} = 1\,581.14\ kg/order.$$

3. Calculation of savings:

If the company orders 1 581.14 kg of cocoa in comparison to the original 375 kg of cocoa, the following can be stated:

- It increases the tied-up capital from 375×3.6 = 1 350.00 EUR/order to 1 581.14×3.6 = 5 692.104 EUR/order.
- It reduces the number of orders from 18 000/375 = 48 to 18 000/1 581.14 = 11.38, which results in a lower total cost of transport from the original EUR 12 000 EUR/year to 2 846.05 EUR/year.
- Total annual costs will be decreased from the original $Ncr(Qoriginal) = Nsr + Nor = 40\,763 + 32\,560 = 73\,323\ EUR/year$ to $Ncr(Qnew) = Nsr + Nor = 42\,934 + 23\,406 = 66\,340\ EUR/year$ this represents savings of ***6 983 EUR/year***.

Total savings can also be quantified:

- the costs of the original ordering system $Ncr(original) = \frac{Q}{2} \times Ns + \frac{I}{Q} \times No = \frac{375}{2} \times 3.6 + \frac{18\,000}{375} \times 250 = 675 + 12\,000 = 12\,675\ EUR/year$,
- the costs of the new ordering system $Ncr(new) = \frac{Q}{2} \times Ns + \frac{I}{Q} \times No = \frac{1\,581.14}{2} \times 3.6 + \frac{18\,000}{1\,581.14} \times 250 = 2\,846.052 + 2\,846.05 = 5\,692.102\ EUR/year$,
- the amount of savings = *Ncr(original) – Ncr(new) =12 675 – 5 692.102 =* ***6 983 EUR/year***.

4. The calculation of the length of the delivery cycle, the stock order level and the time when it is needed to order supplies:

$t_{d_{opt}}$ – cycle of stock ordering,

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r – stock order level,
t_r – time when it is needed to order supplies.

$$t_{d_{opt}} = \frac{Q_{opt}}{I} = \frac{1\,581.14}{18\,000} = 0.0878\ years = 32\ days,$$

$$r = I \times t - \left\lfloor \frac{t}{t_d} \right\rfloor \times Q_{opt} = 18\,000 \times 1 - \left\lfloor \frac{1}{0{,}0878} \right\rfloor \times 1\,581.14$$
$$= 18\,000 - \lfloor 11.4 \rfloor \times 1\,581.14$$
$$= 18\,000 - 11 \times 1\,581.14$$
$$= 18\,000 - 17\,392.54 = 607.46\ kg,$$

$$t_r = t_d - \left(t - \left\lfloor \frac{t}{t_d} \right\rfloor \times t_d\right) = 0.0878 - \left(1 - \left\lfloor \frac{1}{0.0878} \right\rfloor \times 0.0878\right)$$
$$= 0.0536\ years = 19.6\ days.$$

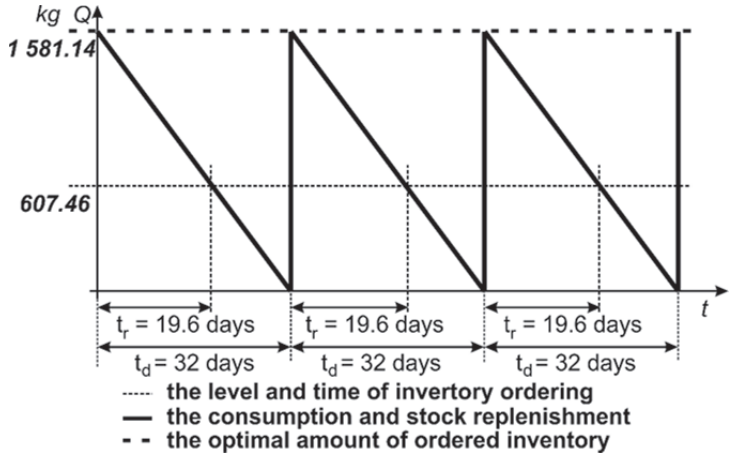


Figure 65 – Diagram of adding, ordering and consumption of cocoa, the stock in a warehouse

Conclusion: The objective function of the total monthly costs *Ncr (Q)*, after the change in method of managing the ordering process, is equal to 5 692 EUR/year, the optimum amount ordered is 1 581.14 kg of cocoa and the stock order level is when there is 607.46 kg of cocoa in stock. The delivery cycle is t_d = 32 days (Figure 65). The time of ordering new material is 19.6 days from the previous delivery of material to the warehouse.

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7.1.1.1.1 The inventory management model with a deficit

The previously defined model (Figure 66) does not consider the possible occurrence of a deficit in stocks (in general and inherently, deterministic models do not enable it). In reality, there can (and does) occur a situation where a customer does not get the goods they desire, there are no raw materials or supplies for some unforeseen reason, i.e. there is a deficit d in the supply system. Allowing for a deficit, which has a stochastic character in deterministic models, represents the ambition to replace basic stochastic models of inventory management (Novak et al. 2012). The deficiency model can be classified into the following groups:

- with postponed consumption,
- with lost consumption.

The basic model of inventory management with a deficit is primarily a model dependent on ordered quantity and time. These are cases where the supply available at the time of the delivery cycle t_d is not able to provide the resources required for production, for consumption or the market for some reason. The system tries to fill the missing parts of inventory, i.e. d deficiency, in the next order. With this type of deficit it assumed that the deficit is always of the same size. The supply cycle t_d in the deficit model consists of two periods t_{d1} a t_{d2} (7.14) i.e.

$$t_d = t_{d1} + t_{d2} \tag{7.14}$$

At time t_{d1}, consumption is covered with the necessary raw materials, materials or goods. At time t_{d2} there is a deficit of some stock for the consumption requirements.

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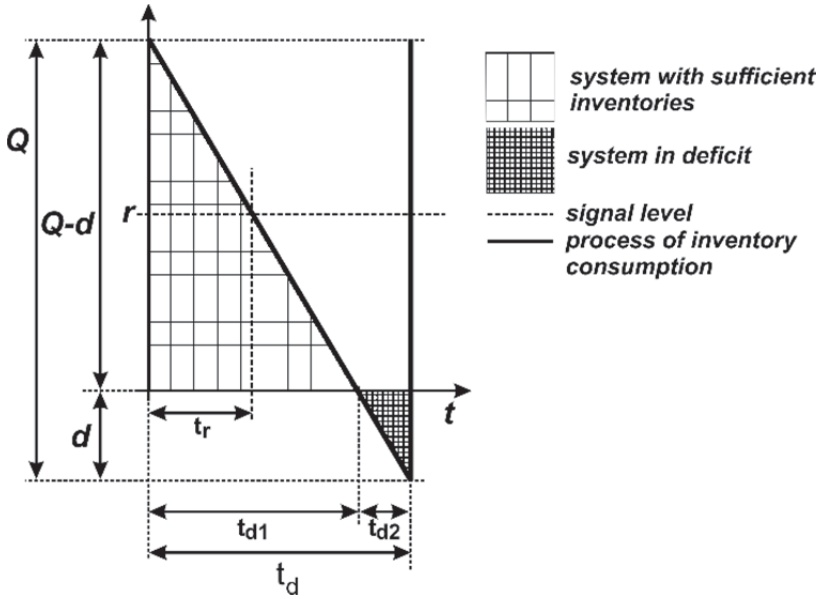


Figure 66 – Diagram of a system of stock consumption with a deficit

Like in the previous model, the aim is to make the warehouse operations more efficient e.g. to reduce, minimize the cost of process of supply of a warehouse, i.e. to minimize the total annual costs of managing the supply process *Ncr(Q,d)* (7.15). In terms of the objective function of total annual costs it is necessary to calculate the costs associated with a deficit of inventory during the year.

$$\min z = Ncr(Q,d) = Nsr + Nor + Ndr \tag{7.15}$$

***z* – the objective function of the total annual cost** that must be minimized,
***Ncr(Q,d)* – the total annual costs** of managing the supply process in a warehouse,
***Nsr* – the annual cost of physically maintaining inventories**,
***Nor* – the annual costs of ordering**, i.e. administrative costs related to the preparation and dispatch of orders. Costs represent total fixed costs related to administrative acquisition of supplies,
***Ndr* – the costs associated with the accrued deficit of stocks during the year**,

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***Nd* – the costs associated with the accrued deficit** calculated per quantity unit of deficit and time when there is not stock available for consumption requirements,
***d* – deficit of stocks** that are missing at time t_{d2} to meet consumption requirements; this is the amount of inventory missing for consumption requirements,
***Q-d* – the amount of stocks** which are drawn upon for consumption requirements at time t_{d1}.

In this case, after adjustment, it is a function of two variables – **the optimal level of stocks Q_{opt}** and **stock deficit *d***. Other unknown variables that reflect the time characteristics of existing stocks and the deficit i.e. t_{d1} a t_{d2} may be replaced by relationships resulting from the similarity of triangles (Domeova, Berakova 2004). Thus, it is possible to obtain an overall cost function with only two unknowns. The extreme of function z is obtained by partial derivatives (7.16) according to amount Q and deficit d. Subsequently, the derivation is solved for when it is equal to zero, as a system of two equations with two unknowns. The result is the determination of the optimal order quantity Q_{opt} and the optimal amount of outstanding orders d.

$$\frac{dNcr(Q,d)}{dQ} = 0 \wedge \frac{dNcr(Q,d)}{dd} = 0 \tag{7.16}$$

The annual costs of physically maintaining stocks *Nsr* depend on the average amount of stock ordered $\bar{Q}$, the delivery cycle, the time of the existence of the stock in the warehouse t_{d1}, unit costs of physical storage Ns, and turnover v. Since it is a similarity of triangles (Figure 66), t_{d1} can be expressed (7.17) as:

$$\frac{t_{d1}}{t_d} = \frac{Q-d}{Q} => t_{d1} = \frac{Q-d}{Q} \times t_d = \frac{Q-d}{Q} \times \frac{Q}{I} = \frac{Q-d}{I}, \tag{7.17}$$

then the annual costs of physically maintaining stocks (7.18) are calculated as:

$$Nsr = \bar{Q} \times t_{d1} \times Ns \times v = \frac{Q-d}{2} \times t_{d1} \times Ns \times \frac{I}{Q} = \frac{Q-d}{2} \times \frac{Q-d}{I} \times Ns \times \frac{I}{Q} = \frac{(Q-d)^2}{2 \times Q} \times Ns. \tag{7.18}$$

The annual cost of preparing and processing orders *Nor* (7.19) depends on the number of orders during a year v and order release costs *No*.

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$$Nor = v \times No = \frac{I}{Q} \times No \tag{7.19}$$

The total annual costs associated with deficit of stocks *Ndr* are expressed as the mean deficit $\bar{d}$, the delivery cycle at the time of deficit t_{d2}, the number of orders during a year *v* and the costs related to the deficit at the time as *Nd*. The similarity of triangles is valid, thus t_{d2} can be calculated as (7.20):

$$\frac{t_{d2}}{t_d} = \frac{d}{Q} => t_{d2} = \frac{d}{Q} \times t_d = \frac{d}{Q} \times \frac{Q}{I} = \frac{d}{I}, \tag{7.20}$$

then the annual costs associated with stock deficits can be quantified (7.21) as:

$$Ndr = \bar{d} \times t_{d2} \times v \times Nd = \frac{d}{2} \times t_{d2} \times \frac{I}{Q} \times Nd = \frac{d}{2} \times \frac{d}{I} \times \frac{I}{Q} \times Nd = \frac{d^2}{2Q} \times Nd. \tag{7.21}$$

Substituting into the objective function, the total annual cost of managing the supply process *Ncr(Q,d)* (7.22) for an individual partial cost takes the form of the objective function, which will be the basis for determining function extremes.

$$\min z = Ncr(Q,d) = \frac{(Q-d)^2}{2\times Q} \times Ns + \frac{I}{Q} \times No + \frac{d^2}{2Q} \times Nd \tag{7.22}$$

The first extreme, from the expressed objective function, is obtained by differentiating its quantity *Q*, and solving as equal to zero (7.23).

$$\frac{dNcr(Q,d)}{dQ} = \frac{\frac{(Q-d)^2}{2\times Q}\times Ns + \frac{I}{Q}\times No + \frac{d^2}{2Q}\times Nd}{dQ} =$$
$$\frac{(2Q-2d)\times 2Q - (Q^2-2Qd+d^2)\times 2}{4\times Q^2} \times Ns - \frac{I}{Q^2} \times No - \frac{d^2\times 2}{4\times Q^2} \times Nd =$$
$$\frac{4\times Q^2 - 4\times Qd - 2\times Q^2 + 4\times Qd - 2\times d^2}{4\times Q^2} \times Ns - \frac{I}{Q^2} \times No - \frac{d^2\times 2}{4\times Q^2} \times Nd =$$
$$\frac{2\times Q^2 - 2\times d^2}{4\times Q^2} \times Ns - \frac{I}{Q^2} \times No - \frac{d^2}{2\times Q^2} \times Nd =$$
$$\frac{Q^2\times Ns - d^2\times Ns - d^2\times Nd}{2\times Q^2} - \frac{I}{Q^2} \times No = 0 =>$$

$$\frac{Q^2\times Ns - d^2\times Ns - d^2\times Nd}{2\times Q^2} = \frac{I}{Q^2} \times No$$

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$$\frac{Q^2\times Ns-d^2\times Ns-d^2\times Nd}{2}=I\times No$$
$$Q^2\times Ns-d^2\times(Ns+Nd)=2\times I\times No$$

$$Q^2\times Ns=2\times I\times No+d^2\times(Ns+Nd)$$
$$Q^2=\frac{2\times I\times No+d^2\times(Ns+Nd)}{Ns}$$
$$Q=\sqrt{\frac{2\times I\times No+d^2\times(Ns+Nd)}{Ns}} \tag{7.23}$$

The second extreme, from the expressed objective function, is obtained by differentiating the amount of the deficit *d*, which is equal to zero after differentiating (7.24).

$$\frac{dNcr(Q,d)}{dd}=\frac{\frac{(Q-d)^2}{2\times Q}\times Ns+\frac{I}{Q}\times No+I\times Oc+\frac{d^2}{2\times Q}\times Nd}{dd}=$$
$$\frac{(-2\times Q+2\times d)\times 2Q-\left(Q^2-2\times Qd+d^2\right)\times 0}{4\times Q^2}\times Ns+0+0+\frac{2\times d\times 2Q-d^2\times 0}{4\times Q^2}\times Nd=$$
$$\frac{d-Q}{Q}\times Ns+\frac{d}{Q}\times Nd=0=>\frac{d\times Ns-Q\times Ns+d\times Nd}{Q}=0$$
$$\frac{d\times(Ns+Nd)-Q\times Ns}{Q}=0$$
$$d\times(Ns+Nd)=Q\times Ns$$
$$d=\frac{Q\times Ns}{Ns+Nd} \tag{7.24}$$

After the adjustments there are two equations with two unknowns that need to be further adjusted into the final form (7.25).

$$Q=\sqrt{\frac{2\times I\times No+d^2\times(Ns+Nd)}{Ns}}$$
$$d=\frac{Q\times Ns}{Ns+Nd}$$
$$Q^2=\frac{2\times I\times No+\left(\frac{Q\times Ns}{Ns+Nd}\right)^2\times(Ns+Nd)}{Ns}=\frac{2\times I\times No}{Ns}+\frac{Ns^2\times Q^2}{Ns\times(Ns+Nd)}=$$
$$\frac{2\times I\times No}{Ns}+\frac{Ns\times Q^2}{Ns+Nd}=>$$

$$Q^2-\frac{Ns\times Q^2}{Ns+Nd}=\frac{2\times I\times No}{Ns}$$

$$Q^2\times\left(1-\frac{Ns}{Ns+Nd}\right)=\frac{2\times I\times No}{Ns}$$

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$$Q^2 = \frac{\frac{2\times I\times No}{Ns}}{1-\frac{Ns}{Ns+Nd}}$$

$$Q^2 = \frac{\frac{2\times I\times No}{Ns}}{\frac{Ns+Nd-Ns}{Ns+Nd}} = \frac{2\times I\times No\times(Ns+Nd)}{Ns\times Nd} =>$$

$$Q_{opt} = \sqrt{\frac{2\times I\times No\times(Ns+Nd)}{Ns\times Nd}} = \sqrt{\frac{2\times I\times No}{Ns}} \times \sqrt{\frac{Ns+Nd}{Nd}} \quad (7.25)$$

The adjustments have the result that the optimum amount of ordered stocks is proportional to the optimal delivery of stocks model without deficit, and a constant that depends on storage costs *Ns* and costs related to stock deficiency *Nd*.

The expression of the deficit *d* is obtained by the substitution of *Q* back into the second equation (7.26).

$$d = \frac{\sqrt{\frac{2\times I\times No\times(Ns+Nd)}{Ns\times Nd}}\times Ns}{Ns+Nd} = \frac{Ns\times\sqrt{2\times I\times No\times(Ns+Nd)}}{(Ns+Nd)\times\sqrt{Ns\times Nd}} = Ns\times(2\times I\times No)^{\frac{1}{2}}\times$$
$$(Ns+Nd)^{\frac{1}{2}}\times(Ns+Nd)^{-1}\times Ns^{-\frac{1}{2}}\times Nd^{-\frac{1}{2}} =$$
$$Ns^{\frac{1}{2}}\times(2\times I\times No)^{\frac{1}{2}}\times(Ns+Nd)^{-\frac{1}{2}}\times Nd^{-\frac{1}{2}} = \frac{\sqrt{2\times I\times No\times Ns}}{\sqrt{Nd\times(Ns+Nd)}} => d =$$
$$\sqrt{\frac{2\times I\times No\times Ns}{Nd\times(Ns+Nd)}} \quad (7.26)$$

Total annual costs *Ncr(Q,d)* (7.27) are expressed by cost function *u*. The expressed formulae are substituted by the optimal amount of inventory ordered Q_{opt} and the deficit *d*. After the adjustments it goes to:

$$\min u = Ncr(Q,d) = \frac{Q_{opt}-d}{2}\times t_{d1}\times Ns\times\frac{I}{Q_{opt}} + \frac{I}{Q_{opt}}\times No + \frac{d}{2}\times t_{d2}\times$$
$$\frac{I}{Q_{opt}}\times Nd = \frac{(Q_{opt}-d)^2}{2\times Q_{opt}}\times Ns + \frac{I}{Q_{opt}}\times No + \frac{d^2}{2Q_{opt}}\times Nd =$$
$$\sqrt{2\times I\times No\times Ns}\times\sqrt{\frac{Nd}{Ns+Nd}}. \quad (7.27)$$

Because the ratio $\frac{Nd}{Ns+Nd}$ will always be less than or equal to 1, the total variable costs in the model from an unfulfilled order will be less than in the previous model.

The expression of the times in a delivery cycle t_{d1} a t_{d2} is based on the similarity of triangles and the aspect of the ratio $\frac{t_{d1}}{t_d} = \frac{Q-d}{Q}$ a $\frac{t_{d2}}{t_d} = \frac{d}{Q}$. For

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simplification the substitution of $X = \frac{t_{d1}}{t_d}$ and $Y = \frac{t_{d2}}{t_d}$, is introduced then it results from the defined formula, that *X* expresses the ratio of the time during which consumption requirements are satisfied to the total time of the delivery cycle and *Y* represents the ratio of the time during which consumption requirements are not currently satisfied to the total time of the delivery cycle. In terms of probability theory, the ratio of a part to the whole reflects the probability of the given part occurring. Similarly, it can be stated that *X* (7.28) expresses the probability that the requirements of consumption will be satisfied and *Y* (7.29) expresses the probability that the requirements of consumption will not be satisfied. From the above, mentioned it can be stated that *X* + *Y* = *1* and after substitutions and adjustments the following holds:

$$X = \frac{t_{d1}}{t_d} = \frac{Q-d}{Q} = \frac{Nd}{Ns+Nd}, \tag{7.28}$$

$$Y = \frac{t_{d2}}{t_d} = \frac{d}{Q} = 1 - X = \frac{Ns}{Ns+Nd} => d = Q \times Y. \tag{7.29}$$

The probability of *X*, i.e. consumption will be satisfied and the probability of *Y*, i.e. the consumption will not be satisfied depend only on the amount of costs related to the deficit *Nd*, or on the level of costs associated with storage *Ns*. If the costs associated with the deficit *Nd* are significantly high in comparison with the costs associated with storage *Ns*, the probability of dissatisfaction of consumption requirements *Y* will be close to 0, and the probability of satisfying consumption requirements *X* will be close to 1. When the costs associated with storage Ns are significantly high relative to the costs associated with the deficit *Nd*, the opposite situation will occur i.e. the probability of non-satisfaction of consumption requirements will be close to 1. The stock order level *r* (7.30) can be calculated as in the previous models, but from the total amount it is necessary to deduct the stock deficit from unfulfilled needs.

$$r = I \times \left(t - \left\lfloor \frac{t}{t_d} \right\rfloor t_d\right) - d = I \times t - \left\lfloor \frac{t}{t_d} \right\rfloor \times Q_{opt} - d \tag{7.30}$$



Task: As an example, the text from the previous model is used. There are the situations within supply where breaches have occurred in cardboard boxes into which chocolate products are put and there is a need to perform additional handling when putting in the finished products into boxes. The cost for repair is 350 EUR per year. The maximum annual state of the deficit is 300 kg.

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I = 18 000 kg/year, No = 12 000 / 48 = 250 EUR/transport, Ns = 0.12×30 = 3.6 EUR/kg, Nd = 350/300 = 1.17 EUR/kg, d = 300 kg.

1. Calculation of optimal order amount Q_{opt}:

$$Q_{opt} = \sqrt{\frac{2\times I\times No}{Ns}} \times \sqrt{\frac{Ns+Nd}{Nd}} = \sqrt{\frac{2\times 18\,000\times 250}{3.6}} \times \sqrt{\frac{3.6+1.17}{1.17}} = 1\,581.14 \times 2.02 = 3\,193.9028\ kg.$$

2. Calculation of the time period when the system operates without a deficit t_{d1} and the time period when the system is already in deficit t_{d2}:

$$t_{d1} = \frac{Q-d}{I} = \frac{3\,193.9028-300}{18\,000} = 0.1608\ year = 58.68\ days,$$

$$t_{d2} = \frac{d}{I} = \frac{300}{18\,000} = 0.0167\ year = 6.08\ days,$$

$$X = \frac{t_{d1}}{t_d} = \frac{0.1608}{0.1775} = 0.906.$$

1. Calculation of value of the objective function of the total annual costs *Ncr(Q,d)*:

$$Ncr(Q,d) = \sqrt{2\times I\times No\times Ns} \times \sqrt{X} = \sqrt{2\times 18\,000\times 250\times 3.6} \times \sqrt{0.906} = 5\,692.1 \times 0.952 = 5\,417.97\ \text{eur/year}.$$

2. Calculation of the length of the delivery cycle t_{dopt} and the stock ordering level r:

$$t_{d_{opt}} = \frac{Q_{opt}}{I} = \frac{3\,193.9028}{18\,000} = 0.17742\ year = 64.77\ days,$$

$$r = I\times t - \left\lfloor \frac{t}{t_d} \right\rfloor \times Q_{opt} - d = 18\,000\times 1 - \left\lfloor \frac{1}{0.17742} \right\rfloor \times 3193.9028 - 300 = 18\,000 - 5\times 3193.9028 - 300 = 1\,730.486\ kg.$$

3. Calculation of the time when it is necessary to order stocks:

$$t_r = t_d - \left(t - \left\lfloor \frac{t}{t_d} \right\rfloor \times t_d\right) = 0.17742 - \left(1 - \left\lfloor \frac{1}{0.17742} \right\rfloor \times 0.17742\right) = 0.06452\ year = 23.5498\ days.$$

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Deterministic models of inventory management greatly simplify the view of the fact the real developed market affects the consumption of supplies, goods and products rather stochastically.

7.1.1.2 Stochastic Models of Inventory Management

The previous models have been devoted to deterministic, precise determination of the demand for stocks or products. In reality, this is rarely clearly defined, due to the behaviour of the market. The market is a constantly evolving and changing system, the behaviour and development of which cannot be determined unambiguously. For this reason, the inventory strategy of industrial concerns and other firms tries to take uncertain behaviour into consideration using a certain amount of inventory. The stocks can be either over the required amount, i.e. something remains in stock after the planned period or under the required amount, i.e. they expect that everything will run out and a certain number of customers will remain dissatisfied.

In practice, many companies need to keep various amounts of reserve stocks in warehouses, which depending on market behaviour may not even be used and considerable financial resources are tied up maintaining this greater flexibility that provides them with a certain degree of competitiveness.

Inventory management in a stochastic environment makes it more difficult to determine the correct amount of stock to order and to determine the optimal stock order level *r*. There are several approaches to solving and eliminating the stochastic behaviour of the market:

- statistical assessment of consumption over a time period, determination of the optimal value and its standard deviation, forecasting methods, taking into account cycles, trends and periods of consumption,
- determination of the average amount of consumption for a given period (too inaccurate),
- simulation and defining the probability of distribution of demand by the introduction of mean demand and its variance, where variance reflects the stochastic nature of market behaviour,
- keeping an additional constant base stock to cover stochastic behaviour in the warehouse,
- to “play it safe”, to guarantee supplies only for contracted orders.

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7.1.1.2.1 The control of stochastic inventory consumption – the fixed order quantity method

The previous models work with a constant and known level of consumption and in the case of the deficiency models, with the condition where damage to input materials and raw material which is also known is taken into account. In reality, certainty of constant consumption is rare, the companies would have to have regular and long-term consumption of products by contract. Most companies and businesses operate with a high degree of uncertainty which could lead to a surplus of products for the outlet warehouses, useless supplies of raw materials or lack of production resources caused by sudden demand from customers. Uncertainty of market behaviour is caused by other effects related to political, economic, technical, social and logistical aspects.

For these above reasons, it is appropriate to manage the stochastic consumption of materials using the fixed order quantity method. In principle, the method (Figure 67) follows the order signal level r, e.g. defined as the minimum level of inventory that is reached or exceeded, it is necessary to order further supplies with a fixed amount of stocks Q. As the intensity of consumption is dependent on market developments (either high or low) therefore the time when there will be an order of a new stock Q is always different and the level of stocks in the warehouse will also be different, as well as the time cycle of order execution and delivery time t_i. The intensity of consumption is also uncertain.

Within the model with a fixed order quantity it is necessary, for inventory control, to define a constant amount Q that will be ordered; to determine the signal level (r), which determines the moments when it is needed to order additional supplies. The amount of signal level r is dependent on the delivery period t and the amount of daily consumption of inventories I_D.

The variables are defined based on the previous models, which are represented by the Harris - Wilson formula (7.11) and therefore $Q = Q_{opt}$. The signal level r (7.31) can be defined as the sum of average consumption of stocks during the delivery period (average length of delivery period) $\overline{I_t}$ and the base stock PZ.

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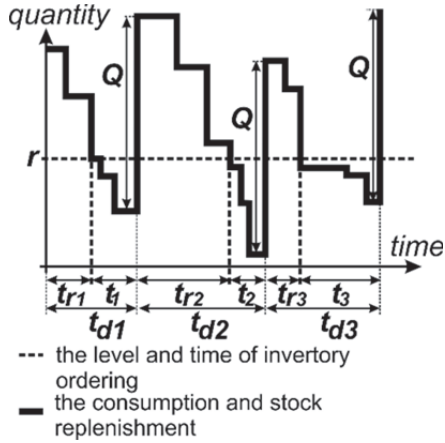


Figure 67 – The inventory management system with the fixed order quantity

$$r = \overline{I_t} + PZ = \overline{I_D} \times \bar{t} + PZ \tag{7.31}$$

$\overline{I_t}$ – the average consumption of the stock during the delivery period,
$\overline{I_D}$ – the average daily consumption of the stock,
$\bar{t}$ – the average length of the delivery period,
PZ – the size of the base stock.

As was mentioned at the beginning of the chapter, there may be several approaches to resolving and eliminating the stochastic behaviour of the market in terms of stock management and also the same approaches may be used to determine the size of the base stock *PZ*. In terms of statistics the base stock can be calculated (7.32):

$$PZ = k \times \sigma_{I_t} \tag{7.32}$$

k – the coefficient of supply assurance,
σ_{I_t} – the standard deviation of stock consumption during delivery.

The coefficient of supply assurance k expresses the probability that supplies will be covered during the delivery period. If the number is greater than 1, there is an effort to completely cover requirements for supplies during the delivery period. If the number is less than 1, it means that in some cases it may happen that there is insufficient inventory to cover customer requirements or production. In reality, the costs of 100%

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coverage of requirements of production are high and therefore companies and businesses try to determine a lower coefficient *k*, to cover 80 – 90% of requirements. The costs of the occasional risk of losing an order are lower than the costs of maintaining inventory of 100% during the year. Of course, it is better to prevent such a situation occurring.

The standard deviation of stock consumption (7.33) during the delivery period σ_{I_t} can be calculated (Lenort 2012):

$$\sigma_{I_t} = \sqrt{\bar{t} \times \sigma_{I_D}^2 + \bar{I_D^2} \times \sigma_t^2} \tag{7.33}$$

$\bar{t}$ – the average length of the delivery period,
σ_{I_D} – the standard deviation of daily consumption,
$\bar{I_D}$ – the average daily consumption,
σ_t – the standard deviation of the delivery period.

The standard deviation of stock consumption during the delivery period σ_{I_t} is controlled by a Gaussian-normal probability distribution (Lenort 2010). In order to determine the coefficient of stock assurance, cases are only considered where they exceed the average consumption of the stock during the delivery period, which may be around 50%. The value of the coefficient of supply assurance *k* is determined by a number of tables, literature and specialized statistical programs. For example, with a value of coefficient *k = 1.036*, availability of service is provided at 85% and the risk of lack of supplies is 15%; if the coefficient *k = 2.326*, availability of service is provided at 99% and the risk of lack of supplies is 1%.

From this simple example it shows that to completely eliminate the risk of lack of supplies it is needed to have a several times higher amount of a stock and therefore companies would have far more resources tied-up in stocks.



Task: A company, operating in the automotive industry, buys aluminium castings, which are used as a skeleton for placing the control unit. The unit price of a casting is *h* = 1300 EUR/unit. The company orders 4000 or 5000 castings based on the current inventory in the warehouse at the time of ordering. The company management wants to save storage costs and use the funds for renovation of one of the assembly lines. In terms of the solution, data is available about stock replenishment to the warehouse and daily consumption of castings for the last three months (Table 9). Daily consumption of castings is regularly, between 20 to 1200 units, and

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delivery time is in the interval from 1 to 5 days. The execution costs of one order are *No* = 3000 EUR. The annual cost of maintaining inventory units is estimated at 20% of the value of casting $\pi = 0.2$. To determine the amount of savings, the fixed order quantity method should be applied. The management of this company requires that the new manner of managing inventory should ensure 90% coverage of consumption.

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Table 9 – The statistics of stock replenishment and daily consumption of castings

Day	Ordered, (delivery cycle)	Delivered	Consumption	Inventories	Day	Ordered, (delivery cycle)	Delivered	Consumption	Inventories	Day	Ordered, (delivery cycle)	Delivered	Consumption	Inventories
0	5000			2200	The initial state of the warehouse activity									
1			250	1950	31			300	1600	61			800	1230
2	3		1000	950	32	4		1200	400	62	3	5000	400	5830
3		5000	550	5400	33		5000	200	5200	63			520	5310
4			1200	4200	34			300	4900	64			400	4910
5			800	3400	35			350	4550	65			600	4310
6			550	2850	36			400	4150	66			750	3560
7	5000		1200	1650	37			450	3700	67			900	2660
8			850	800	38			500	3200	68	5000		1000	1660
9	4		300	500	39	4000		550	2650	69	2		900	760
10			400	100	40	2		600	2050	70		5000	700	5060
11		5000	200	4900	41		4000	1000	5050	71			350	4710
12			20	4880	42			600	4450	72			900	3810
13			350	4530	43	4000		600	3850	73			1000	2810
14			890	3640	44	2		500	3350	74	5000		1000	1810
15	4000		1200	2440	45		4000	950	6400	75			600	1210
16	1	4000	200	6240	46			900	5500	76	3		600	610
17			20	6220	47			850	4650	77		5000	600	5010
18			1200	5020	48	5000		800	3850	78			700	4310
19			20	5000	49	2		750	3100	79			350	3960
20			300	4700	50		5000	200	7900	80			20	3940
21			1200	3500	51			650	7250	81			400	3540
22	4000		900	2600	52			600	6650	82	4000		700	2840
23			800	1800	53			1100	5550	83			750	2090
24			300	1500	54			1200	4350	84			800	1290
25	5		250	1250	55			300	4050	85	5		550	740
26			200	1050	56			200	3850	86			550	190
27		4000	500	4550	57			100	3750	87		4000	20	4170
28			1200	3350	58			20	3730	88			600	3570
29	5000		1200	2150	59	5000		1200	2530	89			500	3070
30			250	1900	60			500	2030	90			700	2370

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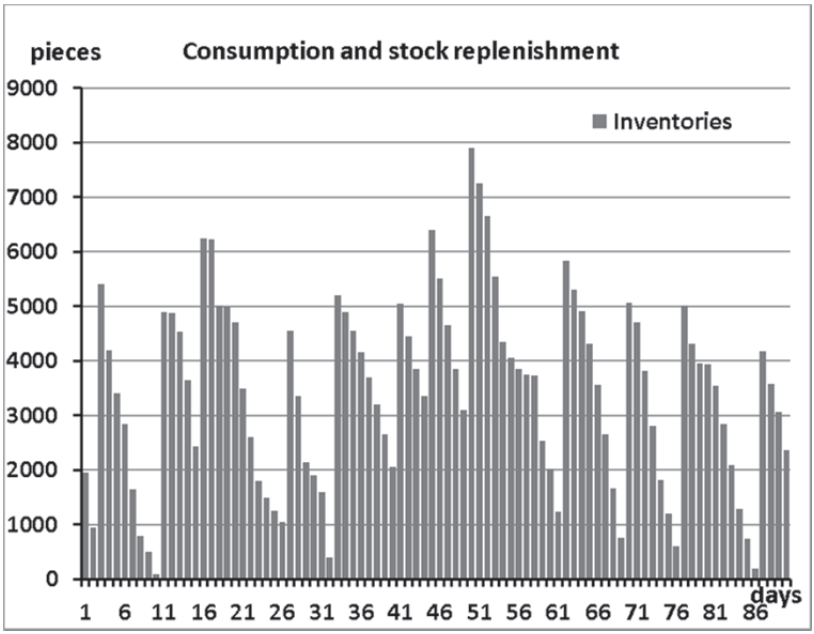


Figure 68 – Diagram of the stock levels in the warehouse over three months

1. The costs of the current inventory management system:

Average daily consumption:

$\overline{I_D} = 609\ pcs/day.$

Standard deviation of daily consumption:

$$\sigma_{I_D} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(I_{ij} - \overline{I_D}\right)^2} = \sqrt{\frac{10\ 411\ 245.56}{90}} = 340\ pcs/day,$$

I_{ij} – consumption of material item i in day j, expressed in pieces,
i – analysed material,
j – monitored day,
n – number of days for which the analysis was provided.

Estimated annual stock consumption:

$I = 609 \times 365 = 222\ 285\ pcs/year.$

Average stock size:

$$\bar{Z} = \frac{\Sigma inventories}{number\ of\ monitored\ items} = \frac{310\ 800}{91} = 3\ 415\ pcs/day.$$

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Stock turnover:

$O = \bar{Z}/\overline{I_d} = 3\,415/609 = 5.6\ days.$

Average length of the delivery period:

$\bar{t} = \frac{\Sigma lengths\ of\ delivery\ cycles}{number\ of\ delivery\ cycles} = \frac{36}{12} = 3\ days.$

Standard deviation of the delivery period:

$\sigma_t = 1.225\ days.$

Average order size:

$\bar{Q} = \frac{55\,000}{12} = 4\,583\ pcs.$

Total costs related to the management of inventories can be calculated:

$Ncr(Q1) = \pi \times h \times \bar{Z} + \frac{I}{\bar{Q}} \times No = 0.2 \times 1\,300 \times 3\,415 + \frac{222\,285}{4\,583} \times 3\,000 = 887\,980 + 145\,506 \cong 1\,033\,486\ EUR/year,$

π – the share of the annual costs for maintaining the stock unit where the value of the stock unit = 0.2.

2. The application of fixed order quantity as a new inventory management system:

Fixed order quantity:

$Q = \sqrt{\frac{2 \times 222\,285 \times 3\,000}{0.2 \times 1\,300}} \cong 2\,265\ pcs.$

The inventory management must ensure 90% of level service coverage, i.e. the assurance coefficient k = 1.282, signal level:

$r = \overline{I_t} + PZ = \overline{I_D} \times \bar{t} + PZ = \overline{I_D} \times \bar{t} + k \times \sqrt{\bar{t} \times \sigma_{I_D}^2 + \overline{I_D^2} \times \sigma_t^2} = 609 \times 3 + 1.282 \times \sqrt{3 \times 340^2 + 609^2 \times 1.225^2} = 1\,827 + 1\,549 = 3\,376\ pcs.$

Using the fixed order quantity method a new, modified schedule of replenishing and ordering a stock in a warehouse can be obtained (Table 10) and the level of inventory in a warehouse changes from the range 100 to 7 900 (Figure 68) to the range 30 to 5 170 (Figure 69) demonstrating a significant fall of the level of material in stock.

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Table 10 – Statistics on the replenishment of stock and the daily consumption of castings after the introduction of the fixed order quantity method

Day	Ordered, (delivery cycle)	Delivered	Consumption	Inventories	Day	Ordered, (delivery cycle)	Delivered	Consumption	Inventories	Day	Ordered, (delivery cycle)	Delivered	Consumption	Inventories
0	2265			2200	The fixed order quantity method									
1	3		250	1950	31	3		300	1720	61	4		800	1470
2			1000	950	32	2265	2265	1200	2785	62			400	1070
3	2265	2265	550	2665	33	2		200	2585	63	2265	2265	520	2815
4	4		1200	1465	34		2265	300	4550	64	2		400	2415
5			800	665	35			350	4200	65		2265	600	4080
6			550	115	36			400	3800	66	2265		750	3330
7	2265	2265	1200	1180	37	2265		450	3350	67	2		900	2430
8	2265	2265	850	2595	38	3		500	2850	68		2265	1000	3695
9	5		300	2295	39			550	2300	69	2265		900	2795
10			400	1895	40		2265	600	3965	70	2		700	2095
11			200	1695	41	2265		1000	2965	71		2265	350	4010
12			20	1675	42	5		600	2365	72	2265		900	3110
13		2265	350	3590	43			600	1765	73	3		1000	2110
14	2265		890	2700	44			500	1265	74			1000	1110
15	4		1200	1500	45			950	315	75	2265	2265	600	2775
16			200	1300	46	2265	2265	900	1680	76	2		600	2175
17			20	1280	47	3		850	830	77		2265	600	3840
18	2265	2265	1200	2345	48			800	30	78	2265		700	3140
19	2		20	2325	49	2265	2265	750	1545	79	3		350	2790
20		2265	300	4290	50	4		200	1345	80			20	2770
21			1200	3090	51			650	695	81		2265	400	4635
22	2265		900	2190	52			600	95	82			700	3935
23	2		800	1390	53	2265	2265	1100	1260	83	2265		750	3185
24	2265	2265	300	3355	54	2265	2265	1200	2325	84	5		800	2385
25	2		250	3105	55	5		300	2025	85			550	1835
26		2265	200	5170	56			200	1825	86			550	1285
27			500	4670	57			100	1725	87			20	1265
28			1200	3470	58			20	1705	88	2265	2265	600	2930
29	2265		1200	2270	59	2265	2265	1200	2770	89			500	2430
30			250	2020	60			500	2270	90			700	1730

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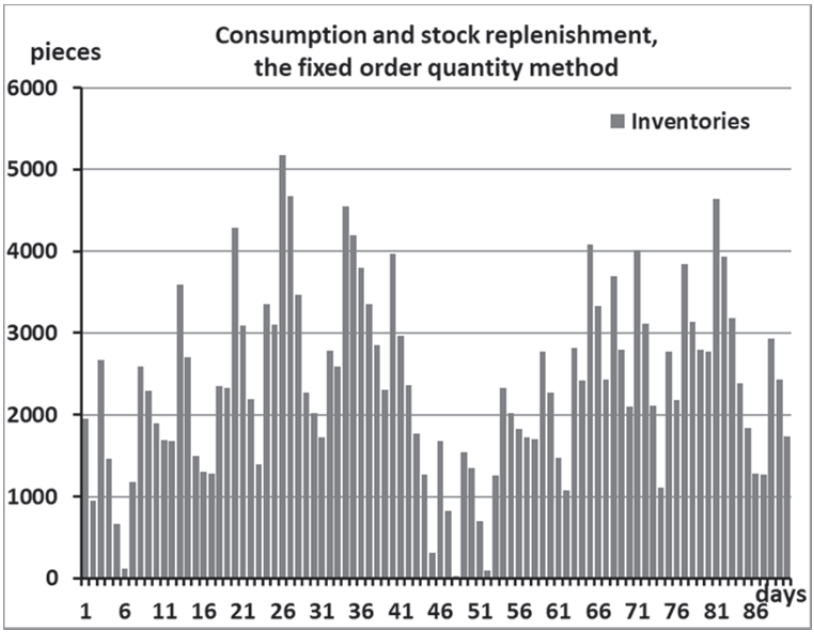


Figure 69 – Diagram of the stock level in a warehouse for three months after the introduction of the fixed order quantity method

1. The costs of the new inventory management system:

Average daily consumption:

$\overline{I_D} = 609\ ks/day.$

Standard deviation of daily consumption:

$\sigma_{I_D} = 340\ ks/day.$

Estimated annual stock consumption:

$I = 609 \times 365 = 222\ 285\ pcs/year.$

Average stock size:

$$\bar{Z} = \frac{\Sigma inventories}{number\ of\ monitored\ items} = \frac{213\ 950}{91} = 2\ 351\ ks/day.$$

Stock turnover:

$O = \bar{Z}/\overline{I_d} = 2\ 351/609 = 3.86\ days.$

Average length of the delivery period:

$$\bar{t} = \frac{\Sigma lengths\ of\ delivery\ cycles}{number\ of\ delivery\ cycles} = \frac{72}{24} = 3\ days.$$

Standard deviation of the delivery period:

$\sigma_t = 1.225\ days.$

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Average order size:

$\bar{Q} = \frac{56\,625}{25} = 2\,265\ pcs.$

The total costs related to the management of inventories can be calculated as:

$Ncr(Q2) = \pi \times h \times \bar{Z} + \frac{I}{\bar{Q}} \times No = 0.2 \times 1\,300 \times 2\,351 + \frac{222\,285}{2\,265} \times 3\,000 = 611\,260 + 294\,417 \cong 905\,677\ EUR/year.$

2. After the introduction of the fixed order quantity method as a new inventory management system:

It would be possible to save *Ncr(Q1) - Ncr(Q2) = 1 033 486 - 905 677 =* ***127 809 EUR/year*** using the fixed order quantity method.

7.1.1.2.2 The control of stochastic inventory consumption - fixed time period method

The next possibility for stochastic inventory consumption control is the fixed time period method (Figure 70). In this method, different amounts of stocks Q_i are ordered at regular intervals t_d, to reach the maximum required level of stocks S in the warehouse. The quantity to be ordered is equal to the difference between the maximum required level of a stock and the actual state of the same stock in the warehouse at the time of issuing the order.

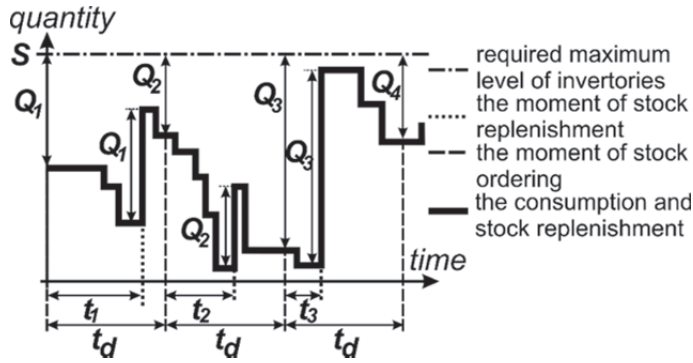


Figure 70 – The inventory management system with a fixed time period

The application of the fixed time period method is again based on the Harris-Wilson formula which is used to calculate the optimal order quantity Q_{opt}. In the next step it is necessary to determine the optimal stock ordering

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cycle, delivery cycle t_d. If the number of orders per year is v then the ordering cycle td (7.34) for one year can be expressed as:

$$t_d = t_{d_{opt}} = 365/v = \frac{365}{\frac{I}{Q_{opt}}} = \frac{365 \times Q_{opt}}{I}. \quad (7.34)$$

The maximum required level of stocks S (7.35) represents the sum of the amount of stocks that is needed to fulfil requirements at the time of the delivery cycle $t_{d_{opt}}$ and the amount of stocks that are needed to fulfil the requirements with the average time of delivery period $\bar{t}$ and the amount of the base stock PZ which covers the uncertainty of the system (Lenort 2010).

$$S = Q_{d_{opt}} + Q_t + PZ =$$
$$\bar{I_D} \times t_{d_{opt}} + \bar{I_D} \times \bar{t} + k \times \sqrt{(t_{d_{opt}} + \bar{t}) \times \sigma_{I_D}^2 + \bar{I_D}^2 \times \sigma_t^2} =$$
$$\bar{I_D} \times (t_{d_{opt}} + \bar{t}) + k \times \sqrt{(t_{d_{opt}} + \bar{t}) \times \sigma_{I_D}^2 + \bar{I_D}^2 \times \sigma_t^2} \quad (7.35)$$



Task: To compare this method with the previous method of inventory management, the same example is used as in the previous chapter. We determine the amount of savings if the fixed time period method were applied.

1. The costs of the current inventory management system:

Average daily consumption:

$\bar{I_D} = 609\ pcs/day.$

Standard deviation of daily consumption:

$\sigma_{I_D} = 340\ pcs/day.$

Estimated annual consumption of stock:

$I = 609 \times 365 = 222\ 285\ pcs/year.$

Average stock level:

$\bar{Z} = 3\ 415\ pcs/year.$

Stock turnover:

$O = \bar{Z}/\bar{I_d} = 3\ 415/609 = 5.6\ days.$

Average length of the delivery period:

$\bar{t} = 3\ days.$

Standard deviation of the delivery period:

$\sigma_t = 1.225\ days.$

Average order size:

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$\bar{Q} = 4\,583\ pcs.$

The total costs related to the management of inventory can be calculated as:

$Ncr(Q1) = \pi \times h \times \bar{Z} + \frac{I}{\bar{Q}} \times No = 0.2 \times 1\,300 \times 3\,415 + \frac{222\,285}{4\,583} \times 3\,000 = 887\,980 + 145\,506 \cong 1\,033\,486\ EUR/year,$

π – the share of the annual costs for maintaining stock levels at the max value of the stock unit = 0.2.

2. The application of the fixed time period method:

Effective order size:

$Q_{opt} = \sqrt{\frac{2 \times 222\,285 \times 3\,000}{0.2 \times 1\,300}} \cong 2\,265\ pcs.$

Fixed time period, delivery cycle:

$t_{d_{opt}} = \frac{365 \times 2\,265}{222\,285} \cong 4\ days.$

Inventory management must ensure 90% coverage, i.e. the assurance coefficient $k = 1.282$, maximum required level of stock:

$S = \bar{I_D} \times \left(t_{d_{opt}} + \bar{t}\right) + k \times \sqrt{\left(t_{d_{opt}} + \bar{t}\right) \times \sigma_{I_D}^2 + \bar{I}_D^2 \times \sigma_t^2} =$

$609 \times (4 + 3) + 1.282 \times \sqrt{(4 + 3) \times 340^2 + 609^2 \times 1.225^2} =$

$4\,263 + 1\,498 = 5\,761\ pcs.$

By applying the fixed time period method a new, modified schedule of replenishing and ordering stock for the warehouse can be obtained (Table 11).

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Table 11 – Statistics for the replenishment of stock and daily consumption of castings after the application of the fixed time period method

Day	Ordered, (delivery cycle)	Delivered	Consumption	Inventories	Day	Ordered, (delivery cycle)	Delivered	Consumption	Inventories	Day	Ordered, (delivery cycle)	Delivered	Consumption	Inventories
0	3561			2200	The fixed time period method									
1			250	1950	31			300	4011	61	1	1820	800	4961
2	3		1000	950	32	2950		1200	2811	62			400	4561
3		3561	550	3961	33	3		200	2611	63			520	4041
4	3000		1200	2761	34			300	2311	64	2120		400	3641
5			800	1961	35		2950	350	4911	65			600	3041
6	4		550	1411	36	1250		400	4511	66	5		750	2291
7			1200	211	37	2		450	4061	67			900	1391
8	3400	3000	850	2361	38		1250	500	4811	68	5370		1000	391
9	1	3400	300	5461	39			550	4261	69		2120	900	1611
10			400	5061	40	2100		600	3661	70	4		700	911
11			200	4861	41	3		1000	2661	71			350	561
12	920		20	4841	42			600	2061	72	730	5370	900	5031
13			350	4491	43		2100	600	3561	73	2		1000	4031
14	5		890	3601	44	2700		500	3061	74		730	1000	3761
15			1200	2401	45			950	2111	75			600	3161
16	3560		200	2201	46	5		900	1211	76	3200		600	2561
17		920	20	3101	47			850	361	77	2		600	1961
18	4		1200	1901	48	5761		800	0 (-439)	78		3200	700	4461
19			20	1881	49		2700	750	1511	79			350	4111
20	620	3560	300	5141	50	3		200	1311	80	1670		20	4091
21	2		1200	3941	51		5761	650	6422	81	2		400	3691
22		620	900	3661	52	0		600	5822	82		1670	700	4661
23			800	2861	53			1100	4722	83			750	3911
24	3200		300	2561	54			1200	3522	84	2650		800	3111
25	2		250	2311	55			300	3222	85	3		550	2561
26		3200	200	5311	56	2739		200	3022	86			550	2011
27			500	4811	57			100	2922	87		2650	20	4641
28	2150		1200	3611	58	4		20	2902	88	1720		600	4041
29	2		1200	2411	59			1200	1702	89	2		500	3541
30		2150	250	4311	60	1820	2739	500	3941	90		1720	700	4561

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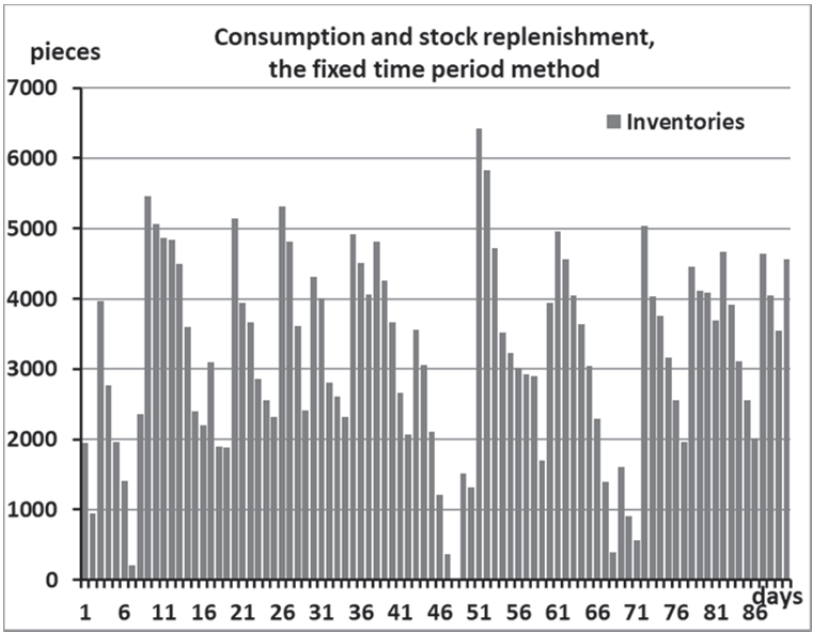


Figure 71 – Diagram of the stock level in the warehouse for three months after the application of the fixed time period method

1. Costs of new inventory management system:

Average daily consumption:

$\overline{I_D} = 609\ pcs/day.$

Standard deviation of daily consumption:

$\sigma_{I_D} = 340\ pcs/day.$

Estimated annual stock consumption:

$I = 609 \times 365 = 222\ 285\ pcs/year.$

Average stock size:

$\bar{Z} = \frac{\Sigma inventories}{number\ of\ monitored\ items} = \frac{289\ 806}{91} = 3\ 185\ pcs/day.$

Stock turnover:

$O = \bar{Z}/\overline{I_d} = 3\ 185/609 = 5.23\ days.$

Average length of the delivery period:

$\bar{t} = 2.909\ days.$

Standard deviation of the delivery period:

$\sigma_t = 1.203\ days.$

Average order size:

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$\bar{Q} = \frac{57\,191}{22} = 2\,600\,pcs.$

The total costs related to the management of inventory can be calculated as:

$Ncr(Q3) = \pi \times h \times \bar{Z} + \frac{I}{\bar{Q}} \times No = 0.2 \times 1\,300 \times 3\,185 + \frac{222\,285}{2\,600} \times 3\,000 = 828\,100 + 256\,483 \cong 1\,084\,583\,EUR/year.$

Calculation of the costs difference when the fixed time period method is applied:

A total of *Ncr(Q1) - Ncr(Q3) = 1 033 486 - 1 084 583 =* ***-51 097 EUR/year*** can be saved using a fixed time period. Since the resulting amount is negative, this approach to managing inventory is worse than the original state, which is mainly due to the high level of the average amount of stock in the warehouse and the high transport cost (Figure 71) with the fixed time period method.

Conclusion: The appropriate means of inventory management for the warehouse in this case is the fixed order quantity method.

Stochastic models of inventory management show possibilities that eliminate the uncertainty of market behaviour. All management approaches require additional costs. Within strategies, some of the costs are directly related to the maintenance of stocks beyond current need and some of the costs are associated with the loss of orders, i.e. costs of lost opportunities.

Depending on the sector in which the company is active, it is possible to apply each of the models described. Large companies that are dependent on thousands of tonnes of raw materials maintain base stocks with a strategic perspective as well as a technological and functional perspective. The present phenomenon of the internet and expanding internet business enable companies to "play it safe" and they do not keep physical stocks, only virtual stocks. When the customer buys some goods through an on-line shop, they order the required product. The customer is informed of the delivery time and is willing to wait for the ordered goods. However, such an approach is rather inefficient for manufacturing companies because it reduces their level of competitiveness.

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CHAPTER EIGHT

LOCATION AS A STRATEGIC DECISION

What you will learn: Location, in terms of distribution logistics, is of strategic and economic importance. A warehouse or production plant, once built, cannot be moved within the short term based on the mood and taste of managers. Therefore, a decision about where to build a distribution or supply warehouse, logistics centre or production plant is of crucial and strategic importance. Decisions on this matter are strategic, long-term and fundamentally affect the function of the distribution site as well as the economics of it. Unnecessarily extended distribution routes require more time, more fuel, more servicing and more costs. Wrong decisions lead to increased costs under the particular implementation of distribution. In the implementation of distribution, a number of systems can be used that provide users with solutions at the level of an expert in the given area. In most cases, these are expert systems. Their use is of decisive importance for distribution logistics from the temporal and functional point of view, as well as in terms of the economic and social aspects. This chapter indicates possible solutions for strategic decisions for the needs of distribution logistics and for the basic classification of expert systems, their structure and the usage of expert systems for the purpose of distribution and logistics.

Basic terms: location, multi-criteria decision making, methods, system.

If we establish a business, or if we want to extend the operations of an existing firm into other regions, or we want to increase the effectiveness of existing shops, it is important to make the correct choice of location for the company, distribution centre, or warehouse. This topic deals with the definitions of location in the specialist literature. A large number of scientists and researchers have addressed location problems (Table 12) and they are described by many authors in their works. The most well-known ones are the theories of location and layout by Weber, Launhard, Tyunen, Kristaller and Lesh.

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Table 12 – Definitions of location and the authors' views about location

Author	Year	View on location
A. Weber[1]	1909	He assumed that the production plant will choose locations that are least costly in terms of operation and development. Transport costs are proportional to the weight of the goods and the distance that raw materials or finished products have to travel.
A. Lesh[2]	1940	**Location** is based on a balanced state with the following conditions: • the location of each enterprise is characterized by the maximum possible benefits to consumers and producers, • enterprises are positioned in such a way that the area is fully used, • there is equality of prices and costs, • all areas of the market have a minimum size in the shape of a hexagon.
D. Malindzak[3]	1997	**Location** is understood as: • the location of a manufacturing process, an enterprise, • the location of a distribution centre, • the positioning of manufacturing operations in the workplace, • the location of a single-purpose machine or piece of equipment.
M. Straka[4]	2013	**Location** is a process, the result of which is the determination of a particular position for the location of a warehouse, a company, a machine, a manufacturing process, people, animals, things and other activities in a particular area, or in the area that best suits the defined conditions and restrictions for such requirements e.g. supplies, production, distribution or trade, strategy and tactics.

[1] Weber, A.: Über den Standort der Industrien, Tübingen, 1909 (English translation, Friedrich, C.J.: Theory of the Location of Industries, University of Chicago Press, 1929)
[2] Lesh, A.: The theory of locating productive forces, 1940
[3] Malindzak, D.: Production logistics I., Stroffek, Kosice, 1996
[4] Straka, M.: Distribution logistics in examples, 2nd ed., F BERG, Kosice, 2012

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The correct position of a company in an area has a major impact on transport costs, the time that is needed for distribution and for all activities associated with distribution. Location is dependent on a number of factors that must be considered when choosing the right place. Two approaches can be used to solve location problems:

- the principle of multi-criteria decision making,
- mathematical and geometric principles.

8.1 Location and Multi-criteria Decision Making

The importance of location for the needs of logistics distribution is greater if companies and enterprises want to remain competitive in the market or they are trying to reduce and minimize costs, which an appropriately located warehouse can help them do. The decision on building a warehouse and where to locate it is of strategic importance and that is why distribution logistics uses the methodological apparatus of multi-criteria decision making for this.

If the choice of the location of a manufacturing process, a distribution centre or an operating centre is dependent on a number of factors and some of them can be economically evaluated and some not, any method of multi-criteria decision making is suitable.

The procedure for the solution of multi-criteria decision making tasks consists of the following steps:

- define the criteria that various options are evaluated by,
- determine the weights for each criterion (non-standardized k_i, or standardized form α_i),
- calculate the overall utility of the particular options,
- select and determine the optimal option based on the efficiency of the options, sometimes as a proportion of total utility and price (costs).

8.1.1 Definition of Criteria

In the case of multi-criteria decision making it is necessary to define the criteria to evaluate various options for solutions. Their ability or capability to fulfil a defined criterion is expressed using a cardinal scale of evaluation (Ocelikova 2002) e.g.: ⟨0;10⟩, {0;1}, ⟨0;100⟩, ⟨1;10⟩, ⟨1;100⟩ (there are methods that do not require the proportionate transfer of values to the cardinal scale, for example the method of distance from a fictional option, where it uses real values).

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The expression of the achievement or failure of the defined criterion can be assessed in two ways (Straka 2007):

- maximizing – the better an option meets the defined criteria, the more points it gets on the cardinal scale,
- minimizing – the better an option meets the defined criteria, the fewer points it gets on the cardinal scale.

8.1.2 Determination of Weights for Defined Criteria

Weights for each criterion can be determined in two ways:

- **Direct methods for determining the weights of criteria** – are methods where weights of each criterion **are evaluated, defined by the deciding entity itself**, they are called non-objectified weights (very simple, very subjective).
- **Indirect methods for determining the weights of criteria** – are more complex and the values of weights are determined by mutual comparison between all defined criteria, they are called objectified weights and attempt to remove or reduce subjectivity.

"Subjectivity cannot be completely removed; it can only be minimized (Straka 2012)." Various open questions of a subjective nature remain for each of the methods: "Why were the following criteria defined?", "Why were these solutions chosen?", "Why was this method chosen?", "Why did the group of experts consist of this number?", "Why was a particular expert not in the expert group?" ....

Criteria weights can be objectified (to reduce subjectivity) by:

1) **group determination of the criteria weights, the expert approach** – a group of experts will define the criteria weights based on their experience – the heuristic approach,
2) **application of indirect methods** for determining the weights of criteria – a mathematical approach,
3) **gradual change of values of the weights of individual criteria** or using different methods and their comparison – a number of solutions are used – combination approach.

Standardization of criteria weights:

The values of criteria weights for particular methods are in a nonstandard form. If we want to compare the values of weights obtained from different methods, it is necessary to convert them into the

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standardized form, whereby it holds that the sum of the standardized criteria weights is equal to 1 (8.1) (Ocelikova 2002, Straka 2012).

$$\sum_{i=1}^{n} \alpha_i = 1 \tag{8.1}$$

α_i – the weight of i^{th} standardised criterion.

The values of weights in a non-standard form can be converted to the standard form using the formula (8.2):

$$\alpha_i = \frac{k_i}{\sum_{i=1}^{n} k_i} \qquad i = 1,2,\ldots,n, \tag{8.2}$$

k_i – the weight of i^{th} non-standard criterion,
n – the number of criteria.

Direct methods for determining weights include, for example:
a) classification of criteria into groups,
b) assignment of points to criteria from the specified point scale,
c) Metfessel allocation,
d) preferential ranking of criteria,
e) rating scale, ….

Indirect methods for determining criteria weights include for example:
a) pair-wise comparisons – Fuller's triangle,
   - with equal value weights of criteria permitted,
   - with equal value weights of criteria not permitted,
b) Saaty's method, ….

8.1.2.1 Direct methods for determining criteria weights

a) For the method of criteria classification into groups, (Straka 2012) the procedure is:
1) Define several groups of criteria of differing importance where each group is assigned a number that reflects the non-standardized criteria weight.
2) The evaluator inserts particular criteria into defined groups, by which each criterion obtains its non-standardized value.
3) The conversion of non-standardized values to standardized ones (Table 13).

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Demonstration: a group of criteria of major importance – 5 points (criteria A, D, E), a group of criteria with medium importance – 3 points (criteria B, F), a group of criteria with low importance – 1 point (criteria C, G).

Table 13 – Transformation of weights to a standardized form in the criteria classification method

Criteria	Non-standard value k_i	Standard value α_i
A	5	5/23=0.22
B	3	3/23=0.13
C	1	1/23=0.04
D	5	0.22
E	5	0.22
F	3	0.13
G	1	0.04
Σ	**23**	**1.00**

b) For the method for the assignment of points to criteria from the specified point scale, (Straka 2012) the procedure is:

1) Define the point scale for criteria evaluation (lower resolution 3 points, 5 points; higher resolution 7 points, 9 points).
2) The evaluator, using the defined scale, evaluates the defined criteria, by which each criterion obtains its non-standardized value.
3) The conversion of non-standardized values to standardized ones (Table 14).



Demonstration: the number of points:
1 – criterion of lowest importance (D),
2 – criterion of low importance (A),
3 – criterion of medium importance (B),
4 – important criterion (C),
5 – highly important criterion (E).

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Table 14 – The transformation of weights to a standardized form with the assignment of points method

Criteria	Non-standard value k_i	Standard value α_i
A	2	2/15=0.13
B	3	3/15=0.20
C	4	4/15=0.27
D	1	1/15=0.07
E	5	5/15=0.33
Σ	**15**	**1.00**

c) For Metfessel allocation, (Straka 2012) the procedure is as follows:

The principle of the method lies in the fact that the evaluator has 100 points to be divided among the criteria, by which the criteria obtain their non-standardized values. Non-standardized values can be converted by comparison to the standardized ones (Table 15). The advantage of the method is that in the case of a higher number of criteria there is the ability to divide points more sensibly and there is less probability of repeating the same number of points as with the above-mentioned methods.



Demonstration: number of points:
20 points – criterion (A),
21 points – criterion (B),
24 points – criterion (C),
25 points – criterion (D),
10 points – criterion (E).

Table 15 – Transformation of weights to a standardized form, Metfessel allocation

Criteria	Non-standard value k_i	Standard value α_i
A	20	20/100=0.20
B	21	21/100=0.21
C	24	24/100=0.24
D	25	25/100=0.25
E	10	10/100=0.10
Σ	**100**	**1.00**

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d) For the method of preferential ranking of criteria, (Straka 2012) the procedure is:

1) Define the preferential ranking of criteria.
2) The evaluator, based on the least important criterion, which has a weighted value of 1, determines how many times more important the other criteria are, giving the other criteria their non-standardized values.
3) The conversion of non-standardized values to standardized ones (Table 16).



Demonstration: The descending preferential order of the criteria is A, D, F, E, C, B. How many times more important is C relative to B, how many times more important is E relative to B, how many times more important is F relative to B, how many times more important is D relative to B, how many times more important is A relative to B?

Table 16 – The transformation of weights to a standardized form under the method of preferential ranking of criteria

Criteria	Non-standard value k_i	Standard value α_i
A	8	8/29=0.28
B	1	1/29=0.03
C	3	3/29=0.10
D	7	7/29=0.24
E	4	4/29=0.14
F	6	6/29=0.21
Σ	**29**	**1.00**

8.1.2.2 Indirect methods for determining the criteria weights

a–1) The pair-wise comparisons method (with equal value weights of criteria allowed (Straka 2013) author's modified option) **(MPC1)**. The original method does not allow equal values. While solving tasks in a practice there often arise situations where the criteria are measurable and there is no reason either in terms of solutions or defined in terms of the criteria to change their obtained values, in *"Distribution Logistics in Examples"* (Straka 2011, 2012) it is proposed to modify the method to allow equal values, which enables the same valuation of criteria. The procedure is:

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1) The criteria matrix is prepared such that defined criteria are entered in the first row and column.
2) The evaluator writes the criterion (Table 17) which is considered more important of the compared criteria (those criteria for which the row and columns intersect) in the cells of the upper triangle of the matrix.

Table 17 – Entering the most important criteria into the cells of the matrix, MPC1

Criteria x_i	A	B	C	D	Number of occurrences k_i
A		A	C	A	
B			C	B	
C				D	
D					

3) The total number of occurrences of the criterion across the upper triangle of the matrix (Table 18) is entered into the column "Number of occurrences" (of the criterion). The number written represents the non-standardized value of criterion weight.

Table 18 – Determination of the total number of occurrences of the criterion, MPC1

Criteria x_i	A	B	C	D	Number of occurrences k_i
A		A	C	A	2
B			C	B	1
C				D	2
D					1
				Sum	6

4) Conversion of the criteria weights to the standardized form (Table 19).

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Table 19 – The conversion of non-standardized values of the criteria weights to the standardized form, MPC1

Criteria x_i	A	B	C	D	Number of occurrences k_i	Standardized weights α_i
A		A	C	A	2	0.33
B			C	B	1	0.17
C				D	2	0.33
D					1	0.17
				Sum	6	1.00

5) A special case occurs (Table 20), when one of the criteria is not written in the upper triangular matrix even once, its number of occurrences is equal to 0. Because the criterion was defined it has a certain weight and it is therefore necessary to add the value 1 to each non-standardized criterion weight value (8.3):

$$k_i = k_i + 1 \qquad i = 1,2,\ldots,n, \tag{8.3}$$

k_i – non-standardized value of the i^{th} criterion.

Table 20 – Determination of the criteria weights for the special case, some of the criteria get a value of 0, MPC1

Criteria x_i	A	B	C	D	Number of occurrences k_i	Number of occurrences k_i+1	Standardized weights α_i
A		A	C	A	2	3	0.30
B			C	B	1	2	0.20
C				C	3	4	0.40
D					**0**	**1**	**0.10**
				Sum	6	10	1.00

a–2) Pair-wise comparisons method (with no allowance of equal value weights of criteria), **Fuller's triangle (MPC2)** (Maca, Leitner 2007; Straka 2012). The procedure is identical to the previous one but equality of values of the criteria weights is not permitted. The original procedure is as follows:

1) Preparation of the criteria matrix, where the defined criteria are entered in the first row and column.
2) The evaluator writes the criterion which is considered the more important of the compared criteria (those criteria for which the

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rows and columns intersect) in the cells of the upper triangle of the matrix.

3) The total number of occurrences of the criterion in **the whole upper triangular matrix** is entered into the column for the "number of occurrences" of the criterion (Table 21). The number written represents the non-standardized value of the criterion weight (or the number of occurrences of the criterion in each row in the matrix).

Table 21 – Entering the number of occurrences for each criterion in the upper triangular part of the matrix, MPC2

Criteria x_i	A	B	C	D	Number of occurrences k_i
A		A	C	A	2
B			C	B	1
C				D	2
D					1
				Sum	6

The principle of pair-wise comparisons with no allowance of equal value weights of criteria excludes a situation whereby the same values of criteria weights could occur. The reason is fact that the criteria are compared in pairs with the aim of marking one of them as more important (the equal evaluation of criteria is not permitted). In the case of a situation where the number of preferences (occurrences) of criteria in the upper triangular matrix is the same for some criteria, it is necessary to use a modification as per formula 8.4 for determination of non-standardized weights:

$$k_i = n + 1 - p_i \qquad i = 1,2,\ldots,n, \tag{8.4}$$

k_i – non-standardized value of i^{th} criterion,
n – number of criteria,
p_i – order of i^{th} criterion based on the number of obtained preferences.

The result of comparisons among the criteria decides the position of the criterion, in the case where the criteria have the same number of preferences i.e. the higher position is awarded to the criterion which is "the winner" of the comparison between the same scores.

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In the example (Table 22), criteria A, C and B, D have the same number of occurrences, which is unacceptable in this procedure and adjustments need to be made based on equation 8.4. The criteria are arranged from the most important to the least important in the following way. Criterion C is in the first position, because it was "the winner" of the comparison with criterion A and it has number of occurrences 2. Criterion A is in the second position, because it has number of occurrences 2. Criterion B is in the third position, because it was "the winner" of the comparison with criterion D and criterion D is last. The arrangement of the criteria is: 1-C, 2-A, 3-B, 4-D. Then, the new values of the non-standardized criteria weights are determined by Table .

Table 22 – Conversion of non-standardized weights to a standardized form, MPC2

Criteria x_i	A	B	C	D	Number of occurrences	$k_i=n+1-p_i$	Number of occurrences k_i	Standardized weights α_i
A		A	C	A	2	$k_1=4+1-2$	3	0.30
B			C	B	1	$k_2=4+1-3$	2	0.20
C				D	2	$k_3=4+1-1$	4	0.40
D					1	$k_4=4+1-4$	1	0.10
				Sum	6		10	1.00

4) The previous approach to determining criteria weights is also applied in the case where some of the criteria occur 0 times (Table 23).

Table 23 – Determination of standardized weights for the special case, MPC2

Criteria x_i	A	B	C	D	Number of occurrences	$k_i=n+1-p_i$	Number of occurrences k_i	Standardized weights α_i
A		A	C	A	2	$k_1=4+1-2$	3	0.30
B			C	B	1	$k_2=4+1-3$	2	0.20
C				C	3	$k_3=4+1-1$	4	0.40
D					**0**	$k_4=4+1-4$	**1**	0.10
				Sum	6		10	1.00

b) For the modified Saaty's method (Straka 2012, 2013), the procedure is:

The original Saaty's method works with the tree structure of criteria analysis (Saaty 1994, 1997). From the point of view of practical use, we will use Saaty's method as modified by the author.

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1) Preparation of a criteria matrix, where the defined criteria are entered in the first row and column.
2) The evaluator writes a value in the cells of the upper triangular matrix that corresponds to the comparison between the criterion in the relevant row and the criterion in the relevant column (Table 24) and the reciprocal value *1/x* is written in the lower triangular part of the matrix (8.5) (Table 25, Table 26). If the second criterion is more important than the first criterion, the order of criteria for completing the table is changed.

Table 24 – Description of the point scale, modified Saaty's method

Points x	Description
1	Criteria are equally significant
3	The first criterion is slightly more significant than the second criteria
5	The first criterion is more significant than the second criterion
7	The first criterion is much more significant than the second criterion
9	The first criterion is absolutely more significant than the second criterion
The values 2, 4, 6, 8 can be used for finer distinction	

Table 25 – Point evaluation of the criteria in the upper triangular part of the matrix, modified Saaty's method

Criteria x_i	A	B	C	D
A		3	3	9
B			5	5
C				1
D				

The following formulae are used:

$$s_{ij} = 1, \forall i = j; \quad s_{ij} = {}^{1}/_{s_{ji}}, \forall i \neq j; \quad i = 1,2,\ldots,n;\ j = 1,2,\ldots,n; \tag{8.5}$$

s_{ij} – the value which expresses the relationship between the compared criteria,
s_{ji} – reciprocal value of the value s_{ij},
n – the number of criteria,
i, j – index variables.

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Table 26 – Overall point evaluation of the criteria across the whole matrix, modified Saaty's method

Criteria x_i	A	B	C	D
A	1	3	3	9
B	1/3	1	5	5
C	1/3	1/5	1	1
D	1/9	1/5	1	1

	Criteria x_i	A	B	C	D
=>	A	1	3	3	9
	B	0.3333	1	5	5
	C	0.3333	0.2000	1	1
	D	0.1111	0.2000	1	1

3) Summation of values in individual columns (Table 27).

Table 27 – Summation of values in particular columns, modified Saaty's method

Criteria x_i	A	B	C	D
A	1	3	3	9
B	0.3333	1	5	5
C	0.3333	0.2000	1	1
D	0.1111	0.2000	1	1
Sum	**1.7778**	**4.4000**	**10**	**16**

4) Division of the values in individual cells by the sum of their column (Table 28).

Table 28 – Calculation of the new matrix values, modified Saaty's method

Criteria x_i	A	B	C	D
A	0.5625	0.6818	0.3000	0.5625
B	0.1875	0.2272	0.5000	0.3125
C	0.1875	0.0455	0.1000	0.0625
D	0.0625	0.0455	0.1000	0.0625

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5) Summation of the values in each row and dividing them by the total sum of all the values in the matrix to give standardized values of the weights for particular criteria (Table 29).

Table 29 – Calculation of standardized weights for each criterion, modified Saaty's method

Criteria x_i	A	B	C	D	Sum	Standardized weights α_i
A	0.5625	0.6818	0.3000	0.5625	**2.1068**	**0.5267**
B	0.1875	0.2272	0.5000	0.3125	**1.2272**	**0.3068**
C	0.1875	0.0455	0.1000	0.0625	**0.3955**	**0.0989**
D	0.0625	0.0455	0.1000	0.0625	**0.2705**	**0.0676**
Sum	1	1	1	1	4	1
	4					

8.1.3 Calculation of the Overall Utility of Particular Options

The choice of multi-criteria evaluation of options should be based on the nature and importance of the problem being tackled. It is true **that a degree of subjectivity cannot be completely eliminated** but rather it can only be minimized either in determining the weights or in determining the partial utility of options. The approaches to minimizing subjectivity are the same as for the determination of weights.

Objectifying or determining the partial utility of options (reduction of subjectivity) can be performed by (Straka 2012):

1) **group determination of utility, expert approach** – a group of experts defines the partial utility of options based on defined criteria – the heuristic approach,
2) **application of indirect methods** for determining the partial utility of options – a mathematical approach,
3) **gradual change of the partial utility of options based on defined criteria** or using multiple methods and comparing them; a number of solutions are multiplied – this is a combination approach.

Methods for determining the total utility of options can be divided into (Straka 2012):

- **Simple – direct methods** are methods, where options based on defined criteria are evaluated by the deciding entity itself (simple and too subjective) based on a defined cardinal scale of evaluation e.g.: ⟨0;10⟩, {0;1}, ⟨0;100⟩, ⟨1;10⟩, ⟨1;100⟩:

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a) **weighted sum method,**
b) **method of multiplying valuation**,
c) **quadratic graph method**, ...

- **Complex – indirect methods –** the evaluations of options **can be calculated** based on defined criteria e.g.: through their mutual pair-wise comparisons, or other procedures to reduce the degree of subjectivity. The cardinal scale of evaluation is mainly ⟨0;1⟩. Indirect methods include:
  a. **the pair-wise comparison method**,
     1. The complete method (the weights of values and total utility are calculated by pair-wise comparisons).
     2. The combined method (the weights can be calculated using a method other than pair-wise comparison e.g.: Saaty's method).
  b. **modified Saaty's method** – modified AHP method (Analytic Hierarchy Process),
     1. The complete method (the weights of values and total utility are calculated using Saaty's method).
     2. The combined method (the weights can be calculated using a method other than Saaty's method e.g.: the pair-wise comparison).
  c. **distance from a fictional option**, or point, place, firm, ….

8.1.4 Direct Methods for Assessing the Overall Utility of Options

Direct methods include:

a) The weighted sum method (Ocelikova 2002).

In general, the weighted sum method can be written down using the formula (8.6):

$$U_j = \sum_{i=1}^{n} \alpha_i u_{ij} \qquad j = 1, 2, \ldots, \text{m}, \tag{8.6}$$

m – number of evaluated options (places, points),
n – number of defined criteria,
α_i – weight of i^{th} criterion, $\sum_{i=1}^{n} \alpha_i = 1$,
V_j – evaluated option,
u_{ij} – utility of j^{th} option based on the i^{th} criterion,
U_j – overall utility of option (the stability index).

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Option V_j for which it holds that *max* or *min* = {*Uj*} (based on the task type) best fulfils the defined criteria and it is the solution searched for. The problem is solved based on Table 30.

Table 30 – General form of the weighted sum method solution

	Option V_j	V_1		V_2		…	V_m	
Criteria x_i	Criterion scale α_i	Utility u_{i1}	α_i x u_{i1}	Utility u_{i2}	α_i x u_{i2}		Utility u_{im}	α_i x u_{im}
x_1	α_1	u_{11}	$\alpha_1 u_{11}$	u_{12}	$\alpha_1 u_{12}$		u_{1m}	$\alpha_1 u_{1m}$
x_2	α_2	u_{21}	$\alpha_2 u_{21}$	u_{22}	$\alpha_2 u_{22}$		u_{2m}	$\alpha_2 u_{2m}$
x_3	α_3	u_{31}	$\alpha_3 u_{31}$	u_{32}	$\alpha_3 u_{32}$		u_{3m}	$\alpha_3 u_{3m}$
⋮	⋮	⋮		⋮			⋮	
x_n	α_n	u_{n1}	$\alpha_n u_{n1}$	u_{n2}	$\alpha_n u_{n2}$		u_{nm}	$\alpha_n u_{nm}$
Total utility U_j (Stability index)	$\sum\alpha_i = 1$	Weighted Σ	$U_1 = \sum\alpha_i u_{i1}$	Weighted Σ	$U_2 = \sum\alpha_i u_{i2}$	…	Weighted Σ	$U_j = \sum\alpha_i u_{ij}$ i=1,2,...,n j=1,2,...,m

Manufacturing or commercial evaluation factors should be selected for chosen, evaluated places.

Manufacturing factors: availability of raw materials, transport of raw materials, energy consumption, necessary qualified personnel, location in a region, financial resources, environmental impact, climatic conditions, etc.

Commercial factors: the possibility of exports and sales, transport options in a region, communication systems, banking services, competition, prices, taxes and others.



Task: Try to decide the location of a distribution warehouse for one producer of mineral water and soft drinks with the name Water Ltd. located in Milton Keynes, using the weighted sum method. There are three suitable European locations: Berlin, Prague and Vienna. The purpose of the distribution warehouse is to supply all clients of the company in Central Europe. The important criteria for the company in terms of the location of the distribution warehouse are in Table 31.

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Table 31 – Attribution of weights to the chosen criteria using some of the direct methods

Criteria	Weights of criteria αi
Position of the clients	0.30
Available infrastructure	0.20
Sufficient human resources	0.15
Operating and maintenance costs	0.20
Competition in the area	0.15
Σ	1.00

The cardinal scale is within the range ⟨0;10⟩, it follows that the maximum number of points that the option can get is (the value of weights × the value of the cardinal scale) 1 × 10 = 10 The task is solved as a maximization task, i.e. the more points on the cardinal scale attributed to a location under the particular criteria, the better the location fulfils the evaluation criteria (Table 32).

Table 32 – Assessment of selected locations based on the particular criteria

		Berlin		Prague		Wien	
Criteria	Weights of criteria α_i	Utility u_{i1}, ⟨0,10⟩	$\alpha_i \times u_{i1}$	Utility u_{i2}, ⟨0,10⟩	$\alpha_i \times u_{i2}$	Utility u_{i3}, ⟨0,10⟩	$\alpha_i \times u_{i3}$
Position of the clients	0.30	6	1.80	10	3.00	6	1.80
Available infrastructure	0.20	10	2.00	8	1.60	8	1.60
Sufficient human resources	0.15	5	0.75	10	1.50	9	1.35
Operating and maintenance costs	0.20	5	1.00	9	1.80	8	1.60
Competition in the area	0.15	5	0.75	9	1.35	7	1.05
Total utility U_j	$\sum\alpha_i = 1$	Σ	**6.30**	Σ	**9.25**	Σ	**7.4**

The results indicate that the selected criteria for the location of the distribution warehouse are best met by the location Prague. The city of Prague is the location selected for the distribution warehouse.

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b) Multiplying valuation method (Ocelikova 2002)**,**

Generally, the multiplying valuation method can be written down using the formula (8.7):

$$U_j = \prod_{i=1}^{n} \alpha_i u_{ij} \qquad j = 1, 2, \ldots, m, \tag{8.7}$$

m – number of evaluated options (places),
n – number of defined criteria,
α_i – weight of i^{th} criterion, $\sum_{i=1}^{n} \alpha_i = 1$,
V_j – evaluated option,
u_{ij} – utility of j^{th} option based on the i^{th} criterion,
U_j – overall utility of option (the stability index).

The option V_j for which it holds that max or min = $\{U_j\}$ (based on the task type) best fulfils the defined criteria and it is the solution searched for. The problem is solved based on Table 33.

Table 33 – The general form of the solution using the multiplying valuation method

	Option V_j	V_1		V_2		…	V_m	
Criteria x_i	Criterion scale α_i	Utility u_{i1}	$\alpha_i \times u_{i1}$	Utility u_{i2}	$\alpha_i \times u_{i2}$		Utility u_{im}	$\alpha_i \times u_{im}$
x_1	α_1	u_{11}	$\alpha_1 u_{11}$	u_{12}	$\alpha_1 u_{12}$		u_{1m}	$\alpha_1 u_{1m}$
x_2	α_2	u_{21}	$\alpha_2 u_{21}$	u_{22}	$\alpha_2 u_{22}$		u_{2m}	$\alpha_2 u_{2m}$
x_3	α_3	u_{31}	$\alpha_3 u_{31}$	u_{32}	$\alpha_3 u_{32}$		u_{3m}	$\alpha_3 u_{3m}$
⋮	⋮	⋮		⋮			⋮	
x_n	α_n	u_{n1}	$\alpha_n u_{n1}$	u_{n2}	$\alpha_n u_{n2}$		u_{nm}	$\alpha_n u_{nm}$
Total utility U_j (Stability index)	$\sum \alpha_i = 1$		$U_1 = \Pi \alpha_i u_{i1}$		$U_2 = \Pi \alpha_i u_{i2}$	…		$U_j = \Pi \alpha_i u_{ij}$ i=1,2,...,n j=1,2,...,m



Task: Try to choose a flat to purchase for Mr. White in the London area using the multiplying valuation method. There are three suitable flats located in different boroughs of London: the boroughs are "Kensington", "Fulham" and "Brixton". Mr. White works in a shopping centre. The task is

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solved as a minimization task. The important criteria for Mr. White are displayed in Table 34.

Table 34 – Attributions of weights to the chosen criteria by some direct methods

Criteria	Weights of criteria αi
Price of flat	0.10
Distance to work	0.10
Rental and energy costs	0.05
Furniture and appliances	0.35
Floor (opt 2, 3 floor)	0.40
Σ	1.00

The cardinal scale is within the range ⟨0;10⟩. The task is solved as a minimization task, i.e. the fewer points from the cardinal scale attributed to a flat based on the particular criteria, the more the location fulfils the evaluation criteria (Table 35). The smallest multiples of values for particular flats and criteria indicate the flat that best meets the requirements.

Table 35 – Assessment of selected locations based on the particular criteria

		Kensington		Fulham		Brixton	
Criteria	Weights of criteria α_i	Utility u_{i1}, ⟨0,10⟩	$\alpha_i \times u_{i1}$	Utility u_{i2}, ⟨0,10⟩	$\alpha_i \times u_{i2}$	Utility u_{i3}, ⟨0,10⟩	$\alpha_i \times u_{i3}$
Price of flat	0.10	1	0.10	1	0.10	4	0.40
Distance to work	0.10	5	0.50	1	0.10	1	0.10
Rental and energy costs	0.05	1	0.05	2	0.10	4	0.20
Furniture and appliances	0.35	4	1.40	3	1.05	4	1.40
Floor (opt 2, 3 floor)	0.40	3	1.20	4	1.60	3	1.20
Total utility U_j	$\sum\alpha_i = 1$	Π	0.00420	Π	**0.00168**	Π	0.01344

The results show that the best available flat for Mr. White is in "Fulham" as that best meets the selected criteria.

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c) Quadratic graph method (Ocelikova 2002)**,**

In general, quadratic graph methods can be expressed by the formula (8.8):

$$U_j = \sum_{i=1}^{n} \left[\frac{u_{ij} - u_{i_{optimal}}}{u_{i_{optimal}}} \right]^2 \qquad j = 1, 2, \ldots, m, \tag{8.8}$$

m – number of evaluated options (places),
n – number of defined criteria,
u_{ij} – utility of j^{th} option based on the i^{th} criterion,
$u_{ioptimal}$ – optimal value of the utility of the i^{th} evaluated criterion, ($u_{ioptimal} \neq 0$),
U_j – overall utility of evaluated option (the stability index).

Option V_j, for which it holds that min = $\{U_j\}$, best fulfils the defined criteria and it is the option sought, i.e. the solution. The problem is solved based on Table 36, the option can be evaluated based on each criterion using minimization and also maximization but the solution, i.e. **the value of total utility U_j is always based on minimization** this means that the solution sought is option V_j, which received the fewest points.

Table 36 – General form of the solution of the quadratic graph method

	Option V_j	V_1		V_2		…	V_m	
Criteria x_i	Optimal value $u_{ioptimal}$	Utility u_{i1}	$[(u_{i1}-u_{ioptimal})/u_{ioptimal}]^2$	Utility u_{i2}	$[(u_{i2}-u_{ioptimal})/u_{ioptimal}]^2$		Utility u_{im}	$[(u_{im}-u_{ioptimal})/u_{ioptimal}]^2$
x_1	$u_{1optimal}$	u_{11}	$[(u_{11}-u_{1optimal})/u_{1optimal}]^2$	u_{12}	$[(u_{12}-u_{1optimal})/u_{1optimal}]^2$		u_{1m}	$[(u_{1m}-u_{1optimal})/u_{1optimal}]^2$
x_2	$u_{2optimal}$	u_{21}	$[(u_{21}-u_{2optimal})/u_{2optimal}]^2$	u_{22}	$[(u_{22}-u_{2optimal})/u_{2optimal}]^2$		u_{2m}	$[(u_{2m}-u_{2optimal})/u_{2optimal}]^2$
x_3	$u_{3optimal}$	u_{31}	$[(u_{31}-u_{3optimal})/u_{3optimal}]^2$	u_{32}	$[(u_{32}-u_{3optimal})/u_{3optimal}]^2$		u_{3m}	$[(u_{3m}-u_{3optimal})/u_{3optimal}]^2$
⋮	⋮	⋮		⋮			⋮	
x_n	$u_{noptimal}$	u_{n1}	$[(u_{n1}-u_{noptimal})/u_{noptimal}]^2$	u_{n2}	$[(u_{n2}-u_{noptimal})/u_{noptimal}]^2$		u_{nm}	$[(u_{nm}-u_{noptimal})/u_{noptimal}]^2$
Total utility U_j (Stability index)	⟨0;KH⟩	Σ	$U_1=\Sigma[(u_{i1}-u_{ioptimal})/u_{ioptimal}]^2$	Σ	$U_2=\Sigma[(u_{i2}-u_{ioptimal})/u_{ioptimal}]^2$	…	Σ	$U_j=\Sigma[(u_{ij}-u_{ioptimal})/u_{ioptimal}]^2$ i=1,2,...,n j=1,2,...,m

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Task: Decide on the selection of location for a branch drugstore of a company involved in the sale of chemist's goods using the quadratic graph method. There are four suitable locations L1, L2, L3 and L4. Important criteria and the optimal values for location selection are in Table 37.

Table 37 – Optimum values of particular factors

Criteria	Optimal value
Number of inhabitants	10
Access roads	10
Competition	10
Position within the location	10
Utility networks	10

The cardinal scale is in the range ⟨0;10⟩. The more points from the cardinal scale that are attributed to a location under the particular criteria, the more the location fulfils the evaluation criteria (Table 38). The smallest sum of calculated deviations from the optimal value for each location indicates the location that is most suitable for location of the drugstore branch.

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Table 38 – Assessment of selected locations based on the particular criteria

		Location L1		Location L2	
Criteria	$u_{i,optimal}$	Utility u_{i1}, ⟨0,10⟩	$[(u_{i1}-u_{i,optimal})/u_{i,optimal}]^2$	Utility u_{i2}, ⟨0,10⟩	$[(u_{i2}-u_{i,optimal})/u_{i,optimal}]^2$
Number of inhabitants	10	7	0.09	6	0.16
Access roads	10	7	0.09	7	0.09
Competition	10	4	0.36	8	0.04
Position within the location	10	5	0.25	7	0.09
Utility networks	10	8	0.04	8	0.04
Total utility U_j		Σ	**0.83**	Σ	**0.42**
		Location L3		**Location L4**	
Criteria	$u_{i,optimal}$	**Utility u_{i3}, ⟨0,10⟩**	$[(u_{i3}-u_{i,optimal})/u_{i,optimal}]^2$	**Utility u_{i4}, ⟨0,10⟩**	$[(u_{i4}-u_{i,optimal})/u_{i,optimal}]^2$
Number of inhabitants	10	8	0.04	7	0.09
Access roads	10	8	0.04	8	0.04
Competition	10	4	0.36	5	0.25
Position within the location	10	4	0.36	6	0.16
Utility networks	10	8	0.04	9	0.01
Total utility U_j		Σ	**0.84**	Σ	**0.55**

The results show that the best location for the drug-store branch is location L2, that balances all the criteria with the smallest deviation from optimal values.

8.1.5 Indirect Methods Assessing the Overall Utility of Options

The indirect methods include:

a) Method of pair-wise comparison (Straka 2012)

The method of pair-wise comparison uses the equation (8.9) of the weighted sum method to determine the overall utility of options U_j:

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$$U_j = \sum_{i=1}^{n} \alpha_i u_{ij} \qquad j = 1, 2, \ldots, m, \tag{8.9}$$

m – number of evaluated options (places),
n – number of defined criteria,
α_i – weight of the i^{th} criterion, $\sum_{i=1}^{n} \alpha_i = 1$,
V_j – evaluated option,
u_{ij} – utility of the j^{th} option based on the i^{th} criterion,
U_j – overall utility of evaluated option (the stability index).

The option V_j for which it holds that min = $\{U_j\}$, (based on the task type) best fulfils the defined criteria and it is solution sought.

The solution is based on the same table as in the weighted sum method (Table). The difference is that all data points which are entered in the table are calculated from pair-wise comparisons. It follows that if the sum of the weights of the criteria is 1 and the options may obtain a maximum value of 1 by the defined criteria, then the maximum number of points (overall utility of the option), which the option can achieve, is 1 × 1 = 1. The real results are in the range $\langle 0,1 \rangle$.

The values of partial utility u_{ij} of each option based on defined criteria, are determined by pair-wise comparison of each option for each defined criterion (similar to determining the weights with the method of pair-wise comparison), i.e. the number of defined criteria means the number of times it is necessary to make comparisons.

Procedure:

1) Defining criteria and setting their weight values. The weights are calculated using the pair-wise comparison method with the complete method of pair-wise comparison, and weights are determined by any of the other methods, e.g. Saaty's method or the combined method.
2) Creation of the option matrix, where the defined options are entered in the first row and column.
3) The evaluator enters, in the upper triangular matrix cells, the option that is the most important from comparison with the options in the row/column based on the defined criteria. If those options in mutual comparison meet the defined criteria equally, the marks for both options are entered into the cell.
4) Under the column "Number of occurrences" a number is entered for the total number of occurrences of an option across the whole upper triangular part of the matrix.

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5) Conversion from the number of the occurrences of the option to the value of the importance of the option based on the defined criteria Σ=1. In the case where some option achieves a value of 0 and if it does not meet the defined criteria at all, this value remains. If it partly fulfils the defined criterion but it is last in comparison with other options, then it is possible to make an adjustment and increase the value for all options by 1.
6) Conversion to values in the standardized form.
7) Calculation of overall utility and determination of the best option.



Task: Decide the location of a logistics centre (LC), when there are three appropriate options V1, V2 and V3 using the method of pair-wise comparison. The values of the criteria weights A, B, C, D are determined using the method of pair-wise comparison (the full method of the pair-wise comparison, without equality of values permitted, MPC2). Transformation to the standardized form needs to be performed. The task is solved as a minimization task.

1) The determination and calculation of criteria weights by pair-wise comparison and their conversion into a standardized form (Table 39).

Table 39 – Calculation of standardized criteria weights, MPC2

Criteria x_i	A	B	C	D	$k_i=n+1-p_i$	Non-standardized weights k_i	Standardized weights α_i
A		A	C	A	$k_1=4+1-3$	2	0.20
B			C	B	$k_2=4+1-4$	1	0.10
C				D	$k_3=4+1-1$	4	0.40
D					$k_4=4+1-2$	3	0.30
					Sum	10	1.00

2) The calculation of the partial utility by pair-wise comparison and the transformation to standard values based on each criterion (Table 40). An assessor writes, in the upper triangular matrix cells, the option which better meets the defined criteria in comparison with other options.

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Table 40 – Determination of partial utility of particular options, MPC2

Pair-wise comparison of option by criterion A	V1	V2	V3	Number of option occurrences	Utility of the option to criterion A
V1		V1	V3	1	0.3333
V2			V3	0	0
V3				2	0.6667
			Sum	3	1
Pair-wise comparison of option by criterion B	V1	V2	V3	Number of option occurrences	Utility of the option to criterion B
V1		V1	V1	2	0.6667
V2			V2	1	0.3333
V3				0	0
			Sum	3	1
Pair-wise comparison of option by criterion C	V1	V2	V3	Number of option occurrences	Utility of the option to criterion C
V1		V1	V3	2	0.6667
V2			V1	0	0
V3				1	0.3333
			Sum	3	1
Pair-wise comparison of option by criterion D	V1	V2	V3	Number of option occurrences	Utility of the option to criterion D
V1		V1	V1	2	0.6667
V2			V3	0	0
V3				1	0.3333
			Sum	3	1

3) The calculation of the total utility U_j of particular options (Table 41), and the determination of the best option.

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Table 41 – Calculation of the total utility of options, MPC2

	Option	V1		V2		V3	
Criteria x_i	Standardized weights	Utility u_{i1}, ⟨0,1⟩	α_i x u_{i1}	Utility u_{i2}, ⟨0,1⟩	α_i x u_{i2}	Utility u_{i3}, ⟨0,1⟩	α_i x u_{i3}
A	0.20	**0.3333**	0.0667	**0**	0	**0.6667**	0.1333
B	0.10	**0.6667**	0.0667	**0.3333**	0.0333	**0**	0
C	0.40	**0.6667**	0.2667	**0**	0	**0.3333**	0.1333
D	0.30	**0.6667**	0.2000	**0**	0	**0.3333**	0.1000
Total utility U_j	$\sum\alpha_i = 1$	**Σ**	**0.5555**	**Σ**	**0.0333**	**Σ**	**0.3667**

In this case, it is appropriate to build the logistics centre based on option V1.

b) Modified Saaty's method – Modified AHP method (Straka 2012)

Saaty's method for determination of the overall utility of option U_j uses the relationship (8.10) of the weighted sum method:

$$U_j = \sum_{i=1}^{n} \alpha_i u_{ij} \qquad j = 1, 2, \ldots, m, \tag{8.10}$$

m – number of evaluated options (places, places),
n – number of defined criteria,
α_i – weight of the i^{th} criterion, $\sum_{i=1}^{n} \alpha_i = 1$,
V_j – evaluated option,
u_{ij} – utility of the j^{th} option based on the i^{th} criterion,
U_j – overall utility of evaluated option (the stability index).

Option V_j, for which it holds that min = $\{U_j\}$ (based on the task type), best fulfils the defined criteria and is the solution sought.

The solution is based on the same table as in the weighted sum method (Table 30). All the data that are entered in the table are calculated in this case using Saaty's approach of determining the partial utility of options. The maximum number of points (overall utility of the option), which the option can achieve, is 1 × 1 = 1. The real results are in the range ⟨0,1⟩.

The values of partial utility u_{ij} of each option based on defined criteria, are determined using Saaty's approach progressively for each defined criterion (similar to when determining weights by Saaty's method), i.e. the

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number of defined criteria is equal to the number of times it is necessary to make a Saaty calculation.

Procedure:

1) Defining the criteria and setting their weight values. The weights are calculated using Saaty's method with the complete Saaty's method, and weights are determined by any of the other methods, e.g. pair-wise comparison in the combined method.
2) Creating the option matrix, where defined options are entered in the first row and column for criterion x_i.
3) The evaluator enters the option in the cells of the upper triangular matrix which corresponds to the comparison of the option in the row with the option in the column (Table 42) based on the defined criteria, or its reciprocal value 1/x (8.11) (Table 43, Table 44), if the second option is more important than the first option, their positions in the table are changed.

Table 42 – Points evaluation of two compared options, Saaty's method

Points x	Description
1	Options are equally significant in relation to criterion x_i
3	The first option is slightly more significant than the second option in relation to the criterion x_i
5	The first option is more significant than the second option in relation to the criterion x_i
7	The first option is much more significant than the second option in relation to the criterion x_i
9	The first option is absolutely more significant than the second option in relation to the criterion x_i
The values 2, 4, 6, 8 can be used for finer distinction	

$$s_{ij} = 1, \forall i = j;\ s_{ij} = {}^{1}/_{s_{ji}}, \forall i \neq j;\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,m; \qquad (8.11)$$

s_{ij} – the value that expresses the relationship between the two compared options,
s_{ji} – reciprocal of the value s_{ij},
m – the number of options,
i, j – index variables.

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Table 43 – Points evaluation of options across the matrix based on criterion A (equations 8.11), the modified Saaty's method

Comparison of options according to criterion A	V1	V2	V3
V1	1	1/3	5
V2	3	1	3
V3	1/5	1/3	1

4) Summation of values in individual columns (Table 44).

Table 44 – Calculation of the sums in each column of criterion A, Saaty's method

Comparison of options according to criterion A	V1	V2	V3
V1	1	1/3	5
V2	3	1	3
V3	1/5	1/3	1
Sum	**4.2**	**1.667**	**9**

5) The value in the cell is divided by the sum of the appropriate column (Table 45).

Table 45 – Calculation of new matrix of values based on criterion A, Saaty's method

Comparison of options according to criterion A	V1	V2	V3
V1	0.238	0.2	0.556
V2	0.714	0.6	0.333
V3	0.048	0.2	0.111

6) Summing the values in each row and dividing them by the total sum of the values in the matrix to get the values for the partial utility of options based on the defined criteria (Table 46).

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Table 46 – Calculation of partial utility of options based on criteria A, Saaty's method

Comparison of options according to criterion A	V1	V2	V3	Sum	Partial utility of options according to criterion A
V1	0.238	0.2	0.556	**0.994**	**0.3313**
V2	0.714	0.6	0.333	**1.647**	**0.5490**
V3	0.048	0.2	0.111	**0.359**	**0.1197**
Sum	1	1	1	**3**	**1**
	3				

7) The values for utility are written into the table (the weighted sum method), the procedure is repeated from step 2 until the utility of options has been calculated for each criterion.
8) The calculation of overall utility U_j and the best option is determined.



Task: Decide the location for company F, by considering three appropriate options V1, V2, V3 using modified Saaty's method (AHP). The values of criteria weights A, B, C, D are to be determined using Saaty's method too. The task is solved as a maximization task.

1) Determining criteria and calculating criteria weights using Saaty's method (Table 47).

Table 47 – Points evaluation of criteria across the matrix and the calculation of standardized criteria weights, modified Saaty's method

Criteria x_i	A	B	C	D
A	1	3	3	9
B	1/3	1	5	5
C	1/3	1/5	1	1
D	1/9	1/5	1	1
Sum	**16/9**	**22/5**	**10**	**16**

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Criteria x_i	A	B	C	D	Sum	Standardized weights α_i
A	9/16	15/22	3/10	9/16	**2.1068**	**0.5267**
B	3/16	5/22	1/2	5/16	**1.2273**	**0.3068**
C	3/16	1/22	1/10	1/16	**0.3955**	**0.0989**
D	1/16	1/22	1/10	1/16	**0.2705**	**0.0676**
Sum	**1**	**1**	**1**	**1**	**4**	**1**
	4					

2) Calculating the partial utility values (Table 48) using Saaty's method with respect to each criterion.

Table 48 – Calculation of partial utility for each option and each criterion

Comparison of options according to criterion A	V1	V2	V3
V1	1	3	5
V2	1/3	1	3
V3	1/5	1/3	1
Sum	**23/15**	**13/3**	**9**

Comparison of options according to criterion A	V1	V2	V3	Sum	Partial utility of options according to criterion A
V1	15/23	9/13	5/9	**1.9000**	**0.6333**
V2	5/23	3/13	1/3	**0.7815**	**0.2605**
V3	3/23	1/13	1/9	**0.3185**	**0.1062**
Sum	**1**	**1**	**1**	**3**	**1**
	3				

Comparison of options according to criterion B	V1	V2	V3
V1	1	5	3
V2	1/5	1	5
V3	1/3	1/5	1
Sum	**23/15**	**31/5**	**9**

Comparison of options according to criterion B	V1	V2	V3	Sum	Partial utility of options according to criterion B
V1	15/23	25/31	1/3	**1.7920**	**0.5973**
V2	3/23	5/31	5/9	**0.8473**	**0.2824**
V3	5/23	1/31	1/9	**0.3608**	**0.1203**
Sum	**1**	**1**	**1**	**3**	**1**
	3				

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Comparison of options according to criterion C	V1	V2	V3
V1	1	1	2
V2	1	1	4
V3	1/2	1/4	1
Sum	5/2	9/4	7

Comparison of options according to criterion C	V1	V2	V3	Sum	Partial utility of options according to criterion C
V1	2/5	4/9	2/7	1.1302	0.3767
V2	2/5	4/9	4/7	1.4159	0.4720
V3	1/5	1/9	1/7	0.4540	0.1513
Sum	1	1	1	3	1
	3				

Comparison of options according to criterion D	V1	V2	V3
V1	1	3	4
V2	1/3	1	3
V3	1/4	1/3	1
Sum	19/12	13/3	8

Comparison of options according to criterion D	V1	V2	V3	Sum	Partial utility of options according to criterion D
V1	12/19	9/13	1/2	1.8239	0.6080
V2	4/19	3/13	3/8	0.8163	0.2721
V3	3/19	1/13	1/8	0.3598	0.1199
Sum	1	1	1	3	1
	3				

3) Calculating the total utility U_j of particular options (Table 49) and determining the best option.

Table 49 – Calculation of the total utility of particular options

	Option	V1		V2		V3	
Criteria x_i	Standardized weights	Utility u_{i1}, ⟨0,1⟩	$\alpha_i \times u_{i1}$	Utility u_{i2}, ⟨0,1⟩	$\alpha_i \times u_{i2}$	Utility u_{i3}, ⟨0,1⟩	$\alpha_i \times u_{i3}$
A	0.5267	**0.6333**	0.3336	**0.2605**	0.1372	**0.1062**	0.0559
B	0.3068	**0.5973**	0.1833	**0.2824**	0.0867	**0.1203**	0.0369
C	0.0989	**0.3767**	0.0372	**0.4720**	0.0467	**0.1513**	0.0150
D	0.0676	**0.6080**	0.0411	**0.2721**	0.0184	**0.1199**	0.0081
Total utility U_j	$\sum\alpha_i = 1$	Σ	**0.5952**	Σ	0.2890	Σ	0.1159

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In this case, it is advisable to locate company F in accordance with option V1.



Task (combined task): Decide about the rental of a warehouse – S, considering three appropriate options V1, V2, and V3 using the method of pair-wise comparison with equal values permitted. The values of criteria weights A, B, C, D are to be determined using Saaty's method (combined pair-wise comparison method). The task is solved as a maximization task.

1) Determining and calculating criteria weights using Saaty's method (Table 50), comparing options and numerical evaluation, dividing the value in a cell by the sum of the corresponding column, dividing the sum of a row by the total sum of the matrix.

Table 50 – Points evaluation of criteria across the matrix and the calculation of standard criteria weights, modified Saaty's method

Criteria x_i	A	B	C	D
A	1	9	1/5	3
B	1/9	1	5	1/7
C	5	1/5	1	1
D	1/3	7	1	1
Sum	6.444	17.200	7.200	5.143

Criteria x_i	A	B	C	D	Sum	Standardized weights α_i
A	0.1552	0.5233	0.0278	0.5833	**1.2896**	**0.3224**
B	0.0172	0.0581	0.6944	0.0278	**0.7976**	**0.1994**
C	0.7759	0.0116	0.1389	0.1944	**1.1208**	**0.2802**
D	0.0517	0.4070	0.1389	0.1944	**0.7920**	**0.1980**
Sum	**1**	**1**	**1**	**1**	**4**	**1**
	4					

2) Calculating the partial utility by pair-wise comparison (Table 51) and transforming it to standard values based on each criterion. The evaluator enters the option in the upper triangular part of the matrix which better meets the defined criteria in comparison with the other option.

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Table 51 – Calculation of partial utility for each option and each criterion

Pair-wise comparison of options by criterion A	V1	V2	V3	Number of occurrences of the option	Utility of the options to criterion A
V1		V1	V3	1	0.3333
V2			V2	1	0.3333
V3				1	0.3333
			Sum	3	1
Pair-wise comparison of options by criterion B	V1	V2	V3	Number of occurrences of the option	Utility of the options to criterion B
V1		V1	V3	1	0.3333
V2			V2	1	0.3333
V3				1	0.3333
			Sum	3	1
Pair-wise comparison of options by criterion C	V1	V2	V3	Number of occurrences of the option	Utility of the options to criterion C
V1		V1	V2	1	0.3333
V2			V2	2	0.6667
V3				0	0
			Sum	3	1
Pair-wise comparison of options by criterion D	V1	V2	V3	Number of occurrences of the option	Utility of the options to criterion D
V1		V2	V1	1	0.3333
V2			V2	2	0.6667
V3				0	0
			Sum	3	1

3) The calculation of the total utility U_j of particular options (Table 52) and the determination of the best option.

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Table 52 – Calculation of total utility for the particular options

	Option	V1		V2		V3	
Criteria x_i	Standardized weights	Utility u_{i1}, ⟨0,1⟩	α_i x u_{i1}	Utility u_{i2}, ⟨0,1⟩	α_i x u_{i2}	Utility u_{i3}, ⟨0,1⟩	α_i x u_{i3}
A	0.3224	**0.3333**	0.1075	**0.3333**	0.1075	**0.3333**	0.1075
B	0.1994	**0.3333**	0.0665	**0.3333**	0.0665	**0.3333**	0.0665
C	0.2802	**0.3333**	0.0934	**0.6667**	0.1868	**0.0000**	0.0000
D	0.1980	**0.3333**	0.0660	**0.6667**	0.1320	**0.0000**	0.0000
Total utility U_j	$\sum\alpha_i = 1$	Σ	0.3334	Σ	**0.4928**	Σ	0.1740

In this case, it is advisable to rent warehouse S based on option V2.

By combining the methods for calculating the weights of criteria with the methods for calculating partial utility, it is possible to create new options for methods suitable for solving tasks requiring multi-criteria decision-making.

c) Distance from the fictional option (Fiala et al. 1994), point, place, or firm. The basic principle of the method consists of defining a fictional option (a firm), which is obtained from existing utility values for each criterion and the option with the best (or worst, depending on the solution) evaluation for it. The best option is determined using Euclidean distance and it is the option which is the closest to the fictional option (in the case of worst values it is the option which is furthest from the fictional option).

The following procedure is followed:

1) Defining partial utility u_{ij} for each option (by the calculation-pairing method, Saaty's method, or values are determined statistically, or with economic indicators).
2) Adding another fictional option V_f to the evaluated options for which the utility value for each criterion is defined as the best value (max., min.) for the values of the particular options for the given criteria.
3) Calculating arithmetic averages $\overline{u_i}$ (8.12) from the utility values for each defined criterion (without the values of the fictional option):

$$\bar{u}_i = \frac{1}{m}\sum_{j=1}^{m} u_{ij} \qquad i = 1,2,\ldots,n, \tag{8.12}$$

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m – the number of options,
n – the number of criteria.

4) Calculating the standard deviations s_i (8.13) for each defined criterion (without the values of the fictional option).

$$s_i = \sqrt{\frac{1}{m}\sum_{j=1}^{m}(u_{ij} - \bar{u}_i)^2} \qquad i = 1,2,\dots,n \tag{8.13}$$

5) Values of partial utility u_{ij} are converted to a standardized form ${u_{ij}}^{norm}$, if the best criteria value for partial utility is max. (8.14):

$$\begin{aligned} {u_{ij}}^{norm} &= (u_{ij} - \bar{u}_i)/s_i \qquad i = 1,2,\dots,n; j = 1,2,\dots,m, \\ {u_{if}}^{norm} &= (u_{if} - \bar{u}_i)/s_i \qquad i = 1,2,\dots,n; f = m+1. \end{aligned} \tag{8.14}$$

If the best criteria value for partial utility is min. (8.15):

$$\begin{aligned} {u_{ij}}^{norm} &= -(u_{ij} - \bar{u}_i)/s_i \quad i = 1,2,\dots,n; j = 1,2,\dots,m, \\ {u_{if}}^{norm} &= -(u_{if} - \bar{u}_i)/s_i \quad i = 1,2,\dots,n; f = m+1. \end{aligned} \tag{8.15}$$

6) Several metrics can be used ((Euclidean distance 8.16, 8.17), 8.18, 8.19) to calculate the distance d_j from the fictional option, the best option has the smallest distance (or the longest distance):

$$d_j = \sqrt{\sum_{i=1}^{n}\alpha_i(u_{if} - u_{ij})^2} \qquad j = 1,2,\dots,m, \tag{8.16}$$

$$d_j = \sqrt{\sum_{i=1}^{n}\alpha_i\left(\frac{u_i^* - u_{ij}}{u_i^* - u_i^o}\right)^2} \qquad j = 1,2,\dots,m, \tag{8.17}$$

$$d_j = \sum_{i=1}^{n}\alpha_i\left|u_{if} - u_{ij}\right| \qquad j = 1,2,\dots,m, \tag{8.18}$$

$$d_j = \max\left(\alpha_i\left|u_{if} - u_{ij}\right|\right) \quad i = 1,2,\dots,n; j = 1,2,\dots,m, \tag{8.19}$$

m – number of options,
n – number of criteria,
α_i – weight of criteria a i,
d_j – distance of option j from (fictional) option f,
u_{if} – partial value of utility of criterion i for option f,

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u_{ij} – partial value of utility of criterion i for option j,
u_i^* – best value of the i^{th} criterion,
u_i^o – worst value of the i^{th} criterion.

The special metric is called the Ivanovic distance (8.20); it considers the weights of each implicit criterion in terms of the impact of pair-wise correlation coefficients. The advantage of the method is that it is not necessary to define the criteria weights in advance, because the determination of their values is directly a part of the relationship.

$$d_j = \frac{\left|u_{1f} - u_{1j}\right|}{s_1} + \sum_{i=2}^{n} \frac{\left|u_{if} - u_{ij}\right|}{s_i} \prod_{k=1}^{i-1} (1 - \left|r_{ki}\right|) \quad j = 1, 2, \ldots, m, \tag{8.20}$$

r_{ki} – correlation coefficient of the k^{th} and the i^{th} criteria.



Task: Decide to purchase a parcel of land for the construction of a distribution warehouse – DS, when considering four appropriate options V1, V2, V3 and V4 using the method of distance from the fictional option. The values of five criteria weights are determined by experts. There is statistical data (Table 53) for each option and defined criteria. Use Euclidean distance to calculate the distance from the fictional option

$$d_j = \sqrt{\sum_{i=1}^{n} \alpha_i (u_{if} - u_{ij})^2} \qquad j = 1, 2, \ldots, m.$$

Table 53 – Statistical data required for the selection of a suitable option

Criteria x_i	Option V1	Option V2	Option V3	Option V4	Search value	Weights α_i
Criterion 1	30.01	30.56	25.56	21.25	max.	0.20
Criterion 2	0.22	0.12	0.43	0.23	max.	0.25
Criterion 3	25	96	55	67	max.	0.10
Criterion 4	10.25	25.33	12.25	45.34	min.	0.15
Criterion 5	0.12	0.22	0.55	0.11	min.	0.30
					Σ	1.00

1) Inserting the fictional option, calculating averages and standard deviations (Table 54).

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Table 54 – Calculation of averages and standard deviation

Criteria x_i	Option V1	Option V2	Option V3	Option V4	Arithmetic mean u_i	Standard deviation s_i	Fictional option Vf
Criterion 1	30.01	30.56	25.56	21.25	26.845	3.7674	30.56
Criterion 2	0.22	0.12	0.43	0.23	0.25	0.1125	0.43
Criterion 3	25	96	55	67	60.75	25.4595	96
Criterion 4	10.25	25.33	12.25	45.34	23.2925	13.9847	10.25
Criterion 5	0.12	0.22	0.55	0.11	0.25	0.1785	0.11

2) Transforming partial utility u_{ij} to the standard form, calculating the distance from the fictional option using the Euclidean distance metric (Table 55).

Table 55 – The calculation of the total utility for particular options

Criteria x_i	Option V1	Option V2	Option V3	Option V4	Fictional option Vf	Weights α_i
Criterion 1	0.840	0.986	-0.341	-1.485	0.986	0.20
Criterion 2	-0.267	-1.156	1.600	-0.178	1.600	0.25
Criterion 3	-1.404	1.385	-0.226	0.245	1.385	0.10
Criterion 4	0.933	-0.146	0.790	-1.577	0.933	0.15
Criterion 5	0.728	0.168	-1.681	0.784	0.784	0.30
Euclidean distance d_i	1.286	1.479	1.561	1.757		1.00
	1	2	3	4		

In this case, the company should purchase a parcel of land for the distribution warehouse – DS based on option V1, since this option is globally the closest to the values of the fictional option.

8.2 Location using Mathematical-geometrical Methods

The aim of geometrical methods is to calculate the coordinates of the optimal location within the region for operations management, a distribution centre or a warehouse, whereby the costs of a connection between the calculated centre and existing sites are as low as possible. The basis is to minimize the chosen cost criterion, which is most commonly used for assessment.

The first step is the region location map, in which the location of the distribution centre is found at coordinate axis *x, y*. Every place that is part

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of the evaluation or has some relation to the distribution centre sought, has its coordinates $[x_i, y_i]$ determined in the coordinate system (Figure 72).

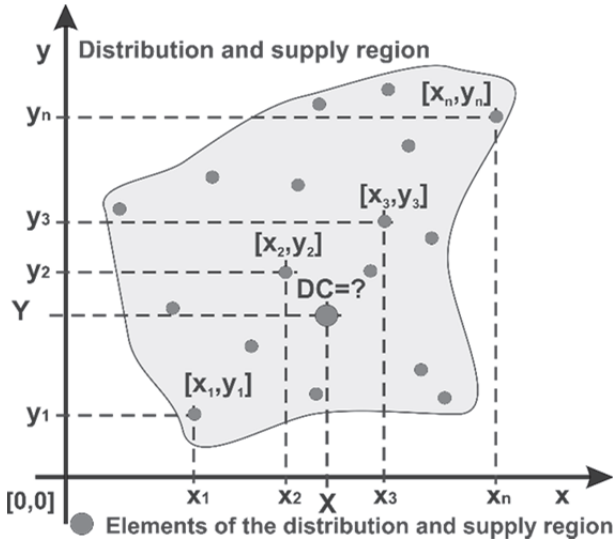


Figure 72 – The location of a distribution region into the coordinate system

The second step is to establish the objective function that it is necessary to minimize in the case of a cost perspective. The objective function (8.21) is characterized by Transport Cost – TC (Cooper 1964).

$$\min z = TC = \sum_{i=1}^{n} M_i C_i d_i \tag{8.21}$$

M_i – transported quantity (energy, materials, products),
C_i – price for the transport of a unit of the i^{th} material (energy, products),
d_i – distance to the i^{th} customer from the distribution centre *DC [x, y]*,
n – number of places evaluated.

Other criteria can be used such as the quantity of goods, unit price, e.g. number of vehicles, number of devices or only the quantity or the unit price can be chosen for the objective functions where appropriate.

Distance d_i has great importance for the further calculation of the coordinates to find the distribution centre, which can be chosen depending on the region for which the location is sought (8.22, 8.23, 8.24, 8.25). Depending on the character of the region, the distance of distribution

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places from the distribution centre sought can be expressed as (Gros 2003):

- the axial distance

$$d_i = |x - x_i| + |y - y_i|, \tag{8.22}$$

- the quadratic distance

$$d_i = (x - x_i)^2 + (y - y_i)^2, \tag{8.23}$$

- the direct distance

$$d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2}, \tag{8.24}$$

- the direct coordinated distance

$$d_i = k\sqrt{(x - x_i)^2 + (y - y_i)^2}, \tag{8.25}$$

$[x, y]$ – coordinates of the distribution centre sought,
$[x_i, y_i]$ – coordinates of distribution places in the distribution region,
i – index of distribution places entering the calculation, value range of 1,2,3,…, n,
n – number of distribution places entering the calculation,
k – coordination value, usually 1.2.

The axial distance (8.22) is useful for locating a distribution centre in a distribution region of a city with a rectangular network of streets.

The quadratic distance (8.23) is significant for locating transmitters in a region.

The direct distance (8.24) is significant for locating a distribution centre for aviation or in regions connected with a direct distribution trajectory.

The direct coordinated distance (8.25) is used for connections of distribution places with a curved distribution trajectory e.g. in road or rail transport. The coordination value is standardly a value of 1.2, which increases the length of a road by 20% of the direct length.

8.2.1 Location using the Axial Distance

In this case, the real distances between the distribution centre sought and various places in a region are replaced by "axial distances" $d_i = |x - x_i| + |y - y_i|$ (Figure 73).

The axial distance represents the sum of the absolute values for how far from x_{opt} and y_{opt} the potential distribution centre is from distribution places in the distribution region.

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[*x, y*] – coordinates of the potential distribution centre,
[x_i, y_i] – coordinates of distribution places in the distribution region,
i – index of distribution places in the calculation, value range of 1, 2, 3, …, n,
n – number of distribution places in the calculation.

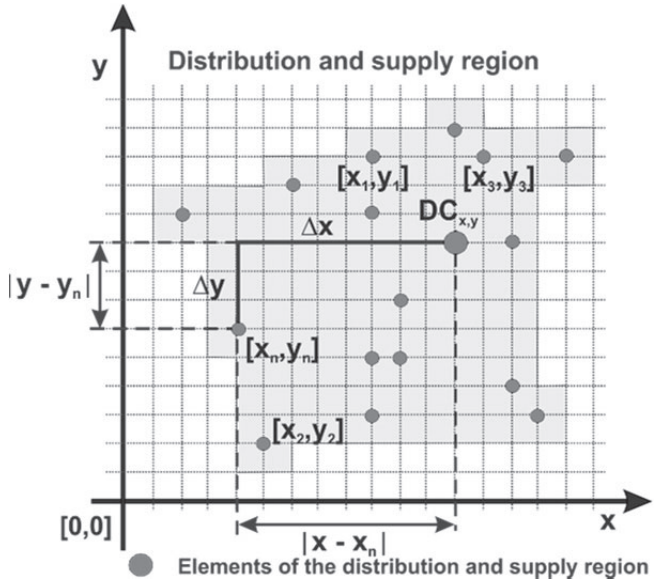


Figure 73 – The axial distance between the places in a distribution region

After the substituting total transport costs into the objective function we get:

$$\min z = TC = \sum_{i=1}^{n} M_i C_i(|x - x_i| + |y - y_i|) = \min \sum_{i=1}^{n} M_i C_i |x - x_i| + \min \sum_{i=1}^{n} M_i C_i |y - y_i| . \quad (8.26)$$

In order to achieve the minimization of the objective function (8.26), it is necessary that $|x - x_i| = \min \cap |y - y_i| = \min$, it follows that any x must be equal to x_i, and any y must be equal to y_i. It would be the best if they were close or equal to 0 but then distribution places would have to be all at one place and when solving tasks, such a state is just a hypothetical idea. Consequently, in order to achieve the minimization of the objective function the following must hold:

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- a maximum of half of the coordinates x_i must be placed to the left and at the same time a maximum of half of the coordinates x_i must be placed to the right from the sought x coordinate of the distribution centre,
- a maximum of half of the coordinates y_i must be placed above and at the same time a maximum of half of the coordinates y_i must be placed below the sought y coordinate of the distribution centre.

The procedure for determination of the sought distribution centre coordinates x, y consists of the following steps.

1) Distribution places that are part of the solution are arranged in ascending order of coordinates x_i.
2) The cumulative value is calculated for each place $M_i.C_i$.
3) The sought x coordinate of the distribution centre will be equal to coordinate x_i for which the cumulative value $M_i.C_i$ first exceeds the value $\frac{1}{2}\sum_{i=1}^{n} M_i C_i$.
4) Distribution places that are part of the solution are arranged in ascending order of the coordinates y_i.
5) The cumulative value is calculated for each place $M_i.C_i$.
6) The y coordinate of a distribution centre is equal to the coordinate y_i at which the cumulative value $M_i.C_i$ first exceeds the value $\frac{1}{2}\sum_{i=1}^{n} M_i C_i$.



Task: Determine the best place to build a pharmacy in a town (Figure 74), which will also serve as a central warehouse (DC) of medicines and hospital supplies for neighbouring pharmacies, using axial distance location. The coordinates of customers, amount of goods received and the price of material transport per unit are shown in Table 56.

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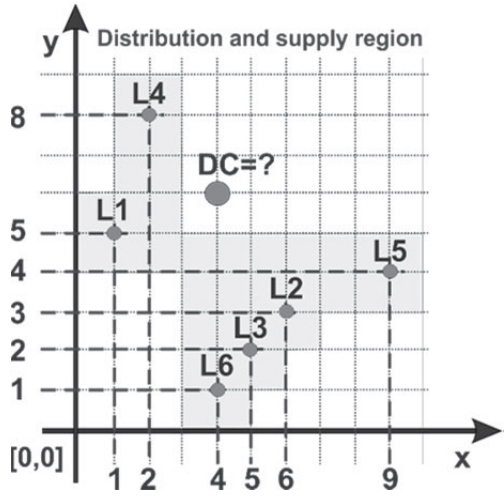


Figure 74 – The graphical representation of the location of pharmacies in a town

Table 56 – The quantities, prices and coordinates of distribution places

Purchaser	Mi (pcs)	Ci (EUR)	xi	yi
L1	150	10	1	5
L2	200	6	6	3
L3	20	30	5	2
L4	100	10	2	8
L5	90	9	9	4
L6	130	15	4	1

The procedure to determine distribution centre coordinates *x, y* consists of the following steps.

1. Distribution places that are part of the solution are arranged in ascending order (Table 57) based on coordinates x_i.

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Table 57 – x coordinates of customers in ascending order

Purchaser	Mi (pcs)	Ci (EUR)	xi
L1	150	10	1
L4	100	10	2
L6	130	15	4
L3	20	30	5
L2	200	6	6
L5	90	9	9

2. The accumulated value of M_iC_i (Table 58) is calculated for each place.

Table 58 – Calculation of the cumulative value M_iC_i

Purchaser	Mi (pcs)	Ci (EUR)	xi	cumul. MiCi
L1	150	10	1	1500
L4	100	10	2	2500
L6	130	15	4	4450
L3	20	30	5	5050
L2	200	6	6	6250
L5	90	9	9	7060

3. The sought coordinate x of the location of the pharmacy is equal to the coordinate x_i in which the accumulated value M_iC_i first exceeds the value $\frac{1}{2}\sum_{i=1}^{n} M_iC_i$ => 7060/2 = 3530. It means that the first value of $x_i = 4$ exceeds this value => the first coordinate of the location of the pharmacy is $x = 4$ (Table 59).

Table 59 – Determination of the optimal value of coordinate x for the central warehouse of medicines

Purchaser	Mi (pcs)	Ci (EUR)	xi	cumul. MiCi
L1	150	10	1	1500
L4	100	10	2	2500
L6	130	15	**4**	**4450**
L3	20	30	5	5050
L2	200	6	6	6250
L5	90	9	9	7060

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4. Distribution places that are part of the solution are arranged in ascending order (Table 60) based on the coordinates y_i.

Table 60 – y coordinates of customers in ascending order

Purchaser	Mi (pcs)	Ci (EUR)	yi
L6	130	15	1
L3	20	30	2
L2	200	6	3
L5	90	9	4
L1	150	10	5
L4	100	10	8

5. The accumulated value M_iC_i (Table 61) is calculated for each place.

Table 61 – Calculation of the cumulative value M_iC_i

Purchaser	Mi (pcs)	Ci (EUR)	yi	cumul. MiCi
L6	130	15	1	1950
L3	20	30	2	2550
L2	200	6	3	3750
L5	90	9	4	4560
L1	150	10	5	6060
L4	100	10	8	7060

6. The searched coordinate y of the location of the pharmacy is equal to the coordinate y_i in which the accumulated value M_iC_i first exceeds the value $\frac{1}{2}\sum_{i=1}^{n} M_iC_i$ => 7060/2 = 3530. It means that the first value of y_i = 3 exceeds this value => the second coordinate of the location of the pharmacy is y = 3 (Table 62).

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Table 62 – Determination of the optimal value of coordinate y for the central warehouse of medicines

Purchaser	Mi (pcs)	Ci (EUR)	yi	cumul. MiCi
L6	130	15	1	1950
L3	20	30	2	2550
L2	200	6	3	3750
L5	90	9	4	4560
L1	150	10	5	6060
L4	100	10	8	7060

$$z = TC = \sum_{i=1}^{n} M_i C_i (|x - x_i| + |y - y_i|) = 26\,860$$

The results indicate that the place sought to build a pharmacy has the coordinates *x, y* = [4,3] (Figure 75). The value of the objective function after substituting in to the relationship is 26 860.

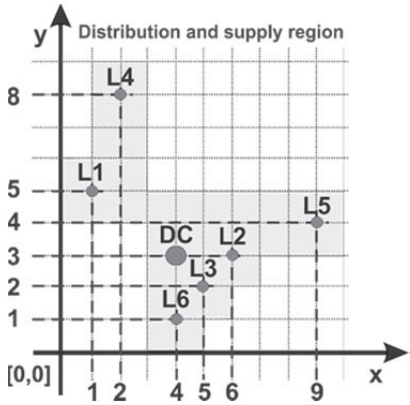


Figure 75 – Graphical representation of the solution for the central warehouse location sought

8.2.2 Location using Quadratic Distance

The distance d_i is expressed as quadratic distance $d_i = (x - x_i)^2 + (y - y_i)^2$ in the objective function $\min z = TC = \sum_{i=1}^{n} M_i C_i d_i$. Such an expression of distance is important in

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seeking a location for transmitters of different types or if costs are increased with the square of the distance (Gros 2003). Substituting into the objective function of transport costs:

$$\begin{gathered}\min z = TC = \sum_{i=1}^{n} M_i C_i((x - x_i)^2 + (y - y_i)^2) = \\ \sum_{i=1}^{n}\left(M_i C_i(x^2 - 2xx_i + {x_i}^2) + M_i C_i(y^2 - 2yy_i + {y_i}^2)\right).\end{gathered} \tag{8.27}$$

It is necessary to obtain the coordinates for the optimal location of a distribution centre *DC [x, y] =?* to achieve minimization of the objective function (8.27). Because it is necessary to obtain the optimal coordinates of location of a distribution centre *DC [x, y]* it must hold that the derivation of the objective function *TC* by *x* is equal to 0, as well as the derivation of objective function *TC* by *y* is equal to 0 (8.28):

$$\frac{\partial TC}{\partial x} = 0 \cap \frac{\partial TC}{\partial y} = 0. \tag{8.28}$$

We obtain the location sought for a distribution centre, warehouse or transmitter by substituting into the formulas (8.28.1, 8.28.2) to calculate the coordinates *x, y:*

$$\begin{gathered}\frac{\partial TC}{\partial x} = \\ \frac{\partial \sum_{i=1}^{n}(M_i C_i x^2 - 2M_i C_i x x_i + M_i C_i {x_i}^2 + M_i C_i y^2 - 2M_i C_i y y_i + M_i C_i {y_i}^2)}{\partial x} = \\ \sum_{i=1}^{n}(2M_i C_i x - 2M_i C_i x_i) = 0 \Rightarrow x = \frac{\sum_{i=1}^{n} M_i C_i x_i}{\sum_{i=1}^{n} M_i C_i},\end{gathered} \tag{8.28.1}$$

$$\begin{gathered}\frac{\partial TC}{\partial y} = \\ \frac{\partial \sum_{i=1}^{n}(M_i C_i x^2 - 2M_i C_i x x_i + M_i C_i {x_i}^2 + M_i C_i y^2 - 2M_i C_i y y_i + M_i C_i {y_i}^2)}{\partial y} = \\ \sum_{i=1}^{n}(2M_i C_i y - 2M_i C_i y_i) = 0 \Rightarrow y = \frac{\sum_{i=1}^{n} M_i C_i y_i}{\sum_{i=1}^{n} M_i C_i}.\end{gathered} \tag{8.28.2}$$



Task: Determine the place to build a central warehouse (DC) using quadratic distance. The coordinates of customers, the amount of goods received and the price of material transport per unit is shown in Table 63, the location of customers is shown in Figure 76.

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Table 63 – Quantities, prices and coordinates of distribution places

Purchaser	Mi (pcs)	Ci (EUR)	xi	yi
S1	50	10	1	2
S2	60	12	8	7
S3	50	9	2	5
S4	70	8	6	7

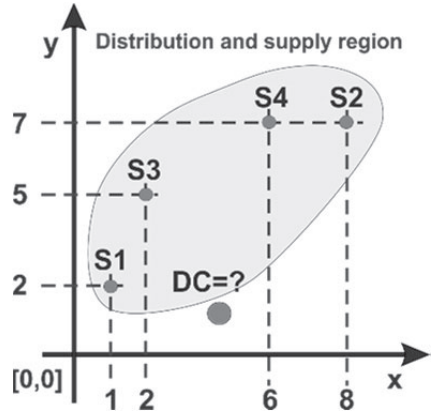


Figure 76 – Location of customers in the distribution region

We add the necessary values to the formula for calculation of the coordinates and then progressively calculate the value of coordinate *x* and the value of coordinate *y* for the distribution centre sought.

$$x = \frac{\sum_{i=1}^{n} M_i C_i x_i}{\sum_{i=1}^{n} M_i C_i} = \frac{50\times10\times1+60\times12\times8+50\times9\times2+70\times8\times6}{50\times10+60\times12+50\times9+70\times8} = \frac{500+5760+900+3360}{500+720+450+560} = \frac{10520}{2230} = 4.7$$

$$y = \frac{\sum_{i=1}^{n} M_i C_i y_i}{\sum_{i=1}^{n} M_i C_i} = \frac{50\times10\times2+60\times12\times7+50\times9\times5+70\times8\times7}{50\times10+60\times12+50\times9+70\times8} = \frac{1000+5040+2250+3920}{500+720+450+560} = \frac{12210}{2230} = 5.5$$

The distribution centre sought has the coordinates $\mathbf{DC_{x,y}=[4.7; 5.5]}$ (Figure 77).

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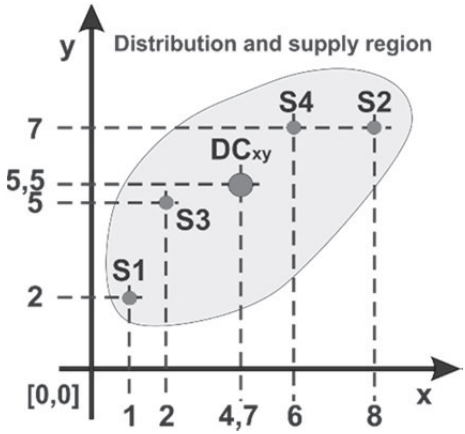


Figure 77 – The location of the distribution centre in the distribution region

$$z = TC = \sum_{i=1}^{n} M_i C_i((x - x_i)^2 + (y - y_i)^2) = 28\,028.2$$

The value of the objective function, substituting into the formula is **28 028.2**.

8.2.3 Location using Direct Distance, Cooper's Iteration Method

In this approach, the real distances between locations of places in a region are replaced by a direct connection which may be calculated as the diagonal of a right-angled triangle (Figure 78).

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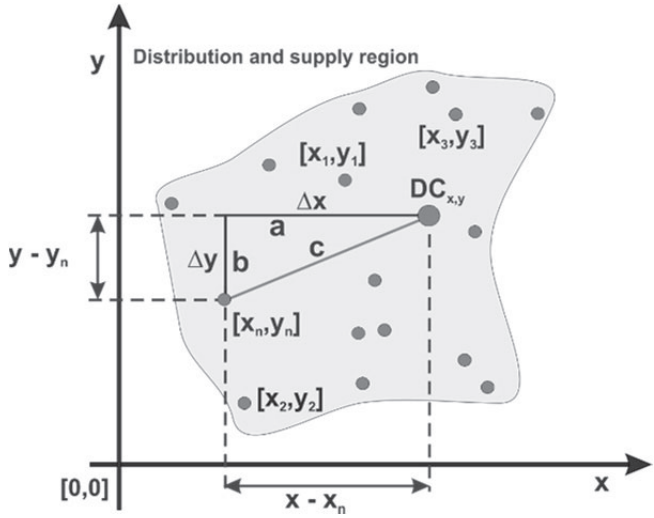


Figure 78 – Direct distance between places in the distribution region

Individual distances between a distribution centre and places (8.29) can be calculated as follows (Straka 2004):

$$c^2 = a^2 + b^2 \Rightarrow {d_i}^2 = (x - x_i)^2 + (y - y_i)^2 \Rightarrow \\ d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2}, \tag{8.29}$$

i – index of distribution places in the calculation, it takes the following values: 1, 2, 3, … n,
n – the number of distribution places in the calculation.

The distance expressed above is applied to the objective function of transport costs (8.30) (Cooper 1964).

$$\min z = TC = \sum_{i=1}^{n} M_i C_i \sqrt{(x - x_i)^2 + (y - y_i)^2} \tag{8.30}$$

Because it is necessary to obtain the optimal coordinates for the location of a distribution centre *DC [x, y] =?*, it must hold that the derivation of the objective function *TC* by *x* is equal to 0, as well as the derivation of objective function *TC* by *y* is equal to 0 (8.31):

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$$\frac{\partial TC}{\partial x} = 0 \cap \frac{\partial TC}{\partial y} = 0. \tag{8.31}$$

H_1 – the value of the partial derivative (8.31.1), which gives us a value for how far, in the x-axis direction, is $x^{(opt)} = x^{(DC)}$.

$$\frac{\partial TC}{\partial x} = \sum_{i=1}^{n} M_i C_i \frac{1}{2}[(x - x_i)^2 + (y - y_i)^2]^{-\frac{1}{2}} (2x - 2x_i) = \sum_{i=1}^{n} \frac{2M_i C_i (x - x_i)}{2\sqrt{(x - x_i)^2 + (y - y_i)^2}} = \sum_{i=1}^{n} \frac{M_i C_i (x - x_i)}{\sqrt{(x - x_i)^2 + (y - y_i)^2}} = H_1 \tag{8.31.1}$$

The calculation of coordinate $x^{(1)}$ of a distribution centre is denoted as:

$$A_1 = \sum_{i=1}^{n} \frac{M_i C_i}{\sqrt{(x - x_i)^2 + (y - y_i)^2}} \Rightarrow$$
$$H_1 = A_1 \sum_{i=1}^{n} (x - x_i) \Rightarrow \sum_{i=1}^{n} (x - x_i) = \frac{H_1}{A_1}. \tag{8.32}$$

$\sum_{i=1}^{n} (x - x_i)$ denotes the sum of distances (+,–) from a distribution centre. That is why we denote it as ΔX_1 (8.32), then $\Delta X_1 = \frac{H_1}{A_1}$ and the new value for (the coordinate) $x^{(1)}$ of the distribution centre (8.33) is calculated as the difference of the old value $x^{(0)}$ and the distance ΔX_1 from the distribution centre,

$$x^{(1)} = x^{(0)} - \Delta X_1, \text{ in general, } x^{(p+1)} = x^{(p)} - \Delta X_{p+1}, \tag{8.33}$$

p – the order of iterations, index of the optimum sought; it takes the values 0,1,2,3,….

Similarly, the calculation of the coordinate y progresses.

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$$\frac{\partial TC}{\partial y} = \sum_{i=1}^{n} M_i C_i \frac{1}{2}[(x-x_i)^2+(y-y_i)^2]^{-\frac{1}{2}}(2y-2y_i) = \sum_{i=1}^{n} \frac{2M_iC_i(y-y_i)}{2\sqrt{(x-x_i)^2+(y-y_i)^2}} = \sum_{i=1}^{n} \frac{M_iC_i(y-y_i)}{\sqrt{(x-x_i)^2+(y-y_i)^2}} = R_1 \quad (8.31.2)$$

R_1 – the value of the partial derivative (8.31.2), which gives us a value for how far, in the y-axis direction, is $y^{(opt)} = y^{(DC)}$.

The calculation of coordinate $y^{(1)}$ of a distribution centre.
If we denote

$$B_1 = \sum_{i=1}^{n} \frac{M_iC_i}{\sqrt{(x-x_i)^2+(y-y_i)^2}} \Rightarrow$$
$$R_1 = B_1 \sum_{i=1}^{n}(y-y_i) \Rightarrow \sum_{i=1}^{n}(y-y_i) = \frac{R_1}{B_1}. \quad (8.34)$$

$\sum_{i=1}^{n}(y-y_i)$ denotes the sum of distances (+,–) from a distribution centre, that is why we denote it as ΔY_1 (8.34), then $\Delta Y_1 = \frac{R_1}{B_1}$ and the new value for (the coordinate) $y^{(1)}$ of a distribution centre (8.35) is calculated as the difference between the old value $y^{(0)}$ and the distance ΔY_1 from the distribution centre,

$$y^{(1)} = y^{(0)} - \Delta Y_1, \text{ in general, } y^{(p+1)} = y^{(p)} - \Delta Y_{p+1}. \quad (8.35)$$

p – the order of iterations, index of optimum sought; it takes values 0,1,2,3,….

d_i has different values with the calculation of $y^{(1)}$, because the last calculated value $x^{(1)}$ is used, although the formula is the same it is referred to as B_1. The calculation procedure is based on the **utopian point method**, this means that during the calculation of the x coordinate, y is considered to be optimal and subsequently during the calculation of the y coordinate, x is considered to be optimal.

An iterative approach successively calculates $x^{(1)}$, $y^{(1)}$, $x^{(2)}$, $y^{(2)}$, $x^{(3)}$, $y^{(3)}$, …, $x^{(opt)}$, $y^{(opt)}$. Initial values $x^{(0)}$ and $y^{(0)}$ can be calculated so as to lead to the need for fewer iterations or real initial values can be specified e.g.

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$x^{(0)}=0$, $y^{(0)}=0 \Rightarrow [x^{(0)};y^{(0)}]= [0;0]$. Initial values (8.36) can be calculated as:

$$x^{(0)} = \frac{\sum_{i=1}^{n} M_i C_i x_i}{\sum_{i=1}^{n} M_i C_i}, \; y^{(0)} = \frac{\sum_{i=1}^{n} M_i C_i y_i}{\sum_{i=1}^{n} M_i C_i}. \tag{8.36}$$

The iterative calculation ends when the chosen accuracy of calculation ε is achieved (8.37, 8.38, 8.39, 8.40). The calculation ends when accuracy is achieved by some of the possibilities (Straka 2007):

- according to the *x*-axis, $\left|x^{(p+1)} - x^{(p)}\right| \leq \varepsilon,$ (8.37)
- according to the *y*-axis, $\left|y^{(p+1)} - y^{(p)}\right| \leq \varepsilon,$ (8.38)
- according to the *x* and *y*-axis simultaneously, $\left|x^{(p+1)} - x^{(p)}\right| \leq \varepsilon \cap \left|y^{(p+1)} - y^{(p)}\right| \leq \varepsilon,$ (8.39)
- according to the objective function change *z*,
$$\Delta z = \left|z^{(p+1)} - z^{(p)}\right| = \left|TC^{(p+1)} - TC^{(p)}\right| = \left| \sum_{i=1}^{n} M_i C_i \sqrt{\left(x^{(p+1)} - x_i\right)^2 + \left(y^{(p+1)} - y_i\right)^2} - \sum_{i=1}^{n} M_i C_i \sqrt{\left(x^{(p)} - x_i\right)^2 + \left(y^{(p)} - y_i\right)^2} \right| \leq \varepsilon, \tag{8.40}$$
- according to the change in the movement of the calculated coordinates, the calculation ends when the values of the calculated coordinates of two successive iterations do not change, e.g. the values of calculated coordinates are identical.

p – order of iterations, index of optimum sought, it takes the values 0,1,2,3,….



Task: Calculate the location of a distribution warehouse which will be a common distribution centre for several companies (Figure 79) using Cooper's iteration method with direct distance. The coordinates of customers, the amount of goods received and the price of material transport per unit are shown in Table 64. The location of the distribution centre must use accuracy ε = 0.1, on the *x*-axis, and also on the *y*-axis. The initial coordinates have the values of $[x^{(0)};y^{(0)}]= [0;0]$.

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Table 64 – The quantities, prices and coordinates of distribution places

Purchaser	Mi (pcs)	Ci (EUR)	xi	yi
O1	550	10	3	5
O2	320	12	7	1
O3	210	11	2	9
O4	450	13	12	7
O5	130	15	10	8

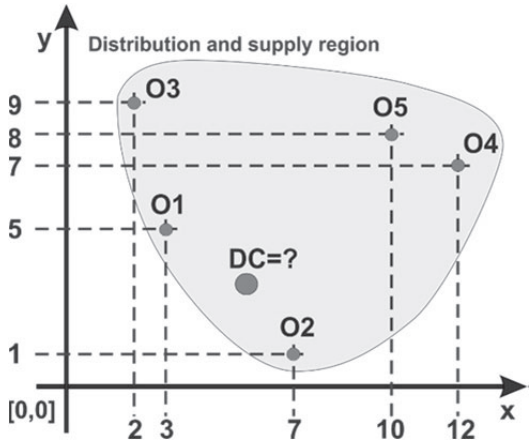


Figure 79 – The location of customers in the distribution region

The first approximation to the optimum coordinates $x^{(opt)}$, $y^{(opt)}$ of the searched distribution centre is the calculation of the coordinate $x^{(1)}$, using the following formula:

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$$H_1 = \sum_{i=1}^{n} \frac{M_i C_i \left(x^{(0)} - x_i\right)}{\sqrt{(x^{(0)} - x_i)^2 + (y^{(0)} - y_i)^2}} = \frac{550 \times 10(0-3)}{\sqrt{(0-3)^2 + (0-5)^2}} +$$
$$\frac{320 \times 12(0-7)}{\sqrt{(0-7)^2 + (0-1)^2}} + \frac{210 \times 11(0-2)}{\sqrt{(0-2)^2 + (0-9)^2}} +$$
$$\frac{450 \times 13(0-12)}{\sqrt{(0-12)^2 + (0-7)^2}} + \frac{130 \times 15(0-10)}{\sqrt{(0-10)^2 + (0-8)^2}} =$$
$$\frac{-16500}{\sqrt{34}} - \frac{26880}{\sqrt{50}} - \frac{4620}{\sqrt{85}} - \frac{70200}{\sqrt{193}} - \frac{19500}{\sqrt{164}} =$$
$$-2829.7 - 3801.4 - 501.1 - 5053.1 - 1522.7 = -13708.0$$

$$A_1 = \sum_{i=1}^{n} \frac{M_i C_i}{\sqrt{(x^{(0)} - x_i)^2 + (y^{(0)} - y_i)^2}} = \frac{550 \times 10}{\sqrt{(0-3)^2 + (0-5)^2}} +$$
$$\frac{320 \times 12}{\sqrt{(0-7)^2 + (0-1)^2}} + \frac{210 \times 11}{\sqrt{(0-2)^2 + (0-9)^2}} +$$
$$\frac{450 \times 13}{\sqrt{(0-12)^2 + (0-7)^2}} + \frac{130 \times 15}{\sqrt{(0-10)^2 + (0-8)^2}} =$$
$$\frac{5500}{\sqrt{34}} + \frac{3840}{\sqrt{50}} + \frac{2310}{\sqrt{85}} + \frac{5850}{\sqrt{193}} + \frac{1950}{\sqrt{164}} =$$
$$943.2 + 543.1 + 250.6 + 421.1 + 152.3 = 2310.3$$

$$\Delta X_1 = \frac{H_1}{A_1} = \frac{-13708}{2310.3} = -5.933 \Rightarrow$$
$$x^{(1)} = x^{(0)} - \Delta X_1 = 0 - (-5.933) = 5.933$$

Similarly, the value of coordinate $y^{(1)}$ is calculated using formulae *R1* and *B1*, **but instead of $x^{(0)}$ the value of the coordinates $x^{(1)}$ is now substituted for in the calculation**.

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$$R_1 = \sum_{i=1}^{n} \frac{M_i C_i \left(y^{(0)} - y_i\right)}{\sqrt{(x^{(1)} - x_i)^2 + (y^{(0)} - y_i)^2}} = \frac{550 \times 10(0-5)}{\sqrt{(5.933-3)^2 + (0-5)^2}} +$$
$$\frac{320 \times 12(0-1)}{\sqrt{(5.933-7)^2 + (0-1)^2}} + \frac{210 \times 11(0-9)}{\sqrt{(5.933-2)^2 + (0-9)^2}} +$$
$$\frac{450 \times 13(0-7)}{\sqrt{(5.933-12)^2 + (0-7)^2}} + \frac{130 \times 15(0-8)}{\sqrt{(5.933-10)^2 + (0-8)^2}} =$$
$$\frac{-27500}{\sqrt{33.6}} - \frac{3840}{\sqrt{2.1}} - \frac{20790}{\sqrt{96.5}} - \frac{40950}{\sqrt{85.8}} - \frac{15600}{\sqrt{80.5}} =$$
$$-4744.2 - 2649.9 - 2116.4 - 4420.9 - 1738.7 = -15670.1$$

$$B_1 = \sum_{i=1}^{n} \frac{M_i C_i}{\sqrt{(x^{(1)} - x_i)^2 + (y^{(0)} - y_i)^2}} = \frac{550.10}{\sqrt{(5.933-3)^2 + (0-5)^2}} +$$
$$\frac{320.12}{\sqrt{(5.933-7)^2 + (0-1)^2}} + \frac{210.11}{\sqrt{(5.933-2)^2 + (0-9)^2}} +$$
$$\frac{450.13}{\sqrt{(5.933-12)^2 + (0-7)^2}} + \frac{130.15}{\sqrt{(5.933-10)^2 + (0-8)^2}} =$$
$$\frac{5500}{\sqrt{33.6}} + \frac{3840}{\sqrt{2.1}} + \frac{2310}{\sqrt{96.5}} + \frac{5850}{\sqrt{85.8}} + \frac{1950}{\sqrt{80.5}} =$$
$$948.8 + 2649.9 + 235.2 + 631.6 + 217.3 = 4682.8$$

$$\Delta Y_1 = \frac{R_1}{B_1} = \frac{-15670.1}{4682.8} = -3.346 \Rightarrow$$
$$y^{(1)} = y^{(0)} - \Delta Y_1 = 0 - (-3.346) = 3.346$$

The first calculated coordinates are $x^{(1)}$, $y^{(1)}$=[5.933; 3.346]. Now, a decision follows as to whether the calculated coordinates are of the required accuracy. The accuracy of the *x* and *y* axis is:

$$\left|x^{(p+1)} - x^{(p)}\right| \le \varepsilon \cap \left|y^{(p+1)} - y^{(p)}\right| \le \varepsilon \Rightarrow$$

$$\left|5.933 - 0\right| \le 0.1 \cap \left|3.346 - 0\right| \le 0.1 \Rightarrow 5.933 \le 0.1 \cap 3.346 \le 0.1 \Rightarrow$$

the condition of the accuracy requirement for finishing the calculation **IS NOT** fulfilled so the calculation continues to the next iteration.

Thereafter the calculation of the coordinate $x^{(2)}$ follows and for that one the already calculated values $x^{(1)}$, $y^{(1)}$ are used. This continues, until the required accuracy of calculation is reached and the final values of *x, y* are

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the coordinates sought for the distribution centre. Other calculated values of coordinates are:

$$x^{(2)},y^{(2)} = [8.317;\ 4.511];$$
$$|6.317-5.933| \le 0.1 \cap |4.511-3.346| \le 0.1 \Rightarrow$$
$$0.384 \le 0.1 \cap 1.165 \le 0.1 \Rightarrow NO,$$

$$x^{(3)},y^{(3)} = [8.422;\ 5.054];$$
$$|6.422-6.317| \le 0.1 \cap |5.054-4.511| \le 0.1 \Rightarrow$$
$$0.105 \le 0.1 \cap 0.543 \le 0.1 \Rightarrow NO,$$

$$x^{(4)},y^{(4)} = [8.502;\ 5.247];$$
$$|6.502-6.422| \le 0.1 \cap |5.247-5.054| \le 0.1 \Rightarrow$$
$$0.08 \le 0.1 \cap 0.193 \le 0.1 \Rightarrow NO,$$

$$x^{(5)},y^{(5)} = [8.570;\ 5.313];$$
$$|6.570-6.502| \le 0.1 \cap |5.313-5.247| \le 0.1 \Rightarrow$$
$$0.068 \le 0.1 \cap 0.066 \le 0.1 \Rightarrow YES.$$

The calculated coordinates $x^{(5)},y^{(5)} = [8.570;\ 5.313]$ (Figure 80) are the place sought for the distribution centre and the condition of calculation accuracy is fulfilled.

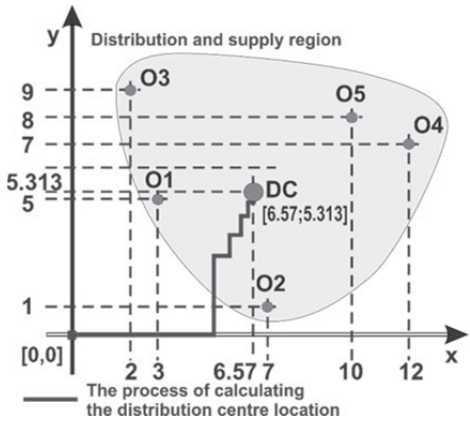


Figure 80 – Graphical representation of the solution of the location of a distribution centre

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8.2.4 Location using the Direct Coordinated Distance

The real distances between particular places in a region are replaced by direct corrected links in this approach. The procedure is similar as when using direct distance but, since road transport is considered (at least, not air transport), then it is necessary to use the corrective value *k* in solutions so the direct coordinated distance (8.41) can be calculated as:

$$d_i = k.d_i' = k\sqrt{(x - x_i)^2 + (y - y_i)^2}. \tag{8.41}$$

The corrective value *k* is the expression for the real shape of trajectories between places that are not connected by straight lines (Figure 81) (Straka 2007). Usually, it takes the value 1.2 which extends by 20% the direct distance between places.

This distance is substituted into the objective function of transport costs (8.42).

$$\min z = TC = \sum_{i=1}^{n} M_i C_i k\sqrt{(x - x_i)^2 + (y - y_i)^2} = k\sum_{i=1}^{n} M_i C_i \sqrt{(x - x_i)^2 + (y - y_i)^2} \tag{8.42}$$

Another procedure for calculating the location of a distribution centre is analogous to the procedure using the direct distance.

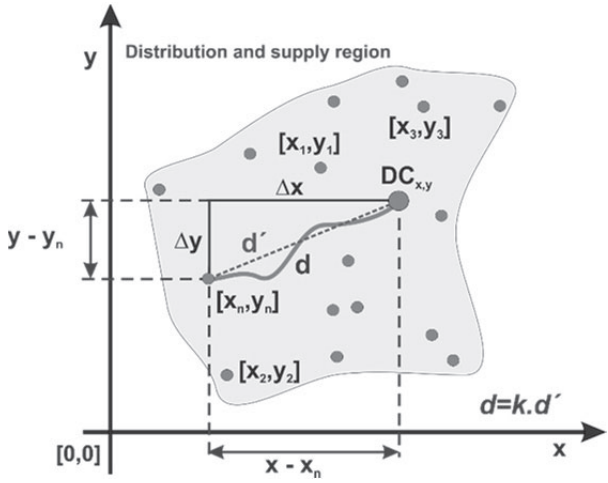


Figure 81 – Direct coordinated distance between places in a distribution region

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Because it is necessary to obtain the optimal coordinates of the location of a distribution centre *DC[x,y] = ?*, it must hold that the derivation of the objective function *TC* by *x* is equal to 0, as well as the derivation of the objective function *TC* by *y* is equal to 0 (8.43):

$$\frac{\partial TC}{\partial x} = 0 \cap \frac{\partial TC}{\partial y} = 0. \tag{8.43}$$

H_1 – the value of the partial derivative (8.44), which gives us a value for how far, in the *x*-axis direction, is $x^{(opt)} = x^{(DC)}$.

$$\begin{gathered} \frac{\partial TC}{\partial x} = \\ k\sum_{i=1}^{n} M_i C_i \frac{1}{2}[(x-x_i)^2 + (y-y_i)^2]^{-\frac{1}{2}}(2x - 2x_i) = \\ k\sum_{i=1}^{n} \frac{2M_i C_i (x-x_i)}{2\sqrt{(x-x_i)^2+(y-y_i)^2}} = \\ k\sum_{i=1}^{n} \frac{M_i C_i (x-x_i)}{\sqrt{(x-x_i)^2+(y-y_i)^2}} = H_1 \end{gathered} \tag{8.44}$$

Calculating the coordinate $x^{(1)}$ of the distribution centre.

If we denote:

$$\begin{gathered} A_1 = k\sum_{i=1}^{n} \frac{M_i C_i}{\sqrt{(x-x_i)^2+(y-y_i)^2}} \Rightarrow \\ H_1 = A_1 \sum_{i=1}^{n}(x - x_i) \Rightarrow \sum_{i=1}^{n}(x - x_i) = \frac{H_1}{A_1}. \end{gathered} \tag{8.45}$$

$\sum_{i=1}^{n}(x - x_i)$ denotes the sum of distances (+,–) from the distribution centre, that is why we denote it as ΔX_1 (8.45, 8.45.1), then

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$$\Delta X_1 = \frac{H_1}{A_1} = \frac{k\sum_{i=1}^{n} \frac{M_i C_i (x-x_i)}{\sqrt{(x-x_i)^2+(y-y_i)^2}}}{k\sum_{i=1}^{n} \frac{M_i C_i}{\sqrt{(x-x_i)^2+(y-y_i)^2}}} = \frac{\sum_{i=1}^{n} \frac{M_i C_i (x-x_i)}{\sqrt{(x-x_i)^2+(y-y_i)^2}}}{\sum_{i=1}^{n} \frac{M_i C_i}{\sqrt{(x-x_i)^2+(y-y_i)^2}}}. \quad (8.45.1)$$

The new value for (the coordinate) $x^{(1)}$ (8.46) of the distribution centre is calculated as the difference between the old value $x^{(0)}$ and the distance ΔX_1 from a distribution centre,

$$x^{(1)} = x^{(0)} - \Delta X_1, \text{ in general, } x^{(p+1)} = x^{(p)} - \Delta X_{p+1}, \quad (8.46)$$

p – order of iterations, index of the optimum sought; it takes values 0,1,2,3,….

Similarly, the calculation of the coordinate y proceeds.

$$\frac{\partial TC}{\partial y} = k\sum_{i=1}^{n} M_i C_i \frac{1}{2}[(x-x_i)^2+(y-y_i)^2]^{-\frac{1}{2}}(2y-2y_i) = k\sum_{i=1}^{n} \frac{2M_i C_i (y-y_i)}{2\sqrt{(x-x_i)^2+(y-y_i)^2}} = k\sum_{i=1}^{n} \frac{M_i C_i (y-y_i)}{\sqrt{(x-x_i)^2+(y-y_i)^2}} = R_1 \quad (8.47)$$

R_1 – the value of the partial derivative (8.47), which gives us a value for how far, in the y-axis direction, is $y^{(opt)} = y^{(DC)}$.

Calculating the coordinate $y^{(1)}$ of the distribution centre.

If we denote:

$$B_1 = k\sum_{i=1}^{n} \frac{M_i C_i}{\sqrt{(x-x_i)^2+(y-y_i)^2}} \Rightarrow$$
$$R_1 = B_1 \sum_{i=1}^{n}(y-y_i) \Rightarrow \sum_{i=1}^{n}(y-y_i) = \frac{R_1}{B_1}. \quad (8.48)$$

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$\sum_{i=1}^{n}(y-y_i)$ denotes the sum of distances (+,–) from the distribution centre, that is why we denote it as ΔY_1 (8.48, 8.48.1), then

$$\Delta Y_1 = \frac{R_1}{B_1} = \frac{k\sum_{i=1}^{n}\frac{M_i C_i (y-y_i)}{\sqrt{(x-x_i)^2+(y-y_i)^2}}}{k\sum_{i=1}^{n}\frac{M_i C_i}{\sqrt{(x-x_i)^2+(y-y_i)^2}}} = \frac{\sum_{i=1}^{n}\frac{M_i C_i (y-y_i)}{\sqrt{(x-x_i)^2+(y-y_i)^2}}}{\sum_{i=1}^{n}\frac{M_i C_i}{\sqrt{(x-x_i)^2+(y-y_i)^2}}}. \quad (8.48.1)$$

The new value for (the coordinate) $y^{(1)}$ (8.49) of the distribution centre is calculated as the difference between old value $y^{(0)}$ and the distance ΔY_1 from the distribution centre,

$$y^{(1)} = y^{(0)} - \Delta Y_1, \text{ in general, } y^{(p+1)} = y^{(p)} - \Delta Y_{p+1}. \quad (8.49)$$

d_i has different values for the calculation of $y^{(1)}$, because it uses the last calculated value $x^{(1)}$, although the formula is the same as referred to in B_1.

The procedure for calculation shows that the correction value does not affect the optimal location of the distribution centre, but only the value of the objective function.

The iterative calculation procedure is analogous to the procedure of direct distance.

The iterative approach successively calculates $x^{(1)}$, $y^{(1)}$, $x^{(2)}$, $y^{(2)}$, $x^{(3)}$, $y^{(3)}$, …, $x^{(opt)}$, $y^{(opt)}$. The iterative calculation ends when the chosen accuracy of calculation ε is achieved. The calculation ends when the accuracy is achieved (8.50, 8.51, 8.52, 8.53) by some of the possibilities (Straka 2007):

- according to the *x*-axis, $\left|x^{(p+1)} - x^{(p)}\right| \le \varepsilon$, (8.50)
- according to the *y*-axis, $\left|y^{(p+1)} - y^{(p)}\right| \le \varepsilon$, (8.51)
- according to the *x* and *y*-axis simultaneously, $\left|x^{(p+1)} - x^{(p)}\right| \le \varepsilon \cap \left|y^{(p+1)} - y^{(p)}\right| \le \varepsilon$, (8.52)

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- according to objective function change z,

$$\Delta z = \left| z^{(p+1)} - z^{(p)} \right| = \left| k\sum_{i=1}^{n} M_i C_i \sqrt{\left(x^{(p+1)} - x_i\right)^2 + \left(y^{(p+1)} - y_i\right)^2} - k\sum_{i=1}^{n} M_i C_i \sqrt{\left(x^{(p)} - x_i\right)^2 + \left(y^{(p)} - y_i\right)^2} \right| \leq \varepsilon, \tag{8.53}$$

- according to the change in the movement of the calculated coordinates, the calculation ends when the values of the calculated coordinates of two successive iterations do not change, e.g. the values of the calculated coordinates are identical.

p – order of iterations, index of optimum sought, it takes the values 0, 1, 2, 3, etc.

This deduction shows that the expression of the distance between the direct and coordinated distance does not affect the accuracy of determining the distribution centre location.

8.3 Expert Systems

The amount of data or information that a human is capable to process per time unit is negligible in comparison with a computer. Because of this, humans attempt to use intuitive tendencies to skip irrelevant, unimportant possibilities for solutions on the basis of experience gained. This approach is referred to as heuristic or empirical when a human is able to find important solutions and procedures in a very short time. A human who is able to find requested solutions fast and properly on the basis of his specific knowledge and experience is known as an expert in a certain field. Systems that are built on principles similar to human (expert) solving approaches are known as expert systems.

The aim of programmers is to make programs available to users that use procedures and solutions analogous to the procedures and solutions of experts in a certain field. **The expert system** (ES) is the name for a program, an algorithm, which is capable of providing solutions at the expert level.

These expert systems must be capable of actions which are performed by a human (expert) to achieve the desired target e.g. monitoring,

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information processing, analysis, failure identification, synthesis, proposal of solutions, planning, projecting, construction, testing, diagnostics and others. Expert systems are able to perform computer analysis and make decisions on a subject and are able to provide quality information to help with a decision, or to determine directly the procedure for reaching a solution based on their knowledge and the data at their disposal.

Expert systems, work by imitating human (expert) activities and therefore they have to consist of parts that are similar to human activities as well as their knowledge and communication with the environment. In general, the elements constituting expert systems can be divided into the following parts (Figure 82) (Straka 2005):

- the knowledge base,
- the database,
- the interference, combination mechanism,
- the advisory, support system,
- the communication interface, system for human-computer communication.

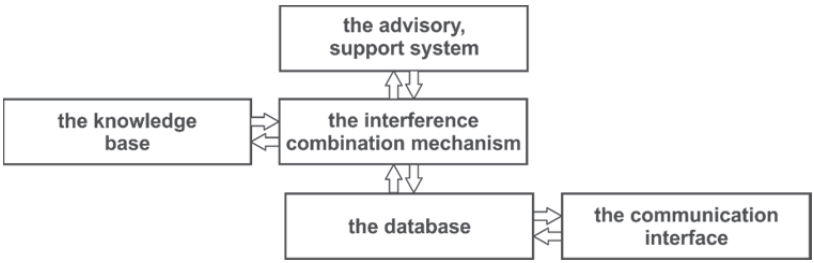


Figure 82 – The schema / structure of the expert system[5]

The knowledge base is the part of the expert system which is prepared or provided by experts on a certain issue in cooperation with software specialists.

The advisory, support system or subsystem is the part of the expert system, which provides support for users.

The database is the part of the expert system that is filled by users of the system and it awaits input requirements from a user, with which the interference mechanism queries the knowledge base in order to obtain the desired result. Based on the data entered via a communication interface

[5] Straka, M., Malindzak, D. a kol.: Distribution logistics, Expres Publicit Kosice, Kosice, 2005 (Original in Slovak)

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(via the computer keyboard), the database can be filled and communication with the system is enabled.

Expert systems can be divided into (Straka 2007):

- problem-oriented ES,
- problem-independent ES,
- closed ES,
- open ES,
- diagnostic ES,
- planning ES.

Problem-based expert systems are systems that are specifically aimed at solving problems in a specified area, their knowledge base is predetermined.

Problem-independent expert systems are systems, the purpose of which is determined after the addition of the knowledge base, which is not predetermined.

Closed expert systems are prepared software applications without any further possibility for development.

Open expert systems allow users to create or change them into a form as required for problem solution or based on user requirements.

Diagnostic expert systems are based on a pre-determined knowledge base model that solves specified problems.

Planning expert systems are based on a defined initial state and the desired target of a solution and they determine the sequence of steps to reach the target.

Expert systems commonly enable skilled users to work with and evaluate problems at the level of experts. Expert systems accelerate and improve users' work at different levels of a company. They are not influenced by emotions and intuitions. They work in dangerous environments and they can work continuously and automatically. Globally, it is possible to say that expert systems are very good helpers in solving a wide range of problems and accelerate the decision-making of people in management activities.

8.3.1 Expert Systems for Solving Distribution Tasks

An expert distribution system is a software solution for distribution tasks (problems) with the design and selection of optimal or appropriate and effective solutions. An expert distribution system incorporates all of the algorithmic parts (Figure 82) or their modification.

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Nowadays there are many expert distribution systems on the market, for example: Sygic (Figure 83), Nvigon (Figure 84), Tom Tom (Figure 8), iGO (Figure 86) and web applications like: www.viamichelin.com (Figure 87) and others that operate on the basis of known digital maps of regions, or systems that can solve specific distribution and transport tasks such as the programs Alokacia, Doprava 3K and others.

The user of such a system uses the digital maps in these systems to define the distribution places that need to be served by the distribution route. The system proposes an exact distribution route based on the setup properties. Another advantage of such systems is the use of the global positioning system to monitor means of transport.

The overall commercial use of such systems is for planning and proposing an optimal route between two known points on a digital map. With these systems it is possible to plan distribution routes in advance for vehicles without the need for any additional control systems such as global positioning systems. To verify the operation and use of vehicles, it is sufficient to check the odometer reading in the vehicle and to compare it with the plan of the distribution route.

Such use of "expert systems" is simple, not very expensive and very efficient.



Figure 83 – Sygic Car Navigation works with the car's built-in infotainment system[6]

[6] http://www.sygic.com/content/2–car-navigation/1–car-connectivity/01b_device.svg

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The disadvantage of these commonly available systems is that they cannot work with any big or small region, for example planning internal distribution within plants or larger warehouses. Another disadvantage of these systems is that they do not enable the creation of groups of distribution places or the choice of a distribution centre or distribution warehouses within a known region based on known distribution and location methods. From the point of view of distribution, there are some shortcomings.



Figure 84 – The new NAVIGON app combines precise navigation with individual usage life[7]



Figure 85 – TomTom's Navigation Engine, implements complex navigation algorithms and the logic required for a full turn-by-turn navigation application[8]

[7] https://www.navigon.com/wp-content/themes/navigon_2016/img/mobileapp_ios_en.png

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Figure 86 – iGO Navigation app is optimised for in-car or pedestrian use[9]

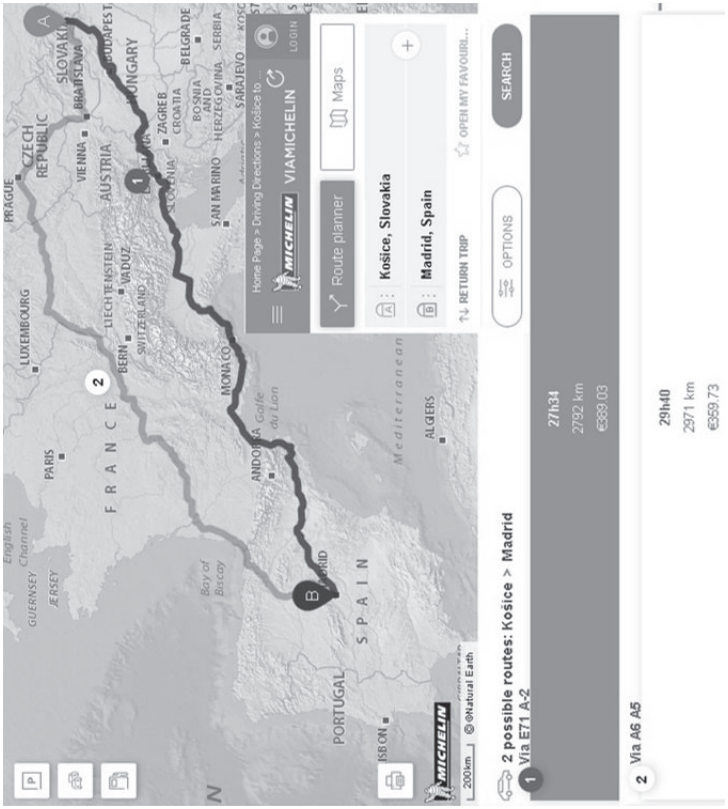


Figure 87 – Example of use of the www.viamichelin.com system to plan a route from Kosice to Madrid[10]

[8] https://webassets2.tomtom.com/94675.png
[9] https://www.igonavigation.com/
[10] https://www.viamichelin.com/

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CHAPTER NINE

MODELLING TRANSPORT TASKS

What you will learn: Since economics has had, has now and will continue to have a major impact on solving and implementing the distribution of products, goods and materials, it is necessary to establish delivery plans so that the overall solution is at the lowest cost. There are a variety of methods to solve transport planning tasks that provide acceptable basic solutions and methods that provide optimal solutions. These methods are justified even when they do not consider all the parameters that need to be considered in real distribution. This chapter addresses the solution of tasks relating to creating distribution plans.

Basic terms: modelling, transport tasks, methods, relations.

This is mainly about increasing the effectiveness of processes associated with the transport of raw materials, products and semi-products between producers, suppliers, customers and consumers when solving transport tasks. Optimizing the selection of suppliers and the quantities of raw materials delivered using transport has a significant effect on total production costs. That is why it is important to increase the effectiveness of manufacturing processes and to minimize transport costs when working on such transport tasks.

Properly defining relations between individual distribution places is the basis for the successful solution of distribution tasks and the optimization of a distribution process.

In practice, the case very often occurs where a manager has to decide on the selection of contractors for various business entities, to decide on production for individual machines and equipment or to plan the distribution of goods while minimizing the distribution path and maximizing the places served.

The incorrect choice of suppliers may not directly affect production but it certainly affects the cost of transporting materials. The effort in optimizing distribution and distribution activities is to minimize the total

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cost of transport and distribution of a company. Modelling and solving distribution problems can bring an optimal arrangement of distribution.

Among the main distribution tasks, in terms of problem solutions, it is possible to include:

- transport tasks,
- circular tasks.

9.1 Formulation of Transport Tasks, Type of Relation $m \times n$

Transport tasks are a specific type of distribution task where it is necessary to find and define the best way to transport goods between certain entities of distribution, i.e. to define suppliers and quantities of raw materials that will be distributed to individual consumers. Transport tasks solve **relations of *m x n* type, from many to many**. In general, transport tasks can be expressed using the following variables:

D_m – suppliers of raw materials,
a_m – capacity of suppliers,
m – the number of suppliers,
S_n – consumers of raw materials,
b_n – the capacity requirements of consumers,
n – the number of consumers,
x_{ij} – the amount of material transported from place i to place j,
c_{ij} – the costs of material distribution from place i to place j or distances, the time between places D_i and S_j.

Models of this type of tasks are for minimization, with the aim being to find an optimal transport plan (Figure 88), to pick-up from suppliers and deliver quantities of raw materials in such a way that the total transportation costs are minimized and consumer demands are fulfilled to the maximum extent (Straka 2012).

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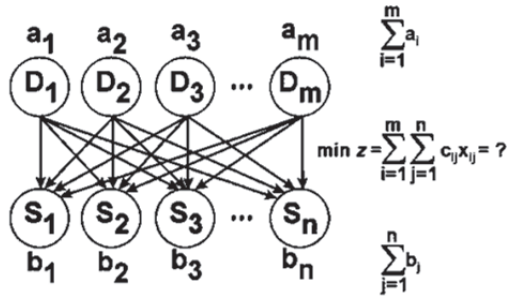


Figure 88 – Schematic representation of possible links between suppliers and their buyers

The initial state of the system can be interpreted using the table (Table 65), which relates the relation between capacities of suppliers and capacity requirements of consumers.

Table 65 – The transport table and its values

Suppliers	Consumers					Capacity of suppliers
	S_1	S_2	S_3	…	S_n	
D_1	c_{11} x_{11}	c_{12} x_{12}	c_{13} x_{13}	…	c_{1n} x_{1n}	a_1
D_2	c_{21} x_{21}	c_{22} x_{22}	c_{23} x_{23}	…	c_{2n} x_{2n}	a_2
D_3	c_{31} x_{31}	c_{32} x_{32}	c_{33} x_{33}	…	c_{3n} x_{3n}	a_3
⋮	⋮	⋮	⋮		⋮	⋮
D_m	c_{m1} x_{m1}	c_{m2} x_{m2}	c_{m3} x_{m3}	…	c_{mn} x_{mn}	a_m
Consumer requirements	b_1	b_2	b_3	…	b_n	$\sum_{i=1}^{m} a_i ? \sum_{j=1}^{n} b_j$

Traditional transport tasks can be formulated using the following general task.

Here are available $i=1, 2,\ldots, m$ suppliers D_i and their supply capacity possibilities a_i. Consumers S_j are known $j=1, 2,\ldots, n$ and their capacity

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requirements b_j, and transport costs c_{ij} between suppliers and consumers are also known.

The solution to the problem is to decide which suppliers will supply customers and what quantities x_{ij} of goods the suppliers will supply to particular consumers so as to minimize transport costs and to maximize the satisfaction of consumers' requirements. An unknown variable x_{ij} represents the quantity of goods that will be distributed by supplier i to consumer j. The objective function (9.1) can be expressed by the relationship:

$$\min \; z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}. \tag{9.1}$$

If the number of suppliers is m and the number of consumers is n, then the following holds for quantities of raw materials:

$$\sum_{i=1}^{m} x_{ij} = b_j \; j=1, 2, \ldots, n. \tag{9.2}$$

The sum of column (9.2) expresses the sum of all supplies from various suppliers, to cover the demand of a consumer.

The sum of the row (9.3) expresses the sum of all supplies from one supplier to particular consumers, within the capacity of the supplier:

$$\sum_{j=1}^{n} x_{ij} = a_i \; i=1, 2, \ldots, m. \tag{9.3}$$

If the case occurs where the quantity of supplied raw materials is equal to the quantity of required raw materials then it is a balanced transport task (9.4).

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j \tag{9.4}$$

In practice, there is more often a state where the supply available from suppliers exceeds the requirements of consumers (9.5),

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$$\sum_{i=1}^{m} a_i > \sum_{j=1}^{n} b_j \tag{9.5}$$

or where consumer demand exceeds the capacities of suppliers (9.6).

$$\sum_{j=1}^{n} b_j > \sum_{i=1}^{m} a_i \tag{9.6}$$

If either of these cases occur, then it is an unbalanced transport task. Any unbalanced model can be transformed into a balanced state. If the requirements are greater than the capacities, the transport model may be balanced by the introduction of a fictitious supplier (Table 66) to model D_{m+1} i.e. adding a new row with zero transport costs c_{m+1j}= 0 for $j = 1, 2, \ldots, n$.

Table 66 – Expanding the transport table with a fictitious supplier

Suppliers	Consumers					Capacity of suppliers
	S_1	S_2	S_3	…	S_n	
D_1	c_{11} x_{11}	c_{12} x_{12}	c_{13} x_{13}	…	c_{1n} x_{1n}	a_1
D_2	c_{21} x_{21}	c_{22} x_{22}	c_{23} x_{23}	…	c_{2n} x_{2n}	a_2
D_3	c_{31} x_{31}	c_{32} x_{32}	c_{33} x_{33}	…	c_{3n} x_{3n}	a_3
⋮	⋮	⋮	⋮		⋮	⋮
D_m	c_{m1} x_{m1}	c_{m2} x_{m2}	c_{m3} x_{m3}	…	c_{mn} x_{mn}	a_m
D_{m+1}	0 x_{m+11}	0 x_{m+12}	0 x_{m+13}	…	0 x_{m+1n}	a_{m+1}
Consumer requirements	b_1	b_2	b_3	…	b_n	$\sum_{i=1}^{m} a_i ? \sum_{j=1}^{n} b_j$

If the capacities are greater than the requirements, the transport model may be balanced by the introduction of a fictitious consumer (Table 67) in

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the model S_{n+1}, i.e. adding a new column with zero transport costs $c_{in+1} = 0$ for $i=1, 2, \ldots, m$.

Table 67 – Expanding the transport table to include a fictitious consumer

Suppliers	Consumers						Capacity of suppliers
	S_1	S_2	S_3	…	S_n	S_{n+1}	
D_1	c_{11} x_{11}	c_{12} x_{12}	c_{13} x_{13}	…	c_{1n} x_{1n}	0 x_{1n+1}	a_1
D_2	c_{21} x_{21}	c_{22} x_{22}	c_{23} x_{23}	…	c_{2n} x_{2n}	0 x_{2n+1}	a_2
D_3	c_{31} x_{31}	c_{32} x_{32}	c_{33} x_{33}	…	c_{3n} x_{3n}	0 x_{3n+1}	a_3
⋮	⋮	⋮	⋮		⋮	⋮	⋮
D_m	c_{m1} x_{m1}	c_{m2} x_{m2}	c_{m3} x_{m3}	…	c_{mn} x_{mn}	0 x_{mn+1}	a_m
Consumer requirements	b_1	b_2	b_3	…	b_n	b_{n+1}	$\sum_{i=1}^{m} a_i ? \sum_{j=1}^{n} b_j$

The requirements for non-negativity of variables (9.7) with solutions of transport tasks i.e.:

$$x_{ij} \geq 0 i=1, 2, \ldots, m; j=1, 2, \ldots, n. \quad (9.7)$$

The transport model can be defined based on the above equations and inequalities (9.8) (Florekova 1999):

For the set of solutions of systems of equations and inequalities $\sum_{i=1}^{m} x_{ij} = b_j$, $\sum_{j=1}^{n} x_{ij} = a_i$, $x_{ij} \geq 0$; $i=1, 2, \ldots, m$; $j=1, 2, \ldots, n$, (9.8) it is needed to find the minimum of the linear form $\min z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}$; if $\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j$ meaning to find such numbers x_{ij} for which the objective function is minimized.

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The model of transport task has $m \times n$ variables with $m + n$ constraints. The non-degenerated basic solution of the task has $m + n - 1$ non-zero values. If the number of occupied fields is less than $m + n - 1$ then the task has a degenerated solution. Degeneration of the task can be removed by introducing zero values in the fields in such a way as not to create a closed circuit.

The defined transport model can be written down as follows (9.9):

$$\begin{aligned}
&\min z = c_{11}x_{11} + c_{12}x_{12} + \mathrm{K} + c_{1n}x_{1n} + c_{21}x_{21} + c_{22}x_{22} + \mathrm{K} \\
&+ c_{2n}x_{2n} + c_{m1}x_{m1} + c_{m2}x_{m2} + \mathrm{K} + c_{mn}x_{mn} \\
&x_{11} + x_{12} + \mathrm{K} + x_{1n} = a_1 \\
&x_{21} + x_{22} + \mathrm{K} + x_{2n} = a_2 \\
&\qquad\qquad \vdots \\
&x_{m1} + x_{m2} + \mathrm{K} + x_{mn} = a_m \\
&x_{11} + x_{21} + \mathrm{K} + x_{m1} = b_1 \\
&x_{12} + x_{22} + \mathrm{K} + x_{m2} = b_2 \\
&\qquad\qquad \vdots \\
&x_{1n} + x_{2n} + \mathrm{K} + x_{mn} = b_n \\
&x_{ij} \geq 0 \quad \text{where} \quad i=1, 2, \ldots, m; \quad j=1, 2, \ldots, n.
\end{aligned} \tag{9.9}$$

9.2 Methods suitable for Solving Transport Tasks, Type of Relation $m \times n$

Methods designed specifically for this type of linear programming problems are used to solve transport tasks. The Simplex method, however, is universal and suitable for all types of linear optimization models but it is not used because of the large simplex tables and difficult processing. The selection and use of methods can be divided into two categories:

- permissive methods of the default basic solution,
  - the North West Corner method (NWC),
  - the Index method,
  - Vogel's approximation method – the VAM method,
- methods leading to the optimal solution,
  - the Hungarian method,
  - Dantzig's general method,
  - the modified method – MODI.

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9.2.1 The North West Corner Method

The North West Corner method (NW Corner) enables a default basic solution of the transport task to be obtained very quickly and easily. The transport table is completed starting with the upper left corner at the x_{11} position. The rule of for filling the table is from left to right and top to bottom. First, the capacities of suppliers in the row are used up and then the consumers' demands are filled in the column (Florekova 1999). When filling in the transport table with the position of x_{11}, three cases can arise:

1) $a_1 > b_1$, 2) $a_1 < b_1$, 3) $a_1 = b_1$.

In the first case, when the capacity of a supplier exceeds the requirements of a consumer, the requirements of the first consumer $x_{11} = b_1$ are satisfied and all other values in the column will take the value 0, i.e. $x_{i1} = 0$ for $i=2, \ldots, m$. Then we move to the next position in row x_{12} until the capacity of the first supplier is used up (Table 68). When the capacity of the first supplier is used up then we move to the row below, in the column where the requirements of a consumer were not fully satisfied.

Table 68 – Procedure for filling the table using the NW Corner method when $a_1>b_1$

Suppliers	Consumers					Capacity of suppliers
	S_1	S_2	S_3	…	S_n	
D_1	c_{11} $x_{11}=b_1$	c_{12} x_{12}	c_{13} x_{13}	…	c_{1n} x_{1n}	a_1
D_2	c_{21} 0	c_{22} x_{22}	c_{23} x_{23}	…	c_{2n} x_{2n}	a_2
D_3	c_{31} 0	c_{32} x_{32}	c_{33} x_{33}	…	c_{3n} x_{3n}	a_3
⋮	⋮	⋮	⋮		⋮	⋮
D_m	c_{m1} 0	c_{m2} x_{m2}	c_{m3} x_{m3}	…	c_{mn} x_{mn}	a_m
Consumer requirements	b_1	b_2	b_3	…	b_n	$a_1>b_1$

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In the second case, when consumer demand exceeds the capacity of a supplier, the first supplier's capacity is used up x_{11} = a1 and all other values in the row will take the value 0, i.e. $x_{1j} = 0$ pre j = 2, ..., n. Then we move to the row below x_{21}, and a similar procedure runs until the requirement of the first consumer is satisfied (Table 69). After filling in the requirements, the procedure continues by moving to the side column in a row, where the capacity of a supplier has not been fully used up.

Table 69 – Procedure for filling the table using the NW Corner method when $b_1 > a_1$

Suppliers	Consumers					Capacity of suppliers
	S_1	S_2	S_3	…	S_n	
D_1	c_{11} $x_{11}=a_1$	c_{12} 0	c_{13} 0	…	c_{1n} 0	a_1
D_2	c_{21} x_{21}	c_{22} x_{22}	c_{23} x_{23}	…	c_{2n} x_{2n}	a_2
D_3	c_{31} x_{31}	c_{32} x_{32}	c_{33} x_{33}	…	c_{3n} x_{3n}	a_3
⋮	⋮	⋮	⋮		⋮	⋮
D_m	c_{m1} x_{m1}	c_{m2} x_{m2}	c_{m3} x_{m3}	…	c_{mn} x_{mn}	a_m
Consumer requirements	b_1	b_2	b_3	…	b_n	$a_1 < b_1$

In the third case, where consumer demands are equal to the capacity of a supplier, $x_{11} = a_1 = b_1$, all other values in the row and column take the value 0, i.e. $x_{1j} = 0$ for $j=2, 3, \ldots, n$ and $x_{i2} = 0$ for $i=2, \ldots, m$ (Table 70). The next movement is to position x_{22} because there is no longer available capacity of the supplier in the first row and there are no longer any additional requirements of the consumer in the first column.

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Table 70 – Procedure for filling the table using the NW Corner method when $a_1=b_1$

Suppliers	Consumers					Capacity of suppliers
	S_1	S_2	S_3	…	S_n	
D_1	c_{11} $x_{11}=a_1=b_1$	c_{12} 0	c_{13} 0	…	c_{1n} 0	a_1
D_2	c_{21} 0	c_{22} x_{22}	c_{23} x_{23}	…	c_{2n} x_{2n}	a_2
D_3	c_{31} 0	c_{32} x_{32}	c_{33} x_{33}	…	c_{3n} x_{3n}	a_3
⋮	⋮	⋮	⋮		⋮	⋮
D_m	c_{m1} 0	c_{m2} x_{m2}	c_{m3} x_{m3}	…	c_{mn} x_{mn}	a_m
Consumer requirements	b_1	b_2	b_3	…	b_n	$a_1=b_1$

The NW Corner method is fast and simple, but it ignores the minimum value of the objective function (it does not reflect transport costs) but only the constraints of the distribution task. The resulting solution may not be optimal but it is an acceptable solution. Therefore, there is a need for further adjustments to the table using one of the methods for finding optimal solutions to the transport task.



Task: Prepare a bread distribution plan from bakeries to individual sellers. The goods are placed in four bakeries: P_1 has 50 loaves, P_2 has 50 loaves, P_3 has 60 loaves and P_4 has 70 loaves of bread available. The loaves of bread have to be transported to four customers, whereby the first customer O_1 requests 25 loaves, the second customer O_2 requests 35 loaves, the third customer O_3 requests 55 loaves, and the fourth customer O_4 requests 65 loaves of bread. Shipping rates are given in Table 71, rates are per unit of goods.

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Table 71 – Shipping rates per unit of goods

c_{ij}	O_1	O_2	O_3	O_4
P_1	24	25	28	27
P_2	22	28	29	32
P_3	34	32	31	33
P_4	28	27	25	32

Table 72 – Transport table with input parameters, unbalanced

Suppliers	Consumers				Capacity of suppliers
	O_1	O_2	O_3	O_4	
P_1	24 x_{11}	25 x_{12}	28 x_{13}	27 x_{14}	50
P_2	22 x_{21}	28 x_{22}	29 x_{23}	32 x_{24}	50
P_3	34 x_{31}	32 x_{32}	31 x_{33}	33 x_{34}	60
P_4	28 x_{41}	27 x_{42}	25 x_{43}	32 x_{44}	70
Consumer requirements	25	35	55	65	230 < 180

Table 73 – Transport table with input parameters, balanced

Suppliers	Consumers					Capacity of suppliers
	O_1	O_2	O_3	O_4	O_5	
P_1	24 x_{11}	25 x_{12}	28 x_{13}	27 x_{14}	0 x_{15}	50
P_2	22 x_{21}	28 x_{22}	29 x_{23}	32 x_{24}	0 x_{25}	50
P_3	34 x_{31}	32 x_{32}	31 x_{33}	33 x_{34}	0 x_{35}	60
P_4	28 x_{41}	27 x_{42}	25 x_{43}	32 x_{44}	0 x_{45}	70
Consumer requirements	25	35	55	65	50	230 = 230

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The Objective Function

The value of the objective function represents the total costs of transport. There have to be found x_{ij} values such that the value of the objective function is minimal.

$$\min\ z = \sum_{i=1}^{4}\sum_{j=1}^{4} c_{ij}x_{ij} =$$

$$24\times x_{11} + 25\times x_{12} + 28\times x_{13} + 27\times x_{14} +$$
$$22\times x_{21} + 28\times x_{22} + 29\times x_{23} + 32\times x_{24} +$$
$$34\times x_{31} + 32\times x_{32} + 31\times x_{33} + 33\times x_{34} +$$
$$28\times x_{41} + 27\times x_{42} + 25\times x_{43} + 32\times x_{44}$$

Binding Conditions

The total amount of goods to be delivered to customers is smaller than that available in distribution warehouses (Table 72). Consequently, the transport task is unbalanced. As the capacities of the suppliers are greater than the requirements of customers, it is necessary to include the fictitious O_5 customer into the transport table that will request 50 loaves. This aligns the capacities with the requirements and the task becomes balanced (Table 73).

If a fictitious customer was not included in the transport table, then acute inequalities would be used in the constraints, i.e. the sum of the number of customer requirments in the rows would be smaller or at least equal to the capacity of the suppliers:

$$\sum_{j=1}^{n} x_{ij} \le a_i \qquad \text{for } i=1, 2, 3, 4.$$

The following constraints result from the transport table:

$x_{11} + x_{12} + x_{13} + x_{14} + x_{15} = 50$ capacity of bakery P_1,
$x_{21} + x_{22} + x_{23} + x_{24} + x_{25} = 50$ capacity of bakery P_2,
$x_{31} + x_{32} + x_{33} + x_{34} + x_{35} = 60$ capacity of bakery P_3,
$x_{41} + x_{42} + x_{43} + x_{44} + x_{45} = 70$ capacity of bakery P_4,
$x_{11} + x_{21} + x_{31} + x_{41} = 25$ customer requirements O_1,
$x_{12} + x_{22} + x_{32} + x_{42} = 35$ customer requirements O_2,
$x_{13} + x_{23} + x_{33} + x_{43} = 55$ customer requirements O_3,

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$x_{14} + x_{24} + x_{34} + x_{44} = 65$ customer requirements O_4,

$x_{15} + x_{25} + x_{35} + x_{45} = 50$ fictitious customer requirements O_5,

$x_{ij} \geq 0$ for *i=1, 2, 3, 4; j=1, 2, 3, 4, 5.*

Table 74 – Solution of the transport task using the NW Corner method

Suppliers	Consumers					Capacity of suppliers
	O_1	O_2	O_3	O_4	O_5	
P_1	24 **25**	25 **25**	28 0	27 0	0 0	50
P_2	22 0	28 **10**	29 **40**	32 0	0 0	50
P_3	34 0	32 0	31 **15**	33 **45**	0 0	60
P_4	28 0	27 0	25 0	32 **20**	0 **50**	70
Consumer requirements	25	35	55	65	50	230 = 230

The transport task has *m+n-1* non-zero values, i.e. 4+5-1 = 8 occupied items $x_{ij}>0$ (Table 74). From this, it follows that the task has a non-degenerated solution. The value of the objective function is obtained by substituting the missing values x_{ij} into the objective function.

$$\min \quad z = \sum_{i=1}^{4} \sum_{j=1}^{4} c_{ij} x_{ij} = 24 \times 25 + 25 \times 25 + 28 \times 10 +$$

$$29 \times 40 + 31 \times 15 + 33 \times 45 + 32 \times 20 = 5255$$

The matrix of delivered quantities: $X_{NW} = \begin{bmatrix} 25 & 25 & 0 & 0 & 0 \\ 0 & 10 & 40 & 0 & 0 \\ 0 & 0 & 15 & 45 & 0 \\ 0 & 0 & 0 & 20 & 50 \end{bmatrix}$

and the value of the objective function is: $z_{NW} = 5\,255$.

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9.2.2 The Index Method – Stepping Stone

Since the NW Corner method ignores cost minimization in the objective function, the proposed solution can be very "distant" from the optimal values. Therefore, there are more suitable approximate methods for determination of the basic solutions, including the index method.

The procedure for completing the fields of the traffic table using the index method is similar to the NW Corner method with the difference that completion begins in the field with the lowest positive tariff for transport and as it continues, it jumps (it steps) to the field with the second lowest positive tariff for transport. The procedure is repeated until the sources of suppliers are used up or the requirements of consumers are satisfied. Fields with zero tariffs are completed last (Heizer, Render 2007; Straka 2012).

In the event that there are multiple fields with the same low tariffs of transport, then the principle is that the priority is with the field with the lowest *i* and *j* indexes.

The index method can bring an optimal solution of the transport task for small dimensions of transport tables i.e. for small numbers of suppliers and customers.



Task: Prepare a plan for delivering frozen products to individual customers using the index method. The goods are located in three ice-houses. Ice-house M_1 has 150 units of goods available, M_2 has 70 units available and M_3 has 30 units of frozen products available. Products must be shipped to three customers. The first customer S_1 requires 95 units, the second customer S_2 requires 115 units, and the third customer S_3 requires 125 units. Shipping rates are shown in Table 75, rates are per unit of goods.

Table 75 – Shipping rates per unit of goods

c_{ij}	S_1	S_2	S_4
M_1	15	20	10
M_2	30	25	12
M_3	22	10	31

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Table 76 – Transport table with input parameters, unbalanced

Suppliers	Consumers			Capacity of suppliers
	S_1	S_2	S_3	
M_1	15 x_{11}	20 x_{12}	10 x_{13}	150
M_2	30 x_{21}	25 x_{22}	12 x_{23}	70
M_3	22 x_{31}	10 x_{32}	31 x_{33}	30
Consumer requirements	95	115	125	250 > 335

Table 77 – Transport table with input parameters, balanced

Suppliers	Consumers			Capacity of suppliers
	S_1	S_2	S_3	
M_1	15 x_{11}	20 x_{12}	10 x_{13}	150
M_2	30 x_{21}	25 x_{22}	12 x_{23}	70
M_3	22 x_{31}	10 x_{32}	31 x_{33}	30
M_4	0 x_{41}	0 x_{42}	0 x_{43}	85
Consumer requirements	95	115	125	335 = 335

Objective Function

The value of the objective function represents the total costs of transport. Such x_{ij} values have to be found for which the value of the objective function is minimal.

$$\min\ z = \sum_{i=1}^{3}\sum_{j=1}^{3} c_{ij}x_{ij} = 15\times x_{11} + 20\times x_{12} + 10\times x_{13} +$$

$$30\times x_{21} + 25\times x_{22} + 12\times x_{23} + 22\times x_{31} + 10\times x_{32} + 31\times x_{33}$$

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Binding Conditions

The total amount of goods to be delivered to customers, is greater than what is available in the distribution warehouses (Table 76). Consequently, the transport task is unbalanced. As the requirements of customers are greater than the capacity of suppliers, it is necessary to include the fictitious M_4 supplier into the transport table that will have the capacity of 85 units of frozen products. This aligns the capacities with the requirements and the task becomes balanced (Table 77).

If a fictitious supplier was not included in the transport table, then inequalities would be used in the constraints, i.e. the sum of the capacities of suppliers in the columns would be smaller or at least equal to the customer requests:

$$\sum_{i=1}^{m} x_{ij} \leq b_j \qquad \text{for } j=1, 2, 3.$$

The following constraints result from the transport table:

$$x_{11} + x_{12} + x_{13} = 150 \qquad \text{capacity of ice-house } M_1,$$
$$x_{21} + x_{22} + x_{23} = 70 \qquad \text{capacity of ice-house } M_2,$$
$$x_{31} + x_{32} + x_{33} = 30 \qquad \text{capacity of ice-house } M_3,$$
$$x_{41} + x_{42} + x_{43} = 85 \qquad \text{capacity of fictitious ice-house } M_4,$$
$$x_{11} + x_{21} + x_{31} + x_{41} = 95 \qquad \text{customer requirements } S_1,$$
$$x_{12} + x_{22} + x_{32} + x_{42} = 115 \qquad \text{customer requirements } S_2,$$
$$x_{13} + x_{23} + x_{33} + x_{43} = 125 \qquad \text{customer requirements } S_3,$$
$$x_{ij} \geq 0 \qquad \text{for } i=1, 2, 3, 4; \quad j=1, 2, 3.$$

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Table 78 – Solution of the transport task using the index method

Suppliers	Consumers			Capacity of suppliers
	S_1	S_2	S_3	
M_1	15 25	20 0	10 125	150
M_2	30 0	25 70	12 0	70
M_3	22 0	10 30	31 0	30
M_4	0 70	0 15	0 0	85
Consumer requirements	95	115	125	335 = 335

The transport task has $m+n-1$ non-zero values, i.e. 4+3-1 = 6 occupied items $x_{ij}>0$ (Table 78). From this, it follows that the task has a non-degenerated solution. The value of the objective function is obtained by assigning missing values for x_{ij} to the objective function:

$$\min\ z=\sum_{i=1}^{3}\sum_{j=1}^{3}c_{ij}x_{ij}=15\times 25+20\times 0+10\times 125+30\times 0+$$

$$25\times 70+12\times 0+22\times 0+10\times 30+31\times 0=3675.$$

The matrix of delivered quantities: $X_{INDEX}=\begin{bmatrix}25 & 0 & 125\\ 0 & 70 & 0\\ 0 & 30 & 0\\ 70 & 15 & 0\end{bmatrix}$

and the value of the objective function is: $z_{Index} = 3\ 675$.

9.2.3 Vogel's Approximation Method

Another method that considers cost minimization in the objective function is Vogel's approximation method – the VAM method. Another advantage of this method, unlike the index method, is that it takes other convenient connections into account. The fields are filled with the lowest costs for transporting goods using the index method, which also forces the selection of fields with unfavourable, high transport tariffs at the end of the solution. The VAM method, besides the costs, also takes into account

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the differences (gaps) between the lowest tariffs in rows and columns of the transport table (Straka 2012). The procedure for solution using the VAM method is as follows:

1) The absolute values of differences between the two lowest positive tariffs for each row and column of the table are calculated into separate supporting rows and columns of the transport table.
2) The largest value of the calculated differences is selected from the rows and columns,
   a. If the value comes from a row, the lowest tariff for transport in the row is found, the highest possible value is assigned to this field.
   b. If the value comes from a column, the lowest tariff for transport in the column is found and the highest possible value is assigned in this field.
   c. If there are several differences with the same value in rows and columns, then the lowest tariff for transport in these rows and columns is found, and this is filled with the highest possible value.
   d. If there are multiple fields with the equally low transport tariffs in the searched rows and columns with the same differentiation, then the field with the lowest *i* and *j* will be filled.
3) After filling in a field it is necessary to check if the capacity of a supplier has been used up in a row or if the requirements of a consumer are satisfied in the column. If so, this row or column is removed from further evaluation.
4) New differences are calculated for the remaining rows and columns and the procedure continues from step number 2.
5) When reaching the state where it is no longer possible to calculate the differences of rows and columns, completion of the remaining fields of the traffic table is performed using the index method.

The results obtained using the VAM method often represent optimal values or their difference from optimum is negligible.



Task: Prepare a distribution plan for four customers using Vogel's approximation method. The goods are placed in three places, in three distribution warehouses. Warehouse D_1 has 130 units available, D_2 has 270 units available and D_3 has 175 units available. Customer O_1 needs 53 units, O_2 needs 35 units, O_3 needs 55 units, and O_4 needs 95 units of material. Shipping rates are shown in Table 79, rates are per unit of goods.

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Table 79 – Shipping rates per unit of goods

c_{ij}	O_1	O_2	O_3	O_4
D_1	45	48	34	35
D_2	56	25	37	34
D_3	29	38	34	32

Table 80 – Transport table with input parameters, unbalanced

Suppliers	Consumers				Capacity of suppliers
	O_1	O_2	O_3	O_4	
D_1	45 x_{11}	48 x_{12}	34 x_{13}	35 x_{14}	130
D_2	56 x_{21}	25 x_{22}	37 x_{23}	34 x_{24}	270
D_3	29 x_{31}	38 x_{32}	34 x_{33}	32 x_{34}	175
Consumer requirements	53	35	55	95	575 < 238

Table 81 – Transport table with input parameters, balanced

Suppliers	Consumers					Capacity of suppliers
	O_1	O_2	O_3	O_4	O_5	
D_1	45 x_{11}	48 x_{12}	34 x_{13}	35 x_{14}	0 x_{15}	130
D_2	56 x_{21}	25 x_{22}	37 x_{23}	34 x_{24}	0 x_{25}	270
D_3	29 x_{31}	38 x_{32}	34 x_{33}	32 x_{34}	0 x_{35}	175
Consumer requirements	53	35	55	95	337	575 = 575

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The Objective Function

The value of the objective function represents the total costs of transport. Such values of x_{ij} have to be found for which the value of the objective function is minimal.

$$\min z = \sum_{i=1}^{3}\sum_{j=1}^{4} c_{ij}x_{ij} =$$

$$45\times x_{11} + 48\times x_{12} + 34\times x_{13} + 35\times x_{14} +$$
$$56\times x_{21} + 25\times x_{22} + 37\times x_{23} + 34\times x_{24} +$$
$$29\times x_{31} + 38\times x_{32} + 34\times x_{33} + 32\times x_{34}$$

Binding Conditions

The sum of the amount of goods which need to be delivered to customers, is smaller than that available in distribution warehouses (Table 80). Consequently, the transport task is unbalanced. As the requirements are smaller than the capacities, it is necessary to include the fictitious customer O_5 into the transport table that will request 337 units of product. This aligns the capacities with the requirements and the task becomes balanced (Table 81).

If a fictitious customer was not included in the transport table, then acute inequalities would be used in the constraints, i.e. the sum of the number of customer requests in the rows is smaller or at least equal to the capacity of the suppliers:

$$\sum_{j=1}^{n} x_{ij} \le a_i \qquad \text{for } i=1, 2, 3.$$

The following constraints resulted from the transport table:

$x_{11} + x_{12} + x_{13} + x_{14} + x_{15} = 130$ capacity of warehouse D_1,

$x_{21} + x_{22} + x_{23} + x_{24} + x_{25} = 270$ capacity of warehouse D_2,

$x_{31} + x_{32} + x_{33} + x_{34} + x_{35} = 175$ capacity of warehouse D_3,

$x_{11} + x_{21} + x_{31} = 53$ customer requirements S_1,

$x_{12} + x_{22} + x_{32} = 35$ customer requirements S_2,

$x_{13} + x_{23} + x_{33} = 55$ customer requirements S_3,

$x_{14} + x_{24} + x_{34} = 95$ customer requirements S_4,

$x_{15} + x_{25} + x_{35} = 337$ fictitious customer requirements O_5,

$x_{ij} \ge 0$ for $i=1, 2, 3;$ $j=1, 2, 3, 4, 5.$

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Table 82 – Solution of the transport task using Vogel's approximation

Suppliers	Consumers					Capacity of suppliers	Differences (gaps)		
	O_1	O_2	O_3	O_4	O_5				
D_1	45 0	48 0	34 55	35 0	0 75	130-130 =0 130	1	1	1
D_2	56 0	25 35	37 0	34 95	0 140	270-270 =0 270	9	9	3
D_3	29 53	38 0	34 0	32 0	0 122	175-175 =0 175	3	2	2
Consumer requirements	53-53= 0 53	35-35= 0 35	55-55= 0 55	95-95= 0 95	337-337= 0 337	575 = 575			
Differences	16	13	0	2	0				
	-	13	0	2	0				
(gaps)	-	-	0	2	0				

The transport task has $m+n-1$ non-zero values, i.e. 3+5-1 = 7 occupied items $x_{ij}>0$ (Table 82). From this, it follows that the task has a non-degenerated solution. The value of the objective function is obtained by assigning to the objective function the missing values x_{ij}:

$$\min\ z = \sum_{i=1}^{3}\sum_{j=1}^{4} c_{ij}x_{ij} = 34\times 55 + 25\times 35 + 34\times 95 + 29\times 53 = 7512.$$

The matrix of delivered quantities: $X_{VOGEL} = \begin{bmatrix} 0 & 0 & 55 & 0 & 75 \\ 0 & 35 & 0 & 95 & 140 \\ 53 & 0 & 0 & 0 & 122 \end{bmatrix}$

and the value of the objective function is: $z_{Vogel} = 7\,512$.

9.2.4 The MOdified DIstribution – MODI

The MODI method enables the calculation of the improvement of transport for each cell (field in the matrix), which has not been used or contains a traffic quantity equal to 0. The MODI method is among the methods that lead to the optimal solution (Heizer, Render 2007; Straka 2012). To use the MODI method it is necessary first to establish acceptable basic solutions using one of the basic methods (the NW Corner, the index method, the VAM). The MODI method, unlike other methods that lead to the optimal solution, does not need a large amount of time or complex calculations. The MODI method provides new ways of finding unused routes with the highest index of improvement. When the index

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with the largest improvement is identified, only one closed route is observed. This route helps to determine the maximum number of units that can be transported through the best unused route. The MODI method, for its calculation, requires a basic non-degenerate solution, i.e. a solution which has exactly $m + n - 1$ occupied cells in the matrix. If the basic solution is degenerated, it is necessary to put many small numbers $k\ (k \rightarrow 0)$ in the solution matrix so that the degeneration is removed. These small numbers are inserted into any unoccupied cells of the matrix. A small number k is used only for the ability to compute using the MODI method and it is not reflected in the objective functions, work is performed with it as with any number.

Using the MODI method (Straka 2012):

1) Calculate a basic, feasible solution using any of the methods from the NW Corner, the index method, the VAM method.

2) Find out if there is a better possibility for the solution:

2.1) calculate supportive values of the row and column indexes R_i, S_j (9.10) for each occupied cell, i.e. cell, which has non-zero values for goods transport quantity.

$$R_i + S_j = c_{ij} \tag{9.10}$$

R_i – supportive value associated to row i,
S_j – supportive value associated to column j,
c_{ij} – unit transport costs, costs from the i^{th} supplier to the j^{th} consumer.

For the calculation it holds that the first value is equal to 0, i.e. for example $R_1 = 0$, the costs are known from the matrix, other supportive variables R_i and S_j are calculated from defined equations with one unknown.

2.2) The index of improvement is calculated I_{ij} (9.11) for each unoccupied cell i.e. the cell which has zero values of goods transport quantity after the basic solution.

$$I_{ij} = c_{ij} - R_i - S_j \tag{9.11}$$

I_{ij} – the index of improvements belongs to the unoccupied cell in row i and column j,
R_i – supportive value associated to the row i,

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S_j – supportive value associated to the column j,
c_{ij} – unit transport costs, costs from the i^{th} supplier to the j^{th} consumer.

2.3) If there is a negative index of improvement I_{ij}, there is a better option for material delivery x_{ij} from supplier i to consumer j. In the case of more negative indexes, the one is chosen which has the highest negative value. In the case of equality of negative indexes of improvements, the one is used that belongs to the cell with the lower transport tariff.

3) If there is a better option, Dantzig's closed cycles and index method is used to adjust the solutions.

3.1) The first position is occupied by the one that has the smallest index of improvement in the matrix of solutions. The sign "+" is written into the cell. In the row or in the column, i.e. horizontally and vertically a cell is searched for which has a non-zero quantity for material transported $x_{ij} \neq 0$. The sign "-" is written into it and at the same time there is a break in the direction, i.e. if it was horizontal it turns to the vertical direction. If it was vertical it turns to the horizontal direction. This procedure of marking cells is repeated until the cycle reaches the initial field, i.e. the cell (field) with the smallest index of improvement. *The straight line can pass through occupied and unoccupied fields. Where there is a cell with zero quantity for transport, it is not possible to insert the symbol "-", but only "+". It is not possible to carry a negative quantity of goods.* After the cells in the matrix are filled in there should be the same number of signs "+" and "-". Dantzig's cycles (Heizer, Render 2007; Straka 2013) can have different shapes (Figure 89).

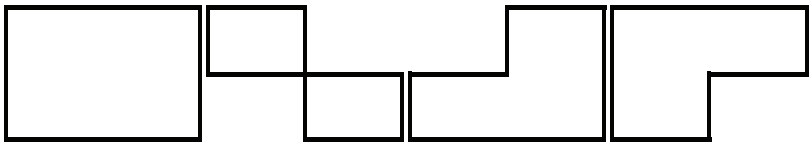


Figure 89 – Examples of Dantzig's cycles

3.2) The smallest transported quantity x_{ij} is selected from the cells which are marked "-" and this quantity is moved between the cells i.e. in the cells marked as "+" it is incremented and in the

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cells marked as "-" the chosen quantity is decremented so as to fulfil the conditions of suppliers' capacities and consumers' demands. Again, it is necessary to repeat the calculation of indexes of improvements I_{ij}, i.e. the whole point no. 2. This procedure is repeated until all the indexes of improvements are positive.

4) If the negative index of improvement I_{ij} does not exist (all the indexes of improvements are positive or zero), then the solution is optimal. As the final step, it is necessary to calculate the value of the objective function

$$\min \quad z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}.$$



Task: The input data from previous methods will be used for this case study. Prepare a bread distribution plan from bakeries to individual sellers using the MODI method. The goods are located in four bakeries P_1 has 50 loaves, P_2 has 50 loaves, P_3 has 60 loaves and P_4 has 70 loaves of bread available. Loaves of bread have to be transported to four customers, when the first customer O_1 requests 25 loaves, the second customer O_2 requests 35 loaves, the third customer O_3 requests 55 loaves, and the fourth customer O_4 requests 65 loaves of bread. Create an acceptable basic solution using the VAM method.

Step 1: The following constraints result from the transport table:

$x_{11} + x_{12} + x_{13} + x_{14} + x_{15} = 50$ capacity of bakery P_1,

$x_{21} + x_{22} + x_{23} + x_{24} + x_{25} = 50$ capacity of bakery P_2,

$x_{31} + x_{32} + x_{33} + x_{34} + x_{35} = 60$ capacity of bakery P_3,

$x_{41} + x_{42} + x_{43} + x_{44} + x_{45} = 70$ capacity of bakery P_4,

$x_{11} + x_{21} + x_{31} + x_{41} = 25$ customer requirements O_1,

$x_{12} + x_{22} + x_{32} + x_{42} = 35$ customer requirements O_2,

$x_{13} + x_{23} + x_{33} + x_{43} = 55$ customer requirements O_3,

$x_{14} + x_{24} + x_{34} + x_{44} = 65$ customer requirements O_4,

$x_{15} + x_{25} + x_{35} + x_{45} = 50$ fictitious customer requirements O_5,

$x_{ij} \geq 0$ for $i=1, 2, 3, 4;$ $j=1, 2, 3, 4, 5.$

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Table 83 – Basic solution of the transport task performed using the VAM method

Suppliers	Consumers					Capacity of suppliers	
	O_1	O_2	O_3	O_4	O_5		
P_1	24 0	25 0	28 0	27 50	0 0	50	1,2,x
P_2	22 25	28 20	29 0	32 5	0 0	50	6,1,1,4
P_3	34 0	32 0	31 0	33 10	0 50	60	1,1,1,1
P_4	28 0	27 15	25 55	32 0	0 0	70	2,2,2,5
Consumer requirements	25	35	55	65	50	230 = 230	
	2,x	2,2,1,1	3,3,4,x	5,5,0,0			

The transport task has $m+n-1$ non-zero values, i.e. 4+5-*1* = 8 occupied cells (Table 83). From this, it follows that the task has a non-degenerated solution. The value of the objective function is obtained by assigning missing values x_{ij} to the objective function:

$$\min \quad z = \sum_{i=1}^{4} \sum_{j=1}^{4} c_{ij} x_{ij} = 50 \times 27 + 25 \times 22 + 20 \times 28 +$$

$$5 \times 32 + 10 \times 33 + 15 \times 27 + 55 \times 25 = 4730.$$

This plan is more advantageous than the NW corner method. Using the MODI method, it will be determined whether it is optimal.

Step 2.1: For each occupied cell, i.e. cell that has a non-zero amount of transported goods after the basic solution, auxiliary values R_i, S_j are calculated, where $R_1 = 0$.

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$R_1 = 0$
$R_1 + S_4 = c_{14} \Rightarrow 0 + S_4 = 27 \Rightarrow S_4 = 27$
$R_2 + S_4 = c_{24} \Rightarrow R_2 + 27 = 32 \Rightarrow R_2 = 5$
$R_2 + S_1 = c_{21} \Rightarrow 5 + S_1 = 22 \Rightarrow S_1 = 17$
$R_2 + S_2 = c_{22} \Rightarrow 5 + S_2 = 28 \Rightarrow S_2 = 23$
$R_3 + S_4 = c_{34} \Rightarrow R_3 + 27 = 33 \Rightarrow R_3 = 6$
$R_3 + S_5 = c_{35} \Rightarrow 6 + S_5 = 0 \Rightarrow S_5 = -6$
$R_4 + S_2 = c_{42} \Rightarrow R_4 + 23 = 27 \Rightarrow R_4 = 4$
$R_4 + S_3 = c_{43} \Rightarrow 4 + S_3 = 25 \Rightarrow S_3 = 21$

Step 2.2: For each unoccupied cell, i.e. cell that has zero amount of transported goods after the basic solution, the improvement index I_{ij} is calculated.

$I_{11} = c_{11} - R_1 - S_1 \Rightarrow I_{11} = 24 - 0 - 17 = 7$
$I_{12} = c_{12} - R_1 - S_2 \Rightarrow I_{12} = 25 - 0 - 23 = 2$
$I_{13} = c_{13} - R_1 - S_3 \Rightarrow I_{13} = 28 - 0 - 21 = 7$
$I_{15} = c_{15} - R_1 - S_5 \Rightarrow I_{15} = 0 - 0 - (-6) = 6$
$I_{23} = c_{23} - R_2 - S_3 \Rightarrow I_{23} = 29 - 5 - 21 = 3$
$I_{25} = c_{25} - R_2 - S_5 \Rightarrow I_{25} = 0 - 5 - (-6) = 1$
$I_{31} = c_{31} - R_3 - S_1 \Rightarrow I_{31} = 34 - 6 - 17 = 11$
$I_{32} = c_{32} - R_3 - S_2 \Rightarrow I_{32} = 32 - 6 - 23 = 3$
$I_{33} = c_{33} - R_3 - S_3 \Rightarrow I_{33} = 31 - 6 - 21 = 4$
$I_{41} = c_{41} - R_4 - S_1 \Rightarrow I_{41} = 28 - 4 - 17 = 7$
$I_{44} = c_{44} - R_4 - S_4 \Rightarrow I_{44} = 32 - 4 - 27 = 1$
$I_{45} = c_{45} - R_4 - S_5 \Rightarrow I_{45} = 0 - 4 - (-6) = 2$

Step 3: Because there are no negative improvement index values, this step is skipped.

Step 4: As there are no negative improvement index values, the proposed delivery option using the VAM method is optimal.



Task: Prepare a plan for delivering frozen products to individual customers using the MODI method. The goods are located in three ice-houses, when ice-house M_1 has 150 units

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of goods available, M_2 has 70 units available and M_3 has 30 units of frozen products available. Products must be shipped to three customers. The first customer S_1 requires 95 units, the second customer S_2 requires 115 units and the third customer S_3 requires 125 units. Create an acceptable basic solution using the index method.

Step 1: The following constraints result from the transport table:

$x_{11} + x_{12} + x_{13} = 150$ capacity of ice-house M_1,
$x_{21} + x_{22} + x_{23} = 70$ capacity of ice-house M_2,
$x_{31} + x_{32} + x_{33} = 30$ capacity of ice-house M_3,
$x_{41} + x_{42} + x_{43} = 85$ capacity of fictitious ice-house M_4,
$x_{11} + x_{21} + x_{31} + x_{41} = 95$ customer requirements S_1,
$x_{12} + x_{22} + x_{32} + x_{42} = 115$ customer requirements S_2,
$x_{13} + x_{23} + x_{33} + x_{43} = 125$ customer requirements S_3,
$x_{ij} \geq 0$ for $i=1, 2, 3, 4;$ $j=1, 2, 3.$

Table 84 – Basic solution of the transport task using the index – stepping stone method

Suppliers	Consumers			Capacity of suppliers
	S_1	S_2	S_3	
M_1	15 25	20 0	10 125	150
M_2	30 0	25 70	12 0	70
M_3	22 0	10 30	31 0	30
M_4	0 70	0 15	0 0	85
Consumer requirements	95	115	125	335 = 335

The transport task has $m+n-1$ non-zero values, i.e. $4+3-1 = 6$ occupied cells (Table 84). From this, it follows that the task has a non-degenerated solution. The value of the objective function is obtained by assigning missing values x_{ij} to the objective function:

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$$\min\ z = \sum_{i=1}^{3}\sum_{j=1}^{3} c_{ij}x_{ij} = 15\times 25 + 10\times 125 + 25\times 70 + 10\times 30 = 3675.$$

The MODI method will be used to find whether goods delivery is optimal.

Step 2.1: For each occupied cell, i.e. cell that has a non-zero amount of transported goods after the basic solution, auxiliary values R_i, S_j are calculated, where $R_1 = 0$.

$$R_1 = 0$$
$$R_1 + S_1 = c_{11} \Rightarrow 0 + S_1 = 15 \Rightarrow S_1 = 15$$
$$R_1 + S_3 = c_{13} \Rightarrow 0 + S_3 = 10 \Rightarrow S_3 = 10$$
$$R_4 + S_1 = c_{41} \Rightarrow R_4 + 15 = 0 \Rightarrow R_4 = -15$$
$$R_4 + S_2 = c_{42} \Rightarrow -15 + S_2 = 0 \Rightarrow S_2 = 15$$
$$R_2 + S_2 = c_{22} \Rightarrow R_2 + 15 = 25 \Rightarrow R_2 = 10$$
$$R_3 + S_2 = c_{32} \Rightarrow R_3 + 15 = 10 \Rightarrow R_3 = -5$$

Step 2.2: For each unoccupied cell, i.e. cell that has a zero amount of transported goods after the basic solution, the improvement index I_{ij} is calculated.

$$I_{12} = c_{12} - R_1 - S_2 \Rightarrow I_{12} = 20 - 0 - 15 = 5$$
$$I_{21} = c_{21} - R_2 - S_1 \Rightarrow I_{21} = 30 - 10 - 15 = 5$$
$$I_{23} = c_{23} - R_2 - S_3 \Rightarrow I_{23} = 12 - 10 - 10 = -8$$
$$I_{31} = c_{31} - R_3 - S_1 \Rightarrow I_{31} = 22 - (-5) - 15 = 12$$
$$I_{33} = c_{33} - R_3 - S_3 \Rightarrow I_{33} = 31 - (-5) - 10 = 26$$
$$I_{43} = c_{43} - R_4 - S_3 \Rightarrow I_{43} = 0 - (-15) - 10 = 5$$

Step 2.3: Since there is a negative value for the I_{23} improvement index, there is also a better product delivery plan. The adjustment of the matrix begins at position *2,3* because this position has the lowest improvement index.

Step 3.1: We "jump" into the cell with the *2,3* index. The "+" mark is entered into this cell, and vertically, or horizontally we search for the

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nearest non-zero cell, i.e. we go to position *1,3*. The mark "-" is entered into this cell. The movement changes from vertical to horizontal and the next non-zero field is at position *1,1*. This position is marked by a "+" mark, again the direction changes from horizontal to vertical. Go to position *4,1*. This is marked by a "–" mark in the cell, the direction changes to horizontal, go to position *4,2*. This is marked by a "+" mark in the cell, the direction changes to vertical, go to position *2,2*. This is marked by a "-" mark in the cell, the direction changes to horizontal, and we are in the box from which the marking started (Table 85), i.e. Dantzing's cycle is closed.

Table 85 – Creation of Dantzing's cycle

Suppliers	Consumers S_1	Consumers S_2	Consumers S_3	Capacity of suppliers
M_1	15 / 25 +	20 / 0	10 / 125 -	150
M_2	30 / 0	25 / 70 -	12 / 0 +	70
M_3	22 / 0	10 / 30	31 / 0	30
M_4	0 / 70 -	0 / 15 +	0 / 0	85
Consumer requirements	95	115	125	335 = 335

Step 3.2: From the fields marked with "-", the smallest transport quantity x_{ij} is selected and this amount is moved between the cells (in this case it is 70), i.e. in the cells marked "+" it is added and in the cells marked "-", this quantity is deducted in order to fulfil the conditions of suppliers capacities and customers' requirements (Table 86). The solution is degenerate because it does not have $m+n-1$ non-zero values, i.e. $4+3-1=6$ occupied cells, but only 5 cells are occupied. A small number k will be placed into the free cell at position *4,1* to fulfil the condition and the solution will be non-degenerated (Table 87). The calculation of improvement indexes from step 2 is repeated.

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Table 86 – Movement of the smallest planned amount between the marked cells

Suppliers	Consumers			Capacity of suppliers
	S_1	S_2	S_3	
M_1	15 95 +	20 0	10 55 -	150
M_2	30 0	25 0 -	12 70 +	70
M_3	22 0	10 30	31 0	30
M_4	0 0 -	0 85 +	0 0	85
Consumer requirements	95	115	125	335 = 335

Table 87 – Removal of degenerate solution by inserting a small number k (k→0) into the matrix

Suppliers	Consumers			Capacity of suppliers
	S_1	S_2	S_3	
M_1	15 95 +	20 0	10 55 -	150
M_2	30 0	25 0 -	12 70 +	70
M_3	22 0	10 30	31 0	30
M_4	0 k -	0 85 +	0 0	85+k
Consumer requirements	95+k	115	125	335+k = 335+k

Step 2.1: For each occupied, non-zero cell, the auxiliary values R_i, S_j are calculated, whereby $R_1 = 0$.

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$$R_1 = 0$$
$$R_1 + S_1 = c_{11} \Rightarrow 0 + S_1 = 15 \Rightarrow S_1 = 15$$
$$R_1 + S_3 = c_{13} \Rightarrow 0 + S_3 = 10 \Rightarrow S_3 = 10$$
$$R_2 + S_3 = c_{23} \Rightarrow R_2 + 10 = 12 \Rightarrow R_2 = 2$$
$$R_4 + S_1 = c_{41} \Rightarrow R_4 + 15 = 0 \Rightarrow R_4 = -15$$
$$R_4 + S_2 = c_{42} \Rightarrow -15 + S_2 = 0 \Rightarrow S_2 = 15$$
$$R_3 + S_2 = c_{32} \Rightarrow R_3 + 15 = 10 \Rightarrow R_3 = -5$$

Step 2.2`: For each unoccupied, zero cell, the I_{ij} improvement index is calculated.

$$I_{12} = c_{12} - R_1 - S_2 \Rightarrow I_{12} = 20 - 0 - 15 = 5$$
$$I_{21} = c_{21} - R_2 - S_1 \Rightarrow I_{21} = 30 - 2 - 15 = 13$$
$$I_{22} = c_{22} - R_2 - S_2 \Rightarrow I_{22} = 25 - 2 - 15 = 8$$
$$I_{31} = c_{31} - R_3 - S_1 \Rightarrow I_{31} = 22 - (-5) - 15 = 12$$
$$I_{33} = c_{33} - R_3 - S_3 \Rightarrow I_{33} = 31 - (-5) - 10 = 26$$
$$I_{43} = c_{43} - R_4 - S_3 \Rightarrow I_{43} = 0 - (-15) - 10 = 5$$

Step 3`: Since there are no negative values of the improvement index, the proposal for distribution is optimal.

Step 4`: The value of the objective function *z=3115*.

$$\min\ z = \sum_{i=1}^{3}\sum_{j=1}^{3} c_{ij}x_{ij} = 15\times 95 + 10\times 55 + 12\times 70 + 10\times 30 = 3115$$

The total delivery costs are about 560 units (EUR) lower than the basic solution.

9.3 Multi-level Distribution Networks, Circular Tasks, Type of Relation *1* × *m*

There is often a situation, where the distribution space needs to be broken down into smaller parts for some reason in practice, e.g. there is insufficient transport capacity, distribution is highly time-consuming, it takes a great deal of time to load and unload goods, the length of working time does not enable all the places to be served. In these cases, it is necessary to divide one distribution space into several smaller parts, where the centres of these partial regions are defined and distribution is

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implemented within them. It creates a structured, complex distribution network that can have more than two levels. One method for dividing the distribution space into smaller parts is the distribution potential method. Segmentation of the distribution space into smaller parts is solved as a **relation *1 x m*, from one to many** over a structured distribution network.

9.3.1 Method of Distribution Potential (MDP), Multi-level Type of Relation 1 × m

The method of distribution potential is used to create smaller distribution groups to determine the basic structure of the distribution network or to design a multi-level distribution network by combining multi-criteria evaluation with a heuristic approach (Straka 2004). The procedure that defines the basis of the structure of a distribution network is raised from a multi-criteria assessment that organizes distribution places according to their importance or according to the degree of distribution potential, i.e. from the place that has obtained the best distribution evaluation to the place that has obtained the worst evaluation.

The distribution potential, in this case, represents **the ability of a point** to become a superior point in the distribution network relative to other places in the distribution network (Straka 2007). The result of the distribution potential method is the graphical solution of the decomposition of the distribution space into smaller parts, considering the defined criteria. The procedure of the method of distribution potential is as follows:

1) The distribution potential of each point in the evaluation is determined by applying some multi-criteria assessment methods.
2) Evaluated locations are ordered from the best (the highest distribution potential) to the worst (lowest distribution potential).
3) Additional places meeting the defined criteria of time availability (*CaDos*) are assigned from the availability table to the place with the largest distribution potential (Table 88), in this case it is "S_1". These locations create a distribution group, they are removed from the ordering and they are no longer considered in the further process.

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Table 88 – Ordering of places according to distribution potential

		Criterion 1		Criterion 2		...	Criterion h		
Weights		V_1		V_2		...	V_h		(1; 10; 100)
Places		Points	Weights x Points	Points	Weights x Points	...	Points	Weights x Points	SUM
1	S_1	b_{11}	$V_1 \times b_{11}$	b_{12}	$V_2 \times b_{12}$	...	b_{1h}	$V_h \times b_{1h}$	$\Sigma(V_j \times b_{1j})$
2	S_2	b_{21}	$V_1 \times b_{21}$	b_{22}	$V_2 \times b_{22}$	...	b_{2h}	$V_h \times b_{2h}$	$\Sigma(V_j \times b_{2j})$
3	S_3	b_{31}	$V_1 \times b_{31}$	b_{32}	$V_2 \times b_{32}$	...	b_{3h}	$V_h \times b_{3h}$	$\Sigma(V_j \times b_{3j})$
⋮	⋮	⋮	⋮	⋮	⋮		⋮	⋮	⋮
n	S_n	b_{n1}	$V_1 \times b_{n1}$	b_{n2}	$V_2 \times b_{n2}$	...	b_{nh}	$V_h \times b_{nh}$	$\Sigma(V_j \times b_{ij})$

S_i – places of distribution region, $i = 1,2, \ldots, n,$
b_{ji} – points, usefulness of place j to criterion $i, j = 1,2, \ldots, h; i = 1,2, \ldots, n,$
V_j – weight of criteria j, $j = 1,2, \ldots, h,$
n – number of places entering to the evaluation,
h – number of criteria entering to the evaluation.

4) The site with the largest distribution potential is again selected from the places that have not yet been assigned to a distribution group in point 3. The procedure is repeated as in point 3. This procedure, points 3 and 4, is repeated until all locations are included.

Remark 1: After all locations are included as per points 3 and 4, a situation may arise where some places will form separate groups, the time available will be greater than the specified *CaDos* availability time.

5) This process repeats again from point 3, but first it is determined whether there are places that did not join a distribution group, because they were out of the time available. Such a place can be included into the nearest distribution group, if dispersion from the *CaDos* value allows. The procedure is repeated until all the places are sorted.

Remark 2: If there is a situation where there is a limitation of the maximum number of places in the distribution group and the number of places that fulfil the *CaDos* criterion is larger than the maximum number in a group, then this group is created using those places that have the lowest availability times (the shortest distance) to a place with the largest distribution potential of a group.

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Task: Create a structured distribution network and divide a region with ten companies into smaller parts, with a maximum of three companies per distribution group. The priority criterion is the time of availability *CaDos* = 90 minutes (+10%). The time of availability between particular locations, company location coordinates, criteria, and the company evaluation using the selected criteria are defined in Table 89 and Figure 90. Supply at the first level of the distribution network will be from point OX and the next level of the distribution network will be from the point closest to point OX.

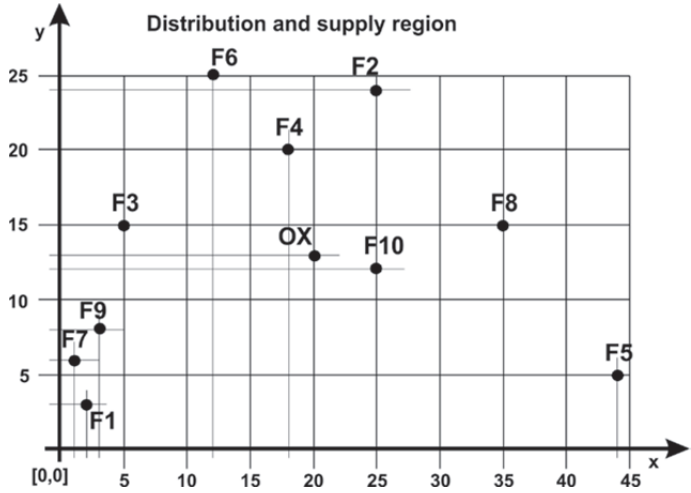


Figure 90 – Location of companies in the distribution region

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Table 89 – Times of availability between companies, coordinates and defined criteria

CaDos (min)	Companies										Coordinates		Criteria				
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	x_i	y_i	economic weight 0.25	technical weight 0.2	strategic weight 0.2	time weight 0.15	infrastructure weight 0.2
F1	0	120	89	100	185	125	10	122	30	98	2	3	8	5	7	6	7
F2	120	0	95	49	100	52	101	60	90	61	25	24	7	7	8	8	7
F3	89	95	0	55	170	56	40	103	32	75	5	15	6	5	6	8	8
F4	100	49	55	0	115	25	92	60	89	55	18	20	7	7	7	9	8
F5	185	100	170	115	0	109	180	45	165	80	44	5	7	7	8	10	8
F6	125	52	56	25	109	0	110	99	102	92	12	25	6	6	5	7	5
F7	10	101	40	92	180	101	0	150	12	95	1	6	8	9	8	8	8
F8	122	60	103	60	45	99	150	0	92	30	35	15	7	6	7	9	6
F9	30	90	32	89	165	102	12	92	0	89	3	8	9	8	9	10	8
F10	98	61	75	55	80	92	95	30	89	0	25	12	8	6	5	6	6
OX	88	69	73	44	122	75	85	73	83	29	20	13					

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The procedure:

1) Calculate the value of distribution potential for each point by applying the weighted sum method.
2) Order companies from "best to the worst" according to their distribution potential (Table 90).

Table 90– Ordering of companies according to distribution potential

	economic	weight 0.25	technical	weight 0.2	strategic	weight 0.2	time	weight 0.15	infrastructure	weight 0.2	Distribution of potential place
F9	9	2.25	8	1.60	9	1.80	10	1.50	8	1.60	**8.75**
F7	8	2.00	9	1.80	8	1.60	8	1.20	8	1.60	**8.20**
F5	7	1.75	7	1.40	8	1.60	10	1.50	8	1.60	**7.85**
F4	7	1.75	7	1.40	7	1.40	9	1.35	8	1.60	**7.50**
F2	7	1.75	7	1.40	8	1.60	8	1.20	7	1.40	**7.35**
F8	7	1.75	6	1.20	7	1.40	9	1.35	6	1.20	**6.90**
F1	8	2.00	5	1.00	7	1.40	6	0.90	7	1.40	**6.70**
F3	6	1.50	5	1.00	6	1.20	8	1.20	8	1.60	**6.50**
F10	8	2.00	6	1.20	5	1.00	6	0.90	6	1.20	**6.30**
F6	6	1.50	6	1.20	5	1.00	7	1.05	5	1.00	**5.75**

3) Assign companies, for which *CaDos* is less than or equal to 90 minutes, to companies with the largest distribution potential (Table 91), according to the distance. Assign a maximum of three companies with the smallest *CaDos*, including the first one with the largest distribution potential, into the first group. Cross these companies off and repeat the process until all of the companies are defined into groups.

Companies F1, F2, F3, F4, F7, F9, F10 fulfil *CaDos* to F9. From these, three need to be selected that have the smallest *CaDos* values and to cross them off from the table and to repeat the procedure (Table 92).

The first group is formed of companies F1, F7, F9.

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Table 91 – Selection of three companies that fulfil CaDos to F9 including F9 company

	Companies									
CaDos (min)	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0	120	89	100	185	125	10	122	30	98
F2	120	0	95	49	100	52	101	60	90	61
F3	89	95	0	55	170	56	40	103	32	75
F4	100	49	55	0	115	25	92	60	89	55
F5	185	100	170	115	0	109	180	45	165	80
F6	125	52	56	25	109	0	110	99	102	92
F7	10	101	40	92	180	101	0	150	12	95
F8	122	60	103	60	45	99	150	0	92	30
F9	30	90	32	89	165	102	12	92	0	89
F10	98	61	75	55	80	92	95	30	89	0

Table 92 – New ordering of companies without those already included in the first group

	economic	weight 0.25	technical	weight 0.2	strategic	weight 0.2	weight 0.15	weight 0.2	Distribution of potential place
F5	7	1.75	7	1.40	8	1.60	1.50	1.60	**7.85**
F4	7	1.75	7	1.40	7	1.40	1.35	1.60	**7.50**
F2	7	1.75	7	1.40	8	1.60	1.20	1.40	**7.35**
F8	7	1.75	6	1.20	7	1.40	1.35	1.20	**6.90**
F3	6	1.50	5	1.00	6	1.20	1.20	1.60	**6.50**
F10	8	2.00	6	1.20	5	1.00	0.90	1.20	**6.30**
F6	6	1.50	6	1.20	5	1.00	1.05	1.00	**5.75**

The procedure is repeated as in point 3. Companies F8 and F10 fulfil *CaDos* to F5 (Table 93). They form a group of three companies together with F5. Cross them off from the table and repeat the procedure (Table 94). Thus, the second group consists of companies F5, F8, F10.

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Table 93 – Selection of three companies that meet CaDos to F5 including F5 company

	Companies							
CaDos (min)	F1	F2	F3	F4	F5	F6	F8	F10
F2	120	0	95	49	100	52	60	61
F3	89	95	0	55	170	56	103	75
F4	100	49	55	0	115	25	60	55
F5	185	100	170	115	**0**	109	**45**	**80**
F6	125	52	56	25	109	0	99	92
F8	122	60	103	60	45	99	0	30
F10	98	61	75	55	80	92	30	0

Table 94 – New ordering of companies without those already included in the groups

	economic	weight 0.25	technical	weight 0.2	strategic	weight 0.2	time	weight 0.15	infrastructure	weight 0.2	Distribution of potential place
F4	7	1.75	7	1.40	7	1.40	9	1.35	8	1.60	**7.50**
F2	7	1.75	7	1.40	8	1.60	8	1.20	7	1.40	**7.35**
F3	6	1.50	5	1.00	6	1.20	8	1.20	8	1.60	**6.50**
F6	6	1.50	6	1.20	5	1.00	7	1.05	5	1.00	**5.75**

The procedure is repeated as in point 3. Companies F2, F3, F6 (those not yet included) fulfil *CaDos* to F4. The third group consists of F4, F6, F2.

The last non-included company, F3, remains, creating a separate region as the division of the distribution space is limited to three companies in one distribution group.

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The first region consists of F1, F7, F9. The second region consists of F5, F8, F10. The third region consists of F4, F6, F2. The fourth region consists of F3 only.

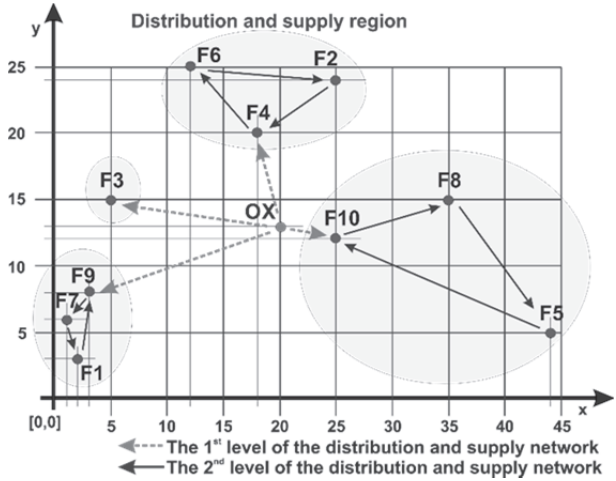


Figure 91 – Arrangement of the distribution region into smaller parts using MDP, proposal of distribution network I.

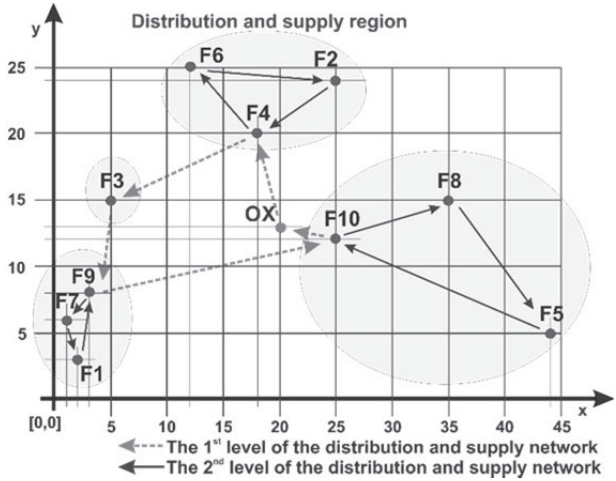


Figure 92 – Arrangement of the distribution region into smaller parts using MDP, proposal of distribution network II.

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The solution shows that the distribution network formed has two levels. The first level consists of a distribution network type of the star (Figure 91) or ring (Figure 92) type, i.e. connections are created between the OX centre and the points F3, F4, F9 and F10. The second level consists of a distribution network of the ring or star type. The ring distribution networks are between points F9, F7, F1, between points F5, F8, F10 and between points F2, F4 and F8.

The appearance of the distribution network depends on the particular system and specific conditions such as the capacity of the means of transport, the time for distribution and other factors.



Task: Create a structured distribution network using the method of distribution potential, divide a region with twenty consumers I1 – I20 into smaller ones. The priority criterion is the availability time for CaDos = 5 minutes (+20%). The availability time between locations, coordinates of consumer location placement, criteria and company evaluation using the selected criteria are in Table 95. Supply at the first level of the distribution network will be from point IX and from the next level of the distribution network it will be from the point closest to central point IX.

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Table 95 – Availability of times between consumers, coordinates, and partial utility values

CaDos (min)	Companies																				Coordinates		Criteria				
	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15	I16	I17	I18	I19	I20	x_i	y_i	economic	technical	strategic	time	infrastructure
																							0.2	0.2	0.2	0.2	0.2
I1	0	22	20	9	15	3	20	12	11	12	25	12	18	9	21	22	13	24	13	2	1	2	7	5	8	8	10
I2	22	0	4	18	12	18	18	13	10	10	6	17	11	15	2	4	14	3	13	21	21	12	2	9	5	9	6
I3	20	4	0	14	13	16	13	9	8	8	5	13	13	11	2	2	10	5	14	19	17	14	5	9	2	5	2
I4	9	18	14	0	16	7	11	5	8	9	19	3	18	3	16	16	5	19	15	10	3	11	6	8	1	1	5
I5	15	12	13	16	0	12	23	13	8	7	17	17	3	13	12	15	15	15	2	13	16	1	7	5	2	2	6
I6	3	18	16	7	12	0	18	8	8	8	22	10	15	6	17	19	10	21	10	3	4	4	5	2	1	5	2
I7	20	18	13	11	23	18	0	10	14	16	15	8	24	12	15	14	8	17	23	21	6	22	4	1	9	2	1
I8	12	13	9	5	13	8	10	0	5	6	14	4	15	2	11	11	2	14	13	12	8	12	2	2	2	5	3
I9	11	10	8	8	8	8	14	5	0	1	14	9	10	5	9	11	7	13	8	10	11	8	5	5	3	6	9
I10	12	10	8	9	7	8	16	6	1	0	14	10	9	6	9	11	8	12	7	10	12	7	7	2	1	9	8
I11	25	6	5	19	17	22	15	14	14	14	0	17	17	17	5	2	14	3	19	24	21	18	8	6	6	7	7
I12	12	17	13	3	17	10	8	4	9	10	17	0	19	4	15	15	3	18	17	13	4	14	8	1	8	8	2
I13	18	11	13	18	3	15	24	15	10	9	17	19	0	15	12	15	17	14	5	16	19	1	5	9	9	2	5
I14	9	15	11	3	13	6	12	2	5	6	17	4	15	0	13	14	4	16	12	9	6	10	2	5	8	3	2
I15	21	2	2	16	12	17	15	11	9	9	5	15	12	13	0	3	12	3	13	20	19	13	1	4	9	5	5
I16	22	4	2	16	15	19	14	11	11	11	2	15	15	14	3	0	12	3	16	21	19	16	2	2	5	6	4
I17	13	14	10	5	15	10	8	2	7	8	14	3	17	4	12	12	0	15	15	13	7	14	5	3	10	9	8
I18	24	3	5	19	15	21	17	14	13	12	3	18	14	16	3	3	15	0	17	23	22	15	5	6	1	8	6
I19	13	13	14	15	2	10	23	13	8	7	19	17	5	12	13	16	15	17	0	11	14	0	9	4	2	5	9
I20	2	21	19	10	13	3	21	12	10	10	24	13	16	9	20	21	13	23	11	0	3	1	7	9	5	2	2
IX	11	7	3	12	16	10	9	8	9	10	15	15	20	11	5	7	9	10	22	12	13	13					

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1) Calculate the values of the distribution potentials of points by applying the weighted sum method.
2) Order companies from "best to worst" based on their distribution potential (Table 96).

Table 96 – Ordering of companies based on distribution potential

	economic	weight 0.2	technical	weight 0.2	strategic	weight 0.2	time	weight 0.2	infrastructure	weight 0.2	Distribution potential of place
I1	7	1.40	5	1.00	8	1.60	8	1.60	10	2.00	**7.60**
I17	5	1.00	3	0.60	10	2.00	9	1.80	8	1.60	**7.00**
I11	8	1.60	6	1.20	6	1.20	7	1.40	7	1.40	**6.80**
I2	2	0.40	9	1.80	5	1.00	9	1.80	6	1.20	**6.20**
I13	5	1.00	9	1.80	9	1.80	2	0.40	5	1.00	**6.00**
I19	9	1.80	4	0.80	2	0.40	5	1.00	9	1.80	**5.80**
I9	5	1.00	5	1.00	3	0.60	6	1.20	9	1.80	**5.60**
I12	8	1.60	1	0.20	8	1.60	8	1.60	2	0.40	**5.40**
I18	5	1.00	6	1.20	1	0.20	8	1.60	6	1.20	**5.20**
I10	7	1.40	2	0.40	1	0.20	9	1.80	8	1.60	**5.40**
I20	7	1.40	9	1.80	5	1.00	2	0.40	2	0.40	**5.00**
I15	1	0.20	4	0.80	9	1.80	5	1.00	5	1.00	**4.80**
I3	5	1.00	9	1.80	2	0.40	5	1.00	2	0.40	**4.60**
I5	7	1.40	5	1.00	2	0.40	2	0.40	6	1.20	**4.40**
I4	6	1.20	8	1.60	1	0.20	1	0.20	5	1.00	**4.20**
I14	2	0.40	5	1.00	8	1.60	3	0.60	2	0.40	**4.00**
I16	2	0.40	2	0.40	5	1.00	6	1.20	4	0.80	**3.80**
I7	4	0.80	1	0.20	9	1.80	2	0.40	1	0.20	**3.40**
I6	5	1.00	2	0.40	1	0.20	5	1.00	2	0.40	**3.00**
I8	2	0.40	2	0.40	2	0.40	5	1.00	3	0.60	**2.80**

3) Creation of group I1–I6–I20.
4) Ordering of companies without those already included.
5) Creation of group I17–I4–I8–I12–I14.
6) Ordering of companies without those already included.
7) Creation of group I11–I3–I15–I16–I18.
8) Ordering of companies without those already included.
9) Creation of group I2.

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10) Ordering of companies without those already included.
11) Creation of group I13–I5–I19.
12) Ordering of companies without those already included.
13) Creation of group I9–I10.
14) Ordering of companies without those already included.
15) Creation of group I7.

The result of the basic division of the distribution region is shown in Figure 93.

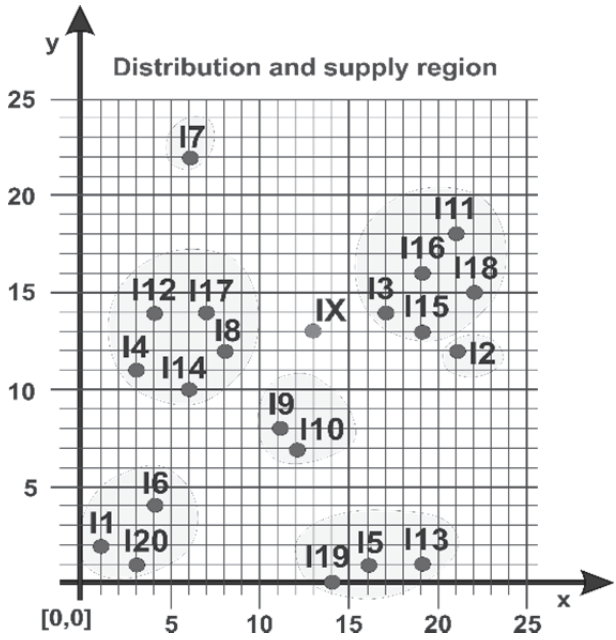


Figure 93 – Division of the distribution region into smaller parts using MDP, preliminary state

16) Checking whether it is possible to integrate places I2, I7 (separate, not included so far) within the 20% percentage reserve. This means that the distribution region may have an average journey of up to 6 minutes. Point I2 can be added to the group I11–I3–I15–I16–I18. Point I7 does not fulfil the availability time criterion even after applying the 20% reserve.

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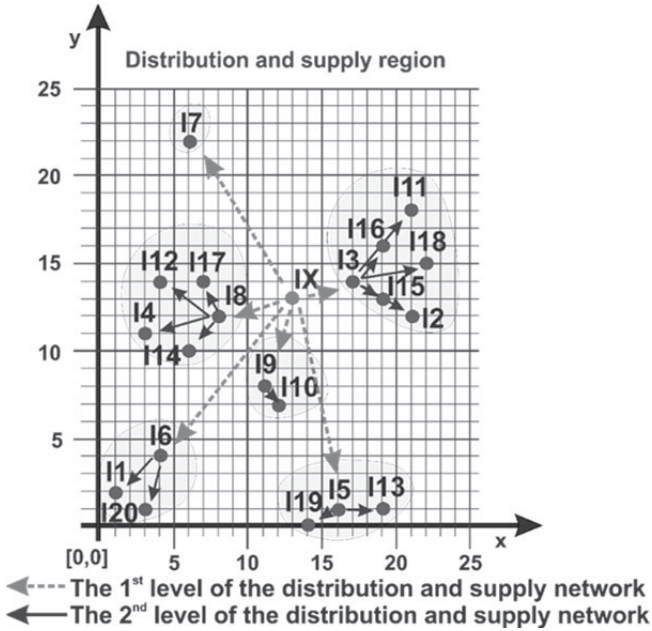


Figure 94 – Division of the distribution region into smaller parts by MDP, final state

The solution shows, that the distribution region will form a two-level, star – star distribution network (Figure 94) or star – ring. The star – star connection is the worst option from an economic point of view. Better are the ring – star combinations or ring – ring. However, even the star – star option ensures compliance with the defined criteria.

The method of distribution potential is helpful in deciding to divide the region into smaller parts and offers segmentation that can be further modified on the basis of further evaluation.

The core of the method consists of the multi-criteria evaluation of the places that form the distribution region. The region is divided according to the selected criteria and their assigned weights, which may not correspond to the geometric segmentation of the distribution space.

The advantage of the method of distribution potential is that a greater number of criteria are taken into account and not just the position of the points in the space themselves. The method offers solutions that may be different from classic geometric and optimization approaches but may be more advantageous in terms of overall judgment.

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9.3.2 Circular tasks, Clarke-Wright's "saving" algorithm, one-level type of relation 1 × m

Circular tasks are a type of task for which the distribution route has to be designed in such a way that the costs of distribution are minimized (optimized) (Straka 2012). Each of the distribution places should be visited just once. The starting point of the distribution circuit is also the final point of the distribution circuit and there are other limitations, such as working time, the capacity of the means of transport, the maximum length of the route, the maximum number of places served, etc. The most famous tasks of this type include the traveling salesman problem or the Chinese postman problem. There are several approaches to solving this type of task:

- algorithms that find the exact solution (suitable for tasks with a small number of nodes in the network),
- heuristic and suboptimal algorithms (approved in a sufficient number of cases, unprovable, they need not guarantee optimal solutions),
- finding a special case, for which it is possible to determine the exact solution.

From practical use and the creation of product distribution plans, the Clarke-Wright savings algorithm seems to be the most suitable method. The advantage of the method is that besides considering the distance between the points to be visited, the method also considers another parameter – the capacity of the means of transport which is used for distribution. Circular tasks are solved as **a relation of type *1* × *m*, from one to many**, mostly as a one-level distribution network.

Variables:
S_j – points served,
x_j – requirements for points served,
DC_x – starting and finishing point – the distribution centre,
d_{xj} – distance between a point and the starting point, $d_{xj} = d_{jx}$ holds,
z – the total number of kilometres needed for distribution (places served),
z_{ij} – the total distance between points i and j,
u_{ij} – savings between points i and j,
n – the number of points to be served,
$j=1, 2, \ldots, n$,
$i=1, 2, \ldots, n$.

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The aim of Clarke-Wright's savings algorithm (Clarke, Wright 1964) is to create a distribution circuit of *z*-length, that contains as many S_j sites as can be served from distribution centre DC in order to optimize (minimize) distribution costs by taking into account other restrictive criteria (e.g. the capacity of the means of transport).

If every point S_j is served separately from distribution centre DC (Figure 95), then the maximum number of kilometres *z* needed for the distribution is double the distance from the centre to each point (9.12).

$$z = 2\sum_{j=1}^{n} d_{xj} \tag{9.12}$$

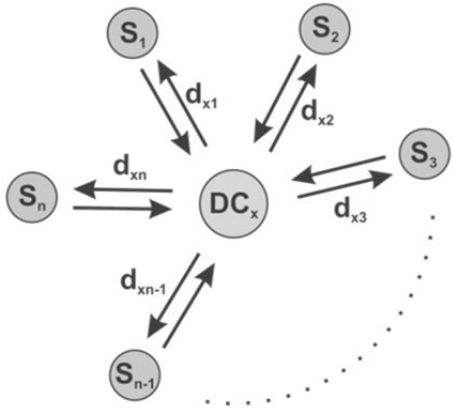


Figure 95 – Worst option for product distribution, each point is served separately

Clarke-Wright's saving algorithm (C-W) (Clarke, Wright 1964; Altinel, Öncan 2005, Straka 2012) is based on an initial arbitrary ordering of the places served. The initial plan for serving places is gradually improved by creating circuits with a larger number of points in a circuit. The criterion of optimality is to minimize the distance *z* (min.) required for the distribution or to maximize savings *u* (max.) in circuit distances.

If two points in one circuit are served from a distribution centre (Figure 96), then the savings *u* of the circuit distance can be calculated as (9.13).

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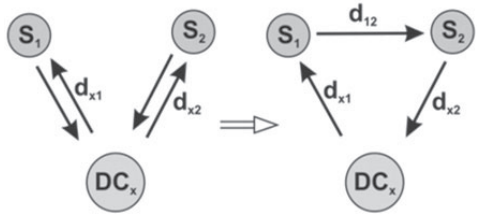


Figure 96 – Optimizing the distribution circuit between two points of a distribution network

$$u_{12} = 2d_{x1} + 2d_{x2} - (d_{x1} + d_{12} + d_{x2}) \tag{9.13}$$
$$u_{12} = d_{x1} + d_{x2} - d_{12}$$

If three points in one circuit are served from a distribution centre (Figure 97), then the savings u of the circuit distance can be calculated as (9.14).

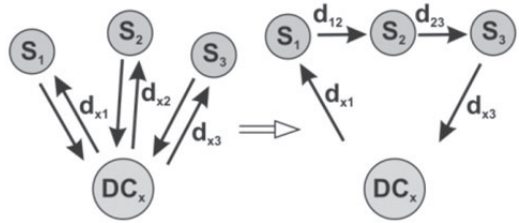


Figure 97 – Optimizing distribution between three points of a distribution network

$$u_{123} = 2d_{x1} + 2d_{x2} + 2d_{x3} - (d_{x1} + d_{12} + d_{23} + d_{x3}) \tag{9.14}$$
$$u_{123} = d_{x1} + 2d_{x2} + d_{x3} - d_{12} - d_{23}$$
$$u_{123} = (d_{x1} + d_{x2} - d_{12}) + (d_{x2} + d_{x3} - d_{23}) = u_{12} + u_{23}$$

Four points in one circuit are served from a distribution centre (Figure 98), so the savings u of the circuit distance can be calculated as (9.15).

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$$z_{1234} = d_{x1} + d_{12} + d_{23} + d_{34} + d_{x4}$$
$$z_{1234} = 2(d_{x1} + d_{x2} + d_{x3} + d_{x4})$$

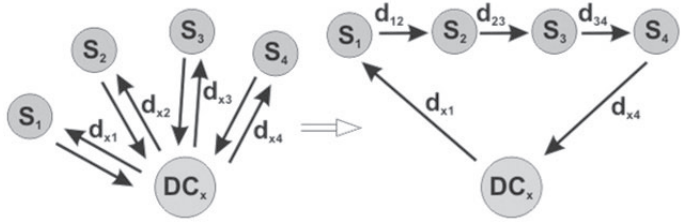


Figure 98 – Optimizing distribution between four points of a distribution network

$$u_{1234} = 2(d_{x1} + d_{x2} + d_{x3} + d_{x4}) - \quad (9.15)$$
$$(d_{x1} + d_{12} + d_{23} + d_{34} + d_{x4})$$
$$u_{1234} = (d_{x1} + d_{x2} - d_{12}) + (d_{x2} + d_{x3} - d_{23}) +$$
$$(d_{x3} + d_{x4} - d_{34}) = u_{12} + u_{23} + u_{34}$$

If *n* points in one circuit are served from a distribution centre (Figure 99), then savings *u* of the circuit distance can be calculated as (9.16).

$$z_{1,K,n} = 2(d_{x1} + d_{x2} + \mathrm{L} + d_{xn})$$
$$z_{1,K,n} = d_{x1} + d_{12} + d_{23} + d_{34} + \mathrm{L} + d_{xn}$$

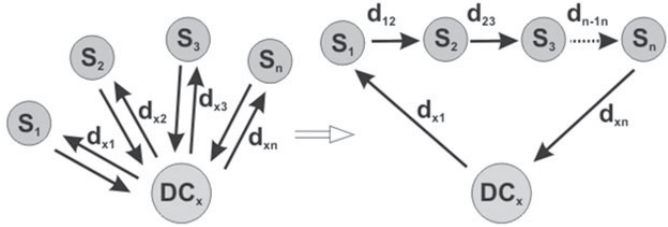


Figure 99 – Optimizing distribution between n points of a distribution network

$$u_{1,K,n} = 2(d_{x1} + d_{x2} + d_{x3} + \mathrm{L} + d_{xn}) - \quad (9.16)$$
$$(d_{x1} + d_{12} + d_{23} + \mathrm{L} + d_{n-1n} + d_{xn})$$
$$u_{1,K,n} = (d_{x1} + d_{x2} - d_{12}) + (d_{x2} + d_{x3} - d_{23}) + \mathrm{L} + (d_{xn-1} + d_{xn} - d_{n-1n}) =$$
$$u_{12} + u_{23} + \mathrm{L} + u_{n-1n}$$

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In creating a circuit of requirements of particular places as part of the application of the algorithm, it is possible to take into account other restrictions e.g. the capacity of the means of transport, working time, time for distribution. The procedure for applying the C-W algorithm is:

- based on a symmetric matrix of distances between points and the real requirements of the points, e.g. the quantity of pallets to be delivered, the volume of transported goods, the number of units,
- the savings matrix u_{ij} is calculated:
  $u_{ij} = d_{xi} + d_{xj} - d_{ij}; \quad i = 1,2,\dots,n-1; \quad j = i+1,\dots,n,$
- the maximum value of savings $max(u_{ij})$ is selected so as to create a possible connection between the centre and the points with the biggest saving, *x-i–j-x*,
- the observance of the points requirements is checked as it can prematurely close a circuit; if there is enough in reserve, the next suitable point is added in this circuit based on the saving in front of *i* or behind *j*, **the created chain must not be split, because it loses the defined saving, points can be added to the edge points, before and after the central point,**
- the next biggest savings are found and the procedure is repeated until all points are included.



Task: Create a product distribution plan for eight customers, whereby the distribution of products starts and ends in a warehouse in Munich. The list of customers, the distances between them and the requirements for transport are given in Table 97. The delivery company has one vehicle at its disposal with a maximum capacity of 100 pallets.

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Table 97 – Distances between particular points and numbers of pallets required

		X	1	2	3	4	5	6	7	8
	Distances between particular points (km)	Munich	P1	P2	P3	P4	P5	P6	P7	P8
1	P1	85	0	156	43	31	115	76	64	27
2	P2	86	156	0	169	165	129	87	121	131
3	P3	129	43	169	0	72	156	83	43	68
4	P4	61	31	165	72	0	88	81	96	36
5	P5	28	115	129	156	88	0	69	118	94
6	P6	42	76	87	83	81	69	0	59	49
7	P7	88	64	121	43	96	118	59	0	62
8	P8	67	27	131	68	36	94	49	62	0
X	Munich	0	85	86	129	61	28	42	88	67
	Number of pallets required		25	55	70	45	35	20	60	40

1) Quantification of the worst product distribution option (distribution network type – star, Figure 100):

$$z = 2\sum_{j=1}^{8} d_{xj} = 2(85+86+129+61+28+42+88+67) = 2\times 586 = 1172 \text{ km}.$$

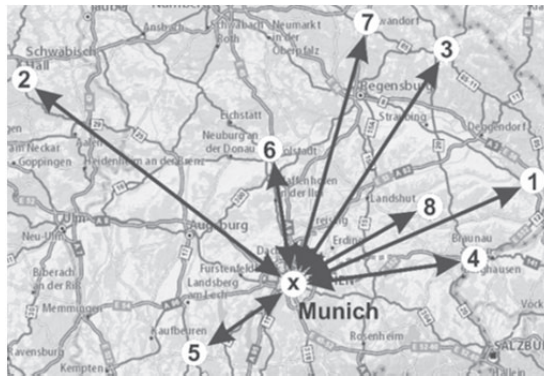


Figure 100 – Graphical representation of the worst product distribution option, the star – type distribution network

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2) Calculation of the savings matrix (Table 98) according to the formula

$u_{ij} = d_{xi} + d_{xj} - d_{ij}$

$i = 1,2, \dots, n-1; j = i+1, \dots, n.$

u_{12} = 85+86-156 = 15;	u_{13} = 85+129-43 = 171;
u_{14} = 85+61-31 = 115;	u_{15} = 85+28-115 = -2;
u_{16} = 85+42-76 = 51;	u_{17} = 85+88-64 = 109;
u_{18} = 85+67-27 = 125;	
u_{23} = 86+129-169 = 46;	u_{24} = 86+61-165 = -18;
u_{25} = 86+28-129 = -15;	u_{26} = 86+42-87 = 41;
u_{27} = 86+88-121 = 53;	u_{28} = 86+67-131 = 22;
u_{34} = 129+61-72 = 118;	u_{35} = 129+28-156 = 1;
u_{36} = 129+42-83 = 88;	u_{37} = 129+88-43 = 174;
u_{38} = 129+67-68 = 128;	
u_{45} = 61+28-88 = 1;	u_{46} = 61+42-81 = 22;
u_{47} = 61+88-96 = 53;	u_{48} = 61+67-36 = 92;
u_{56} = 28+42-69 = 1;	u_{57} = 28+88-118 = -2;
u_{58} = 28+67-94 = 1;	
u_{67} = 42+88-59 = 71;	u_{68} = 42+67-49 = 60;
u_{78} = 88+67-62 = 93;	

Table 98 – Top triangle matrix of savings between particular points

		1	2	3	4	5	6	7	8
	Matrix of savings (km)	P1	P2	P3	P4	P5	P6	P7	P8
1	P1	-	15	171	115	-2	51	109	125
2	P2		-	46	-18	-15	41	53	22
3	P3			-	118	1	88	174	128
4	P4				-	1	22	53	92
5	P5					-	1	-2	1
6	P6						-	71	60
7	P7							-	93
8	P8								-

3) Ordering of the savings from the largest to the smallest and the associated connections (Table 99).

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Table 99 – List of savings between the centre x and two points, ordered from the largest to the smallest

Connection	Savings	Connection	Savings
x-3-7-x (x-7-3-x)	174	x-1-6-x (x-6-1-x)	51
x-1-3-x (x-3-1-x)	171	x-2-3-x (x-3-2-x)	46
x-3-8-x (x-8-3-x)	128	x-2-6-x (x-6-2-x)	41
x-1-8-x (x-8-1-x)	125	x-2-8-x (x-8-2-x)	22
x-3-4-x (x-4-3-x)	118	x-4-6-x (x-6-4-x)	22
x-1-4-x (x-4-1-x)	115	x-1-2-x (x-2-1-x)	15
x-1-7-x (x-7-1-x)	109	x-3-5-x (x-5-3-x)	1
x-7-8-x (x-8-7-x)	93	x-4-5-x (x-5-4-x)	1
x-4-8-x (x-8-4-x)	92	x-5-6-x (x-6-5-x)	1
x-3-6-x (x-6-3-x)	88	x-5-8-x (x-8-5-x)	1
x-6-7-x (x-7-6-x)	71	x-1-5-x (x-5-1-x)	-2
x-6-8-x (x-8-6-x)	60	x-5-7-x (x-7-5-x)	-2
x-2-7-x (x-7-2-x)	53	x-2-5-x (x-5-2-x)	-15
x-4-7-x (x-7-4-x)	53	x-2-4-x (x-4-2-x)	-18

4) Proposal of circuits
   The proposal of circuits is based on Table 100. According to the connection of points with the greatest unused savings, the sum of pallets which need to be delivered in a given circuit is always checked against the capacity of the means of transport.

The biggest saving is in distribution from the centre *x* to point 3, point 7 and back to the centre *x*. The total amount of pallets to be transported is 130, i.e. 30 more than the capacity of the means of transport. This results in an invalid connection.

The second biggest saving is in the *x–1–3–x* circuit, the number of pallets to be transported is 95, which suits the capacity of the vehicle. As nothing more can be inserted into the reserve of 5 pallets, this connection creates the first proposed circuit, i.e. Munich–P1–P3–Munich.

The next saving in order is the connection *x–3–8–x*. As point 3, P3, is already included in the previous circuit, it is not possible to create a circuit from this connection.

The next suitable connection is *x–7–8–x*, i.e. Munich–P7–P8–Munich, which requires the transport of 100 pallets, which will maximize the

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capacity of the means of transport. This connection creates the second proposed circuit.

The third suitable circuit is *x–2–6–x*, i.e. the connection Munich–P2–P6–Munich. The points in the circuit require 75 pallets to be transported, and because there is no point to be served with the free space of 25 pallets, this circuit is the third suitable connection.

The fourth and last circuit is the *x–4–5–x*, i.e. Munich–P4–P5–Munich, which requires the transport of 80 pallets.

Table 100 – Definition of suitable circuits when using the connection with the biggest savings to distribute material and to stay within the capacity of the means of transport

Connection	Savings	Pallets		Connection	Savings	Pallets	
x-3-7-x (x-7-3-x)	174	130		x-1-6-x (x-6-1-x)	51	occupied	
x-1-3-x (x-3-1-x)	171	95	Suitable	x-2-3-x (x-3-2-x)	46	occupied	
x-3-8-x (x-8-3-x)	128	occupied		x-2-6-x (x-6-2-x)	41	75	Suitable
x-1-8-x (x-8-1-x)	125	occupied		x-2-8-x (x-8-2-x)	22	occupied	
x-3-4-x (x-4-3-x)	118	occupied		x-4-6-x (x-6-4-x)	22	occupied	
x-1-4-x (x-4-1-x)	115	occupied		x-1-2-x (x-2-1-x)	15	occupied	
x-1-7-x (x-7-1-x)	109	occupied		x-3-5-x (x-5-3-x)	1	occupied	
x-7-8-x (x-8-7-x)	93	100	Suitable	x-4-5-x (x-5-4-x)	1	80	Suitable
x-4-8-x (x-8-4-x)	92	occupied		x-5-6-x (x-6-5-x)	1	occupied	
x-3-6-x (x-6-3-x)	88	occupied		x-5-8-x (x-8-5-x)	1	occupied	
x-6-7-x (x-7-6-x)	71	occupied		x-1-5-x (x-5-1-x)	-2	unsuitable	
x-6-8-x (x-8-6-x)	60	occupied		x-5-7-x (x-7-5-x)	-2	unsuitable	
x-2-7-x (x-7-2-x)	53	occupied		x-2-5-x (x-5-2-x)	-15	unsuitable	
x-4-7-x (x-7-4-x)	53	occupied		x-2-4-x (x-4-2-x)	-18	unsuitable	

All locations have been integrated into the circuits and therefore circuit creation ends. Total savings against the worst option (the star distribution network) remain to be quantified (Table 101).

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Table 101 – Defining suitable circuits and quantifying the total savings against the worst option

	Definition of suitable circuits			km
Circuit 1	Munich-P1-P3-Munich	X-1-3-X	85+43+129	257
Circuit 2	Munich-P7-P8-Munich	X-7-8-X	88+62+67	217
Circuit 3	Munich-P2-P6-Munich	X-2-6-X	86+87+42	215
Circuit 4	Munich-P4-P5-Munich	X-4-5-X	61+88+28	177
		SUM		866
		Worst option		1172
		Total saving		306

The results show that the distribution will be implemented in four circuits (Figure 101), which will form a flower distribution network with a maximum route length of 866 kilometres. The total savings are 306 kilometres against the worst option.

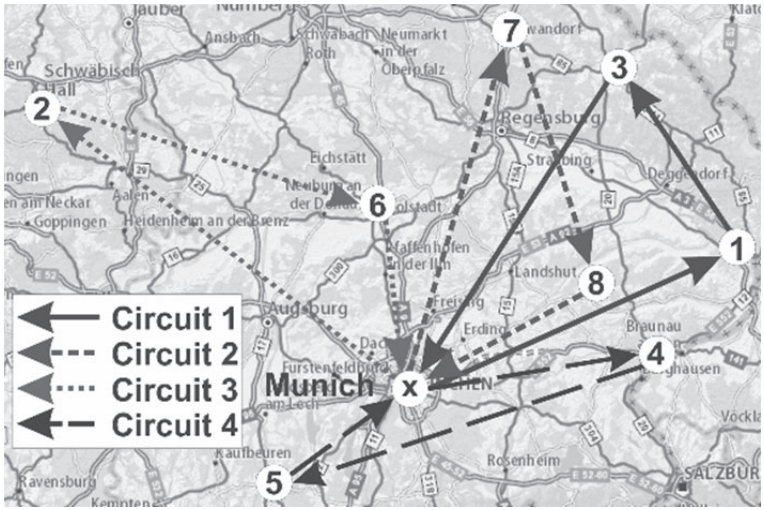


Figure 101 – Graphical representation of the proposed distribution network, a distribution network of the flower type

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Task: Create a product distribution plan for ten customers using Clark-Wright's saving algorithm. Distribution of products will start and end in a warehouse located in the town of Zvolen. The list of customers, the distances between them and the transport requirements are given in Table 102. The company delivering the goods has two means of transport with the following maximum capacities: truck I – 100 pallets and truck II – 150 pallets.

Table 102 – Distances between particular points and number of pallets required

		Xi	Yi	X	1	2	3	4	5	6	7	8	9	10
	Distances between particular points (km)			PX	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	P1	17	4	81	0	60	65	26	138	184	178	158	143	102
2	P2	12	10	24		0	52	34	94	127	121	101	86	45
3	P3	15	17	62			0	74	134	158	153	133	118	41
4	P4	15	3	55				0	112	158	152	132	117	76
5	P5	5	1	72					0	45	75	69	86	93
6	P6	1	2	103						0	35	55	85	117
7	P7	2	10	97							0	20	50	111
8	P8	4	11	77								0	30	92
9	P9	6	16	62									0	92
10	P10	10	15	21										0
X	PX	10	10	0	81	24	62	55	72	103	97	77	62	21
	Number of pallets required				35	60	55	40	20	15	45	70	65	80

Solution:

1) Plot the point location in a plane and quantify the worst product distribution option (the star-type distribution network, Figure 102)

$$z = 2\sum_{j=1}^{10} d_{xj} = 2(81+24+62+55+72+103+97+77+62+21) =$$

$$2\times 654 = 1308 \text{ km}.$$

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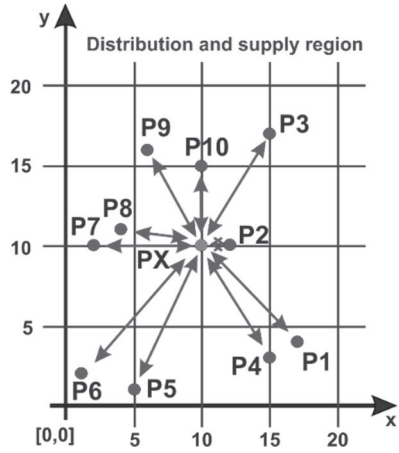


Figure 102 – Graphical representation of the worst product distribution option, the star-type distribution network

2) Calculation of the savings matrix (Table 103) as per the formula $u_{ij} = d_{xi} + d_{xj} - d_{ij}; i = 1, 2, \ldots, m-1; j = i+1, \ldots, n.$

Table 103 – Top triangle matrix of savings between particular points

		Xi	Yi	X	1	2	3	4	5	6	7	8	9	10
	Matrix of savings (km)			PX	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	P1	17	4	81	-	45	78	110	15	0	0	0	0	0
2	P2	12	10	24		-	34	45	2	0	0	0	0	0
3	P3	15	17	62			-	43	0	7	6	6	6	42
4	P4	15	3	55				-	15	0	0	0	0	0
5	P5	5	1	72					-	130	94	80	48	0
6	P6	1	2	103						-	165	125	80	7
7	P7	2	10	97							-	154	109	7
8	P8	4	11	77								-	109	6
9	P9	6	16	62									-	9
10	P10	10	15	21										-
X	PX	10	10	0	81	24	62	55	72	103	97	77	62	21
	Number of pallets required				35	60	55	40	20	15	45	70	65	80

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3) Ordering the savings from the largest to the smallest and the associated connections (Table 104).

Table 104 – List of savings between the centre x and two points, ordered from the largest to the smallest

Connection	Savings	Connection	Savings	Connection	Savings
x-6-7-x (x-7-6-x)	165	x-3-10-x (x-10-3-x)	42	x-1-9-x (x-9-1-x)	0
x-7-8-x (x-8-7-x)	154	x-2-3-x (x-3-2-x)	34	x-1-10-x (x-10-1-x)	0
x-5-6-x (x-6-5-x)	130	x-1-5-x (x-5-1-x)	15	x-2-6-x (x-6-2-x)	0
x-6-8-x (x-8-6-x)	125	x-4-5-x (x-5-4-x)	15	x-2-7-x (x-7-2-x)	0
x-1-4-x (x-4-1-x)	110	x-3-6-x (x-6-3-x)	7	x-2-8-x (x-8-2-x)	0
x-7-9-x (x-9-7-x)	109	x-6-10-x (x-10-6-x)	7	x-2-9-x (x-9-2-x)	0
x-8-9-x (x-9-8-x)	109	x-7-10-x (x-10-7-x)	7	x-2-10-x (x-10-2-x)	0
x-5-7-x (x-7-5-x)	94	x-3-7-x (x-7-3-x)	6	x-3-5-x (x-5-3-x)	0
x-5-8-x (x-8-5-x)	80	x-3-8-x (x-8-3-x)	6	x-4-6-x (x-6-4-x)	0
x-6-9-x (x-9-6-x)	80	x-3-9-x (x-9-3-x)	6	x-4-7-x (x-7-4-x)	0
x-1-3-x (x-3-1-x)	78	x-8-10-x (x-10-8-x)	6	x-4-8-x (x-8-4-x)	0
x-5-9-x (x-9-5-x)	48	x-2-5-x (x-5-2-x)	2	x-4-9-x (x-9-4-x)	0
x-1-2-x (x-2-1-x)	45	x-1-6-x (x-6-1-x)	0	x-4-10-x (x-10-4-x)	0
x-2-4-x (x-4-2-x)	45	x-1-7-x (x-7-1-x)	0	x-5-10-x (x-10-5-x)	0
x-3-4-x (x-4-3-x)	43	x-1-8-x (x-8-1-x)	0	x-9-10-x (x-10-9-x)	-9

4) Proposal of circuits
The proposal of circuits is based on Table 104. Based on connecting points with the greatest unused savings, the sum of pallets which need to be delivered in a given circuit is always checked against the capacity of the means of transport.

The biggest saving is from the distribution centre *x* through point 6, point 7 and back to *x*. The total amount of pallets to be transported is 60, which suits both means of transport in terms of their capacity. This means that this connection is good for now.

The second biggest saving is in the *x–7–8–x* circuit, since point *7* is already connected to point 6, point 8 is attached to the previous pair and a new *x–6–7–8–x* connection is formed. The requirement for the number of pallets to be transported is 130 pieces, which suits the capacity of means of

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transport no. II. There is still a reserve of 20 pallets. The previous *x–6–7–x* connection proposed is no longer valid.

The next saving in the sequence is in the connection *x–5–6–x*. Because point 6 already forms a connection in the *x–6–7–8–x* chain, point 5 can be added to the previous triplet and the new connection *x–5–6–7–8–x* is created. **The rule is that any previous chain cannot be torn apart, but a new point can only be added to the chain just behind or in front of the central point x**. The requirement for the number of pallets to be transported is 150 pieces, which satisfies the capacity of means of transport II and its capacity is totally used, so it is necessary to start creating a new circuit.

The next saving in sequence is in route *x–6–8–x*. Because both points 6 and 8 already form a connection in the previous chain, it is not possible to create a circuit from that connection. The points are occupied.

Points *1, 2, 3, 4, 9* and *10* still remain.

The next suitable connection is *x–1–4–x*, which requires the transport of 75 pallets, which suits both means of transport. This connection forms the basis for the second distribution circuit. According to the savings list table (Table 104), additional points are occupied and the next suitable point is the connection *x–1–3–x*. Because point *1* is already connected to point *4*, point *3* is attached to the previous pair and the new connection *x–3–1–4–x* is created. The requirement for the number of pallets to be transported is 130 units, which satisfies the capacity of means of transport II. There is still a reserve of 20 pallets but this is not enough for any point. The previous proposed connection *x–1–4–x* is not valid anymore and the connection *x–3–1–4–x* forms the second distribution circuit.

The remaining points *2, 9* and *10* are not included. Connections created from the remaining points have zero savings, i.e. the means of transport travels the same number of kilometres as when the points are served separately directly from the centre. In the case of the connection *x–9–10–x*, the distance of the circuit is 9 kilometres worse than separately serving the points. This connection is absolutely unsuitable. Since points *2, 9* and *10* have zero savings, it is possible to create various solutions for the same total savings.

Option 1 (Table 105): Points *2, 9* and *10* form separate circuits *x–2–x*, *x–9–x* and *x–10–x* circuits. They are served by means of transport I in three trips.

Option 2 (Table 106): It is possible to join point *2* with point *9* and point *10* is served separately. Zero kilometres are saved by this connection, but it is within the capacity for means of transport II. Thus, no kilometres are saved but a truck trip is saved, which is also not negligible.

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Option 3 (Table 107): It is possible to join point *2* with point *10* and point *9* is served separately Zero kilometres are saved by this connection, but it is within the capacity for means of transport II. Just as in option 2, one truck trip is saved.

Table 105 – Definition of suitable circuits using the most cost-effective connection for distribution of material while staying within the capacity constraint of the means of transport under Option 1

Connection	Savings	Pallets		Means of transport
X-6-7-X	165	60		
X-6-7-8-X	165+154	130		
X-5-6-7-8-X	130+319	150	Suitable	truck II.
X-6-8-X	125	occupied		
X-1-4-X	110	75		
X-7-9-X	109	occupied		
X-8-9-X	109	occupied		
X-5-7-X	94	occupied		
X-5-8-X	80	occupied		
X-6-9-X	80	occupied		
X-3-1-4-X	78+110	130	Suitable	truck II.
X-5-9-X	48	occupied		
X-2-X	0	60	Suitable	truck I.
X-9-X	0	65	Suitable	truck I.
X-10-X	0	80	Suitable	truck I.
X-9-10-X	-9	unsuitable		

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Table 106 – Definition of suitable circuits using the most cost-effective connection for the distribution of material while staying within the capacity constraint of the means of transport under Option 2

Connection	Savings	Pallets		Means of transport
X-6-7-X	165	60		
X-6-7-8-X	165+154	130		
X-5-6-7-8-X	130+319	150	Suitable	truck II.
X-6-8-X	125	occupied		
X-1-4-X	110	75		
X-7-9-X	109	occupied		
X-8-9-X	109	occupied		
X-5-7-X	94	occupied		
X-5-8-X	80	occupied		
X-6-9-X	80	occupied		
X-3-1-4-X	78+110	130	Suitable	truck II.
X-5-9-X	48	occupied		
X-2-9-X	0	125	Suitable	truck II.
X-10-X	0	80	Suitable	truck I.
X-9-10-X	-9	unsuitable		

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Table 107 – Definition of suitable circuits using the most cost-effective connection for the distribution of material while staying within the capacity constraint of the means of transport under Option 3

Connection	Savings	Pallets		Means of transport
X-6-7-X	165	60		
X-6-7-8-X	165+154	130		
X-5-6-7-8-X	130+319	150	Suitable	truck II.
X-6-8-X	125	occupied		
X-1-4-X	110	75		
X-7-9-X	109	occupied		
X-8-9-X	109	occupied		
X-5-7-X	94	occupied		
X-5-8-X	80	occupied		
X-6-9-X	80	occupied		
X-3-1-4-X	78+110	130	Suitable	truck II.
X-5-9-X	48	occupied		
X-2-10-X	0	140	Suitable	truck II.
X-9-X	0	65	Suitable	truck I.
X-9-10-X	-9	unsuitable		

5) Calculation of the total savings
All places have been integrated into the circuits and therefore circuit creation ends. The total savings must still be quantified against the worst option, which is the star distribution network. Total savings are the same for all three options because of zero savings at points *2, 9* and *10* (Table 108, Table 109, Table 110).

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Table 108 – Definition of suitable circuits and quantification of total savings, Option 1

	Definition of suitable circuits:	Option 1		km
Circuit 1	PX-P5-P6-P7-P8-PX	X-5-6-7-8-X	72+45+35+20+77	249
Circuit 2	PX-P3-P1-P4-PX	X-3-1-4-X	62+65+26+55	208
Circuit 3	PX-P2-PX	X-2-X	24+24	48
Circuit 4	PX-P9-PX	X-9-X	62+62	124
Circuit 5	PX-P10-PX	X-10-X	21+21	42
			SUM	671
			Worst option	1 308
			Total saving	637

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Table 109 – Definition of suitable circuits and quantification of total savings, Option 2

	Definition of suitable circuits:	Option 2		km
Circuit 1	PX-P5-P6-P7-P8-PX	X-5-6-7-8-X	72+45+35+20+77	249
Circuit 2	PX-P3-P1-P4-PX	X-3-1-4-X	62+65+26+55	208
Circuit 3	PX-P2-P9-PX	X-2-9-X	24+86+62	172
Circuit 4	PX-P10-PX	X-10-X	21+21	42
		SUM		671
		Worst option		1 308
		Total saving		637

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Table 110 – Definition of suitable circuits and quantification of total savings, Option 3

	Definition of suitable circuits:	Option 3		km
Circuit 1	PX-P5-P6-P7-P8-PX	X-5-6-7-8-X	72+45+35+20+77	249
Circuit 2	PX-P3-P1-P4-PX	X-3-1-4-X	62+65+26+55	208
Circuit 3	PX-P2-P10-PX	X-2-10-X	24+45+21	90
Circuit 4	PX-P9-PX	X-9-X	62+62	124
		SUM		671
		Worst option		1 308
		Total saving		637

The results show that the distribution will be implemented in four or five circuits (Figure 103) that create a flower-type distribution network with a maximum route length of 671 kilometres. The total savings are 637 kilometres compared to the worst option.

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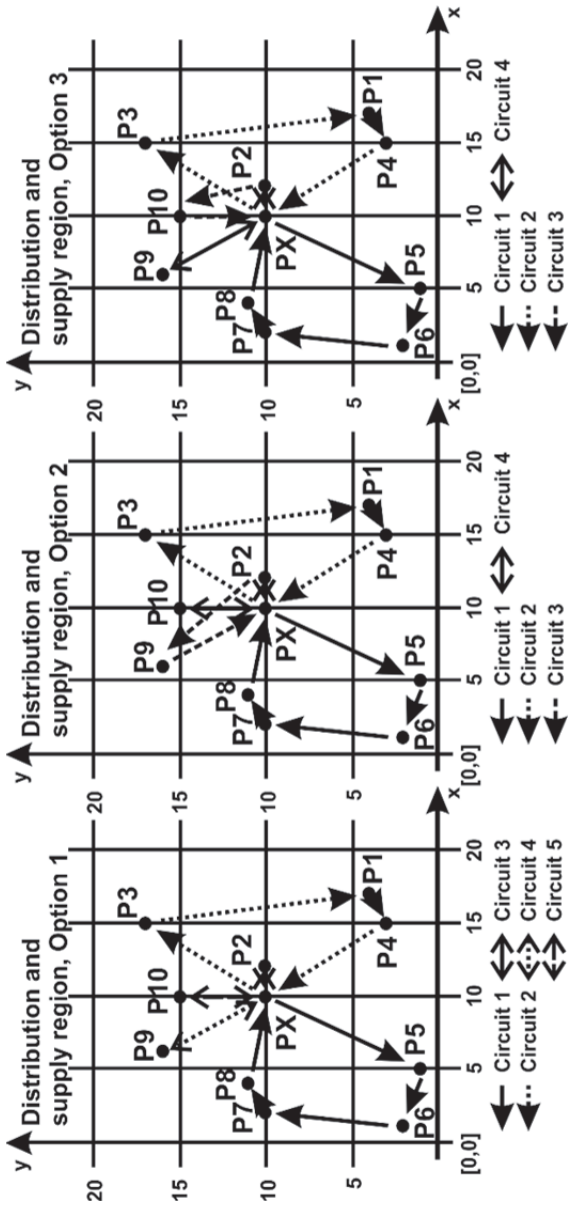


Figure 103 – Graphical representation of the proposed distribution network, which is a flower-type distribution network

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CHAPTER TEN

DIMENSIONING ITEMS IN DISTRIBUTION NETWORKS

What you will learn: In addition to mathematical and analytical approaches, it is also possible to use approaches based on computer simulation and to use human experience in practice, i.e. to use heuristics to solve problems in distribution logistics. This chapter looks at tasks and solutions for dimensioning items in distribution networks using mathematical-analytical apparatus, computer simulation and heuristic options.

Basic terms: capacity, relation, simulation, heuristics.

It is important to define the capacity of distribution network items i.e. to specify their dimensions in relation to defined inputs and outputs, in and out of the individual items of the distribution system and with due regard to anticipated development in future periods, for the purpose of designing a distribution network in addition to optimizing distribution routes, locations of warehouses and companies, traffic reports, selection of carriers, forwarding agents and vehicles and also for the design of the right information system (Straka 2007).

In an existing distribution system, it is necessary to address the optimization of individual items and parts of them. If a company builds a new distribution system, it is important to design and dimension each item.

If it is assumed that the capacity of the distribution source is influenced by the technologies used, the supply and demand in the market, then it is necessary to design capacities of distribution centres in order for the market to function smoothly.

The aim of dimensioning the distribution network items is to design an optimal distribution system with its input capacity into nodes, with its output capacity away from nodes and with capacities which are associated directly with nodes in the distribution network. The point of dimensioning distribution centres and warehouses is to specify volumes or quantities of

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goods and materials in order for the market to function between two sequential deliveries, i.e. coverage of customer requirements and storage costs should be efficient.

Several approaches can be chosen for solutions defining the capacity of distribution centres:

- mathematics,
- simulation,
- heuristics.

A mathematical solution provides information, i.e. its results, which are general for the model used. The functions in this solution are valid for different input data. It is also possible directly to find the input values that can be used to achieve the optimum.

The aim of simulation is to obtain information about the system and its items under an assumed or defined change in the properties of system items and the connections between them. The results of the simulation provide information about the system examined and its items based on the defined parameters (Straka 2006).

A heuristic method is a method in which a heuristic approach is used, i.e. unlike precise mathematical modelling methods it presupposes the modelling of principles used by a human in processing information at various stages of their activities and in solving various tasks which can be only solved by heuristic models. Heuristic and mathematical methods are not in contradiction with each other and are not mutually exclusive. A heuristic procedure often becomes the most appropriate method for practical use due to its repeated use and its basis in accurate mathematical description of the elementary information processes of decision-making, (Reeves 1993).

To determine the dimensioning of the items of the distribution network, it is appropriate to use the following procedure:

- determine the parameters of the distribution network,
  - the number of network nodes, the location of the distribution source, distribution centres, warehouses, consumers, the capacity of input into nodes and the capacity of output away from nodes, the technical equipment of nodes, the capacity of the means of transport, the frequency of supply,
- develop an analytical simulation model, or use a heuristic approach for dimensioning the nodes of the distribution network,
  - creation of an analytical model, simulation model in simulation programs (Tecnomatix, GPSS, EXTENDSIM, Simul8,

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Witness, Visual Components, ...), and a heuristic approach based on the known limitations from practice,

- optimization of the distribution network nodes on the basis of the modelling results and taking into consideration the amounts of insurance reserves and future (planned) developments,
- define the capacity of nodes and the related dimensions of warehouses and distribution centres according to known relationships and using modelling results.

In dimensioning warehouses and distribution centres, the point's position within the system is important. A warehouse or distribution centre which is part of the distribution network of the parent company has a different position to a warehouse or a distribution centre which is a separate legal entity.

A distribution point that is a part of the company and is part of its distribution system is subordinated to the global optimization of the nodes of the distribution network based on the results obtained from modelling, taking into consideration the quantities of base stocks and future (planned) developments, optimizing the firm's priorities to satisfy the requirements of the parent organization.

The aim of a distribution point which is a separate legal entity is to satisfy its own goals of global optimization, therefore it prefers economically advantageous clients and it can even refuse some companies' requests (Straka 2007).

Parameters, that affect the sizing of warehouses and distribution centres are determined by external and internal influences and criteria.

The external criteria are:

- the number of entry routes (customers),
- the frequency of supplies,
- the quantity of goods supplied,
- the number of exit routes (customers),
- the frequency of demands,
- the quantity of goods demanded,
- the mode of transport to and from the warehouse,
- the means of transport.

The internal criteria are:

- the time (duration) of storage of goods,
- the type, sort and size of goods stored,

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- the technical equipment of the warehouses,
- the number of service personnel,
- the size of the area that is available to build a warehouse,
- the mode of in-house transport in the warehouse,
- the character and type of the warehouse (finished goods, semi-products, assembly warehouse, warehouse for maturation of goods, open / closed warehouse, warehouse for special use).

Warehousing and inventory management are intended to:

- receive, control and record incoming shipments, materials and goods,
- ensure smooth receipt and shipping of material and goods,
- provide technical control at input, acceptance of material and related documents (certificates, attestations, receipts),
- process complaints for identified defects and differences,
- provide for the safe assessment and storage of materials under applicable rules, regulations and standards throughout the whole storage period,
- maintain discipline and cleanliness in the warehouses,
- divide, sort, accumulate and prepare materials in the required quantity, quality, time and place in reference to the requirements of customers,
- keep accurate records of goods, perform inventory checking on a regular basis.

10.1 Mathematical approach to Defining the Capacity of Distribution Warehouses

10.1.1 Two-stage Transport Tasks, Linkage Type m × r × n

In reality, some situations very often occur where distribution of materials, goods and finished products is not performed directly to the final consumer but it is implemented through the next stage of the distribution chain, e.g. a warehouse, a distribution centre, a logistics centre, a wholesaler or some other distribution item. This state of implementation of distribution can be schematically described as linkage between *m* producers through *r* warehouses to *n* customers or consumers.

A solution to this task is sought by the application of mathematical models to determine which is best for the defined objective. A

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mathematical function which expresses the solution of defined objective, is a maximization or minimization one.

It is appropriate to comply with the following procedure when making mathematical models (Janacek 2003):

- analyse and define the criteria on which the decision depends (profit, costs, quantity, time, capacity, length, ...),
- create an objective function that takes the defined criteria into account,
- analyse and define limits which are expressed using constants and functions,
- limits have the form of equations and inequalities,
- try to simplify the model developed by the expression of some conditions and variables within other conditions and variables.

Determination of the capacity of a distribution node (buffer storage) can be classified as a separate type of distribution task where satisfying the known requirements of customers is performed through the second level of the distribution network, from buffer storage places (Figure 20). The aim is to minimize the costs for distribution and storage and define the optimal capacity of nodes. In general, the model uses the variables:

$D_1, D_2, D_3, \ldots, D_m$ – suppliers of raw materials,
$a_1, a_2, a_3, \ldots, a_m$ – capacities of suppliers,
m – number of suppliers,
$K_1, K_2, K_3, \ldots, K_r$ – buffer storage,
$e_1, e_2, e_3, \ldots, e_r$ – capacities of buffer storage,
r – number of buffer storage places,
$S_1, S_2, S_3, \ldots, S_n$ – consumers of raw materials,
$b_1, b_2, b_3, \ldots, b_n$ – capacity requirements of consumers,
n – number of consumers,
x_{ip} – amount of material transported from the i^{th} supplier to the place of the p^{th} buffer storage,
y_{pj} – quantity of material from the p^{th} buffer storage to the j^{th} customer,
c_{1ip} – costs 1 – distribution of material from the i^{th} supplier to the p^{th} place of buffer storage,
c_{2pj} – costs 2 – distribution of material from the p^{th} buffer storage to the j^{th} customer.

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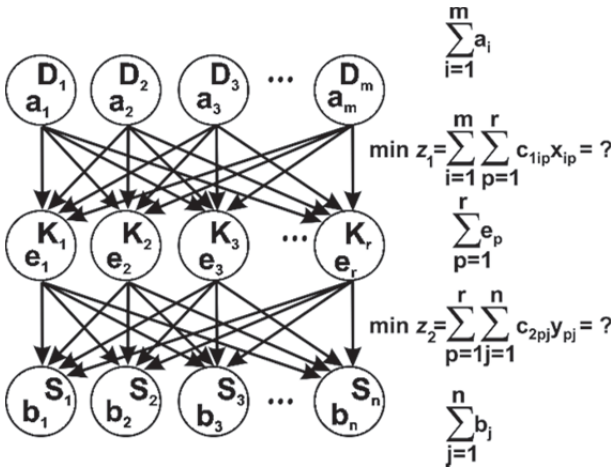


Figure 104 – The general view of links of consumers with suppliers through buffer storage

Formulation of the two-stage transport task depends on the capacities of suppliers, the capacity of buffer storage and the capacity requirements of customers. In order to solve it, the task can be generally defined in such a way that it is necessary to find such values of the variables x_{ip} and y_{pj} at which the objective function z is minimized (10.1) (Brezina 1999, Brezina 2002).

$$\min z = \min z_1 + \min z_2 = \sum_{i=1}^{m}\sum_{p=1}^{r} c_{1ip}x_{ip} + \sum_{p=1}^{r}\sum_{j=1}^{n} c_{2pj}y_{pj} \tag{10.1}$$

with limits $\sum_{p=1}^{r} x_{ip} \le a_i$ for $i=1, 2, \ldots, m$ (10.2)

$$\sum_{i=1}^{m} x_{ip} \le e_p \text{ for } p=1, 2, \ldots, r \tag{10.3}$$

$$\sum_{j=1}^{n} y_{pj} \le e_p \text{ for } p=1, 2, \ldots, r \tag{10.4}$$

$$\sum_{p=1}^{r} y_{pj} \le b_j \text{ for } j=1, 2, \ldots, n \tag{10.5}$$

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$$\sum_{i=1}^{m} x_{ip} = \sum_{j=1}^{n} y_{pj} \text{ for } p=1, 2, \ldots, r \tag{10.6}$$

$$x_{ip} \geq 0 \text{ where } i=1, 2, \ldots, m; p=1, 2, \ldots, r \tag{10.7}$$

$$y_{pj} \geq 0 \text{ where } p=1, 2, \ldots, r; j=1, 2, \ldots, n. \tag{10.8}$$

Optimal values which are needed for transport from sources through buffer storage to consumers can be obtained by specifying the values of variables x_{ip} (10.2), (10.3) and y_{pj} (10.4), (10.5), by keeping the conditions (10.6), (10.7) and (10.8). But a problem may occur with the capacity limits of distribution on the part of a supplier to buffer storage or on the part of a purchaser from buffer storage, which leads to the introduction of further limits into the system of equations and inequalities.

Two-stage transport tasks can be solved as two separate transport tasks, by any of the methods of the basic solution (the NW Corner method, the index method, Vogel's approximation method), or by methods that lead to the optimal solution (Brezina 2002). The first stage in solving separately as simple transport tasks is to solve the part involving delivery of goods from suppliers to buffer storage and the second stage is to solve the simple transport task for the delivery of the goods from buffer storage to consumers. In general, for a non-degenerate solution of the primary single-stage task of transport there exist $(m + n - 1)$ completed fields in the table of solutions. For dual variables there are $m + n$ positions completed in the table of solutions. This means that there is one more dual variable than there are equations, and therefore one single dual variable can be freely chosen. The transport task is balanced if it holds that (10.9) (Brezina 2002).

$$\sum_{i=1}^{m} a_i = \sum_{p=1}^{r} e_p = \sum_{j=1}^{n} b_j \tag{10.9}$$

It is possible to define a dual task (10.10) for the primary defined two-stage transport task (10.1), where the objective function z' is needs to be maximized (Brezina 2002) with limits (10.11, 10.12, 10.13).

$$\max z' = \sum_{i=1}^{m} a_i u_i + \sum_{p=1}^{r} e_p \left(v_p + v_p^*\right) + \sum_{j=1}^{n} b_j w_j \tag{10.10}$$

with limits

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$$u_i + v_p \leq c_{1ip} \quad \text{for } i=1, 2, \ldots, m;\ p=1, 2, \ldots, r \tag{10.11}$$

$$v_p + v_p^* \leq 0 \quad \text{for } p=1, 2, \ldots, r \tag{10.12}$$

$$v_p^* + w_j \leq c_{2jp} \quad \text{for } j=1, 2, \ldots, n;\ p=1, 2, \ldots, r \tag{10.13}$$

If the smallest requirements from all the requirements, i.e. suppliers, customers and buffer storage are those of the customers (10.14):

$$u_i \leq 0 \text{ for } i=1, 2, \ldots, m. \tag{10.14}$$

If the smallest requirements from all the requirements, i.e. suppliers, customers and buffer storage are those of the suppliers (10.15):

$$w_j \leq 0 \text{ for } j=1, 2, \ldots, n. \tag{10.15}$$

The solution of the task, as in many cases, will again depend on Table 111.

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Table 111 – Table of the two-stage transport task and its variables

	Suppliers	v_1		v_2		v_3		...	v_r		Capacity of suppliers
		Buffer stores									
		K_1		K_2		K_3		...	K_r		
u_1	D_1	x_{11}	$c1_{11}$	x_{12}	$c1_{12}$	x_{13}	$c1_{13}$	...	x_{1r}	$c1_{1r}$	a_1
u_2	D_2	x_{21}	$c1_{21}$	x_{22}	$c1_{22}$	x_{23}	$c1_{23}$	...	x_{2r}	$c1_{2r}$	a_2
u_3	D_3	x_{31}	$c1_{31}$	x_{32}	$c1_{32}$	x_{33}	$c1_{32}$	...	x_{3r}	$c1_{3r}$	a_3
⋮	⋮	⋮		⋮		⋮			⋮		⋮
u_m	D_m	x_{m1}	$c1_{m1}$	x_{m2}	$c1_{m2}$	x_{m3}	$c1_{m2}$	...	x_{mr}	$c1_{mr}$	a_m
	Capacity of buffer stores	e_1		e_2		e_3		...	e_r		$\sum_{i=1}^{m} a_i = \sum_{y=1}^{r} e_y = ?$ $\sum_{y=1}^{r} e_y = \sum_{j=1}^{n} b_j = ?$
w_1	S_1	y_{11}	$c2_{11}$	y_{12}	$c2_{12}$	y_{13}	$c2_{13}$	...	y_{1r}	$c2_{1r}$	b_1
w_2	S_2	y_{21}	$c2_{21}$	y_{22}	$c2_{22}$	y_{23}	$c2_{23}$	...	y_{2r}	$c2_{2r}$	b_2
w_3	S_3	y_{31}	$c2_{31}$	y_{32}	$c2_{32}$	y_{33}	$c2_{32}$	...	y_{3r}	$c2_{3r}$	b_3
⋮	⋮	⋮		⋮		⋮			⋮		⋮
w_n	S_n	y_{n1}	$c2_{n1}$	y_{n2}	$c2_{n2}$	y_{n3}	$c2_{n2}$	...	y_{nr}	$c2_{nr}$	b_n
	Consumers	K_1		K_2		K_3		...	K_r		Consumer requirements
		Buffer stores									
		v^*_1		v^*_2		v^*_3		...	v^*_r		

10.1.2 X-stage Transport Tasks, Linkage Type m × r × n × … × z

X-stage transport tasks represent a real model of distribution of products, goods and materials. The sequence of distribution gradually passes from producers, through several storage levels to consumers, i.e. it represents a chain of production, distributor, wholesale, retail and consumer. An X-stage transport task captures distribution problems between manufacturers, suppliers and customers using warehouses located within the system at different organizational levels (Figure 105). Within a unit of transported material, it is possible to simplify the storage costs, or

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to simplify even more so that the storage costs are not taken into account at all. X-stage transport tasks solve **a relation of type m × r × n × … × z, from many, through many, through many, … to many**. In general, X-stage transport tasks can be expressed using the following variables:

$D_1, D_2, D_3, \ldots, D_m$ – Suppliers of raw materials,
$a_1, a_2, a_3, \ldots, a_m$ – Capacities of suppliers,
m – Number of suppliers,
$K^1_1, K^1_2, K^1_3, \ldots, K^1_{r1}$ – Buffer stores *1*,
$e^1_1, e^1_2, e^1_3, \ldots, e^1_{r1}$ – Buffer stores' capacity *1*,
$r1$ – Number of buffer stores *1*,
$K^2_1, K^2_2, K^2_3, \ldots, K^2_{r2}$ – Buffer stores *2*,
$e^2_1, e^2_2, e^2_3, \ldots, e^2_{r2}$ – Buffer stores' capacity *2*,
$r2$ – Number of buffer stores *2*, …
$K^x_1, K^x_2, K^x_3, \ldots, K^{x-1}_{rx-1}$ – Buffer stores *x-1*,
$e^x_1, e^x_2, e^x_3, \ldots, e^{x-1}_{rx-1}$ – Buffer stores' capacity *x-1*,
$rx\text{-}1$ – Number of buffer stores *x-1*,
$S_1, S_2, S_3, \ldots, S_n$ – Consumers of raw materials,
$b_1, b_2, b_3, \ldots, b_n$ – Capacities requirements of consumers,
n – Number of consumers,
x^1_{ip1} – Amount of material transported from the i^{th} supplier to the 1^{st} buffer store at level 1,
x^2_{p1p2} – Amount of material transported from the $p_1{}^{st}$ supplier to the 2^{nd} buffer store at level 2,
x^3_{p2p3} – Amount of material transported from $p_2{}^{nd}$ supplier to the 3^{rd} buffer store at level 3, …
$x^x_{px\text{-}1j}$ – Amount of material transported from $p_{x-1}{}^{th}$ supplier to the x^{th} buffer store at level x,
c^1_{ip1} – Costs of material distribution from the i^{th} supplier to the $p_1{}^{st}$ buffer store at level 1,
c^2_{p1p2} – Costs of material distribution from the $p_1{}^{st}$ supplier to the $p_2{}^{nd}$ buffer store at level 2,
c^3_{p2p3} – Costs of material distribution from the $p_2{}^{nd}$ supplier to the $p_3{}^{rd}$ buffer store at level 3, …
$c^x_{px\text{-}1j}$ – Costs of material distribution from the $p_{x-1}{}^{th}$ supplier to the j^{th} buffer store at level x.

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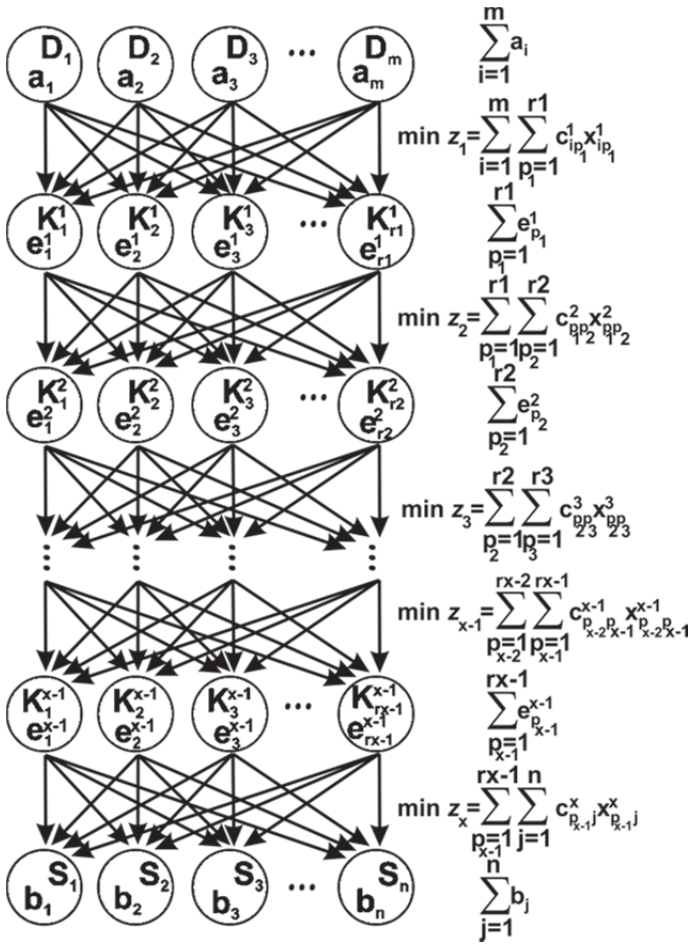


Figure 105 – General view of linkages between consumers and suppliers across several levels of buffer stores

Formulation of an *X*-stage transport task depends on the capacities of suppliers, capacities of several levels of buffer stores and capacity requirements of customers. From the point of view of the solution, a task can be generally defined by the fact that it is necessary to find the values of the variables x^1_{ip1}, x^2_{p1p2}, x^3_{p2p3}, …, $x^x_{px\text{-}1j}$, where the objective function z is minimized (10.16) (Straka 2013).

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$$\min z = \min z_1 + \min z_2 + \mathrm{K} + \min z_x =$$
$$\sum_{i=1}^{m}\sum_{p_1=1}^{r1} c^1_{ip_1} x^1_{ip_1} + \sum_{p_1=1}^{r1}\sum_{p_2=1}^{r2} c^2_{p_1p_2} x^2_{p_1p_2} +$$
$$\sum_{p_2=1}^{r2}\sum_{p_3=1}^{r3} c^3_{p_2p_3} x^3_{p_2p_3} + \mathrm{K} + \sum_{p_{x-1}=1}^{rx-1}\sum_{j=1}^{n} c^x_{p_{x-1}j} x^x_{p_{x-1}j} = \tag{10.16}$$
$$\sum_{i=1}^{m}\sum_{p_1=1}^{r1} c^1_{ip_1} x^1_{ip_1} + \sum_{k=1}^{x-2}\sum_{p_k=1}^{rk}\sum_{p_{k+1}=1}^{rk+1} c^{k+1}_{p_kp_{k+1}} x^{k+1}_{p_kp_{k+1}} + \sum_{p_{x-1}=1}^{rx-1}\sum_{j=1}^{n} c^x_{p_{x-1}j} x^x_{p_{x-1}j}$$

with restrictions

$$\sum_{p_1=1}^{r1} x^1_{ip_1} \le a_i \qquad \text{for } i=1, 2, \ldots, m \tag{10.17}$$

$$\sum_{i=1}^{m} x^1_{ip_1} \le e^1_{p_1} \qquad \text{for } p_1=1, 2, \ldots, r_1 \tag{10.18}$$

$$\sum_{p_2=1}^{r2} x^2_{p_1p_2} \le e^1_{p_1} \qquad \text{for } p_1=1, 2, \ldots, r_1 \tag{10.19}$$

$$\sum_{p_1=1}^{r1} x^2_{p_1p_2} \le e^2_{p_2} \qquad \text{for } p_2=1, 2, \ldots, r_2 \tag{10.20}$$

$$\sum_{p_3=1}^{r3} x^3_{p_2p_3} \le e^2_{p_2} \qquad \text{for } p_2=1, 2, \ldots, r_2 \tag{10.21}$$

$$\sum_{p_2=1}^{r2} x^3_{p_2p_3} \le e^3_{p_3} \qquad \text{for } p_3=1, 2, \ldots, r_3 \tag{10.22}$$

$$\sum_{j=1}^{n} x^x_{p_{x-1}j} \le e^{x-1}_{p_{x-1}} \qquad \text{for } p_{x-1}=1, 2, \ldots, r_{x-1} \tag{10.23}$$

$$\sum_{p_{x-1}=1}^{r_{x-1}} x^x_{p_{x-1}j} \le b_j \qquad \text{for } j=1, 2, \ldots, n \tag{10.24}$$

$$\sum_{i=1}^{m} x^1_{ip_1} = \sum_{p_2=1}^{r2} x^2_{p_1p_2} \qquad \text{for } p_1=1, 2, \ldots, r_1 \tag{10.25}$$

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$$\sum_{p_1=1}^{r1} x^2_{p_1 p_2} = \sum_{p_3=1}^{r3} x^3_{p_2 p_3} \qquad \text{for } p_2=1, 2, \ldots, r_2 \tag{10.26}$$

$$\sum_{p_2=1}^{r2} x^3_{p_2 p_3} = \sum_{p_4=1}^{r4} x^4_{p_3 p_4} \qquad \text{for } p_3=1, 2, \ldots, r_3 \tag{10.27}$$

...

$$\sum_{p_{x-2}=1}^{rx-2} x^{x-1}_{p_{x-2} p_{x-1}} = \sum_{j=1}^{n} x^x_{p_{x-1} j} \quad \text{for } p_{x-1}=1, 2, \ldots, r_{x-1} \tag{10.28}$$

$$x^1_{ip_1} \geq 0 \qquad \text{where} \qquad i=1, 2, \ldots, m;\ p_1=1, 2, \ldots, r_1 \tag{10.29}$$

$$x^2_{p_1 p_2} \geq 0 \qquad \text{where} \qquad p_1=1, 2, \ldots, r_1;\ p_2=1, 2, \ldots, r_2 \tag{10.30}$$

$$x^3_{p_2 p_3} \geq 0 \qquad \text{where} \qquad p_2=1, 2, \ldots, r_2;\ p_3=1, 2, \ldots, r_3 \tag{10.31}$$

...

$$x^x_{p_{x-1} j} \geq 0 \qquad \text{where} \qquad p_{x-1}=1, 2, \ldots, r_{x-1};\ j=1, 2, \ldots, n \tag{10.32}$$

By specifying the values of the variables x^1_{ip1}, x^2_{p1p2}, $x^3_{p2p3}, \ldots, x^x_{px\text{-}1j}$, (10.17) to (10.24), while maintaining conditions (10.25) to (10.32) it is possible to obtain the optimum values of quantities that need to be transported from sources through several levels of buffer stores to consumers.

X-stage transport tasks can be solved as *x* separate transport tasks using basic solution methods or by methods that lead to the optimal solution. The *X*-stage traffic task is balanced when it holds that (10.33).

$$\sum_{i=1}^{m} a_i = \sum_{p_1=1}^{r1} e^1_{p_1} = \sum_{p_2=1}^{r2} e^2_{p_2} = \sum_{p_3=1}^{r3} e^3_{p_3} = \mathrm{K} = \sum_{p_{x-1}=1}^{rx-1} e^{x-1}_{p_{x-1}} = \sum_{j=1}^{n} b_j \tag{10.33}$$

The table for solving an *X*-stage transport task depends on the levels that form the distribution system. To simplify calculations and the solution of the task, it is possible to use a table for solution of a one-level transport task *x*-times in the case of balancing particular levels of the *X*-stage transport task.

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10.2 The Use of Simulation for the Purpose of Defining the Capacity of Distribution Elements

It is possible to consider the distribution centre or warehouse in terms of simulation as:

- a parallel queuing theory system or a multichannel system,
- a queue, a store, a buffer of a system.

In terms of distribution of products and the creation of simulation models it is important to model the road or railway track to obtain the information necessary for improving the quality and effectiveness of the activities of the distribution system. It is possible to consider a road, railway or tramway track as a queuing theory system. A truck which travels a certain distance moves along this path in a certain time, i.e. it is delayed for a certain time that it requires to perform the task of traversing the distance (Straka 2013, Straka et al. 2015). This means that it is possible to model the road in two ways:

- the road as simple service equipment,
- the road as multichannel service equipment.

The road as simple service equipment. It is possible to imagine this as a tunnel, at the end of which outbound trucks and their interval of leaving the tunnel are recorded, i.e. the frequency of trucks exiting the tunnel with its dispersion, representing a delay in simple servicing equipment (Figure 106).

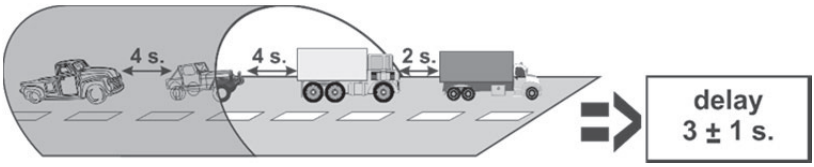


Figure 106 – Road as simple service equipment

The road as multichannel service equipment. It is possible to imagine this as a multi-lane road along which, in the same direction at the same time, a large number of trucks travel, but there can only be one truck in each lane at the same time, i.e. the delay in multichannel service equipment is the time required to overcome the entire length of road with proper dispersion of delay. The capacity of multichannel equipment is determined by the number of pieces of service equipment which it

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consists of. That is why the road as multichannel service equipment needs to be defined with a sufficiently large capacity, (Figure 107):

- either with a sufficiently large number such that a queue is not formed of un-serviced transactions, trucks in front of the multichannel equipment,
- or based on the distance of the road, the average speed of a truck and using the rule of 2 seconds of space between two trucks to calculate the number of trucks, i.e. the capacity of the multichannel equipment which can be on the road at the same time.

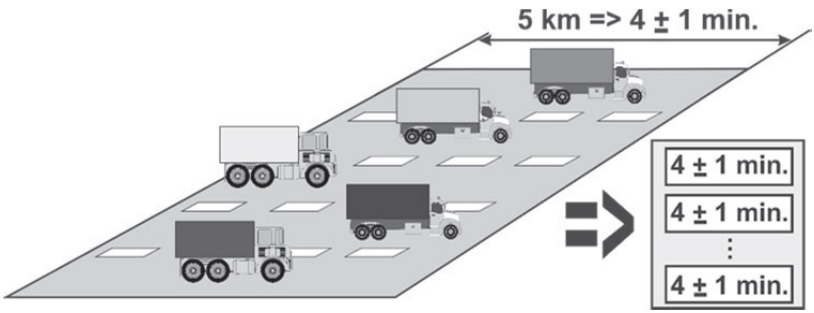


Figure 107 – Road as multichannel service equipment

Similarly, it is possible to model rail or tramways, junctions and other parts of the transport system.

10.2.1 Transactions, Requirements – Basic Dynamic Items

In terms of the simulation model it is important to define the unit(s), which can be a unit of some goods, a box, a pallet, a truck (all goods transported), m^3, *kg, tons*, etc., i.e. the basic dynamic item generally used to refer to transactions or requirements for the solution of problems in dimensioning distribution systems. If transactions within the distribution system represent only one type of goods (one type of transaction) there are sufficient input parameters to a node and output parameters from a node or processing parameters (time of storage) of transactions in a node for the design of distribution system nodes (Straka 2007).

If nodes represent warehouses or distribution centres involving processing large amounts of different types of goods, then in this case each type of goods represents a separate transaction with its parameters relating to input, output and processing times. In terms of simulation it is possible to continue with the generalization of the system parameters and to modify

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requirements for transaction performance in such a way as to work with their averages during a certain time, which is facilitated by the creation of simulation models.

10.2.2 The Warehouse as a Parallel Queuing Theory System, Multichannel System

A parallel queuing system is characterized by the input(s), number(s), of several items of service equipment and outputs in parallel (Figure 108).

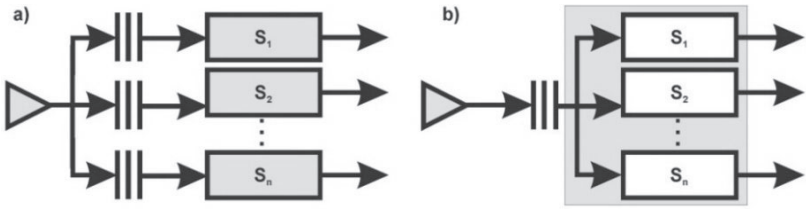


Figure 108 – Schema of a parallel queuing system (a, PQS) and multichannel queuing system (b, MCQS)

A parallel queuing system (PQS) represents servicing equipment organized side by side with a common entry point. The queue can be common or separate, in front of each piece of equipment.

A multi-channel system (MCQS) is considered to be a system, which consists of two or more pieces of servicing equipment side by side with similar or the same servicing parameters (Straka 2017).

Parallel organization of servicing equipment is typical for systems where it is desirable that the system operates quickly with minimum delay of incoming requests. If a warehouse is considered as a parallel queuing system, in this case the usable area is the warehouse or the volume divided into smaller parts, where each part of the warehouse is one servicing place, one piece of service "equipment", depending on the types and kinds of goods located in the warehouse (Figure 109).

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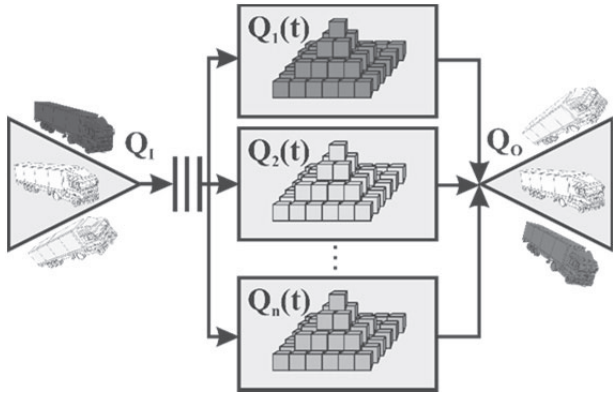


Figure 109 – A warehouse as a parallel system or multi-channel piece of "equipment"

In parallel solutions for storage capacity, defining parameters for different parts of warehouse "servicing equipment" is problematic, because each product is a separate section with its own parameters of "processing", i.e. in terms of storage time, the intensity of input and output from the warehouse. The parameters of the process are determined for each product separately based on the statistics of storage.

10.2.3 A Warehouse as a Queue of Un-serviced Requests

One of possible options for the creation of a simulation model of the distribution centre or warehouse as distribution network item is expressing the warehouse as a queue of un-serviced requirements (Figure 110). The means of transport represents servicing equipment in such system, the parameters of which, in terms of servicing, can be defined from the frequency with which goods are taken and from the capacity of the means of transport.

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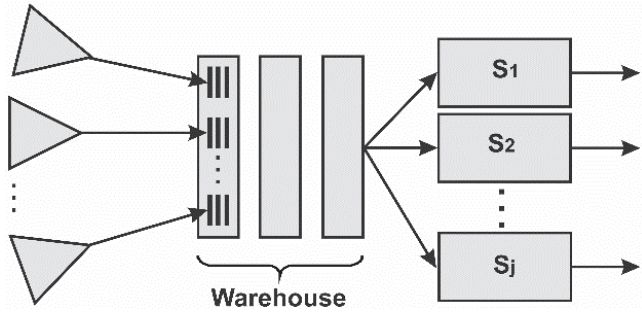


Figure 110 – Diagram of the system, where a warehouse represents a queue of un-serviced requirements

The number of un-serviced requirements which are accumulated in the queue when all servicing equipment is engaged represents the basic parameter for determining the sizing of the warehouse as a distribution network item (Figure 111).

It is possible to obtain information needed for specifying the capacity of the distribution network elements by expressing particular parts of the distribution network as blocks of the simulation model (Figure 112).

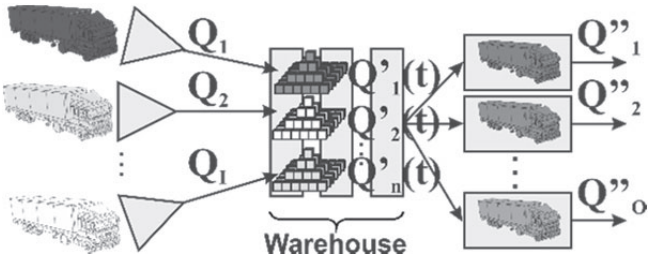


Figure 111 – A warehouse is represented as a queue of un-serviced requirements while the means of transport represent servicing equipment

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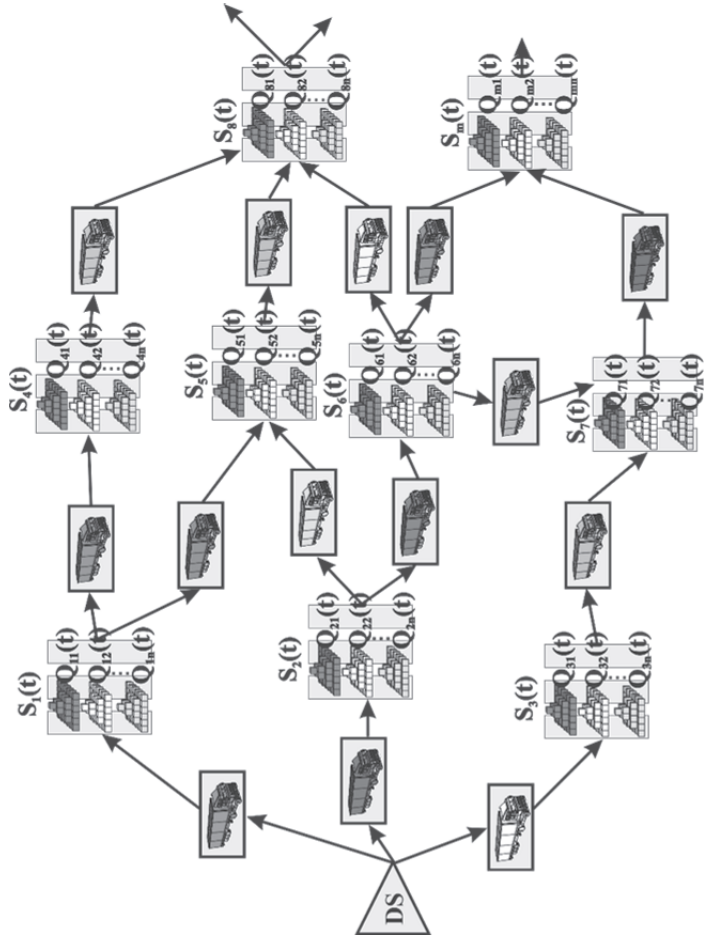


Figure 112 – A distribution network representing a set of items forming the simulation model

10.2.4 Solution of the Transport Task in the Environment of the EXTENDSIM Simulation System



Task: A transport company, which provides transport mainly by pick-up trucks, has received an order to transport food from a nearby train station (the food is in a wagon) to a warehouse that is used as a food reserve for the population in

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that district. The company has the task of transferring as many boxes as possible during one working shift. It is possible to load exactly 50 boxes into one pick-up truck. Since that company has also other contracts that are bound by agreement and delivery dates at the same time, it is necessary to find out how many trucks are needed to transport as many boxes as possible within one working shift – 8 hours. Additional system parameters and transport activity can be defined as follows:

- the trucks will start at 7 o'clock in the morning from the parking area of the company at intervals of 6 to 10 seconds,
- the railway station is located 5 km from the parking area of the company, the trucks need 4 to 5 minutes to travel the distance,
- the space for unloading from the wagon (freight railcar) and loading in trucks, at the railway station is limited and it is possible to load only one truck, loading one truck takes 4 to 6 minutes,
- trucks loaded with goods go to a warehouse that is 20 km away from the railway station; the trucks need 15 to 23 minutes to travel the distance,
- unloading one truck at the warehouse takes 8 to 10 minutes,
- up to 3 trucks can be unloaded at the warehouse at once,
- unloaded trucks return to the railway station for reloading.

Find out how many trucks are needed for the efficient operation of the system, or set up the transport system to maintain the following:

1) loading at the railway station is smooth without idle times,
2) unloading in the warehouse is smooth without idle times.

The whole transport system described and its operation can be captured in the basic schema (Figure 113):

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Figure 113 – The simplified formalized schema of the defined system

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Because it has already been described that the route is actually a service device which creates a delay against the transaction – the means of transport, goods or driver, the basic formalized schema can be modified into a form from which a functional simulation model can be created (Figure 114).

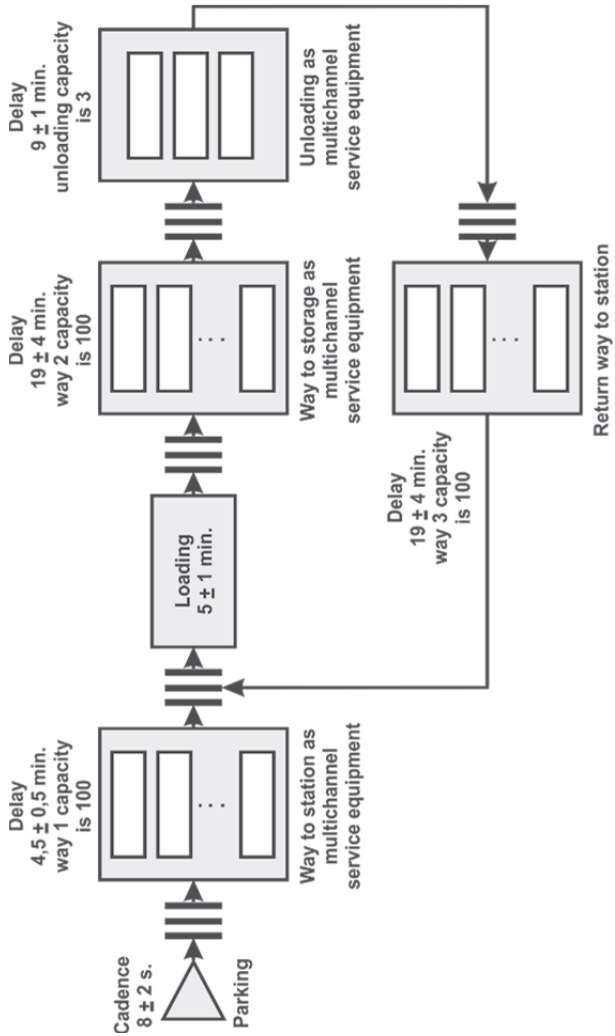


Figure 114 – Overall formalized schema of the defined distribution system

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The next step is converting the formalized schema into a model of the particular simulation system. From the point of view of the simulation model creating and solving the task, the EXTENDSIM simulation system (ver. 8 demo) by Imagine That Inc. (http://www.extendsim.com) will be used. The EXTENDSIM simulation system enables the creation of discrete and continuous simulations, creating 2D and 3D animations from assembled models. Modelling and setting system parameters is easy and fast in EXTENDSIM. EXTENDSIM is an object simulation system, i.e. the whole model will be built using particular blocks for each part of the system model as a set of blocks. It is possible to find out more details and learn how to create models using the EXTENDSIM simulation system from the materials on the manufacturer's website, together with the *help* function in the installed system, many expert articles, or other literature (Straka 2017).

The simulation model which is created in the EXTENDSIM simulation system consists of several blocks joined to a chain according to a logical sequence using the captured formalized schema of the system. A dynamic item in the created model is required; in this case it is represented by pick-up trucks.

It is necessary to set the length of the simulation time, i.e. time of the simulation, before running the simulation and creating the model on the modelling surface. In EXTENDSIM, the time parameters are defined through the main menu, in the RUN tab open Simulation Setup. Within the Setup tab, it is necessary to define the basic simulation time unit, in this case **minutes**, and to define the beginning *"START"* and finish *"END"* of the simulation. Since the distribution will take 8 hours, one work shift (in minutes) is 480 minutes. The start of the simulation is at 0 minutes and the simulation ends at 480 minutes; this is one simulation cycle (Figure 115).

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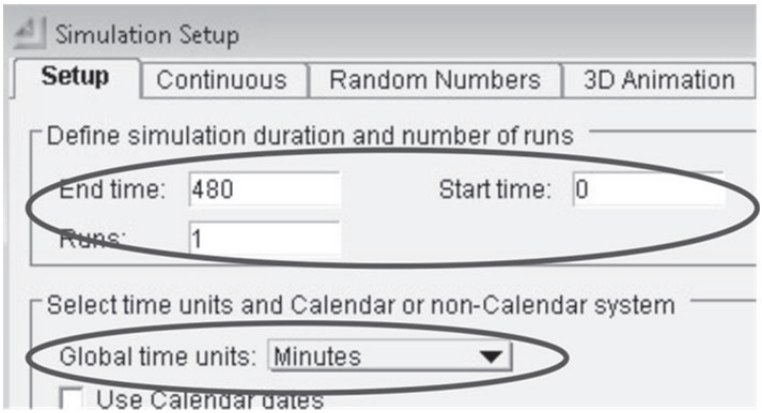


Figure 115 – Set up the simulation time and basic time unit in EXTENDSIM

Once the simulation time and the time unit are set, the model itself is created (Figure 116), representing the transport of products between the railway and the warehouse. The modelling area of the simulation system consists of blocks which represent the particular parts of the system:

1 – the EXECUTIVE block, which represents the simulation time meter and its control, in this case it measures 8 hours – one working shift,

2 – the CREATE block, which represents the truck parking lot from which the trucks will enter the system at an interval of 8 ± 2 seconds and provide the distribution of products,

3 – the group of blocks that represent the route to the railway station. This route is understood as a multichannel service device in front of which a queue of unoccupied trucks (block 3.1 QUEUE) can be created, which come out of this queue and enter the route as a multichannel service device (block 3.2 ACTIVITY, with capacity 100), where they have to be delayed by a specific time of 4.5 ± 0.5 minutes (block 3.3 RANDOM NUMBER). A specific delay is generated for each truck from the defined interval.

4 – the group of blocks that represent the loading of boxes into a truck at the railway station. This activity is understood as a simple service facility in front of which a queue can form of waiting trucks (Block 4.1 QUEUE), which come out of the queue and go into the simple service equipment (Block 4.2 ACTIVITY, with capacity 1), where they have to be delayed for the 5 ± 1 minutes required to load the truck (Block 4.3 RANDOM NUMBER). A specific delay is generated for each truck from the defined interval.

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5 – the group of blocks that represent the route to a warehouse. The route is understood as a multichannel service device in front of which a queue can form of unserved trucks (block 5.1 QUEUE), which come out of this queue and enter the route as a multichannel service device (block 5.2 ACTIVITY, with the capacity 100), where they have to be delayed for specific time of 19 ± 4 minutes (block 5.3 RANDOM NUMBER). A specific delay is generated for each truck from the defined interval.

6 – the group of blocks that represent the unloading of boxes from a truck into the warehouse. This operation is understood as a multichannel device in front of which a queue can form of waiting trucks (block 8.1 QUEUE), which come out of this queue and go on to be unloaded as a multichannel service device (block 8.2 ACTIVITY, with a capacity of 3) where they have to be delayed for a specific time of 9 ± 1 minute, which is required for unloading a truck (block 8.3 RANDOM NUMBER). A specific delay is generated for each truck from the defined interval.

7 – Group of blocks, that represent the route back to the railway station. The route is understood as a multichannel control device in front of which a queue can form of unoccupied trucks (block 7.1 QUEUE), which come out of this queue and enter the route as a multichannel service device (block 7.2 ACTIVITY, with a capacity of 100) where they have to be delayed for a specific time of 19 ± 4 minutes (block 7.3 RANDOM NUMBER), block 7.3, from a defined interval, for each truck it generates a particular delay. A specific delay is generated for each truck from the defined interval.

8 – the block SELECT ITEM IN performs the connection of the flow of trucks coming out of the parking lot with the possible return of trucks from the warehouse. Only one flow of requirements is allowed into the EXTEND at the block entrance.

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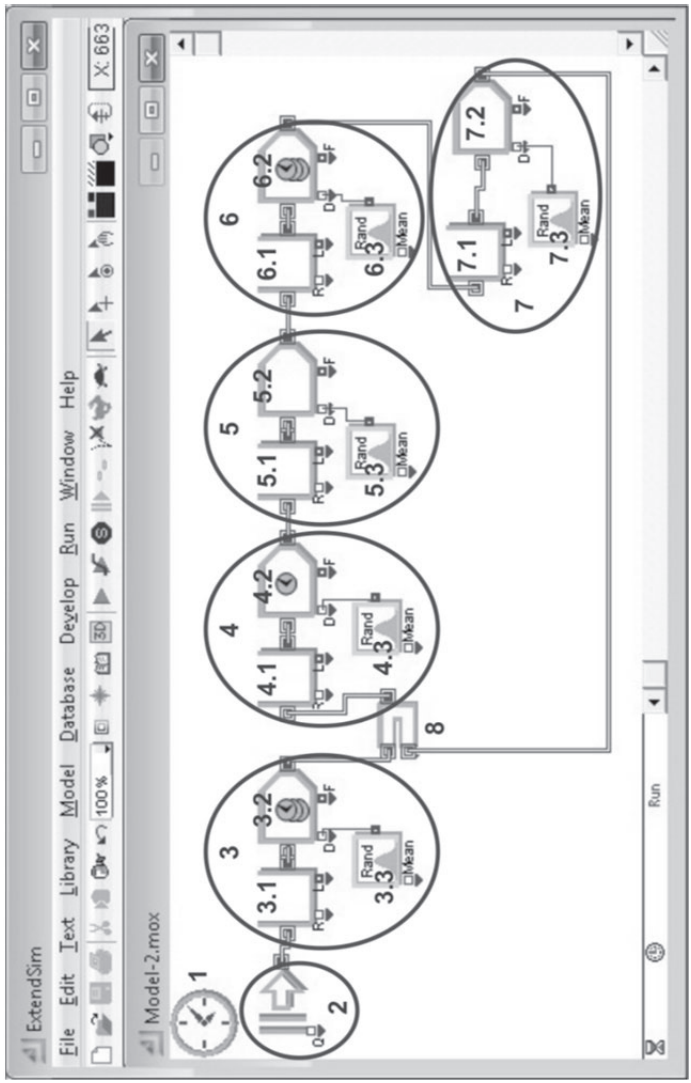


Figure 116 – The Simulation model of the defined distribution system created in EXTENDSIM

Before the simulation runs, it is necessary to set the entry parameters for requirements in the particular blocks, i.e., trucks entering the system and delayed at particular parts of the system.

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In block 2 – CREATE, it is necessary to set the truck entry interval, i.e. starting them from the truck parking lot as a function with normal proportioning with an input interval of 8 ± 2 seconds (Figure 117) and the number of trucks that will be used to distribute products is limited to 3 (Figure 118), in the *"Options"* tab. By sequentially changing the number of input requirements – trucks, that will be used to distribute products, it will show how many trucks are needed for what system status.

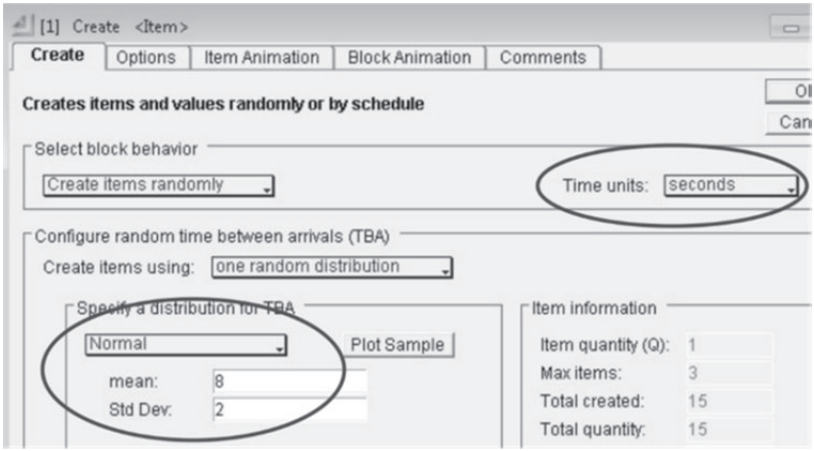


Figure 117 – Set up of the entry parameters of requirements in the CREATE block

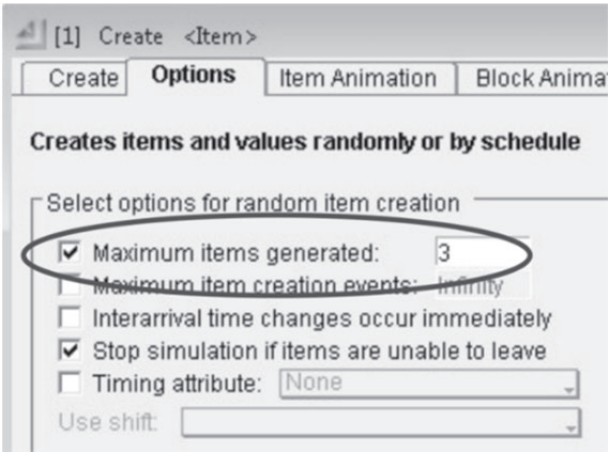


Figure 118 – Setting up the input number limitation in the CREATE block

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In block 3.2 – ACTIVITY, it is necessary to limit (set) the number of trucks that can travel along the route (Figure 119) to 100 (which is a large enough number to avoid creating a queue), the time unit should be set in minutes and the selected item held through connector *"D"*.

In block 3.3 – RANDOM NUMBER, it is necessary to set the delay time on the road as a function with normal proportioning with a delay interval of 4.5 ± 0.5 minutes (Figure 120).

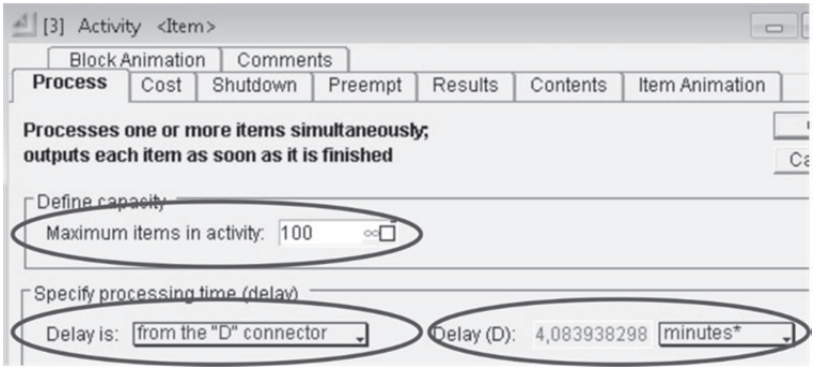


Figure 119 – Set up of the number of trucks that can enter a road at the same time in the ACTIVITY block

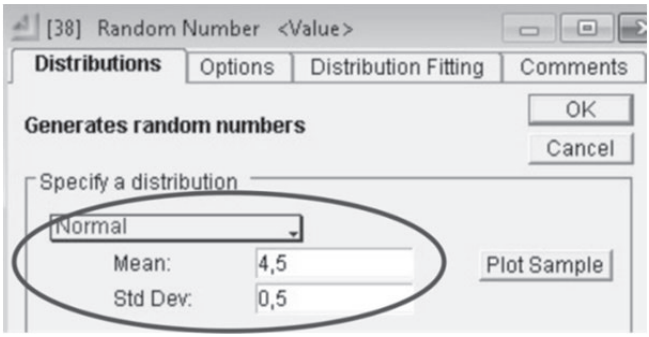


Figure 120 – Set up of the delay time of vehicles in the RANDOM NUMBER block

Similarly, each ACTIVITY block and its delay time must be set in the RANDOM NUMBER block. After setting up particular blocks, it is possible to set "Show 2D Animation" or "Show 3D Animation" in the

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RUN tab before starting the simulation, which shows a 2D (Figure 121) or 3D animation (Figure 122) for better understanding of system performance. If an animated preview is not needed, just run the simulation through the green button or Run Simulation in the RUN tab.

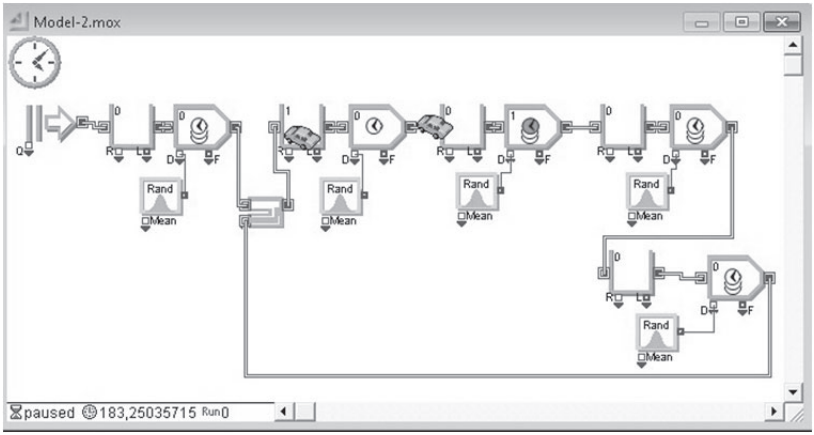


Figure 121 – View of 2D simulation, where the request is represented by a car

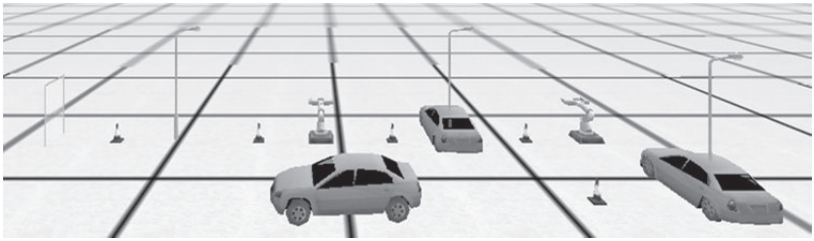


Figure 122 – View of 3D simulation, where the request is represented by a car

From the simulation results, for three trucks carrying goods between the railway station and the warehouse, it can be stated that the utilization of loading at the railway station is 29.4%, whereby 29 trucks were loaded and the utilisation of unloading at the warehouse is 16.8%, whereby 27 trucks were unloaded (Figure 123). After 8 hours of system operation, there were two trucks remaining on the route between the station and the warehouse. The results show, that at both the loading workplace, i.e. at the railway station and also at the unloading workplace, i.e. at the warehouse, idle periods occur and there are reserves.

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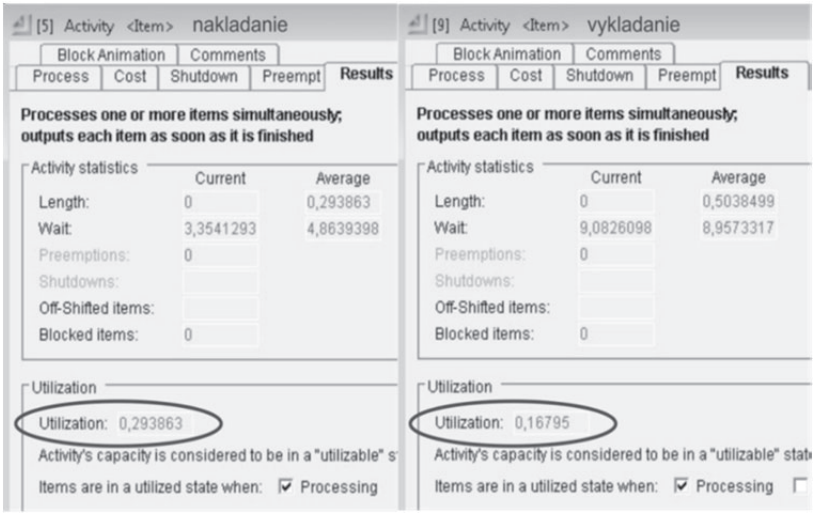


Figure 123 – Utilisation at loading and unloading using three trucks

In the first phase, it is necessary to set up the system so that loading of the pick-ups at the railway station is continuous. In the case of three trucks, the utilisation of the loading workplace at the railway station is about 29%, so by estimation it is possible to send about 9 or more trucks into the system.

As this is a single high-performance shift, it is possible to setup the system with 100% utilisation. For long-term high-performance, there would be a risk that the system would collapse. Generally, the principle is that a system that has no reserve cannot be managed effectively. For this reason, an efficient system is utilized at between 75 – 90%.

In the case of 9 trucks, the utilisation of the workplace at the railway station increases by up to about 82.5%, which represents 78 loaded trucks in 8 hours. In the case of 10 trucks, the utilisation of the workplace is about 89%, in the case of 11 trucks the utilisation of the workplace is about 95% and at 12 trucks the utilisation is about 99%, with loading performed 90 times. Putting more trucks into the system is ineffective.

From the short-term, high utilisation perspective of the loading workplace, 12 trucks can be sent into the system (Figure 124) to ensure continuous loading without idle times, even with a certain amount of waiting in a queue. In the case of long-term system use, it would be better to send 9 or 10 trucks into the system.

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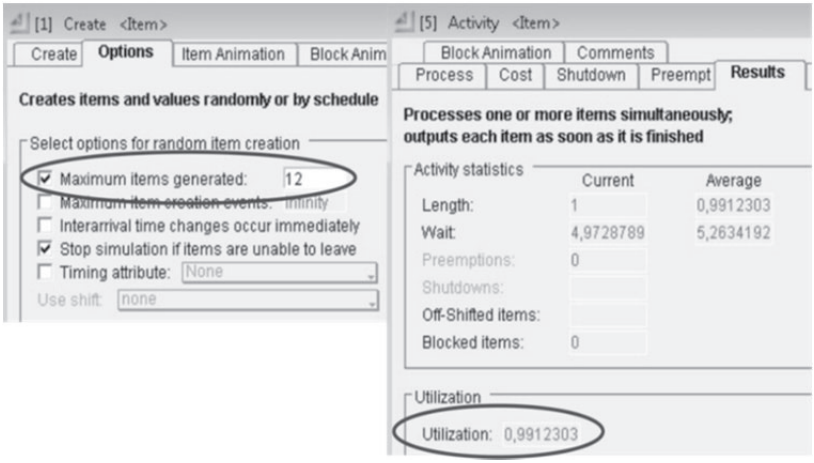


Figure 124 – Utilisation of the loading workplace with a limitation of up to 12 trucks entering the system

It is necessary to set up the system so that unloading in the warehouse is continuous without idle times in the second phase. When 12 trucks provide transport, the utilisation of unloading in the warehouse is 52%, which represents 84 unloaded trucks. As loading at the railway station becomes a bottleneck for a larger number of trucks, it is necessary to improve the workplace at the railway station with additional service equipment so that it would be possible to load two trucks at once. The simulation model is set for 15 trucks to carry goods to a warehouse.

The simulation with 15 delivery trucks and with improved loading shows that the utilisation of unloading will increase to about 80%. In the case of 20 trucks carrying goods, the utilisation of unloading increases up to 94% (Figure 125).

Within the simulation, cases were also tested with 25 trucks, 30 trucks and 50 trucks for transport. The utilisation of unloading in a warehouse remained at about 94% even with a considerable increase in the means of transport available. This means that there is no value in sending more than 20 trucks into the system.

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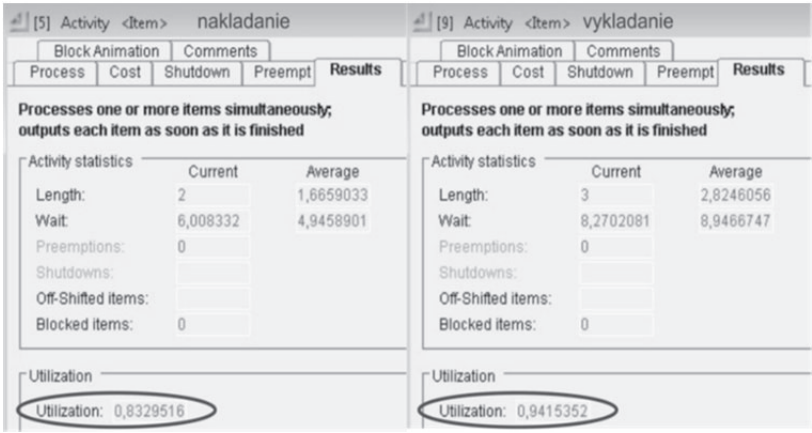


Figure 125 – Utilisation of the loading and unloading workplaces when using 20 trucks and 2 loaders

Conclusion: The system was balanced in accordance with the task requirements using simulation. Simulation is a fast and effective approach to solving bottlenecks within system balancing as well as transport and distribution systems. The solution is to determine the exact number of trucks for individual options and the need for efficient utilization of the system.

10.3 The Heuristic approach to Defining the Capacity of Distribution Warehouses

Heuristics are rules for finding solutions, based on experience, where application increases the probability of finding solutions. Heuristic methods do not guarantee that the solution found is optimal.

Rules are derived from "human" practices, which are used to construct models. The heuristic approach is based on intuition, knowledge and experience – i.e. the inductive creative approach (Malindzak 1996).

The aim of the application of the heuristic approach is to find a solution that is close to the optimum state or is optimal in a relatively short time. The space of the subset of possible solutions in heuristics represents a relatively small area. A specific feature of this approach is that incorrect solutions are also accepted.

Heuristic methods can be compared with the algorithmic solution of tasks (Lenort et al. 2012). The difference between heuristics and

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algorithms is that algorithmic solutions are always optimal when an optimum exists (with a properly designed algorithm). The heuristic approach need not find optimal or indeed any solutions even where they exist.

In terms of the solution process we can divide the application of heuristics into:

- constructive methods,
- optimization methods.

Methods finding an initial solution serve for the analysis of necessary data and offer possible approaches and solutions. Optimization methods provide detailed analyses of the defined targets and criteria to determine a greater number of variations of possible solutions from which the best solution is chosen.

The heuristic approach to solving problems and tasks is very common in life. From frequent use, we learn which situations it is appropriate for. In terms of the speed of the solution with respect to the accuracy of the solution, an algorithm is suitable when there are several possible combinations and heuristics is suitable when there is a very large number of combinations.

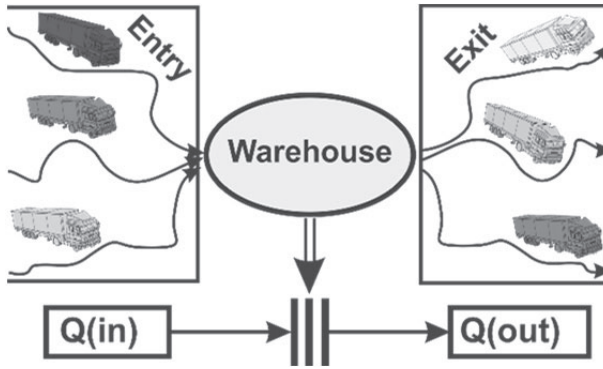


Figure 126 – Determining the capacity of a distribution warehouse as a difference of amounts

Because there is a large number of possible solutions considering the definition of the capacity of distribution nodes (Figure 126) and the vastness of distribution networks, the application of heuristics is a suitable approach to finding solutions. From the point of view of solving tasks in the field of distribution logistics it is possible to define tasks such as:

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- Finding the shortest transport route,
- Finding the shortest circuit (travelling salesman problem, Chinese postman),
- Finding the best method for distribution and collection of material goods,
- Optimizing transported quantities of goods,
- Optimizing the spatial structure of warehouses,
- Dividing the distribution space into smaller parts,
- Optimization of inventories of production sources,
- Scheduling models for a serving system.

There are a lot of heuristics for solution of the defined problems:

- Lin – Kernighan method,
- Christofides algorithm,
- Nearest neighbour algorithm,
- Gradual zoom algorithm,
- Sweep algorithm,
- Clarke-Wright algorithm,
- Combinatorial method with limited return,
- Method of distribution potential,
- Add method,
- Drop method,
- Method of area exchange, …

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IV.

CASE STUDIES AND APPLIED LOGISTICS RESEARCH IN DISTRIBUTION AND SUPPLY

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CHAPTER ELEVEN

APPLIED RESEARCH IN DISTRIBUTION AND SUPPLY LOGISTICS AND THE SOLUTION OF SPECIFIC TASKS IN PRACTICE

What you will learn: Methods from mathematics, heuristics, simulation, design and computer science would lose their meaning if they were not applicable in practice. For this reason, with the motto "It is better to see once than to hear a hundred times", this next chapter demonstrates the application of specific methods and approaches for solving real problems from the practice of distribution logistics. The chapter focuses on the basic definition of a procedure, which is followed by the solution of a particular task in practice and then using six selected projects it shows the real use of the methods in practice with the results achieved and the conclusions drawn.

Basic terms: project, case study, analysis, synthesis, efficiency, applied research.

11.1 The Procedure for Solving Distribution and Supply Problems

Improving the efficiency of distribution, supply and the related solutions of distribution tasks is one of the basic requirements for industrial concerns and other companies to function correctly. Since distribution costs are one of the largest groups of costs, it is very important to properly “tune” distribution in terms of minimizing costs but also in terms of time savings and savings of the means of distribution. Improving the efficiency of distribution and supply can mean a reduction of up to 50% in the cost and time for distribution and supply. Solving distribution and supply tasks consists of basic steps that are common for all types of distribution and supply tasks:

- defining the problem, stating the target and the definition of partial tasks to fulfil the project target,

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- analysis of the project in question, analysis of the current situation, analysis of the available methodologies suitable to address the specific problems,
- deficiencies resulting from the analysis, identification and determination of defects and deficiencies,
- suggestion of possible appropriate solutions,
- choosing the right solution and implementing it,
- evaluation of the results of the solution and comparison with the current state.

Defining the problem, statement of the target and definition of partial tasks

Defining the problem clearly indicates the "weak parts" in the system. The problem needs to be defined, because *"Where there is no problem, there is nothing to solve!"*. Formulation of the target of the task to be solved promotes the monitoring of the defined condition to be achieved. Defined partial tasks, performed within the solved project, should be directed at the defined target. It is very important to define the correct target of the solution, because determining the wrong target leads to solving wrong and non-essential problems, the removal of which does not lead to the distribution system functioning optimally or effectively.

Analysis of distribution in a solved project, analysis of the current situation

Analysis is an essential step in solving distribution tasks. The aim of analysis is to describe how the addressed distribution system works, to describe the ties that exist between the participants in distribution and to point to existing inadequacies. Within analysis it is necessary to apply some of the appropriate methods in the analysis of a particular task. If one cannot decide which analysis method to use, the application of systems analysis and its combination with SWOT analysis or multi-criteria analysis will help. Within analysis it must be remembered to analyse which methodology can be applied to solve the defined problems. Without proper knowledge and methodological apparatus, the researcher will only be able to guess what to do, and the results will be unsubstantiated and highly debatable.

The advantage of system analysis, in addition to understanding the actions and behaviour of the system, lies in defining the parts and sub-parts, chapters and subchapters which need to be described in detail for decomposition. Defining the system and its items creates a clear and transparent structure (Figure 127).

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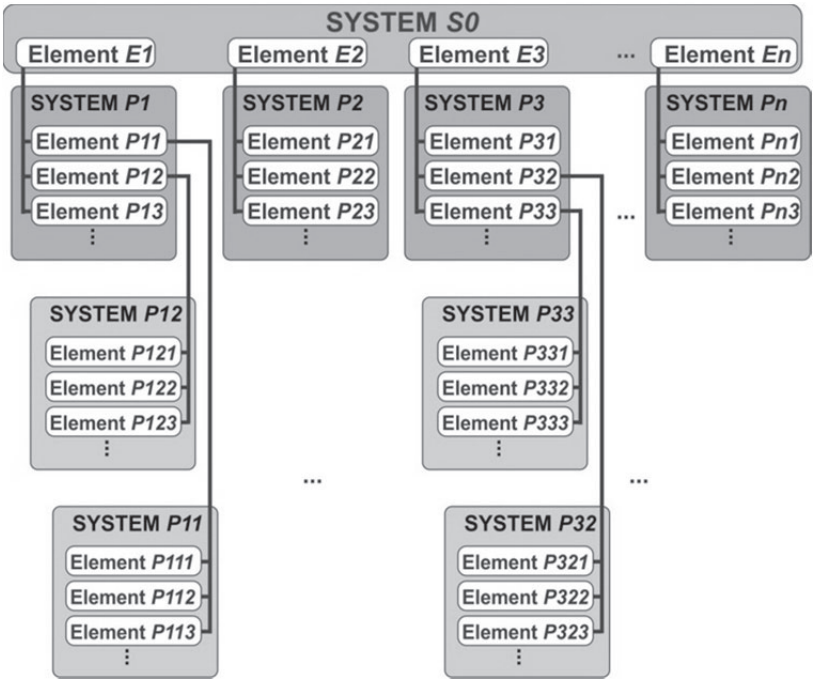


Figure 127 – Graphical representation of the general structure of the system analysis and its items

Deficiencies found during analysis. Identification and determination of problems

In this step it is necessary to find, characterise and describe the deficiencies of distribution that are found by analysis. Description of all the deficiencies of distribution has a significant impact on the process of their subsequent removal or solution. Defining the identified deficiencies determines the structure of further work to solve them. Some of the shortcomings (deficiencies) are associated with each other, i.e. they have causal relations and removing one of them can then eliminate the cause of the others or it may cause the occurrence of a problem at a different point in the system.

Suggestion of possible solutions

The suggestions for possible solutions are a list of solutions that lead to the removal of the observed deficiencies. The basic rule is that each proposed solution can be implemented in practice. It does not make sense

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to use solutions that "look good on paper", but their implementation is impossible i.e. "science-fiction" solutions for companies.

Evaluation of the results of the solution and comparison with the current state

The proposed solution results are obtained by simulation, modelling, analytical, or physical models or from practice and compared with the values of the current state. If the proposed solution has not yet been implemented, values of the current state are compared with the results obtained by simulation and modelling. It is possible to obtain a picture of the total contribution or possible shortcomings before the real implementation of the proposed solutions and to make possible adjustments in this way.

Choosing the right solution and its implementation

If it is needed, choose a solution that will work in practice from the list of proposed solutions. The costs required to implement, the benefits of the implemented solutions, the amount of total savings and difficulty of implementation of the selected solution determine the selection of appropriate solutions to implement in practice. In most cases, the relevant criterion is the largest overall cost savings.

The following chapters show the possible use of certain quantitative and qualitative methods in practice on specific case studies and projects solved in practice. In order to protect the brands of companies for which the tasks were solved, the names of the companies are fictionalized and for this reason no name found in the texts should be associated with any existing company name in the companies register. Any coincidence of name similarity is just random. Data has been changed too, but the problem and the approach to solving it are unchanged.

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V.

CASE STUDIES FROM THE CONCEPTUAL DESIGN OF DISTRIBUTION SYSTEMS

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CHAPTER TWELVE

ANALYSIS AND PROPOSAL FOR CLOTHING DISTRIBUTION WITHIN ALFA, INC.

12.1 Definition of the Problem and Objective of the Task

Clothing distribution for Alfa, Inc. from the town of Puchov is currently provided by the transport company Logistics & Logistics (L&L), which is responsible for the physical distribution of the products to designated locations within a specified time period defined by contract. L&L uses its own means of transport for product distribution (Straka 2007).

It is necessary to assess the current method of distribution operations of the company due to the market expansion of Alfa, Inc. Puchov into other, more remote regions.

The aim of the project is:

- to analyse the current state of distribution,
- to propose a system for product distribution into new regions,
- to maintain the flexibility and reliability of distribution,
- to optimize the product distribution system.

12.2 Analysis of the Present State of Clothing Distribution for Alfa, Inc. Puchov

Logistics & Logistics provides an outsourced service for Alfa, Inc. Puchov for the storage and handling of finished products. L&L is bound by contract to distribute goods within 24 hours from the central warehouse located in Puchov to any location within the Slovak Republic.

Goods distribution by international transport is managed by Alfa in cooperation with the L&L transport company. L&L arranges ordering and services with individual contract carriers. Every day L&L manages approximately 35 truck transport vehicles and approximately 10 smaller lorries for goods delivery within the Slovak Republic.

Alfa, Inc. Puchov pays L&L for the distribution of goods, not by the chargeable kilometre, but by weight of goods transported. The normal

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minimum quantity of goods transported is 10 boxes of adult clothing and 5 boxes with children's clothing. The transport of only one box of clothing is done at an additional cost.

There is a stock of products within the company site. The total amount of stock is approximately 100 thousand items of clothing for adults and 50 thousand items of clothing for children.

Alfa, Inc. Puchov is the owner of production plants in Ufa, Russia and Khartoum, Sudan (Figure 128).



Figure 128 – Production plants of Alfa, Inc. Puchov

The production company in Ufa has a total production volume of approximately 150 thousand items of clothing per year. The production company in Sudan supplies a negligible amount of clothing to the joint venture.

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12.3 Planned Development of Alfa, Inc. Puchov in Domestic and Foreign Markets

In order to maintain the competitiveness of the company in the domestic and world markets, the company has re-evaluated its current distribution system for products and it is trying for a new, more efficient manner of distribution to improve product delivery times, storage costs and overall distribution and to increase customer satisfaction.

The total distribution network of the company consists of two parts:

- the retail distribution network,
- the wholesale distribution network.

12.3.1 Building the Retail Network

Alfa, Inc. Puchov is broadening its range of products in the surrounding countries, i.e. Poland, Czech Republic, Austria and Hungary, with the help of a developed retail network with its own small warehouses and shops within those countries. Distribution between the parent company and its warehouses is provided by the forwarding and transport company. Warehouse management and sales are arranged by Alfa, Inc.

In the Czech Republic, Alfa Inc. uses the distribution network of Beta, Inc. of Brno (Figure 129), which consists of:

- Beta, Inc. Brno,
- joint ventures of Beta, Inc. Brno,
- franchising partners of Beta, Inc. Brno.

Alfa, Inc. Puchov plans that the retail networks in Poland, Austria and Hungary will consist of agreed dealers or similar salespeople as in the Czech Republic. Within the retail network, the total number of retail points in each country is assumed as:

- SVK up to 45 points,
- CZE up to 57 points,
- POL up to 15 points,
- HUN up to 20 points,
- AUT up to 5 points.

The total number of retail points will be 105–142 points, or “stations”.

The condition of establishing a station is that each station can be served within 24 hours or stations can be a maximum of 500 km away

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from the parent company, Alfa, Inc. Puchov. The overall stock level should be 1.2 – 1.5 million items of clothing of different sizes.

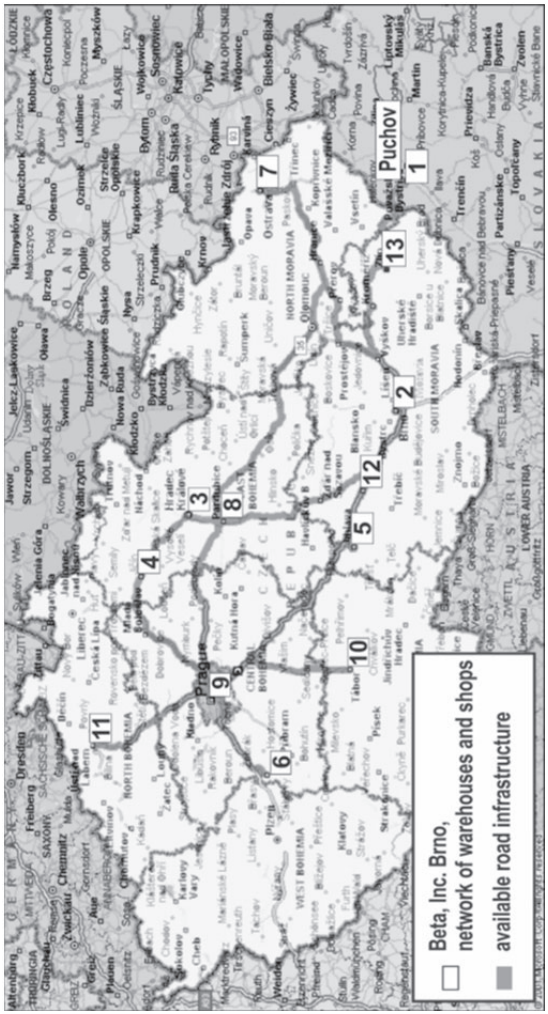


Figure 129 – Sales network of Beta, Inc. Brno

Within a five-hundred-kilometre distribution range (real road distance, not the direct distance "as the crow flies") from the parent company Alfa, Inc. Puchov (Figure 130) lie the whole of the Czech Republic, part of

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Poland, the whole of Slovakia, part of Ukraine including Lvov, Hungary, Austria, Slovenia and parts of Germany, Croatia, Romania, Bosnia and Serbia.



Figure 130 – The real 500 km distribution circuit with the parent company in Puchov[1]



Figure 131 – 24 hours range from the parent company in Puchov without stopping the vehicle[1]

With a clear 24–hour distribution range (real road distance, not the direct distance) it is possible to consider the circuit shown in Figure 131.

[1] Source: http://mapa-mapy.info.sk/

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But, according to the standards of the European Union and its member states, it is necessary to take breaks at specified intervals for drivers to rest, so the overall distribution range is smaller and corresponds to the five-hundred-kilometre distribution circuit criterion.

12.3.2 Wholesale Distribution Network

The wholesale distribution network consists of central distribution points, which are:

- Production, large-scale distribution points:
  - Puchov,
  - Ufa,
  - Khartoum.
- Non-production, large-scale distribution points:
  - Moscow,
  - St. Petersburg,
  - Rostov-on-Don,
  - Tashkent,
  - London.

Retail distribution locations are supplied from these wholesalers' nodes.

12.4 Proposal for the Retail Distribution Network of Alfa, Inc. Puchov

The basic criterion for the design of the distribution network for Alfa, Inc. Puchov is a five-hundred kilometres distribution range or to serve the customer within 24 hours if the goods are in stock within this distribution range. It can be stated that the five-hundred-kilometre distribution circuit is sufficiently small to serve the customer, even in winter, within 24 hours from the Puchov headquarters if required by the customer.

In the Czech Republic the distribution network of Alfa, Inc. Puchov consists of the Beta Inc. Brno distribution network, and the distribution places of this network. Beta, Inc. Brno consists of twelve primary distribution locations:

- Zlin – Malenovice,
- Brno,
- Velke Mezirici,
- Jihlava,
- Pardubice,
- Hradec Kralove,
- Komarov,
- Praha,
- Tabor,
- Usti nad Labem,
- Ostrava – Kuncice,
- Jicin.

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Since the current central warehouse in the Czech Republic is located in Prague, in the case of the distribution of goods eastwards, goods are unnecessarily returned towards the headquarters in Puchov. So, it is necessary to determine a better distribution location for Beta Inc. Brno, to be the central warehouse in the Czech Republic. Here an expert location system will be used to evaluate and select a warehouse.

The aim is to calculate the coordinates of a distribution centre or a warehouse with optimal location within the region. The assumption is that the following data are known:

- purchasers, suppliers, customers – O_i, D_i, Z_i,
- coordinates of stations (X_i, Y_i),
- quantity of transported goods for particular customers M_i.

The region map is shown in *X, Y* coordinate space (Figure 132). Each known place is designated by coordinates $[X_i, Y_i]$. The transport cost (TC) will be determined by (12.1) which will determine the location of the selected central warehouse for Alfa, Inc. Puchov.

$$\min\ z = TC = \sum_{i=1}^{n} M_i C_i d_i \tag{12.1}$$

M_i – quantity transported (pieces, boxes or clothing),
C_i – price unit for transport (conversion per one unit transported),
d_i – customer distance i from the distribution centre,
n – number of delivery places.

To find the optimal coordinates of a distribution centre for Alfa, Inc. Puchov within the Czech Republic, the distribution places of Beta, Inc. Brno are used. The starting point in the coordinate system is the central location of Alfa, Inc. Puchov.

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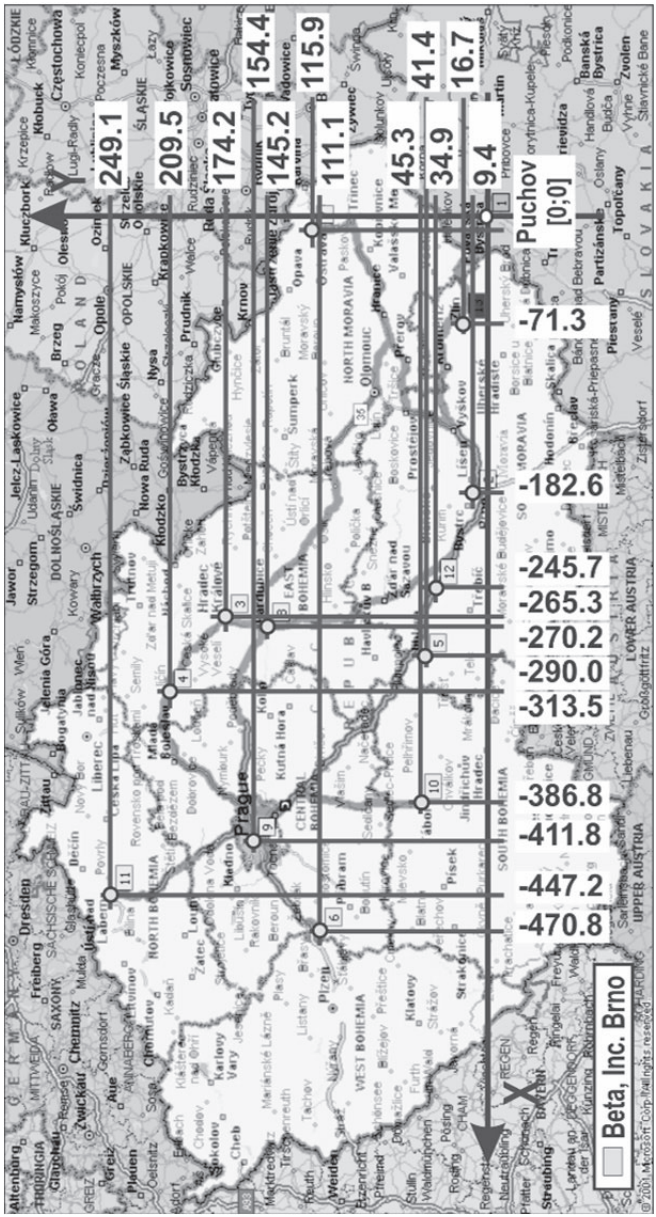


Figure 132 – Distribution places of Beta, Inc. Brno in the X, Y coordinate system

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The specific distribution places have the following coordinates:

Puchov	[0; 0],
Brno	[-182.6; 9.4],
Hradec Kralove	[-265.3; 174.2],
Jicin	[-313.5; 209.5],
Jihlava	[-290.0; 41.4],
Komarov	[-470.8; 111.1],
Ostrava – Kuncice	[-9.8; 115.9],
Pardubice	[-270.2; 145.2],
Praha	[-411.8; 154.4],
Tabor	[-386.8; 45.3]
Usti nad Labem	[-447.2; 249.1],
Velke Mezirici	[-245.7; 34.9],
Zlin – Malenovice	[-71.3; 16.7].

For the calculation of the coordinates of the distribution warehouse sought, an expert program is used. The location closest to the calculated optimal coordinates (Figure 133, Figure 134) of the distribution centre will be the central warehouse for Alfa, Inc. Puchov in the Czech Republic.

In the case of the Czech Republic and the distribution places available within the distribution network of Beta Inc. Brno, the optimal position for the location of the central warehouse for Alfa, Inc. Puchov has the coordinates [-274.98; 108.50]. These coordinates are the nearest coordinates to place *M8* – Pardubice [-270.2; 145.2].

The distribution location in Pardubice is ideally located relative to other distribution locations, so it is advantageous to place the central warehouse for Alfa, Inc. Puchov in Pardubice, if the situation requires.

An important criterion that plays a key role in defining and identifying distribution warehouses is the fact that Alfa, Inc. Puchov pays the transport company per transported kilogram of goods and not for kilometres driven. This is an advantage for Alfa when goods are transported over longer distances because the company does not have to worry about optimal shipping routes.

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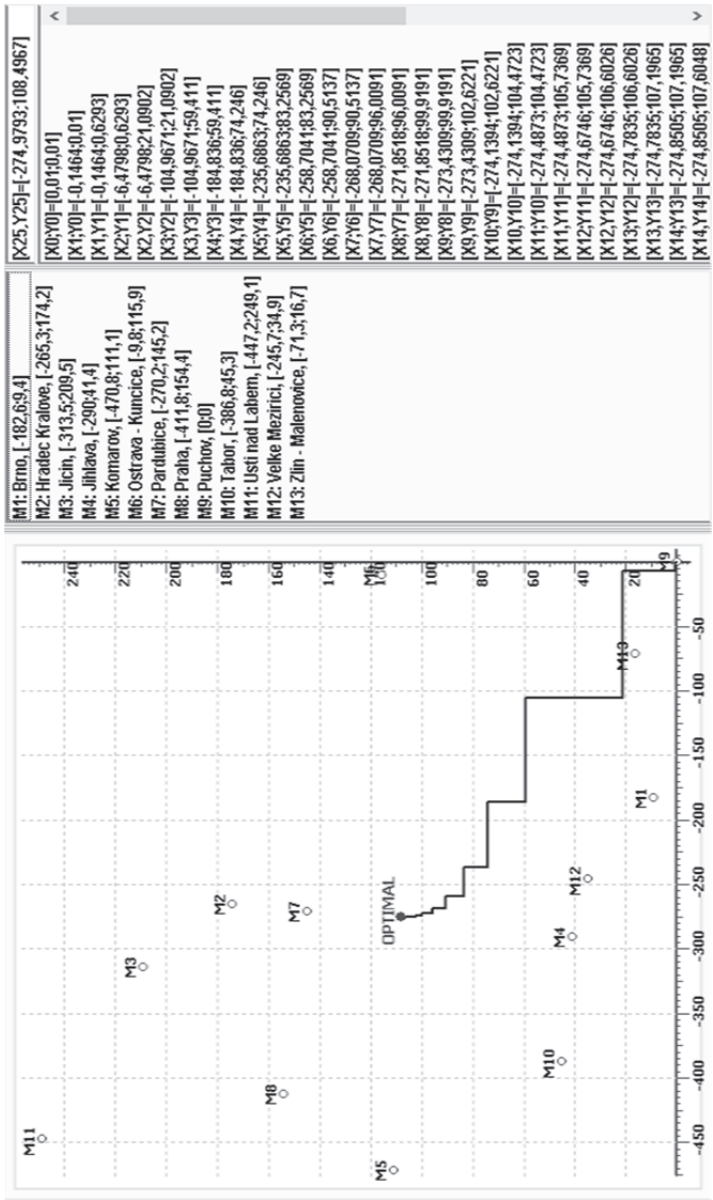


Figure 133 – Software for the calculation of the coordinates for the distribution warehouse for Alfa, Inc. Puchov

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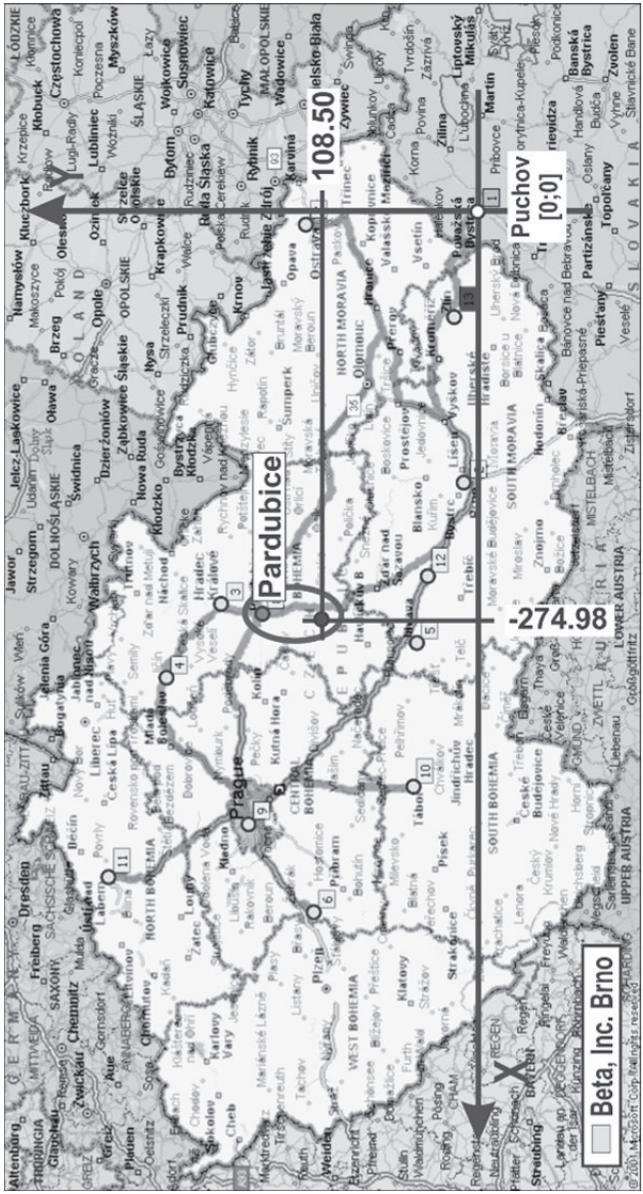


Figure 134 – Graphical representation of the location of the distribution centre warehouse for Alfa, Inc. Puchov in the Czech Republic

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Recommendations:

- The current mode of distribution and payment for weight-dependent transportation is advantageous for Alfa. If there is a change in the contract between the transport company and Alfa, Inc. Puchov, i.e. the nature of the distribution – payment per kilometre is changed, in this case it will also be necessary to optimize the distribution routes and new distribution warehouses will also need to be built.
- Distribution to retail locations in CZE, AUT, HUN, POL, SVK, with respect to the 24-hour policy, must be performed and managed by the headquarters of Alfa, Inc. Puchov. The shape of the distribution network is a two-level star type (Figure 135). The first level of the distribution network consists of the connection of Alfa, Inc. Puchov with the retail distribution points in CZE, AUT, HUN, POL. The second level of the distribution network consists of the connections between the retail points and the final customer.

For the Czech Republic, retail points are known as created by Beta, Inc. Brno. In Slovakia, the retail points are the distribution network of Alfa, Inc. Puchov. In regions like Austria, Hungary and Poland, retail points are to be created in cooperation with companies approached to sell Alfa products or there will be a build-up of Alfa's own sales network in these regions. To build retail locations in AUT, HUN and POL it is advisable to select locations with high potential customer numbers e.g. Linz, Vienna, Graz, Budapest, Debrecen, Krakow, Wroclaw, Warsaw, Poznan. This shows which places should be desirable as retail distribution points on the basis of the sale of the products, till the operation of this emerging network begins.

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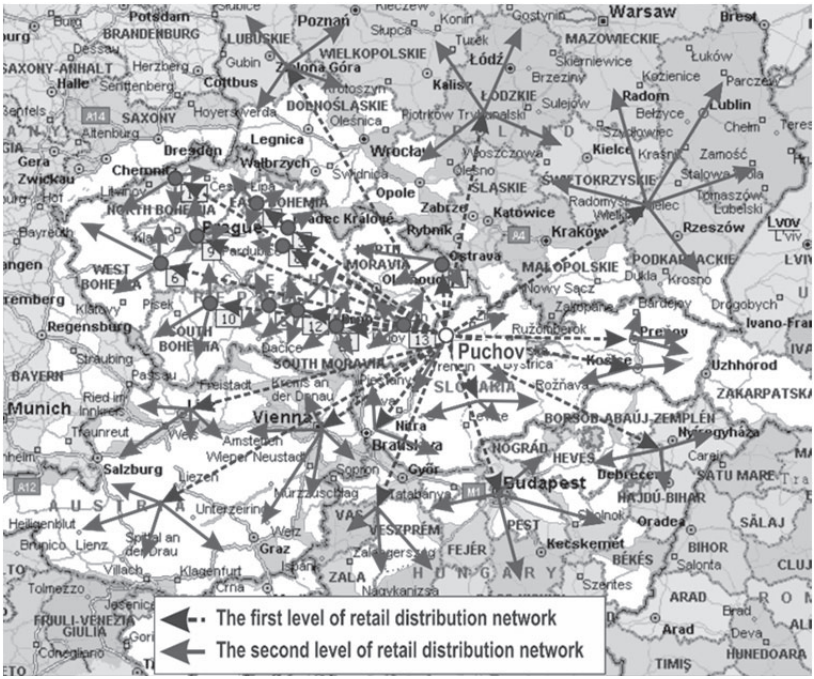


Figure 135 – Structure of the retail distribution network

12.5 Proposal for the Wholesale Distribution Network of Alfa, Inc. Puchov

The wholesale distribution network currently consists of three manufacturing plants (Figure 136):

- Puchov,
- Ufa,
- Khartoum.

Because the distances between these sites are several thousand kilometres and the distribution of products from these locations depends on a fairly long-time requirement, it is desirable to create large non-production distribution locations, the customer potential of which will be able to consume the quantities of products produced, and at the same time, these sites will be strategic nodes for the region (Bancroft 1991). Within the wide coverage of the Russian market, advantageous places for business

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can be those that have a strategic position in the regions of St. Petersburg, Moscow, Rostov-on-Don and have sufficient customer potential. Again, it is necessary to follow the strategy of the company to serve the customer within 24 hours, i.e. the distribution circuits around these locations may have a maximum range of approx. 500 km. These three distribution points are in an ideal position to fulfil this criterion.

There is a strategic position with a good customer base in Tashkent, Uzbekistan. The strategic position of this site is increased by the closeness of one of the world largest markets – the Chinese market, located within the 500 km distribution area of Tashkent (Figure 136). For the future, it is certainly appropriate indeed to place a warehouse in this region.

Because the production potential of the company in Khartoum is still negligible and its production is consumed in planned or existing distribution places, it is unnecessary to consider another large distribution point within Khartoum. If the position of this business grows significantly in the future, it is possible to consider opening up another non-production warehouse.

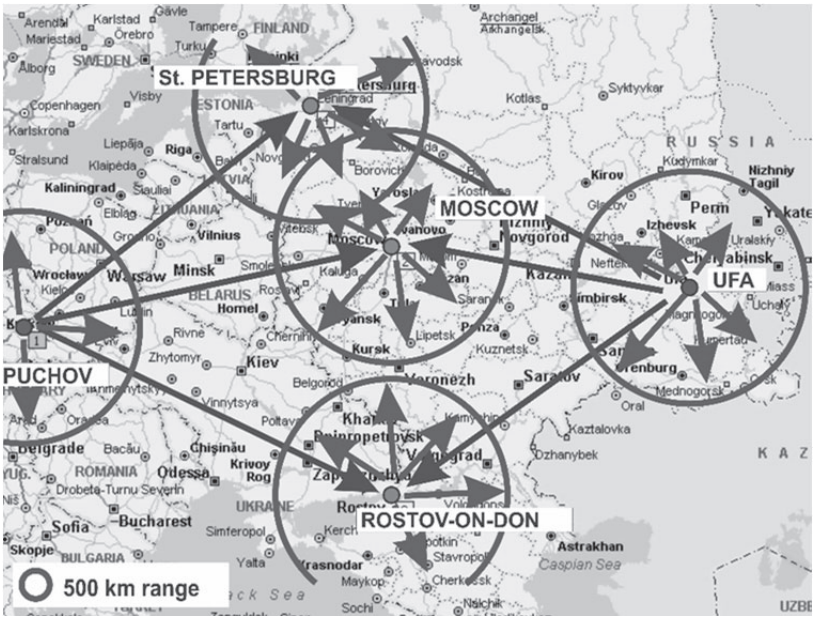
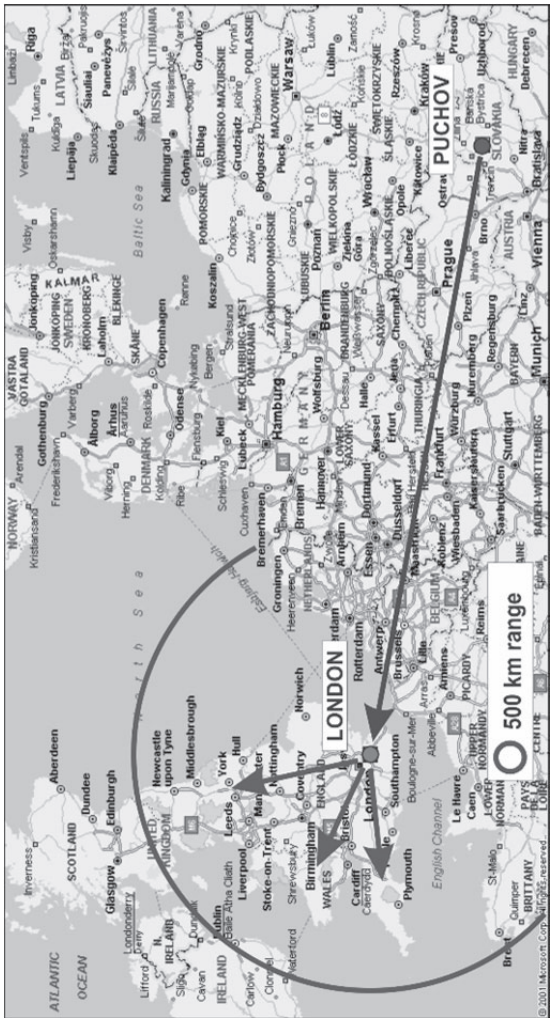


Figure 136 – Large distribution centres covering the breadth of the Russian market and Central Europe

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Within Europe, Britain has an important position and is a large consumer market. As the region is separated from the European mainland by the North Sea, it is advisable to place a large non-production distribution warehouse directly in Britain. The ideal location with a sufficient consumer base in this region is London (Figure 137). It is possible to serve a large part of this island state within 24 hours.


LONDON
500 km range
PUCHOV
Prague
Vienna
Berlin
Hamburg
Warsaw
Munich
Frankfurt
Amsterdam
Rotterdam
Brussels
Paris
Birmingham
Manchester
Leeds
Glasgow
Edinburgh
Dublin
Belfast
Cardiff
Plymouth
Southampton
Norwich
Newcastle upon Tyne
Middlesbrough
Liverpool
Stoke-on-Trent
Coventry
Nottingham
Hull
York
Aberdeen
Dundee
Inverness
Gothenburg
Stockholm
Oslo
Copenhagen
Riga
Vilnius
Minsk
Kaliningrad
Gdynia
Gdańsk
Poznań
Wrocław
Łódź
Katowice
Kraków
Lublin
Rzeszów
Ostrava
Brno
Bratislava
Budapest
Debrecen
Nitra
Trenčín
Žilina
Košice
Presov
Uzhgorod
Lviv
Zamość
Chełm
Białystok
Olsztyn
Elbląg
Bydgoszcz
Toruń
Płock
Radom
Kielce
Częstochowa
Opole
Gliwice
Zielona Góra
Gorzów
Szczecin
Koszalin
Słupsk
Gdańsk
Kaunas
Klaipėda
Šiauliai
Panevėžys
Daugavpils
Pskov
Tallinn
Tartu
Pärnu
Kuressaare
Ventspils
Liepāja
Jelgava
Jūrmala
Tukums
Limbaži
Valmiera
Cēsis
Sigulda
Jēkabpils
Aizkraukle
Jelgava
Rēzekne
Ludza
Preili
Madona
Gulbene
Alūksne
Valka
Valga
Võru
Narva
Sillamäe
Kohtla-Järve
Rakvere
Haapsalu
Kuressaare
Hiiumaa
Saaremaa
Muhu
Vormsi
Dagö
Ösel
Gotland
Visby
Karlskrona
Kalmar
Växjö
Jönköping
Linköping
Örebro
Västerås
Uppsala
Stockholm
Södertälje
Nyköping
Norrköping
Motala
Mjölby
Skövde
Lidköping
Trollhättan
Uddevalla
Strömstad
Kristiansand
Arendal
Grimstad
Lillesand
Tønsberg
Sandefjord
Larvik
Porsgrunn
Skien
Notodden
Kongsberg
Drammen
Hønefoss
Gjøvik
Lillehammer
Hamar
Kongsvinger
Elverum
Røros
Trondheim
Steinkjer
Namsos
Mo i Rana
Mosjøen
Sandnessjøen
Brønnøysund
Rørvik
Kristiansund
Molde
Ålesund
Florø
Førde
Sogndal
Leikanger
Voss
Bergen
Stavanger
Haugesund
Egersund
Flekkefjord
Mandal
Farsund
Lindesnes

In the future, it would be advisable to place large distribution warehouses in parts of Europe, where there is a large consumer base and long-standing tradition, for example, France – Paris, Italy – Milan.

12.6 Assessment of the Results

For Alfa, Inc. Puchov, the current distribution mode does not require distribution warehouses or finding new distribution routes, because payment for the transport of goods is dependent on the weight of the transported goods not on the kilometres travelled, so the full responsibility for the shipment and the delivery times are contracted to the transport company. This manner of performing distribution forces transport and forwarding companies to create their own optimized distribution network with the necessary warehouses too, which is an advantage for Alfa. The current means of distribution of products for Alfa, Inc. Puchov requires sufficient or larger warehouse space in the centre of Puchov, which can be achieved by building new warehouse capacity near the shipment warehouse.

However, it should be noted that it is not possible to increase the size of the warehouse indefinitely because it is costly. Radical change in the company's operations in a market requires a change in the overall functioning of the company. This involves the reassessment of overall production and a change in the planning process. Such changes make it possible to increase production without the need to increase storage capacities.

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CHAPTER THIRTEEN

PROPOSAL FOR THE DISTRIBUTION SYSTEM OF A BRICK FACTORY OF A VIRTUAL COMPANY IN KOSICE

13.1 Definition of the Problem and Objective of the Task

This virtual company is modelled as a system of integrated modules, between which there are links in the forms of information, material and financial flows. The basic modules of the company are represented in Figure 138.

The problem lies in the high costs of distributing the company's product and the need to ensure competitiveness in the future. The aim of the solution is to design a distribution system for the company that will secure the functional side in terms of delivering products to the market with cost effectiveness. All companies mentioned as customers and competitors of the "Brick Factory Kosice" virtual company are only hypothetical, in spite of their real presence in the market. The aim is to show the steps that are needed to perform the analysis and synthesis of the task.

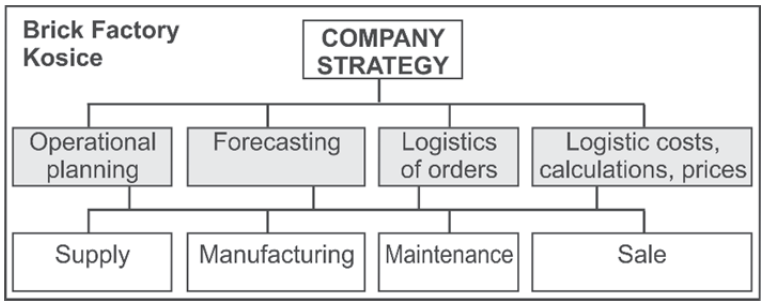


Figure 138 – Modules that make up the virtual company, Brick Factory Kosice

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The scope of the company's business is the manufacture of construction materials. The input raw materials for production are:

- magnesite (own quarrying),
- clay (own clay pit mining),
- gypsum and other purchased additives.

Brick Factory Kosice consists of two divisions (Zofcakova, Straka 2007):

- Division 1 – predominance of continuous-discrete processes, warehouse production, product-based organization of the production process, mining and treatment of raw material, purchase of other input raw materials. This is a PUSH system.
- Division 2 – discrete-continuous processes, production to order in production batches, process orientation, production of construction materials. This is a PULL system.

The output is an assortment of 20 product types that vary in shape, size, and material composition (Figure 139).

13.2 Packaging, Loading and Transportation of Products

The bricks are placed on wooden pallets and fixed with foil (Figure 140). The pallets are loaded onto a vehicle by fork-lift truck and they are shipped to the designated unloading location. The driver is responsible for any damages caused during transport. The Kosice Brick Factory provides transportation if the delivery consists of at least 23 pallets of ceramic fittings (or a corresponding number of ceramic beams and bressumers).

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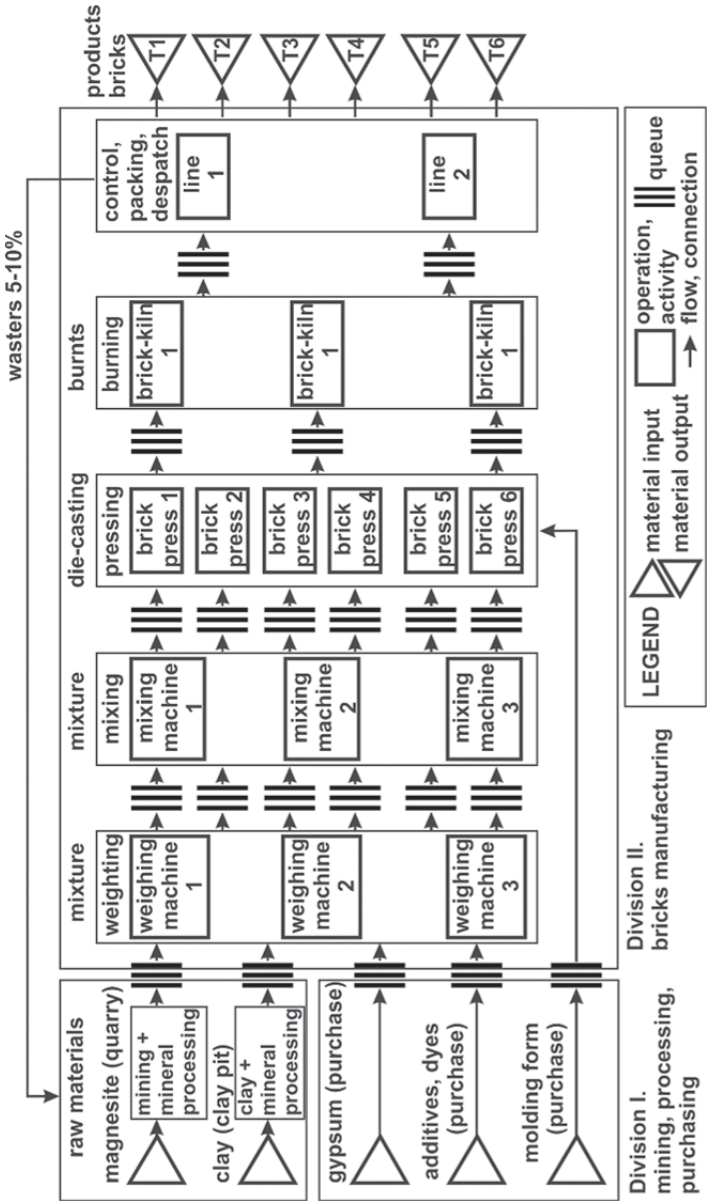


Figure 139 – Presentation of brick production, formalized schema of the manufacturing process

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Loading and handling products:

- When loading pallets, two-sided access to the loading area of the vehicle must be ensured and pallets are placed closely next to each other by the forklift truck. Pallets of bricks are laid on the empty, flat loading surface of the vehicle.
- Brick pallets may not be moved additionally in the loading area.
- Pallets must be secured against movement during transportation.
- Pallet handling can be performed by a forklift, pallet truck or mechanical pallet truck.
- A forklift truck or mechanical handler and a responsible worker must be provided at the place of unloading.

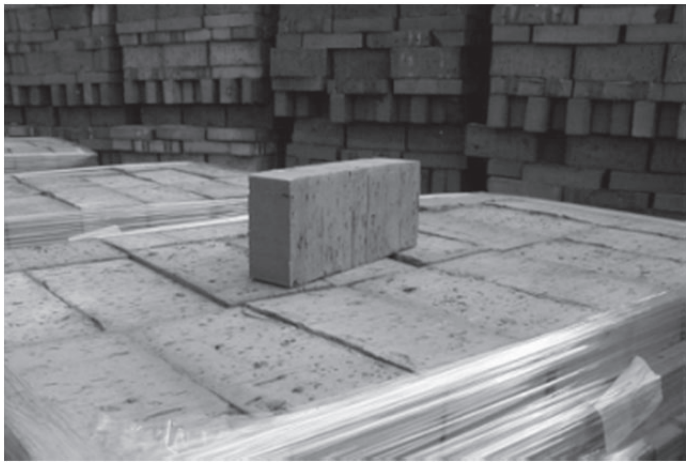


Figure 140 – Bricks placed on a wooden pallet and fixed in place with flexi foil

13.3 Analysis of Brick Sales

It is important for the company to know about its competitors, not only about their strengths and structure, but also about their location and the range to which they operate with successful market presence. This business information helps a company to find its place in the market and to determine the maximum range of activities considered optimal for a company in this sector.

After the careful analysis of companies involved in the production of building materials, 16 competing business units were identified in the research locality (Table 112, Figure 141).

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Table 112 – List of businesses involved in the production of bricks

Object	Brick factory	Based in
1	**Vranovska tehelna**	Cemernianska
2	**Jasim TEHELNE**	Vranov n. T. – Cemerne
3	**Tehelna STOVA, Ltd.**	Drienovska Nova Ves
4	**Ipelske tehelne**	Spisska Nova Ves
5	**Ipelske tehelne**	Lucenec
6	**Ipelske tehelne**	Tornala
7	**Ipelske tehelne**	Breznicka
8	**Ipelske tehelne**	Poltar
9	**Wienerberger, Ltd.**	Lucenec – Fabianka
10	**Wienerberger, Ltd.**	Zlate Moravce
11	**Wienerberger, Ltd.**	Boleraz
12	**SETA Tehelne, Inc.**	Ruzomberok
13	**TEHELNA Preselany Ltd.**	Zilina
14	**Myjavska tehelna, Tova Ltd.**	Preselany
15	**TEHELNA GBELY, Ltd.**	Myjava
16	**Pezinske tehelne – Panelaren, Inc.**	Gbely

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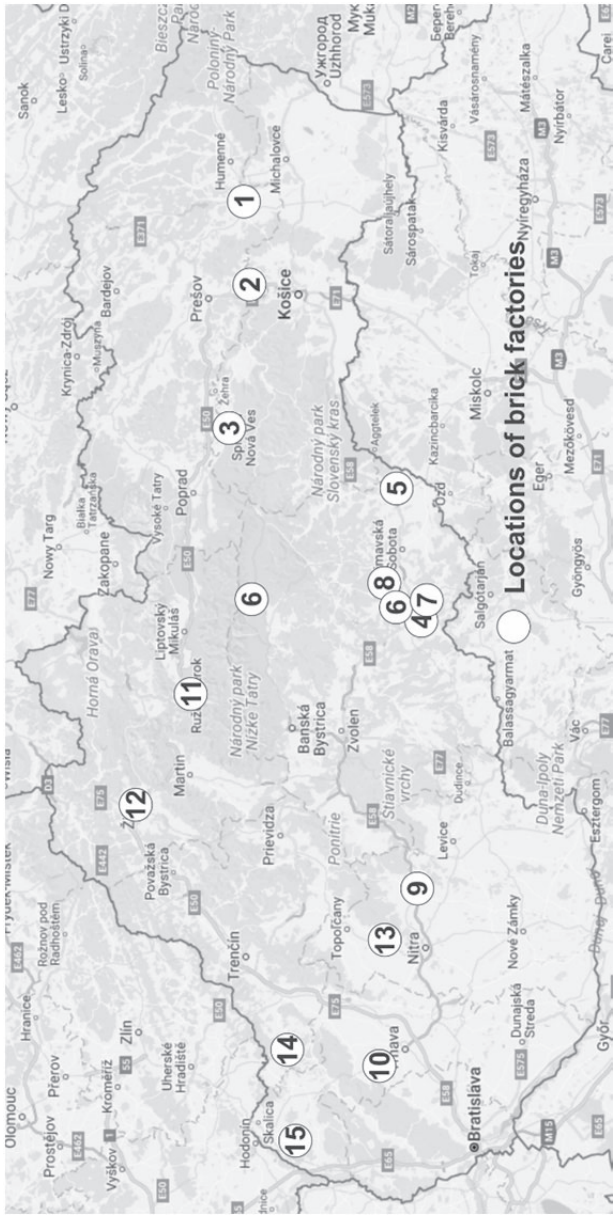


Figure 141 – Locations of competing brick factories in Slovakia

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The results of the market survey and the percentage distribution show that of the competing brick factories in Slovakia, 49% of them use their own freight road transport for distribution within the Slovak Republic, while 38% of them use transport services. The existence of distribution warehouses was confirmed by only two brick factories, representing 13% of the total number. Currently, no brick factory uses freight rail transport for distribution within the Slovak Republic.

The customers of Brick Factory Kosice are companies doing business in construction and building activities, or they are active in selling building materials, i.e. wholesale and retail traders in building materials.

13.4 Proposal for a Suitable Distribution System for Brick Factory Kosice

When defining the topology of the distribution network, one begins with the definition of topology "the field of geometry studying the relationship of the position of geometric formations". The topology of the distribution network examines the interconnections and the location relationships of distribution places that create the distribution network (Straka 2004).

The distribution region within Eastern Slovakia consists of 49 customers. There are 21 customers in the Kosice region, and 28 customers in the Presov region.

13.4.1 One Level Distribution Network – Type "Star"

The "Star" type distribution network is based on the real distance between the production plant and particular customers. The internet expert system at www.viamichelin.com was used to determine the real distances.

In a star-type distribution network (Figure 142), a truck with a trailer performs distribution of bricks from the factory to all 49 customers. There are 49 distribution routes, whereby each distribution route starts at the factory by loading pallets, then it is sent to one of the customers where the brick pallets are unloaded. After unloading the brick pallets, the empty used pallets are loaded and the number of used pallets is equal to the number of pallets of bricks taken. The pallets must be stacked and taken by the shipping worker. Pallet loading is performed with a forklift; the loading time should not exceed 60 minutes. The time required for palletizing is defined as 60 minutes.

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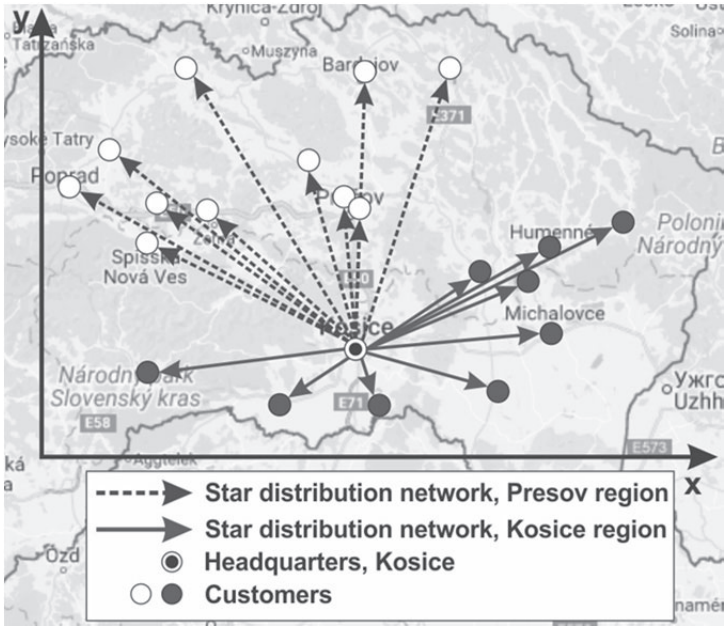


Figure 142 – Distribution network of the "Star" type

The average speed of a truck and trailer with a load capacity of 24 t is 55 km/h. With this type of distribution network, a truck travels about 5750 km and supplies 49 customers with about 1130 tonnes of bricks in about 13 515 minutes. The working time of one truck driver is set at 8 hours. This distribution method takes 28 days to complete.

13.4.2 Structured Distribution Network and Definition of Distribution Warehouses

Several options have to be verified in order to define a suitable two-level distribution network.

1. It is assumed that it is possible to supply building materials to three customers within one day, the other parameters of the system are:

- 1 working day (working shift) = 8 h,
- loading time = 60 min,
- unloading time = 60 min,
- idle time = 15 min.

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The time needed for handling three customers per one business day can be calculated as:

$$3 \times (60 + 60 + 15) = 405\ min = 6.75\ h.$$

The remaining time, the time for distribution during one business day to three customers is:

$$8 - 6.75 = 1.25\ h.$$

The time needed for distribution to one customer with return is:

$$1.25h = 75\ min/3 = 25\ min.$$

The time needed for distribution to one customer in one direction is:

$$25\ min/2 = 12.5\ min.$$

The results of the analysis for three customers show that this method is unrealistic. The availability time is 12.5 *min* and therefore, in comparison with the time intervals between particular customers it is too low. The distribution route to one customer would have to be completed within 25 minutes, which is too short a time in reality.

2. It is assumed that it is possible to supply the building materials to two customers during one day. The other parameters of the system are:

- 1 working day (working shift) = 8 h,
- loading time = 60 min,
- unloading time = 60 min,
- idle times = 15 min.

The time needed for handling two customers per one business day can be calculated as:

$$2 \times (60 + 60 + 15)\ min = 270\ min = 4.5\ h.$$

The remaining time, the time for distribution during one business day to two customers is:

$$8 - 4.5 = 3.5\ h.$$

The time needed for distribution to one customer with return is:

$$3.5\ h = 210\ min/2 = 105\ min.$$

The time needed for distribution to one customer in one direction is:

$$105\ min/2 = 52.5\ min.$$

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From these results, the availability time to use in the "*Method of Distribution Potential*" is *CaDos* = 52.5 minutes, which is sufficient time in terms of the distances between the manufacturer and customers. When calculating the time of availability, idle time of 15 minutes is assumed for each customer.

There is a certain free float that is used to round the availability time to *CaDos* = 57 min.

13.4.2.1 Dividing the distribution region by the "Method of Distribution Potential"

The Method of Distribution Potential (MDP) is used to divide the distribution space into smaller parts, in which locations are defined that will be used as central warehouses of the region. The basis of the method is in the multicriteria assessment of suitable places which have distribution potential, i.e. the ability to be a "leader" of an area. The division of weights for each defined criterion is performed through direct access to the Metfessel allocation (Straka 2012).

Criteria considered under MDP:

- capacity of warehouses,
- technical equipment of warehouses,
- information systems in warehouses,
- infrastructure,
- demand in a region.

Capacity of warehouses, W_i = 24.

A warehouse has long been considered as a passive, subordinate item in the logistics chain. However, its importance has recently been changing significantly. E-commerce and supply chain management are now changing requirements and processes in large and medium-sized companies. Logistics goals (the right product in the right quantity at the right time and at the right place) can only be achieved with an efficient warehouse.

Technical equipment, W_i = 20.

In addition to inventory management, this is mainly about the right choice of warehouse technology. The customer must have at least one truck with a trailer to be used for distribution of construction material within the distribution group as well as the necessary forklift trucks.

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Information system of the warehouse, W_i= 15.

The warehouse must be equipped with barcode reader software. The barcodes placed on the stored goods enable perfect and accurate records of all incoming and outgoing goods as well as the current state of the warehouse.

Infrastructure, W_i = 24.

For the approval of a certain customer in a defined area as a potential location for the distribution warehouse, importance is placed on location at a major traffic junction or near a traffic junction where there is direct connection to the railway and road networks.

Demand in the region, W_i = 17.

Distribution warehouses must be located at the most demand-intensive locations, thereby minimizing the transport costs of delivering products to particular customers.

1. The customer with the greatest distribution potential in this case is O5 (Table 113). Customers who fulfil the availability criterion *CaDos* = 57 min are linked to it (Table 114).

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Table 113 – Ordering of customers "from the best to the worst" according to the number of points obtained in the multi-criteria evaluation

Position	Method of Distribution Potential	Warehouse capacity	Technical equipment	Software equipment	Infrastructure	Quantity taken	SUM weights × points
	weights	24	20	15	24	17	Metfessel allocation
1	05	9	9	9	9	9	900
2	08	9	9	8	9	9	885
3	013	9	9	8	9	9	885
4	023	9	9	9	9	8	883
5	06	9	8	9	9	9	880
6	09	9	8	9	9	9	880
7	047	8	9	9	9	9	876
8	040	9	8	9	9	8	863
9	017	9	9	8	8	9	861
10	020	9	9	8	7	9	837
11	034	8	9	8	8	9	837
12	033	9	8	8	8	8	824
13	012	8	8	9	8	8	815
14	032	9	8	7	8	8	809
15	02	8	9	8	8	7	803
16	03	8	8	8	8	8	800
17	04	8	8	8	8	8	800
18	038	8	8	8	8	8	800
19	048	8	8	8	8	8	800
20	050	8	8	8	8	8	800
21	026	8	9	8	7	8	796
22	014	8	7	8	8	8	780
23	024	8	8	8	7	8	776
24	016	8	8	6	8	8	770
25	037	9	7	8	7	7	763
26	07	7	8	8	8	7	759
27	029	7	7	8	8	8	756
28	022	7	9	8	7	7	755
29	025	7	7	8	7	9	749
30	031	7	8	8	8	6	742
31	018	7	7	7	8	8	741
32	045	7	7	7	8	8	741
33	035	7	7	8	8	7	739
34	036	7	7	8	8	7	739
35	046	7	7	8	8	7	739
36	019	7	7	8	7	8	732
37	010	7	7	7	8	7	724
38	027	7	7	7	8	7	724
39	041	8	7	7	7	7	724
40	049	7	7	8	7	7	715
41	021	6	6	8	8	8	712
42	044	7	6	8	7	8	712
43	039	7	7	7	7	7	700
44	042	7	7	7	7	7	700
45	043	7	7	7	7	7	700
46	028	6	6	7	8	7	680
47	030	6	6	8	8	6	678
48	011	7	7	7	6	7	676
49	015	7	7	6	7	6	668

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Table 114 – List of customers included in the 1st distribution group

ID	*Customers*	
	Name and location	*City*
O2	L & L TRADING	Kosice
O3	BAUMAX SR	Kosice
O4	BAUMAX SR	Kosice
O5	SKANSKA Technologie	Kosice
O6	STAVA IP	Kosice
O7	STAVOSERVIS	Kosice
O8	IINZINIERSKE STAVBY	Kosice
O9	STAVIMAX	Kosice
O10	BITTOVA JOLANA	Cana
O11	STAVOMEGA, Ltd.	Moldava nad Bodvou
O28	EURIS LTD.	Roznava
O29	BAGIRA	Roznava

2. From the locations that have not yet been assigned to any distribution group under point 1, the customer with the largest distribution potential (*O13*) is again selected (Table 115). Customers who fulfil the availability criterion *CaDos* = 57 *min* are linked to it (Table 116).

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Table 115 – Ordering of customers "from the best to the worst" according to the number of points obtained in multi-criteria evaluation

Position	Method of Distribution Potential weights	Warehouse capacity 24	Technical equipment 20	Software equipment 15	Infrastructure 24	Quantity taken 17	SUM weights × points Metfessel allocation
1	O13	9	9	8	9	9	885
2	O23	9	9	9	9	8	883
3	O47	8	9	9	9	9	876
4	O40	9	8	9	9	8	863
5	O17	9	9	8	8	9	861
6	O20	9	9	8	7	9	837
7	O34	8	9	8	8	9	837
8	O33	9	8	8	8	8	824
9	O12	8	8	9	8	8	815
10	O32	9	8	7	8	8	809
11	O38	8	8	8	8	8	800
12	O48	8	8	8	8	8	800
13	O50	8	8	8	8	8	800
14	O26	8	9	8	7	8	796
15	O14	8	7	8	8	8	780
16	O24	8	8	8	7	8	776
17	O16	8	8	6	8	8	770
18	O37	9	7	8	7	7	763
19	O22	7	9	8	7	7	755
20	O25	7	7	8	8	9	749
21	O31	7	8	8	8	6	742
22	O18	7	7	7	8	8	741
23	O45	7	7	7	8	8	741
24	O35	7	7	8	8	7	739
25	O36	7	7	8	8	7	739
26	O46	7	7	8	8	7	739
27	O19	7	7	8	7	8	732
28	O27	7	7	7	8	7	724
29	O41	8	7	7	7	7	724
30	O49	7	7	8	7	7	715
31	O21	6	6	8	8	8	712
32	O44	7	6	8	7	8	712
33	O39	7	7	7	7	7	700
34	O42	7	7	7	7	7	700
35	O43	7	7	7	7	7	700
36	O30	6	6	8	8	6	678
37	O15	7	7	6	7	6	668

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Table 116 – List of customers included in the 2nd distribution group

ID	*Customers*	
	Name and location	*City*
O35	SOAS-VK SLOVAKIA Ltd.	Bardejov
O36	KUKLA FRANTISEK	Bardejov
O37	Peter Pilip BYTSERVIS	Svidnik
O12	BAUMAX SR Ltd.	Presov
O13	EKOPRIM, Ltd.	Presov
O14	MPL TRADING Ltd.	Presov
O15	UNISTAV, LTD.	Presov
O16	HOBBY STAVEBNINY, Ltd.	Presov
O17	STAVMAT IN Ltd.	Presov
O18	KAMIN, Ltd.	Velky Saris
O22	EKO SVIP	Sabinov

3. From the locations that have not yet been assigned in step 2, the customer with the largest distribution potential (*O33*) is again selected (Table 117). Customers who fulfil the availability criterion *CaDos* = 57 min are linked to it (Table 118).

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Table 117 – Ordering of customers "from the best to the worst" according to the number of points obtained in the multi-criteria evaluation

Position	Method of Distribution Potential weights	Warehouse capacity 24	Technical equipment 20	Software equipment 15	Infrastructure 24	Quantity taken 17	SUM weights x points	Metfessel allocation
1	023	9	9	9	9	8	883	
2	047	8	9	9	9	9	876	
3	040	9	8	9	9	8	863	
4	020	9	9	8	7	9	837	
5	034	8	9	8	8	9	837	
6	033	9	8	8	8	8	824	
7	032	9	8	7	8	8	809	
8	038	8	8	8	8	8	800	
9	048	8	8	8	8	8	800	
10	050	8	8	8	8	8	800	
11	026	8	9	8	7	8	796	
12	024	8	8	8	7	8	776	
13	025	7	7	8	7	9	749	
14	031	7	8	8	8	6		742
15	045	7	7	7	8	8		741
16	046	7	7	8	8	7		739
17	019	7	7	8	7	8		732
18	027	7	7	7	8	7		724
19	041	8	7	7	7	7		724
20	049	7	7	8	7	7		715
21	021	6	6	8	8	8		712
22	044	7	6	8	7	8		712
23	039	7	7	7	7	7		700
24	042	7	7	7	7	7		700
25	043	7	7	7	7	7		700
26	030	6	6	8	8	6		678

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Table 118 – List of customers included in the 3rd distribution group

ID	*Customers*	
	Name and location	*City*
O27	Chemkostav Strazske	Strazske
O32	SOAS-BAUMEKO LTD.	Humenne
O33	STAVMAX HUMENNÉ, LTD.	Humenne
O38	SOAS-SUPTRANS Ltd.	Snina
O19	AMPAM	Trebisov
O20	HROMADA Ltd.	Vranov nad Toplou
O21	BETPRES	Vranov nad Toplou
O23	CHEMKOSTAV	Michalovce
O24	Michalovske pozemne stavby	Michalovce
O25	SCORP	Michalovce

4. The process continues as in the previous steps by selecting the remaining customers who have not yet been assigned to any of the previous distribution groups (Table 119). Customers who fulfil the availability criterion *CaDos* = 57 min are linked in (Table 120).

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Table 119 – Ordering of customers "from the best to the worst" according to the number of points obtained in the multi-criteria evaluation

Position	Method of Distribution Potential weights	Warehouse capacity 24	Technical equipment 20	Software equipment 15	Infrastructure 24	Quantity taken 17	SUM weights × points	Metfessel allocation
1	O47	8	9	9	9	9	876	
2	O40	9	8	9	9	8	863	
3	O34	8	9	8	8	9	837	
4	O48	8	8	8	8	8	800	
5	O50	8	8	8	8	8	800	
6	O26	8	9	8	7	8	796	
7	O31	7	8	8	8	6	742	
8	O45	7	7	7	8	8	741	
9	O46	7	7	8	8	7	739	
10	O41	8	7	7	7	7	724	
11	O49	7	7	8	7	7	715	
12	O44	7	6	8	7	8	712	
13	O39	7	7	7	7	7	700	
14	O42	7	7	7	7	7	700	
15	O43	7	7	7	7	7	700	
16	O30	6	6	8	8	6	678	

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Table 120 – List of customers included in the 4th distribution group

ID	*Customers*	
	Name and location	*City*
O30	CANDOM	Spisska Nova Ves
O26	STAVMARKET SLOVSTEIN Ltd.	Spisske podhradie
O31	URANPES	Spisska Nova Ves
O34	KAMEGA Ltd.	Levoca
O39	PIENSTAV	Stara Lubovna
O40	STAVOS-AST, Ltd.	Stara Lubovna
O41	REPKA JOZEF	Stara Lubovna
O42	TATRACOR Ltd.	Stara Lubovna
O43	EVA BRITAŇÁKOVÁ	Kezmarok
O44	RONDO, Ltd.	Kezmarok
O45	IVAN PUKLUS, MICHAL ZEMCAK	Kezmarok
O46	BAU land	Poprad
O47	Arprog	Poprad
O48	STAVEBNINY – TATRY, Ltd.	Poprad
O49	STAV-ING STAVEBNINY Ltd.	Poprad
O50	IDOS Ltd.	Poprad

In the first phase of the division of the region using the method of distribution potential, the region was divided into four unbalanced distribution groups (DG). Customers *O35, O36, O37* formed an individual group, which is unprofitable because of their small number. Along with this fact, due to the time of availability from the brick factory to customers *O35, O36, O37*, they cannot be assigned to the 1st distribution group (Table 125).

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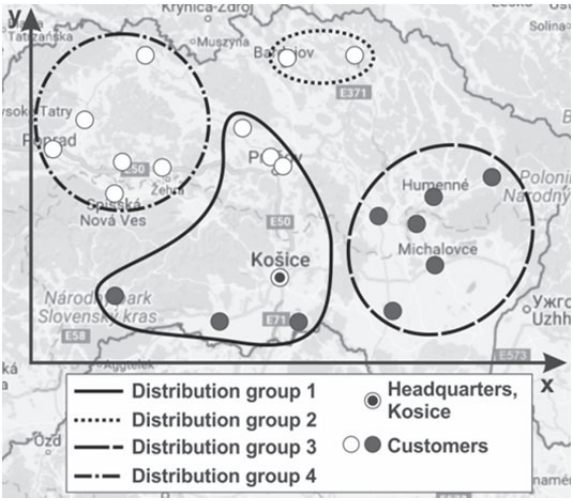


Figure 143 – Proposal for division of the region

From the supplying point of view, it is advisable to create balanced groups and therefore some of customers from the 1st group are moved to the 2nd group (Figure 144). The method of distribution potential will form the basis of the structured distribution network.

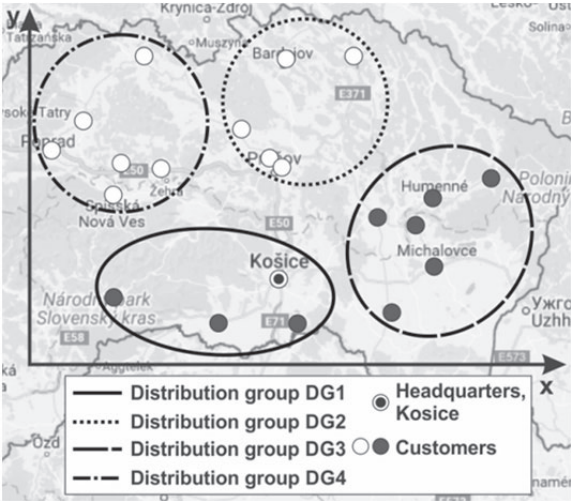


Figure 144 – Dividing the distribution region into four balanced distribution groups

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13.4.2.2 Selection of distribution warehouses, distribution network

The effort and solution, within particular defined distribution groups, is to find a customer who will be superior in the distribution group and locate the distribution warehouse of the group at that point. Because the effort is to achieve the shortest possible distribution route of a vehicle, it is necessary that the sum of the distances from the distribution warehouse to customers will be as short as possible. The condition for the preference of one of the customers in relation to locating the distribution warehouse is to fulfil the defined criteria. The customer with higher evaluation on the criteria has the advantage in selection.

The 1st distribution group (DG1):

The customers in this distribution group will be supplied directly from the brick factory in Kosice. The 1st distribution group is a star-type distribution network (Figure 145). The relation *"1–m"* involves joining a single distribution place at input, i.e. Brick Factory Kosice with *m* distribution places at the output – customers *O2, O3, O4, O5, O6, O7, O8, O9, O10, O11, O28, O29*. The building material is progressively delivered to all customers from the brick factory in Kosice.

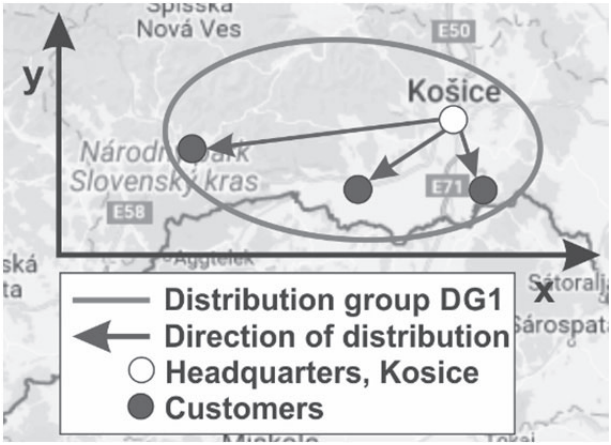


Figure 145 – Distribution group – DG1

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Table 121 – Distances and durations of distribution routes in DG1

Distribution group DG1			Distances	There-back	Time to ride	Total time for material handling	Total driving time	Quantity of goods
	s.n.	Consumers	km	km	min	min	min	t
Brick factory Kosice	1	02	7.6	15.2	18.2	135	153.24	23.069
	2	03	6.9	13.8	16.6	135	151.56	23.069
	3	04	0.8	1.6	1.9	135	136.92	23.069
	4	05	5.6	11.2	13.4	135	148.44	23.069
	5	06	1.1	2.2	2.6	135	137.64	23.069
	6	07	7.2	14.4	17.3	135	152.28	23.069
	7	08	3.3	6.6	7.9	135	142.92	23.069
	8	09	2.6	5.2	6.2	135	141.24	23.069
	9	010	14.1	28.2	33.8	135	168.84	23.069
	10	011	26.8	53.6	64.3	135	199.32	23.069
	11	028	69.2	138.4	166.1	135	301.08	23.069
	12	029	67.1	134.2	161.0	135	296.04	23.069
			212.3	**424.6**	**509.5**		**2129.52**	**276.828**

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A truck with a trailer travels 424.6 km round DG1 while it delivers 276.828 tons of bricks to 12 customers (Table 121). The total distribution time with loading and unloading is 2129.52 min = 35.5 hours. The truck driver's working time is 8 hours so the total distribution of bricks within the 1st distribution group will take 4.5 days.

The 2nd distribution group (DG2):

There are 11 customers from the Presov region in the 2nd distribution group. There are defined factors, which are decisive for the selection of distribution warehouses for those customers. In choosing the optimal customer who also becomes the distribution warehouse for Brick Factory Kosice in this area, the aim is for the truck to travel as short a journey as possible. The customer with the smallest number of kilometres will have the highest evaluation for the decision.

Point *O17* – Stavmat In Ltd., Presov has the highest evaluation of the criteria.

Criterion 1 – Warehouse capacity;

- It has its own storage spaces, the capacity of which is adapted to the storage of building materials.

Criterion 2 – Technical equipment;

- It has 70 trucks and tankers daily.

Criterion 3 – Information system;

- Stavmat In Ltd is becoming the largest business organization offering a complete assortment of building materials in Slovakia over the Internet.

Criterion 4 – Infrastructure;

- Stavmat In has a direct connection to fast routes.

Criterion 5 – Quantity of supplies;

- A wide range of building materials; the company supplies more than 70 shops offering building materials throughout the Slovak Republic and it has been cooperating with the brick factory for four years. It exports and imports goods all over the Czech Republic and Slovakia. It conducts wholesaling business activities, which enables it to provide significant discounts to customers including transport service.

The distance of customer *O17* from the brick factory is 35.5 km. There are 11 customers in the 2nd distribution group. It distributes 253.8 tonnes of bricks into distribution warehouse *O17*, a truck travels 781 km in 2422.2 min = 40.4 hours.

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Table 122 – Distances and times of distribution routes in DG2

Distribution group DG2			Distances	There-back	Time to ride	Total time for material handling	Total driving time	Quantity of goods
	s.n.	Consumers	km	km	min	min	min	t
Brick factory Kosice	1	O12	5.0	10	12.0	135	147.00	23.069
	2	O13	4.0	8	9.6	135	144.60	23.069
	3	O14	3.0	6	7.2	135	142.20	23.069
	4	O15	2.0	4	4.8	135	139.80	23.069
	5	O16	1.0	2	2.4	135	137.40	23.069
	6	O18	6.9	13.8	16.6	135	151.56	23.069
	7	O22	17.9	35.8	43.0	135	177.96	23.069
	8	O35	41.6	83.2	99.8	135	234.84	23.069
	9	O36	42.0	84	100.8	135	235.80	23.069
	10	O37	55.0	110	132.0	135	267.00	23.069
	11	O17	0.0	0	0.0	0	0.00	23.069
			178.4	**356.8**	**428.2**		**1778.16**	**253.759**

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Table 122 shows the distances from distribution warehouse *O17* to other customers within the distribution group. When distributing bricks from the distribution warehouse to other 10 customers, a truck travels 356.8 km in 1778.2 min = 29.6 hours also considering loading and unloading. The 2nd distribution group is the star-type of distribution network (Figure 146).

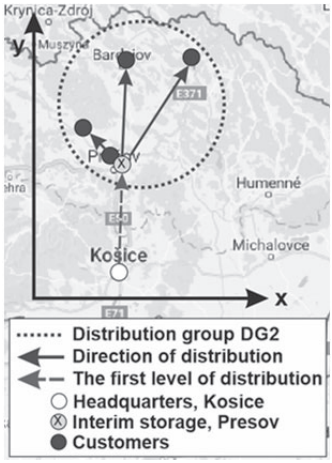


Figure 146 – Distribution group – DG2

A truck with a trailer covers distances of 781 + 356.8 = 1137.8 km within DG2, with 253.8 tons of brick deliveries to 11 customers. The total distribution time with loading and unloading is about 2422.2 min + 1778.2 min = 4200.4 min = 70.0 hours. The truck driver's working time is 8 hours, so the total distribution of the bricks in the 2nd distribution group will take approximately 8.5 days.

The 3rd distribution group (DG3):

The 3rd distribution group consists of 10 customers from the Kosice region. In the method for multi-criteria decision making, customer *O23* – Chemkostav, Michalovce has the highest rating under the criteria. This company fulfils the required criteria for the location to create an intermediate distribution warehouse.

There are 10 customers in the 3rd distribution group. A truck travels 1180 km in 2766 min = 46.1 hours to distribute 230.7 tonnes of bricks from distribution warehouse *O23*. Table 123 shows the distances from distribution warehouse *O23* to other customers within the distribution

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group. When distributing bricks from the distribution warehouse to the other 9 customers, the truck travels 424.6 km with a time of 1724.5 min = 28.7 hours.

Table 123 – Distances and times of distribution routes in DG3

Distribution group DG3			Distances	There-back	Time to ride	Total time for material handling	Total driving time	Quantity of goods
Brick factory Kosice	s.n.	Consumers	km	km	min	min	min	t
	1	019	24.3	48.6	58.3	135	193.32	23.069
	2	020	32.1	64.2	77.0	135	212.04	23.069
	3	021	33.0	66	79.2	135	214.20	23.069
	4	024	3.0	6	7.2	135	142.20	23.069
	5	025	2.0	4	4.8	135	139.80	23.069
	6	027	17.6	35.2	42.2	135	177.24	23.069
	7	032	26.3	52.6	63.1	135	198.12	23.069
	8	033	26.0	52	62.4	135	197.40	23.069
	9	038	48.0	96	115.2	135	250.20	23.069
	10	023	0.0	0	0.0	0	0.00	23.069
			212.3	424.6	509.5		1724.52	230.69

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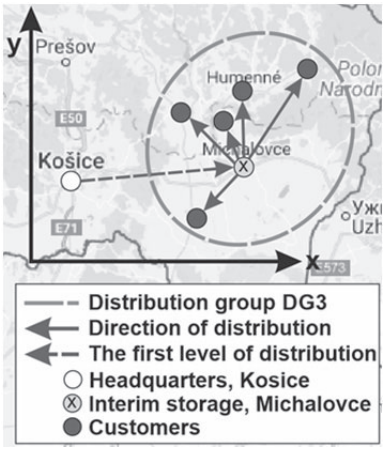


Figure 147 – Distribution group – DG3

The 3rd distribution group is a star-type distribution network (Figure 147). A truck with a trailer covers a total distance of 1180 + 424.6 = 1604.6 km within DG3 with 230.7 tons of brick deliveries to 10 customers. The total distribution time with loading and unloading is about 2766 min + 1724.5 min = 4490.5 min = 74.8 hours. The truck driver's working time is 8 hours, the total distribution of bricks within the 3rd distribution group will take about 9.5 days.

The 4th distribution group (DG4):

The 4th distribution group consists of 16 customers from the Presov region. In the method of multi-criteria decision making, customer *O34* – Kamega Ltd., Levoca has the highest rating under the criteria, this company fulfils the required criteria for the location to create a distribution warehouse.

The 4th distribution group consists of 16 customers. A truck travels 2425.6 km in 5070.72 min = 84.5 hours to distribute 369.1 tonnes of bricks to distribution warehouse *O34*. Table 124 lists the distances from distribution warehouse *O34* to the other customers within the distribution group. When distributing bricks from the distribution warehouse to the other 15 customers, the truck travels 926.4 km in 3136.7 min = 52.3 hours.

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Table 124 – Distances and times of distribution routes in DG4

Distribution DG4	group	Distances	There-back	Time to ride	Total material handling time for	Total driving time	Quantity of goods
s.n.	Consumers	km	km	min	min	min	t
Brick factory Kosice							
1	O26	4.9	9.8	11.8	135	146.76	23.069
2	O30	10.5	21	25.2	135	160.20	23.069
3	O31	10.5	21	25.2	135	160.20	23.069
4	O39	58.0	116	139.2	135	274.20	23.069
5	O40	59.0	118	141.6	135	276.60	23.069
6	O41	58.6	117.2	140.6	135	275.64	23.069
7	O42	58.1	116.2	139.4	135	274.44	23.069
8	O43	25.8	51.6	61.9	135	196.92	23.069
9	O44	25.0	50	60.0	135	195.00	23.069
10	O45	25.5	51	61.2	135	196.20	23.069
11	O46	24.5	49	58.8	135	193.80	23.069
12	O47	25.9	51.8	62.2	135	197.16	23.069
13	O48	25.9	51.8	62.2	135	197.16	23.069
14	O49	25.0	50	60.0	135	195.00	23.069
15	O50	26.0	52	62.4	135	197.40	23.069
16	O34	0.0	0	0.0	0	0.00	23.069
		463.2	926.4	1111.7		3136.68	369.104

The 4th distribution group is a star-type distribution network (Figure 148). A truck with a trailer covers a total distance of 2425.6 + 926.4 = 3352 km within DG4 with 369.104 tons of brick

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deliveries to 16 customers. The total distribution time with loading and unloading is about 5070.72 min + 3136.7 min = 8207.42 = 136.8 hours. The truck driver's working time is 8 hours, the total distribution of bricks within the 4th distribution group will take about 17 days.

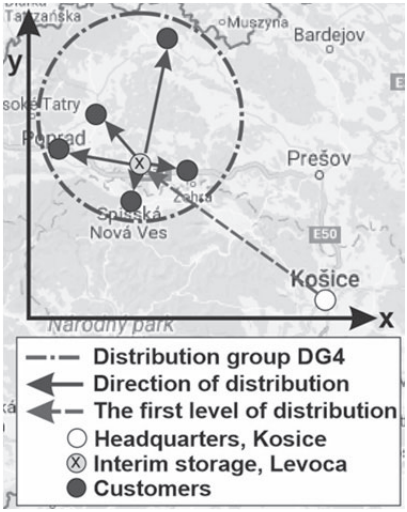


Figure 148 – Distribution group – DG4

13.4.2.3 Evaluation of results for truck transport

The length of journeys for the structured "Star-to-Star" distribution network from Brick Factory Kosice to the distribution warehouse and from the distribution warehouse to the other customers within the distribution groups is evaluated in terms of distance and time (Table 125).

Table 125 – Distances and times for the structured distribution network

	km	min	t
DG1	424.6	2 129.5	276.8
DG2	1 137.8	4 200.4	253.8
DG3	1 604.6	4 490.5	230.7
DG4	3 352.0	8 207.4	369.1
SUM	6 519.0	19 027.8	1 130.4

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The distribution route for the structured "Star-to-Star" distribution network (Figure 149) using three distribution warehouses is 6 519 km long. In comparison with the star-type distribution network, the structured distribution network is 769 km longer, which is also reflected in the distribution time.

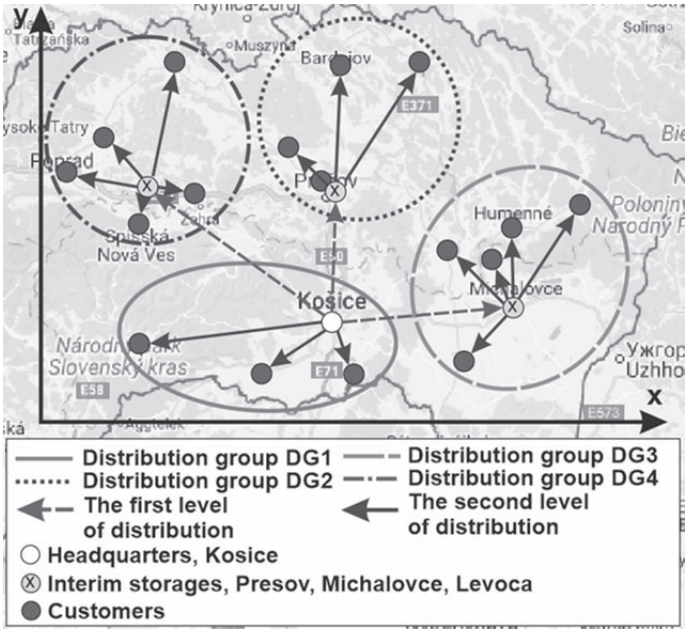


Figure 149 – Structured "Star-to-Star" distribution network

The advantage of the structured distribution network is the rapid fulfilment of customer requirements when delivering goods. Distances from distribution warehouses to customers are significantly lower than from the factory.

The disadvantage of the structured distribution network is the costs incurred in this type of network:

- the costs of transport from production to distribution warehouses,
- the costs of brick transport from distribution warehouses to customers,
- operating costs of warehouses,
- the cost of maintaining stocks in the distribution network.

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13.5 Possibilities for Using Combined Transport

It is important to evaluate the possibilities of combined transport depending on the type of transported goods in order possibly to reduce distribution costs. A suitable option is the possibility of using railway transport on some of the sections or as the first level of the distribution network.

The advantages of railway transport:

- **Safety of goods transportation** is the primary and decisive precondition for the quality of transport. Railway transport is the safest mode of transport compared to other modes of transport.
- **Environmental responsibility**, railway transport in many cases is not only an efficient transport system but, especially an environmentally friendly system because large volumes of goods can be transported over long distances, not only quickly but also with minimal impact on the environment
- **Transport capacity and price conditions**, railway transport enables larger quantities of goods to be transported over long and medium distances at relatively low costs.
- **Lower transport constraints on the types of transported goods** compared to road transport is undoubtedly an advantage of railway transport as well as the transport of certain types of goods that a truck is unable to handle.

13.5.1 Length of the Distribution Track using Railway Transport

Brick Factory Kosice has a direct connection to the railway station in Kosice. The solution used for railway transport presupposes the existence of distribution warehouses at points *O17, O23, O34*. Customers within DG1 are supplied from the brick factory in Kosice by road transport. Distribution warehouses DG2, DG3, DG4 are used to store the ordered quantity of bricks that are designated for certain customers. The goods are transported using railway transport to the distribution warehouses, from where the goods are transported to all customers at once within the distribution group. Subsequently, bricks are delivered by truck transport to the particular customers from distribution warehouses.

Track lengths for the distribution of bricks using railway transport:

- The 2nd distribution group:
  - The distance between the railway stations in Kosice and Presov is 33 km.
  - The quantity of bricks transported is 253.8 tonnes.

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- The 3rd distribution group:
  - The distance between the railway stations in Kosice and Michalovce is 73 km.
  - The quantity of bricks transported is 230.7 tonnes.
- The 4th distribution group:
  - The distance between the railway stations in Kosice and Levoca is 88 km.
  - The quantity of bricks transported is 369.1 tonnes.

The total length of the distribution route, using combined transport (Table 126), is the sum of the routes in the first level distribution network representing railway transport and the sum of the routes in the second level distribution network, representing truck transport.

The two-level distribution network with combined transport needs 2326.4 km of route length compared to the two-level truck transport distribution network, which needs 6519.0 km of route length (Figure 150). This means a reduction in the length of the distribution track of 4192.6 km. Total distribution costs have the decisive influence on the choice of the optimal distribution system.

Table 126 – Total track length with combined transport

km	The 1st level, railway transport	The 2nd level truck transport	SUM
DG1	0.0	424.6	424.6
DG2	33.0	356.8	389.8
DG3	73.0	424.6	497.6
DG4	88.0	926.4	1 014.4
SUM	**194.0**	**2 132.4**	**2 326.4**

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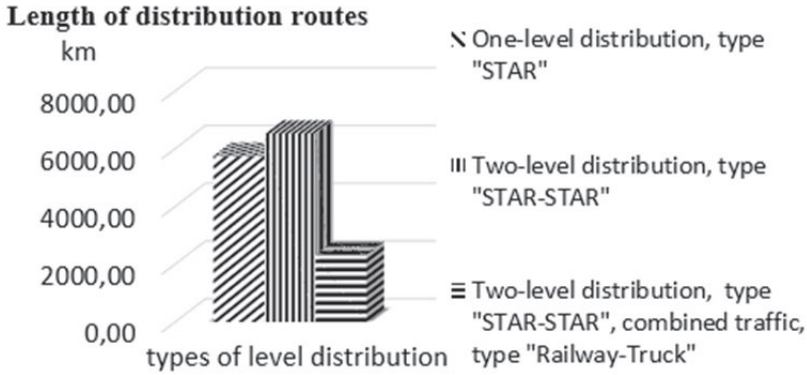


Figure 150 – Comparison of distribution route lengths for particular solutions

13.6 Cost of Distribution Analysis

Costs for railway transport (Railway Company CARGO Slovakia)**:**
Transported goods: Bricks;
Type of wagon: A four-axle covered wagon HAS type;
Type of shipment: ordinary shipment;
Connection: Kosice – Presov;
Weight of goods: 253.8 t;
Transport costs: 1314.24 EUR;
Transport costs per tonne: 5.19 EUR/t;
Connection: Kosice – Michalovce;
Weight of goods: 230.7 t;
Transport costs: 1715.36 EUR;
Transport costs per tonne: 7.44 EUR/t;
Connection: Kosice – Levoca;
Weight of goods: 369.1 t;
Transport costs: 2915.98 EUR;
Transport costs per tonne: 7.90 EUR/t.

Costs for own transport:

The methodical calculation procedure for determining the minimum of costs incurred for road transport is an activity that calculates the costs of transport and other services. The dynamic calculation considers the impact of the operation on a unit cost basis.

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Costs for the star-type distribution network:

- A truck with a trailer travels 5750.4 km.
- It supplies 49 customers with the same quantity of bricks.
- The quantity of goods transported is 1130.381 tonnes.
- It takes 225.26 hours, which is approx. 28 days with an 8–hour working shift.
- The costs for road transport are 6871.62 EUR.

Costs for the distribution network structured with distribution warehouses:

- A truck with a trailer travels 6519 km.
- It supplies all 49 customers with the same quantity of bricks, 23.069 tonnes.
- The quantity of goods transported is 1130.381 tonnes.
- It takes 322.1 hours, which is approx. 40 days with an 8–hour working shift.
- The costs for road transport are 7790.08 EUR.

Costs for the distribution network structured with combined transport:

- The length of the distribution routes by railway is 194 km.
- Costs for railway transport are 5945.58 EUR.
- Time needed for handling and transporting goods is 87.13 hours.
- The length of distribution routes within the distribution circuits where the distribution is carried out by freight transport, is 2132.4 km.
- Time for distribution with own transport 110.7 hours.
- Costs for road transport provided by own means of transport are 2548.18 EUR.
- Total costs when using combined transport are 8493.76 EUR.
- Total length of distribution routes 2326.4 km.

13.7 Selection of the Most Suitable Option, Conclusion and Assessment of Results

The selection of a suitable and efficient solution of the brick distribution system is solved with a multi-criteria decision-making method (Table 127).

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The choice is influenced by the factors:

- f_1 – the costs of the mode of transport,
- f_2 – the number of kilometres travelled in the distribution network with the given mode of transport,
- f_3 – the time required for handling and distribution in the distribution network with the means of transport.

For evaluation of the factors f_1, f_2, f_3, for the particular options, the selected factor evaluation interval is the cardinal scale $Hfi \langle 1; 6 \rangle$;

where: Hf_i – evaluation of f_i Factor,

1 – minimum value of the evaluation,

6 – maximum value of the evaluation.

The multi-criteria method is solved as a maximisation problem with a direct approach to evaluation. The highest evaluation of the criteria is with the star-type distribution network.

Table 127 – The choice of an appropriate solution by multi-criteria evaluation

Criteria	α_i	TYPE "STAR" Hf_i^1	$Hf_i^1 * \alpha_i$	Structured network Hf_i^2	$Hf_i^2 * \alpha_i$	Structured network with combined transport Hf_i^3	$Hf_i^3 * \alpha_i$
Costs	0.34	4	1.36	3	1.02	1	0.34
Number of kilometers	0.33	5	1.65	4	1.32	6	1.98
Time	0.33	5	1.65	4	1.32	6	1.98
SUM	1		4.66		3.66		4.30

All companies offering building materials in Slovakia that are potential competitors of Brick Factory Kosice were analysed and all brick producers selected. This analysis brought knowledge about the performance of distribution in the real environment of brick factories and also considered the percentage utilization of types of transport for the distribution of building materials within Slovakia.

An efficient distribution warehouse structure (in terms of number and location) was proposed for a multi-stage distribution system based on the

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geographical distribution of customers and by the Method of Distribution Potentials.

The above procedure will provide a sufficiently precise solution for the design of the distribution system structure with the use of common software tools. The main emphasis is put on its practical applicability, simplicity and also sufficient accuracy of the results. According to the multi-criteria evaluation, the optimal solution of the task is the star-type distribution network.

The heuristic approach allows the designer to intervene in the selection at any phase. He can further reduce the labour content of the process by selecting permissible potential solutions while considering other specific factors influencing the selection of the right combination of distribution warehouse locations.

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CHAPTER FOURTEEN

PROPOSAL FOR A DISTRIBUTION LOGISTICS AND TRANSPORT SYSTEM AT KAPA, INC.

14.1 Definition of the Problem and Objective of the Task

The problems with the current distribution system are the lack of a unified goods distribution planning system and the lack of explicitly defined rules for the creation of distribution plans. Currently, the distribution plans are dependent on particular workers in the sales department, which causes a considerable degree of inconsistency and the human factor has a great influence on the whole system. That is why the aim of the project is to design a planning system for goods distribution for the company.

Project tasks:

- To analyse the current status of the distribution system at KAPA, Inc. i.e. to identify the strengths and weaknesses of the existing system.
- To conceive the outline of a new distribution unit.
- To design the planning system for goods distribution.
- To design the principles for inserting orders into distribution plans.
- To process the algorithms for distribution planning.

14.2 Characteristics of KAPA, Inc.

KAPA, Inc. has been active in the Slovak and European markets for several decades. In the past, the company was one of the biggest manufacturers of packaging foils in Slovakia and also abroad. Nowadays, the company is focused mainly on producing and printing packaging foils for manufacturers in the food industry and hygienic production.

KAPA, Inc. is a dynamic, customer-oriented company focusing on the research, development, manufacturing and sales of packaging materials. Employees and business experts are constantly trying to increase added value for customers by applying the latest research and development

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knowledge. More than fifty years of manufacturing tradition and valuable experience are perfectly combined with up-to-date technologies. The company can be described with the following facts (Straka 2010):

- The company is owned by management and employees.
- The company constantly invests in the development of human resources.
- The marketing of the company emphasises the motto: *"we know today what you need tomorrow"*.
- The company prefers systematic collaboration with clients.
- It has its own research and development base based on cooperation with Slovak and foreign professional institutions that provides new and innovative approaches for all activities in the company.
- The company uses modern and up-to-date technology at the world level.
- The company has been awarded the ISO 9001 quality management certificate.
- The company is gradually building a TQM quality management system with the gradual introduction of environmental management systems (ISO 14 000).
- The company is building a knowledge management system.

14.3 The Range of Manufactured Goods

KAPA, Inc. deals with the production of basic packaging films, printing them and preparing them for use in the food industry. The product range of the company can be divided into two basic groups:

- the range of monofoils,
- the range of laminates.

The company has its own graphic studio and production of press forms. The staff, currently working at various levels of management and of the manufacturing process, is able to fulfil the most demanding customer requirements at a high level.

14.4 Analysis of the Distribution System at KAPA, Inc.

KAPA, Inc. transports its products to customers through the transportation services offered by the contracted company LAMDA, Ltd. (hereinafter LAMDA). KAPA, Inc. has a limited fleet and it has signed a distribution agreement with LAMDA. Each signed product distribution

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order is individual and it includes the date, destination and weight of the goods to be delivered. The method of billing for transport can be done as:

a) kilometres travelled,
b) weight.

The company predominantly pays for the entire truck ordered, regardless of how it is used. The price for the transport of goods is one way, meaning only the journey to a customer is paid for. KAPA, Inc. does not monitor adherence to routes. However, there is a condition that the shipment should take place within the specified time.

The task of LAMDA is to report any change related to distribution and it takes full responsibility in the event of damage or non-delivery to the customer.

Particular sellers, commercial workers and warehouse workers take care to ensure the distribution of products from KAPA, Inc. They are in charge of contacting LAMDA and ordering a vehicle for the shipment for a specific day and hour and they provide the necessary documents for drivers.

If shipping services are ordered four days in advance, LAMDA offers a 4% discount on the transport cost.

The work of the seller and particular officers included in the business group includes the following activities (Straka 2010):

- receiving orders from the customer,
- finding new business opportunities,
- creating business contracts and negotiating business conditions,
- involvement in the creation of manufacturing plans,
- obtaining information about product stocks and the level of manufacturing,
- checking the progress of orders across the stages of the process in the company,
- communication with the customer, comprehensive customer care,
- receiving customer feedback,
- communication with the warehouse,
- ordering a vehicle for a specific day and hour,
- providing necessary documents for drivers,
- informing the customer where their goods are located.

As shown from the list of sellers' activities, a high level of attention is paid throughout the entire processing of the order, from its receipt at the company to final implementation, while the primary task should be getting orders. For this reason, it is advisable to remove some activities (influence

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on manufacturing plans, distribution plans, vehicle ordering, etc.) in order to concentrate on getting orders. Creation of production plans should be the sole responsibility of the department of production programming. Distribution and related matters should be transferred to the department of transport and distribution, which would deal only with the following activities: creation of distribution plans, documentation, ordering means of transport, monitoring the distribution process. A department should be established for this purpose, as the company has not explicitly defined such a department thus far.

14.5 Warehouses of KAPA, Inc.

KAPA, Inc. has three types of warehouses:

- the warehouse of finished products,
- consignment warehouses in Slovakia,
- customers' warehouses abroad.

The warehouse of finished products receives goods that are directly intended for a customer and are waiting for removal. Products are stored individually for a quite long time according to customer requirements. The average storage time is three months; however, the length of storage time can be extended by mutual agreement with the customer.

The storage of products can be extended for a maximum of four months and after the end of this period a customer is obliged to take back his goods. However, it happens that even after the storage period has elapsed, the customer will not take his products and they still remain in the KAPA, Inc. warehouse.

The products are removed from the warehouse on the basis of a reference sent by a customer to a seller, who subsequently informs the warehouse about the date and quantity of products removed. The reference system is not available to all customers, only to some key customers, and delivery dates to others are known when the order is received (Straka 2010).

14.6 Customers of KAPA, Inc.

Customers of KAPA, Inc. in terms of their location, can be divided into the following three groups: Slovak customers, Czech customers, other customers.

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Customers from Ukraine are one specific group of customers. KAPA, Inc. has a large number of small customers in Ukraine, so there is an attempt to combine orders together. Customers are divided into two groups in terms of priority:

- Priority customers;
  - regular,
  - occasional.
- Ordinary customers;
  - regular,
  - occasional.

Priority regular customers are customers who regularly order products from the company in quantities that are several times higher than ordinary customers. The company has long-term business contracts with such partners.

Priority occasional customers are customers who do not order from the company regularly, only occasionally or randomly as needed, but the ordered quantities and the economic benefit exceed the requirements of ordinary customers several times.

Ordinary regular customers are customers who regularly order products from the company, but the ordered quantities or the economic benefit from the production is not currently decisive for the company.

Ordinary occasional customers are customers who order products from the company occasionally or randomly and the ordered quantities or the economic benefit of their production for the firm is not currently decisive (Straka 2010).

14.7 Application of SWOT Analysis for Evaluation of the Distribution System at KAPA, Inc.

On the basis of the information obtained, the status of KAPA, Inc., focused on the distribution of company products, is summarized using the SWOT analysis, which evaluates the strengths and weaknesses of the system and possible opportunities and threats. Values in SWOT analysis were average based on the anonymous questionnaire created, which was submitted and filled in by five KAPA, Inc. employees. Employees evaluated individual sites of the company in the range of $\langle 0;10 \rangle$, the more the company corresponded to the defined state, the more points the worker assigned from the rating scale. The final SWOT evaluation (Table 128) of the analysis is the state of the company, also expressed in a diagram (Figure 151).

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Table 128 – SWOT analysis of KAPA, Inc.

The SWOT analysis of the distribution system company KAPA, Inc.					
S - Strengths		values	W - Weaknesses		values
Costs	the company does not have its own lorries fleet, it does not cover vehicle maintenance costs, drivers' fees, fuel costs, car insurance, the cost of operating the garage and parking spaces	9.40	Distribution	there is a lot of competence in the work of sellers, which has a negative effect on the production plan and consequently on the distribution plan	9.00
Company	the company has the option of changing the carrier in case of dissatisfaction	10.00		the problems of transport planning at a certain time in advance	7.40
Customer	the seller seeks to obtain information about the state of the product and its level of manufacturing workmanship, if necessary, the effort to push the product into the plan and into production, according to its needs, dealers are planning and ordering the distribution	9.80		problems of creating distribution plans	8.80
				lacking distribution cost estimates	8.20
			Company	long-term choosing the same company may lead the carrier to lose interest in providing the best prices for the business	6.60
	the seller informs the customer where his goods are located	10.00		one company provides about 95% of the distribution business	9.80
average value		9.80	average value		8.30
O - Opportunities		values	T - Threat		values
Distribution Department	creating a separate distribution department in the company that has defined its mission, priorities, responsibilities, and accountability	10.00	Company	orientation of product distribution to one major transport company	9.00
Infrastructure	convenient transport location, accessible airport, rail, convenient connection to the highway network	9.40			
Possibilities	mitigate the majority position of the carrier LAMDA, Ltd.	8.20		great competition in a given business segment	7.40
	regular invitations to tender (once a year) for new entrants	8.80			
	the use of the services of other transport companies	9.80		the reluctance of people to accept the new changes	4.80
average value		9.24	average value		7.07

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On the basis of the results obtained, it is possible to calculate the final state of the company, which is shown as the difference between two adjacent average values:

- X axis:
  average value S - average value W = 9.80 - 8.30 = 1.50,
- Y axis:
  average value O - average value T = 9.24 - 7.07 = 2.17.

It is possible to create a graph diagram (Figure 151) from the calculated values, based on what score the company obtains for the resulting vector and the state in which the quadrant is currently located:

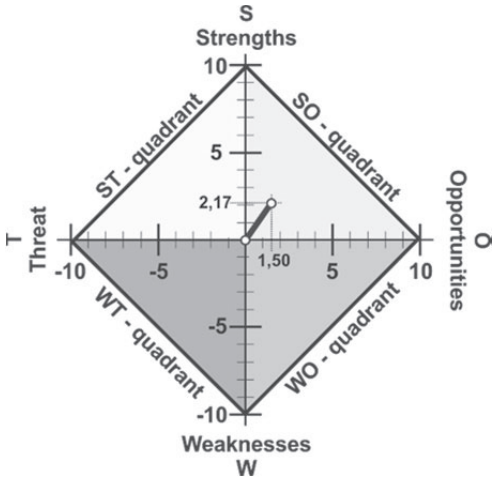


Figure 151 – Resulting status of KAPA, Inc. according to SWOT analysis

Definition of quadrants:

- SO – use strengths to gain a competitive advantage,
- WO – overcome weaknesses by taking advantage of opportunities,
- ST – use strengths to eliminate and to negate threats,
- WT – minimize costs and face threats.

It can be seen from the above diagram, which is based on the above calculations, that the company is located somewhere between "strengths and opportunities" in the SO-quadrant. This means that if KAPA, Inc. wants to maintain its profitability and good market position, it must mainly use its strengths to gain a long-term competitive advantage.

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The strengths of the current distribution system of KAPA, Inc.

Costs

The area of costs is a strength of the current distribution system. As the company does not own a fleet of vehicles, there are no costs for:

- maintenance of vehicles,
- alternation of summer and winter tires,
- drivers' salaries,
- fuel,
- vehicle insurance,
- operation of garages and parking areas.

In the future, the company does not have to make investments in renewal and modernization of the fleet or in the creation of new parking spaces.

New carrier selection

Another strength is that, if KAPA, Inc. is not satisfied with the services provided by the current transport company, a tender for new transport companies may be published after the expiration of the contractual period. Based on the offers, KAPA, Inc. selects the one that most suits the requirements determined.

Customer

The interest of each customer is that his order be given "above-standard" attention and that is just the possibility offered by the current system of order receipt, processing, manufacturing and distribution of KAPA, Inc. products.

Sellers strive to influence the creation of production plans in favour of a received order, they follow the progress of an order through the various stages of the company and they inform a customer about the status of completion of an order in the manufacturing process and about the distribution of the products themselves.

The weaknesses of the current distribution system of KAPA, Inc.

Distribution

It is very important for the company that the manufacturing process be smooth, in accordance with the production plan and without unexpected interventions. However, this cannot be achieved if sellers (even in the customer's interest) try to push their orders into the manufacturing and distribution plans. Such a seller-led approach can lead to chaotic decisions affecting the manufacturing and distribution processes and consequently it

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makes it impossible to optimize these processes. In such a system, it is very difficult to plan the transport of goods to customers, and it is almost impossible to make distribution plans a certain time in advance.

The company

If the same transport company is always selected in the tendering procedures, there is a risk that it will lose its interest in offering its services at the best prices. Therefore, it is necessary to continuously monitor the offers of other transport companies so that a strong distributor cannot "dictate" distribution conditions to the company.

Most distribution is by one carrier

The company itself decides whether to use the services from many companies or to commit to one Transport Company, which gets the status of a majority position. If the company chooses a single transport company, it must not allow it to dictate its own conditions, unfavourable to the company. It is very important for the transport company to be aware of the strength of the competitive environment and to follow not only its interests but also the interests of the company.

The opportunities of the current distribution system of KAPA, Inc.

Department of distribution

One of the opportunities for KAPA, Inc., in the management of out-plant transport is the creation of a distribution department which will have its mission, priorities, competencies and activities. Because the sellers in the particular department have also devoted themselves to the provision of transport and have the necessary experience and practice to manage the distribution activities, it could be an advantageous for KAPA, Inc. to authorize selected workers from this department to deal with distribution.

Possibilities

In every area of human activity, the human factor plays the most important role. If a company decides to adopt positive changes, it has an impact not only on decreasing costs but also on increasing customer satisfaction. KAPA, Inc. has the following options in order to manage goods distribution:

- selecting another carrier for product distribution,
- launching a tender for new carriers,
- using the services of other transport companies.

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The threats of the current distribution system of KAPA, Inc.

Threats to the goods distribution system of KAPA, Inc. consist of:

- the orientation of goods distribution to one major transport company,
- high competition in the given business sector,
- unwillingness of people to accept changes in the company.

14.8 Conceptual Design for the Establishment of a Separate Distribution Department

In terms of a systemic solution for goods distribution in the company, reduced and more efficient expenditure of resources for its implementation, it is desirable for the company to create a *"distribution logistics department"* that would perform all legal, economic and logistical tasks for the goods distribution of the company.

It is possible to find various methods of the distribution system management in practice. The most common are:

a) a separate distribution department, which deals exclusively with distribution

This is a functional organizational structure with a wide range where the particular departments communicate with each other. There is a separate distribution department in the company (Figure 152), which has the responsibility for the distribution system and its task is to ensure its trouble-free operation.

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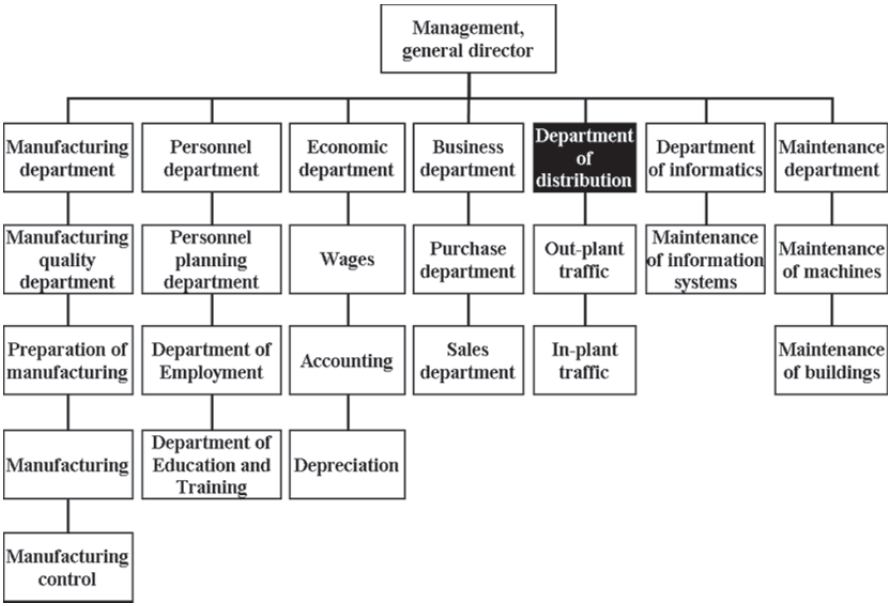


Figure 152 – Alternative "a" – a separate distribution department within the organizational structure

b) distribution is administered within the logistics department

The distribution department is located within the logistics department (Figure 153) and its role is to provide in-plant and out-plant transportation.

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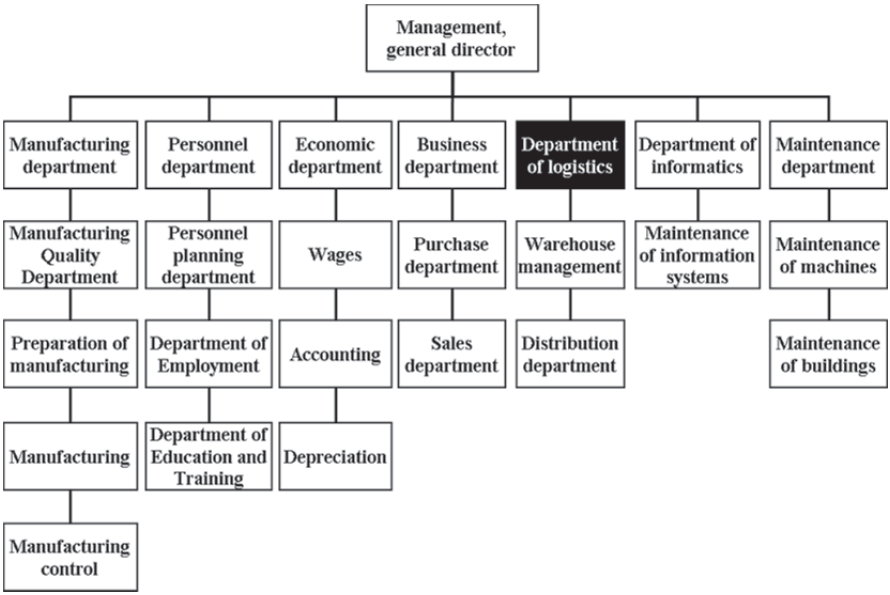


Figure 153 – Alternative "b" – placing distribution in the logistics department

c) distribution falls within the area of warehousing

Another option for the location of the distribution department within a company hierarchy is to place it under the warehouse management department (Figure 154), which will deal with distribution as well as warehouse management.

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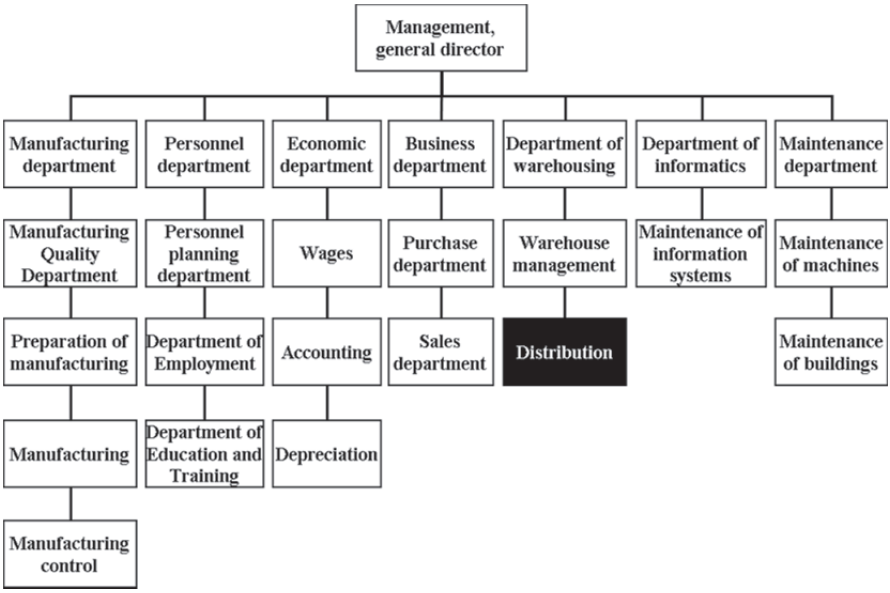


Figure 154 – Alternative "c" – placing distribution under warehousing

d) The sales department deals with distribution

In this case, the distribution department is under the sales department (Figure 155). The role of particular sellers is not only customer care, but also to arrange the distribution of all products.

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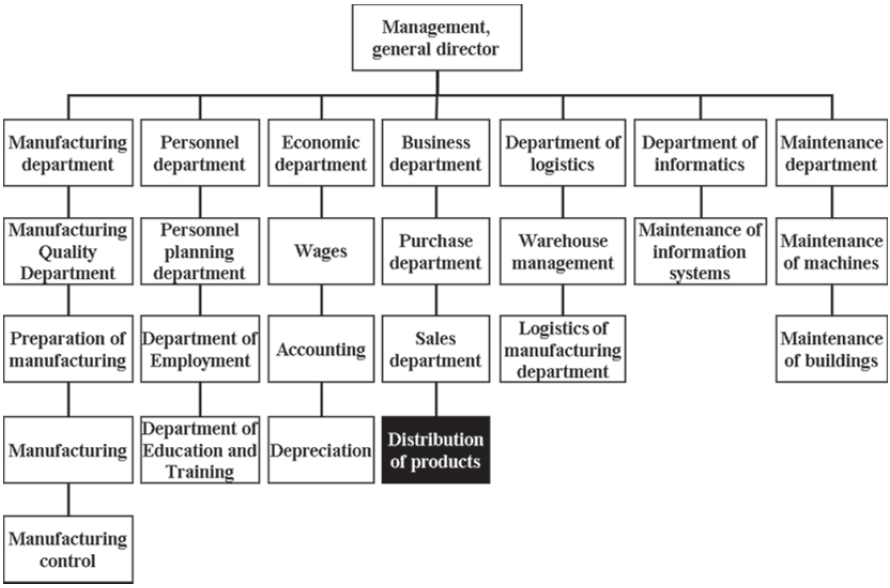


Figure 155 – Alternative "d" – placing distribution under the sales department

14.9 Proposal for Activities of the Distribution Department for KAPA, Inc.

Because particular sellers also have to devote time to manage transport, they have the necessary experience and management experience for activities related to distribution. For KAPA, Inc., it is advantageous to entrust selected workers from this unit with distribution (Straka 2010).

Proposal of the number of employees in the distribution department

In the case of the personnel in the distribution department, the following options may be used:

- create new working positions;
- move certain workers (sellers, staff from the warehouse of finished products).

From the point of view of the activities of the distribution department, it is appropriate to introduce single or two-shift working time (practice and the number of orders, for which everything related to distribution needs to be prepared, will clearly show how many working shifts need to be

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established). In the case of single-shift working time in the department, 2 or 3 employees will suffice. In the case of dual-shift working time, it is necessary for 4 or 5 employees to work in the department. In a job with one or two shifts of working time, it is needed to establish an "emergency service", which will intervene in the case of sudden and unpredictable distribution events. Employees who would provide this emergency service would be available to customers via a mobile phone (or over the Internet).

Authority of the distribution department

The supervisor of the distribution department will be involved in the process of creating production plans in the company. The input data for the department will be data from the production plan for weeks (periods) *N* up to *N+4*. Because the planning system closes the plan for weeks *N* and *N+1*, it is definite and binding for the creation of plans in the distribution department.

Proposal of activities and responsibilities for the distribution department

In order to ensure smooth and trouble-free distribution performance, it is necessary to define precisely which activities and duties are to be performed by employees from the department. These activities should include:

- effective coordination of distribution activities;
- participation of a worker from the distribution department in tendering procedures for the selection of the transport company;
- distribution planning – selection of distribution channels and outlets and planning goods flow for selection in distribution planning;
- creation of a distribution structure – the structure of overall distribution channels along with the routes of the product or product group to customers;
- informing customers about procedures and all changes related to distribution, customer communication;
- informing customers of the expected delivery date (the date, when the goods arrive at the place of delivery);
- creation of distribution plans and timely notification of warehouses for the preparation of shipping items;
- creation of a preliminary costs calculation;
- preparing and solving order combination;
- decisions about the use of own vehicles when executing a "speed order";

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- recording and keeping the statistics about distribution;
- administration related to the activity of the department, preparation of documents related to distribution;
- selection of suitable means of transport, preparation of itineraries of journeys, ordering means of transport;
- planning arrivals and departures of means of transport;
- decision-making about the utilisation of means of transport (usage of pallets, containers).

14.10 Proposal for Creation of Distribution Plans for KAPA, Inc. in Algorithmic Form

The solution of the distribution system in KAPA, Inc. in the form of a technical project is developed to the level of algorithms that enable:

- sorting orders by date of delivery;
- sorting orders in terms of those that will be stored for a certain period of time and those intended for distribution according to the distribution plans and confirmed customer responses;
- combining orders based on the direction of the journey;
- selecting the appropriate type of means of transport in order to maximize its capacity;
- viewing orders to be delivered from the warehouse during a working shift.

14.10.1 Basic and Supporting Parts of the Planning System

For the proper function of the algorithm for the creation of the distribution plan, basic and supportive data is required which should be a part of specific data area files:

- the file "Production Plan for the period *N+1* to *N+4*";
- the file "Product status in terms of stock";
- the file "Calendar".

Another important part of the entire planning system is the ability to perform operations with this data:

- entering it into the system;
- the possibility of viewing created distribution plans;
- making changes to created plans.

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Depending on the authorization level for data handling, the display and content of screen masks for planning system users are important:

- masks, screens for distribution programmers-users;
- masks, screens for sellers-users who need to see the distribution plans for which they are responsible.

14.10.2 Description of Basic Planning System Files

Characteristics of the file "Production plan for the period *N+1* to *N+4*"

This is a list of capacity balanced orders, i.e. the list of orders that can be processed on particular machines during the planning periods.

The *N+1* and *N+4* values represent the planning periods for the creation of production plans and the duration of one period is non-standard but appropriated defined as 3.5 days. This non-standard length of the planning period enables flexible responses to system changes and faster processing of incoming orders, which increases the competitiveness of the company. For the creation of production plans the following principle is important: that planning period *N* is fixed ("no possible changes"), planning starts from the *N+1* period and later, which comes from the “Closed Scheduling System”.

Characteristics of the file "Product status in stock"

The file "Status of Products in Stock" (Table 129) is the list of all accepted orders that have been manufactured in production and which have been received into the warehouse. In terms of defining the delivery terms, the following are distinguished:

- orders that have a specified delivery due-date;
- orders that do not have a specified delivery due-date and are waiting to be called.

The file should contain four groups of information:

- customer information (database of partner-companies);
- product information (final products, reference motifs and patterns);
- product storage history;
- delivery conditions, distribution, packaging (database of purchase contracts).

Orders are gradually added in the order they came from production to the file "Product status in stock".

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Table 129 – List of information that is required for each order in the file "Product status in stock"

Order information		
Item	**Item description**	**Item type**
Customer information		
Customer name	Name of the company	alphabetic
Address	Placement, customer location	alphanumeric
Company registration number (CRN)	Customer company data	alphanumeric
VAT ID Nr. (VATIN) and others (if needed)	Customer company data	alphanumeric
Product information		
Order number	Extract from the order	alphanumeric
Internal order number	Internal code, number, mark	alphanumeric
Product number or Assortment group	Internal code, number, mark	alphanumeric
Ordered quantity	Typical units	numerical
Price per unit	Agreed price	numerical
Foil width	Information needed for ordering a vehicle	numerical
Product storage information		
Past and max. time storage of the order	Storage information	numerical
Recurrence of process	Information for planner about recurrences	numerical
Delivery conditions, distribution, packaging		
Definite delivery date	Term defined by a contract	alphanumeric
Packaging method	Information important for shipping	alphanumeric
Distribution method (vehicle type)	Information important for shipping	alphanumeric

Characteristics of the file, "Calendar"

The "Calendar" file is a support file for creating distribution plans. From this file, the scheduling system will collect information about working days during the present year, the time available for distribution,

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and the number of working shifts, state holidays and other limitations and conditions that may affect the actual creation of distribution plans and functional distribution itself.

Description of basic screen masks

The ability to communicate and complement the distribution planning system will be one of the key preconditions for the proper working of the entire planning system. To do this, it is necessary to have relevant information that is displayed through the screens for authorized persons working with the system. The system should have the following levels:

- *administrative level*
  - the administrative level of the planning system represents a position with unlimited access to each part of the planning system with the ability to modify the planning algorithms but no permission to change information in the system;
- *control and programmer level*
  - the level of the programmer or planner of distribution is the position where a user is allowed to make interventions in the distribution plan;
  - a programmer can change information or data in the planning system;
  - user rights at the programmer level are intended for distribution planners;
- *informational level*
  - the informational level is designed for particular sellers in order to display information about the distribution plans created for particular orders for which they are responsible and to be able to inform the customer about the state of preparation of certain orders.

14.10.3 Basic Algorithm for Creating Distribution Plans

The operation of the algorithm (Figure 156) begins with loading orders into the planning system from the "Production Plan" and "Product status in stock" files. From this list, the orders are categorized into those that are immediately distributed after manufacturing and those that will be stored for a certain time. After sorting the orders, they are arranged on a timeline according to the scheduled delivery date. In order to ensure optimization of the distribution plans, it is necessary to check whether combining orders is possible under the conditions of the same direction of travel. If it is

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possible, orders are combined, if not, the order remains separate on the timeline and it will be distributed separately.

The whole process is executed in a number of repetitions. The number of iterations is assumed to be variable *i*, which takes values from *N+1* to *N+4*. After this process, it is checked whether there is a product in stock meeting the requirements (same reference pattern, motif) of the newly received order. It should be the rule that the same product is dispatched first with the earlier production date and the planner should include it in the distribution plans. The result is distribution plans for sorted and combined orders.

Description of the basic algorithm for the creation of distribution plans (Figure 156):

1) Algorithmic block to ensure exact repetition. The number of repeats is counted using variable *i*, which takes values from *N+1* to *N+4*. These values *N+1* and *N+4* represent the planning periods for the creation of production plans and the duration of one period is 3.5 days. Period *N* is fixed ("no possible change"), planning starts from the *N+1* period and later, which comes out from the Closed Scheduling System.
2) Entering, loading orders into the system. The system loads all available sources of orders, i.e. the "Production Plan" for the period from *N+1* to *N+4* and orders from "Product status in stock".
3) List of orders categorized into two groups. The first group consists of orders that are assigned to the distribution planned for the coming period. The second group consists of orders that will be kept for a certain time and they have a specified storage time.
4) Block that arranges orders on the timeline according to the scheduled delivery date of products to the customer.
5) Condition that determines whether it is possible to combine orders in the direction of a trip. If the condition is true (YES), the order may be combined. If the condition is negatively evaluated (NO), the order is not combined and a list of orders is displayed.

5–1) Block that combines all appropriate orders based on the condition of possible combination according to the direction of travel of the goods distributed.

6) Display of a list of all remaining orders.
7) Display of stored products with the same reference pattern as requested by the customer for a new order.
8) This block enables the planner to be notified that there is a product in stock that fulfils all the requirements (reference pattern and motif) of the newly accepted order. The block will ensure that the same product

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that was manufactured earliest gets to the customer first. (The product with earlier date of manufacture has priority).

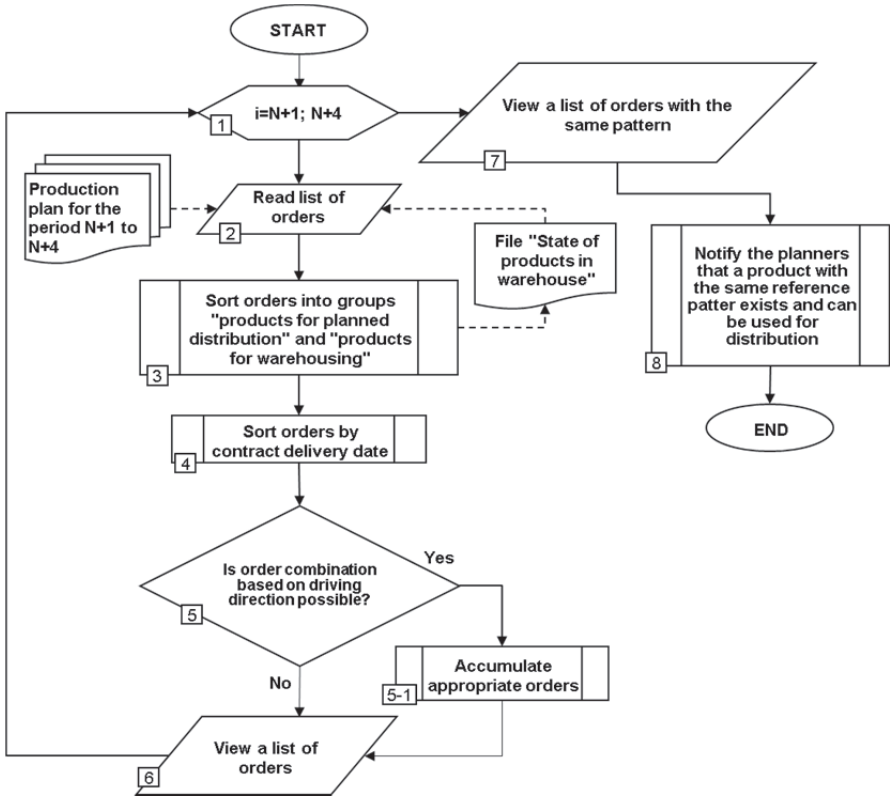


Figure 156 – Basic algorithm for creation of distribution plans

14.11 Summary of the Defined Solutions for KAPA, Inc. Product Distribution System

The object of the problem-solving work on product distribution at KAPA, Inc. is designing a more efficient way to manage the distribution system, preparing distribution plans and physically implementing distribution by introducing several new items into product distribution activity in the company. These items are particularly:

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- establishing a new department of product distribution in the company where all activities related to product distribution for the company are to be collected;
- proposal of the number and activities of employees of the department of product distribution;
- proposal of work activities for which the department of product distribution is responsible;
- creation of an automated system (in the form of algorithms) for delivering orders to the department of distribution.

The benefits of the proposed solutions are as follows:

- creation of a unified product distribution planning system;
- definition of the rules for the creation of distribution plans;
- reducing the impact of the human factor on the creation of distribution plans;
- creation of distribution plans in advance at a certain time.

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VI.

CASE STUDIES IN THE FIELD OF LOCATION PROBLEM SOLVING

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CHAPTER FIFTEEN

LOCATION OF WAREHOUSES FOR GAMA, INC. SECOVCE

15.1 Definition of the Problem and Objective of the Task

Agricultural crops are distributed for GAMA, Inc. Secovce by a transport company that has the obligation to transport the products physically to the designated place within a certain time.

Because the input raw material for processing is grown seasonally, it is necessary to store the input raw material for most of the year. The selection of warehouses, their position and the storage costs greatly influence the final price of the product.

Due to the expansion of the company in the region of eastern Slovakia and for the purpose of shortening supply and distribution routes, it is necessary to propose a location for a new warehouse which will form the second centre within the distribution network.

15.2 Storage Analysis in the Company

The storage system of GAMA, Inc. is decentralized. The company also uses warehouses in particular regions of Slovakia in addition to its own warehouse located at the processing site (Kropokova, Straka 2007).

The most important store is its own high-capacity warehouse, which is located on the company site. Its storage capacity is about 85 000 tonnes of agricultural crops. The advantage of using their own warehouse is unlimited right of use.

In addition to its own warehouse, the company concludes annual storage and warehousing agreements with various organizations, especially with specialized public warehouses, in order to extend its storage facilities. The subject of these contracts is the storage of oilseed and sunflower seed, which is exclusively the property of the depositor, i.e. GAMA, Inc. Secovce.

The depositor undertakes to pay the contracted sum for the services provided from the date of receipt of the goods by the warehouse keeper,

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with respect to the input quantities of the goods weighed on the scales of the warehouse keeper. Output quantities are weighed by the warehouse keeper and are respected by the depositor up to ±0.5% of weight. Transport from the warehouse keeper to the depositor is paid by the depositor.

Such contracts are concluded for a period commencing on 1st of July of the given year, when harvest time is beginning and they end on the 30th of June of the following year. The subject of the contracts is oilseed and sunflower seed. This system allows growers of agricultural crops from individual regions of Slovakia to shorten transport routes from the place of the production site to the processing plant in Secovce. This also reduces transport costs. However, these are transferred to GAMA, Inc., which provides transportation from these public warehouses to the processing site. In the end, this is reflected in the fact that for the primary producers putting their production into the above-mentioned warehouses there is a contractually agreed deduction from the fixed purchase price of agricultural crops. Damage or other degradation of agricultural crops during storage is protected by insurance contracts. Practically there are no stocks of finished products in the company, because all the production of vegetable oils takes the form of a semi-finished product, which still needs to be finalized. For this reason, this oil is not stored but immediately after processing it is placed in special tanker wagons which are then transported by railway to the company, GAMA – Final, Inc. Bratislava, where finishing takes place. However, two large-volume tanks with a volume of 100 m^3 are used to ensure "standby redundancy" at GAMA, Inc., Secovce. The only material to be stored is the pressings which arise during production.

15.3 Company Transportation Analysis

Transport at GAMA, Inc. Secovce can be divided into in-plant and out-plant transport. In-plant transport plays a much more important role than out-plant. This is due to the in-house processing of agricultural crops. This means that the raw material transported to the place of processing, whether by rail or by road, is transported using a special mechanism from the particular means of transport into grain silos with a capacity of approximately 85 000 tonnes. The transport of raw materials from silos to presses is carried out by means of Redler conveyors. At the same time, pressings (secondary products) are transferred from the press to the silo in the same way. In 24 hours, approximately 210 tons of seeds are transported from and about 100 tons of pressings are transported into the

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silo. The main product, raw oil, is transported by pipelines directly to the railway wagons. All production and transport is performed on a highly automated basis; this means that additional costs associated with a large workforce are not incurred by the company (Kropokova, Straka 2007).

Two basic types of transport, rail and road transport, are used in out-plant transport. The entire transport chain starts with harvest in July. Subsequently, crop seeds are transported either to the place of processing, i.e. to GAMA, Inc. Secovce, or into spare warehouses. In this case, growers use lorry transport, i.e. tippers and trailers. The particular quantities and purchase prices are agreed in advance with growers.

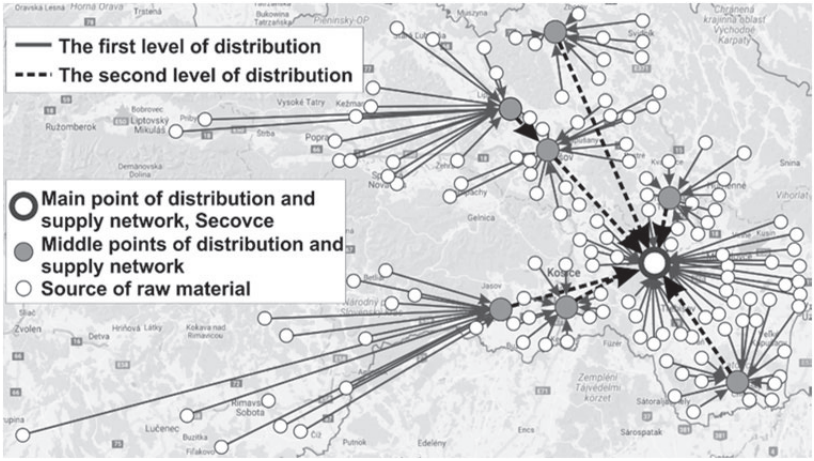


Figure 157 – Distribution network (feeder transport) for the company GAMA, Inc. Secovce

Where a grower supplies the raw material directly to the company, he gets a pre-determined amount of money in proportion to the quantity. If a grower supplies the raw material to particular warehouses, he is subject to a certain deduction from the determined purchase price that is fixed irrespective of the distance of the warehouse from the company. The growers organize transport to particular warehouses by themselves. The transport of raw material from warehouses to the company is performed via railways or road transport and is covered by GAMA, Inc. Secovce. The amount of raw material to be transported from particular growers to a specifically determined warehouse (Figure 157) and the timescale for the transport of the raw material from particular warehouses are determined by the company according to its needs. From a theoretical point of view, it is

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possible to classify this logistical network (Banyai, Cselenyi 2004) as a feeder transport, multi-level, star-type network.

Railway transport is agreed on the basis of a "Contract on the conditions of freight transport for the national transport of goods" with Slovak Railways.

The contract specifies that the transported goods are from commodity group No.: 03 – Foodstuffs. It also defines the mode of transport, either individually or by whole train. In the case of whole-train transport, the following conditions must be fulfilled:

a) the minimum weight of the train must be 800 tons,
b) for shipment of goods not by whole train, GAMA, Inc. submits consignments from one sending railway station to the second railway station of destination with only one consignment note and a statement of wagons,
c) in the case of the shipment of goods by whole train, GAMA, Inc. submits a consignment note with each consignment and complies with the requirement to make a train from one sending railway station to the second railway station of destination.

When examining railway transport, the starting point is the differing physical nature of the transported materials. Mass substrates are transported from particular warehouses into the company. Mass substrates are transported from the company, i.e. pressings of agricultural crops, but in addition there is also the liquid product – vegetable oil. Pressings are usually transported in food wagons on the route Secovce – Bratislava. These pressings are directed to the port of Bratislava, where they are transferred onto a ship and then transported abroad, where they are used as an additive in compound feedstuffs. The oil itself is transported in tanks to GAMA – Final, Inc. Bratislava, where it is subject to final processing.

15.4 Proposal for the Location of the Company Distribution Centre

To make a proposal for the location for the company distribution centre, an expert system for location was used, working on the principle of Cooper's iteration method.

The map of the region with the marked warehouses was placed in the coordinate system and each warehouse was defined by its coordinates (Figure 158, Table 130).

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Figure 158 – Positions of the warehouses of GAMA, Inc. Secovce in eastern Slovakia

Table 130 – Defined coordinates of places in the calculation

Warehouse		Coordinates	
		x_i	y_i
Cana	**M1**	9.1	6.5
Cecejovce	**M2**	5.3	6.1
Presov	**M3**	7.2	15.1
Bardejov	**M4**	7.9	21.6
Vranov nad Toplou	**M5**	14.2	12.7
Pribenik	**M6**	19.1	1.9
Sabinov	**M7**	5.6	17.3
Secovce	**M8**	13.8	8.7

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15.5 Location without Considering Warehouse Capacity in the Distribution System

The basis of this approach is the equivalence of all warehouses in the evaluation. The quantities received and the prices of agricultural crops placed in particular warehouses by unit are not considered in the calculation. This means that all warehouses are equivalent and only the distribution of their positions in the area (Benkő 2004, Kropokova, Straka 2007) will determine the optimal position for location of the distribution centre. Two approaches were selected to determine the location:

- without considering the warehouse in Secovce,
- considering the warehouse in Secovce.

The first approach is an attempt to determine the appropriate position of the raw material processing area in relation to the surrounding warehouses. The second approach defines an appropriate position including with regard to the warehouse in Secovce.

The calculations show that the position for the location of the processing point defined in point [8.932; 12.5908] is appropriate for the first approach. This point on the map corresponds to the surroundings of Presov, between the villages of Mirkovec and Drienov (Figure 159). Because in practice companies try to use existing warehouses' capacities, it would be preferable to place the distribution centre directly in Presov or nearby. In this location, the objective function is closest to the minimum value.

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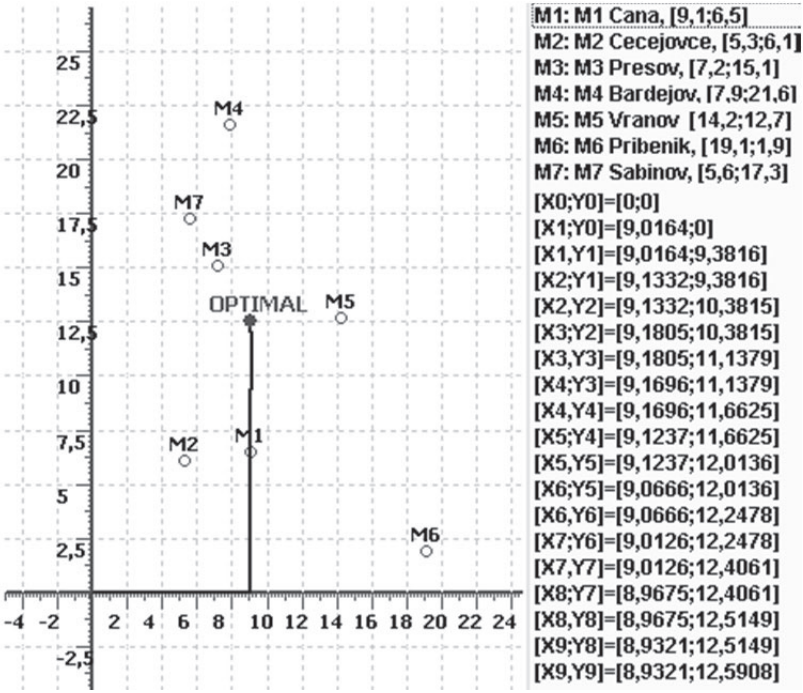


Figure 159 – Graphical representation of the optimal position without considering the warehouse in Secovce

Considering the warehouse located directly at the production plant in Secovce, the optimal position for the production site is point [10.3886; 10.9671] (Figure 160), near the villages of Backovik and Kecerovce. The calculation is also performed using unit quantities and prices, considering the equivalence of the locations in the calculation.

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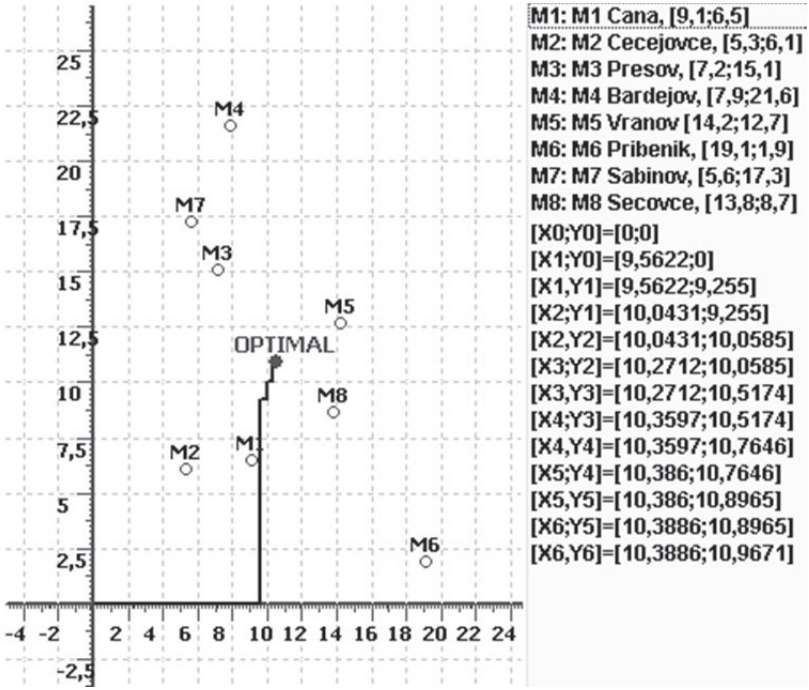


Figure 160 – Graphical representation of the optimal position also considering the warehouse in Secovce

15.6 Location Considering the Capacities of Warehouses in the Distribution System

This variation of the calculation considers the current warehouses' capacities in the distribution system and it does not view them as having equivalent status, i.e. the greater the warehouse capacity, the more important it is within the system. Statistics are used to define the relevant quantities of stored crops and the price, which also considers transport costs (Table 131) to each warehouse.

The largest storage capacity is in the silo located directly in Secovce and therefore it is the most important point in the system, which is confirmed by the calculation of the location (Figure 161).

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Table 131 – Quantities of raw materials stored in warehouses during the year and the relevant price

Warehouse		x_i	y_i	M_i [t]	C_i [EUR/t]
Cana	**M1**	9.1	6.5	815.049	212
Cecejovce	**M2**	5.3	6.1	1 875.832	212
Presov	**M3**	7.2	15.1	2 009.615	212
Bardejov	**M4**	7.9	21.6	627.314	212
Vranov nad Toplou	**M5**	14.2	12.7	2 194.815	212
Pribenik	**M6**	19.1	1.9	1 234.570	212
Sabinov	**M7**	5.6	17.3	2 599.057	212
Secovce	**M8**	13.8	8.7	50 000	229

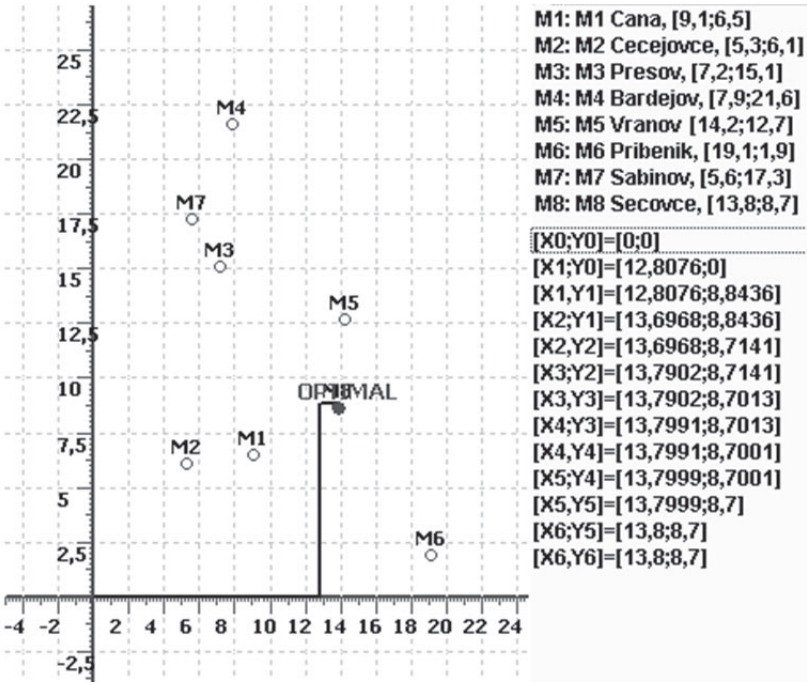


Figure 161 – Graphical representation of the optimal position, considering the quantities and prices of raw materials in warehouses

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15.7 Location of a New Place for Production

In order to "expand" the company to other parts of Eastern Slovakia, it is appropriate to divide the region into two areas, the Presov and Kosice regions, to make optimal utilisation of the production site located in Secovce. There are four warehouses for each area to supply each site with agricultural crops. The principle of equality of quantity and price holds for all warehouses, i.e. the quantities taken and prices will be set as the value 1. The area can be appropriately divided from east to west (E-W, Table) or from north to south (N-S, Table).

To divide the region in the W-E direction there is M1 = Sabinov, M2 = Bardejov, M3 = Presov, M4 = Čečejovce, M5 = Čana, M6 = Vranov n. T., M7 = Secovce, M8 = Pribeník.

Table 132 – Defined warehouse groups dividing the region, E-W

Group 1:		Group 2:	
Sabinov	**M1**	**Cana**	**M5**
Bardejov	**M2**	**Vranov nad Toplou**	**M6**
Presov	**M3**	**Secovce**	**M7**
Cecejovce	**M4**	**Pribenik**	**M8**

For the first group, i.e. for warehouses in Sabinov, Bardejov, Presov and Cecejovce, the optimal distribution centre becomes point [6.98; 15.22] at the position of the village of Maly Saris near Presov. The first crop production plant should be located at this point or at the nearest place with a warehouse, in Presov.

For the second group of warehouses, the optimal centre is in Secovce. This position is very advantageous because Secovce already performs this task currently (Figure 162).

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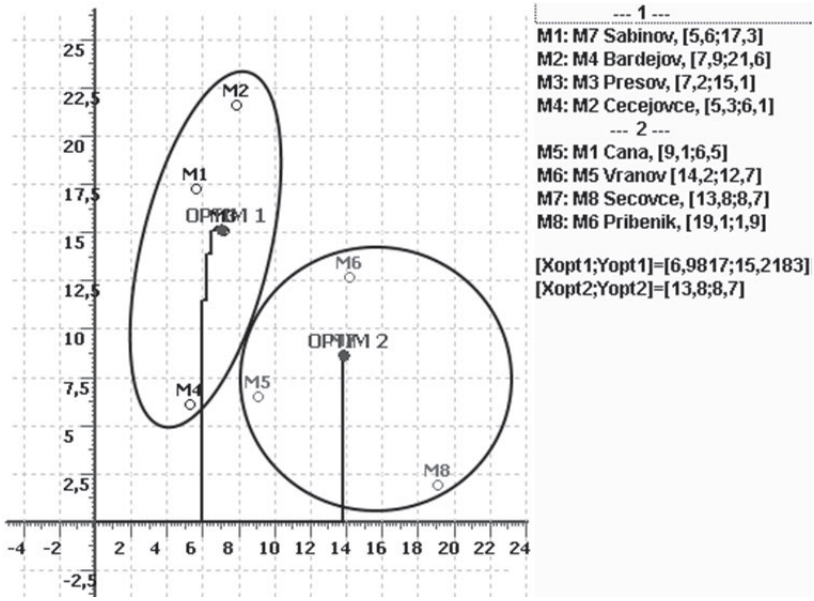


Figure 162 – Dividing the East Slovak region in the East – West direction

To divide the region in the N-S direction there are M1 = Sabinov, M2 = Bardejov, M3 = Vranov n. T., M4 = Presov, M5 = Cana, M6 = Cecejovce, M7 = Secovce, M8 = Pribenik.

Table 133 – Defined warehouse groups for regional distribution, N-S

Group 1:		Group 2:	
Sabinov	**M1**	**Cana**	**M5**
Bardejov	**M2**	**Cecejovce**	**M6**
Presov	**M3**	**Secovce**	**M7**
Vranov nad Toplou	**M4**	**Pribenik**	**M8**

Under the second option for divinding the region, the optimal position for the groups was obtained as [7.36; 16.3], [9.32; 6.48] (Figure 163), which correspond to the positions of the villages of Velky Saris near Presov and Cana near Kosice.

From the point of view of building the centres, the first way is more advantageous because it is possible to use the existing centre in Secovce and there is no need to relocate production to another site.

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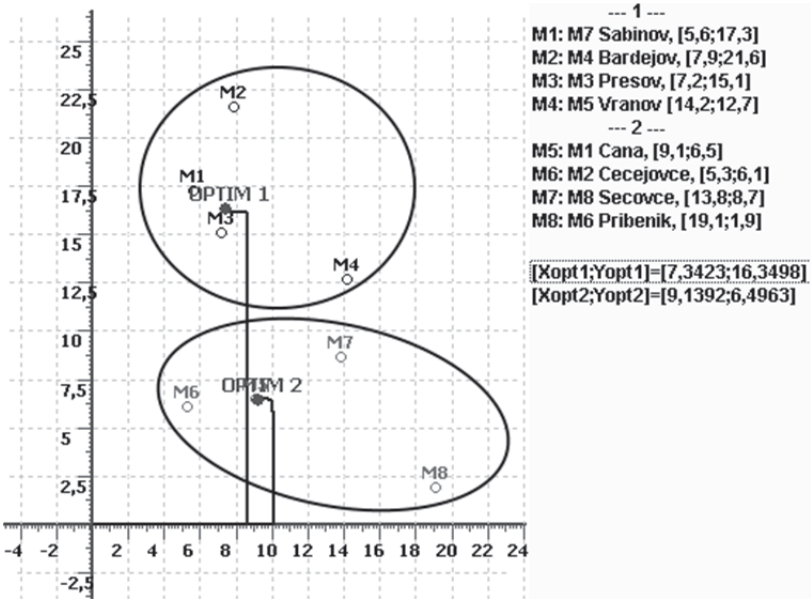


Figure 163 – Dividing the East Slovak region in the North – South direction

15.8 Assessment of Results

The results of solution show that with the current location of warehouses in eastern Slovakia and with the currently stored quantities, the location of Secovce is correct for a distribution centre. If the particular warehouses with increasing storage capacities were equal to the central warehouse in Secovce then it would be appropriate to transfer production to the area surrounding the city of Presov.

From the point of view of the future direction of the company and its expansion, with the present location of resources the planned second crop processing plant should be situated in Maly Saris, or in the city of Presov.

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CHAPTER SIXTEEN

PROPOSING LOCATIONS FOR OPERATIONAL ADMINISTRATION FOR THE NEEDS OF A POWER TRANSMISSION SYSTEM

16.1 Definition of the Problem and Objective of the Task

The topic of the following case study and the main task is to select a place for "OPERATIONAL ADMINISTRATION (OA)" from a number of power stations, which in the new structure of the power transmission system are to ensure the operation of subordinate power stations within a certain region.

In order to reorganize the functioning of the Power Transmission System (PTS), it is necessary to divide the PTS into regions in which operational administration will have a central position that will look after subordinate power stations. The aim of the task is to determine and to define PTS regions with their service stations and to determine their subordinate power stations. The basic condition is that the distance of the power stations from operational administration should be a journey of about 1–1.5 hours by car.

16.2 Characteristics of the PTS - Analysis of the Current State

There are 20 power distribution stations under the management of the PTS. Their location depends on 400kV and 220kV lines (Figure 164).

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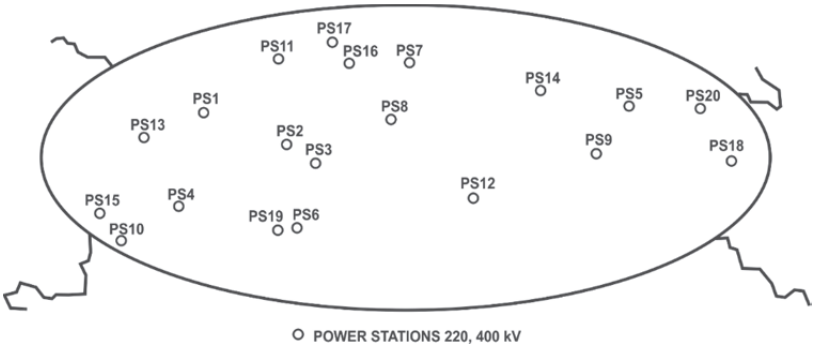


Figure 164 – Location of power stations relevant to the management of the Power Transmission System

The power stations (PS) fulfil the function of electricity transmission and simultaneously they are the supply nodes in the wholesale and retail networks. The electrical stations are part of the 400kV, 220kV and 110kV networks.

The basic structure of the PTS consists of four parts, each of these parts has importance:

- Energy process control centre (EPCC),
- Headquarters of PTS,
- Power stations (PS),
- Power transmission network.

The energy process control centre is in charge of monitoring the entire transmission system. Monitoring is carried out continuously by workers who monitor the state of the transmission system on the light board. In the event of a breakdown at the distribution or transformer stations, a fault is signalled to the control room. Basic malfunction information can be obtained from network monitoring, such as (Straka 2004):

- approximate location of the fault, the particular power station, the outlet and lines,
- probable cause of the malfunction,
- report on the operation of automatic protection.

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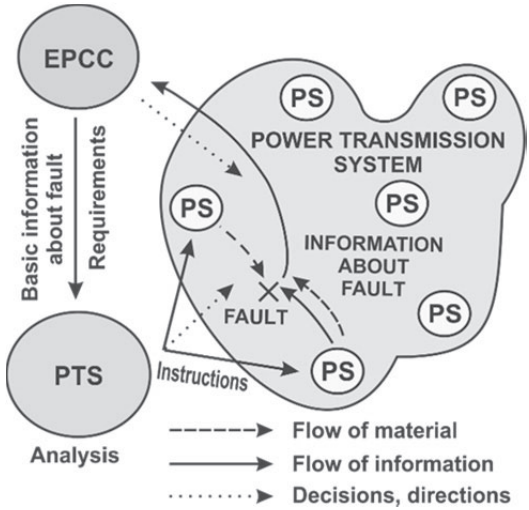


Figure 165 – Basic schema of activity of the Power Transmission System

Based on this available information, an EPCC control worker informs PTS headquarters about the fault (Figure 165). If the fault occurs during working time, he informs the coordination department at PTS headquarters, if it is at another time, he informs the emergency service.

After informing PTS headquarters, the EPCC control worker makes interventions in the transmission system remotely using all available means to minimize damage and to ensure that the transmission network is not overloaded and to secure the transmission and delivery functions.

The department of coordination at PTS headquarters or the emergency service analyses and evaluates the situation. After evaluation, it provides information and places demands on the teams which have to find out more details about the fault that occurred. If it is technically possible, the teams perform repairs on the equipment where the fault occurs and using the means that they have available so as to bring the equipment back into service.

Power stations are in charge of ensuring operations associated with the removal of faults occurring in particular distribution stations. The power stations also provide scheduled maintenance on distribution stations. If necessary, power stations provide an examination of the fault which occurs in the transmission system and they provide the necessary information needed to analyse the fault in terms of details in the EPCC or in the PTS headquarters.

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The transmission power network consists of cable distributions that serve for the transmission of electricity (Straka 2004).

16.3 Deficiencies Resulting from the Current Situation and Possibilities for Solution

The structure of the power stations is based on a way of working that requires:

- a large number of employees,
- a large number of ineffective techniques used,
- most of the work needs to be done in an internal manner, which may not be economically advantageous.

There are two approaches that have been chosen to identify and define groups of power stations and then to locate operational administration:

- the multi-criteria evaluation approach,
  - stations that best meet the selected criteria become the operational administration,
- the geometric approach,
  - stations closest to the calculated coordinates become the operational administration.

16.4 Application of the Method of Distribution Potential for the Needs of PTS Location

The model to decide the location of the operational administration sites has a hierarchical structure that consists of:

- determination of the optimal number of operational administration regions,
- determination of the optimal location of the operational administration sites.

The operational administration site (OA) is the place that takes care of the safe operation of subordinate power stations within a particular region. It provides the material, people and technology needed to perform all activities at the power stations.

In terms of location theory, this means the location of services at multiple points within a region. The territory of Slovakia can be taken as one whole region or it can be feasibly divided into 2, 3, 4, 5, ... *n* regions in several ways. The number of options for regional division increases

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with the number of operational administration regions that we want to divide the power stations between. The task is to find the optimal number of regions and their structure.

The potential of a power station is the calculated evaluation of the power station using the following procedure and it expresses the potential of the power station to become an operational administration site.

The choice of location for a production process, distribution or operation centre is dependent on a number of factors, some of which can be economically evaluated and others not, so a multi-criteria decision making method is very appropriate (Straka 2004).

16.4.1 Selection and Evaluation of Criteria for Multi-criteria Analysis

After analysis of the current state, the following criteria are defined as factors for selection of the optimal location for operational administration:

- the economic criterion,
- the amount of energy transferred,
- the technical safety criterion,
- the time criterion,
- the technical condition criterion.

Weights are assigned to particular selected criteria so that the sum of the weights is 100 – under the Metfessel allocation application (Table 134). It is assumed that all the selected criteria have some importance. In this case all criteria have the same importance. In the next step, the power stations are evaluated according to the selected criteria (Straka 2004).

Table 134 – Selected criteria and their importance for the calculation in the rest of the procedure

Factors, criteria	**Weight of the factor W_i**
The economic criterion	20.00
The strategic criterion	20.00
The technical safety criterion	20.00
The technical condition criterion	20.00
Time criterion	20.00
	$\sum_{i=1}^{n} W_i=100$

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The economic criterion

The economic criterion is very important for choosing the optimal location for operational administration. This criterion should properly include the costs associated with the direct, own consumption of certain power stations:

- own energy consumption per year for certain power stations,
- costs needed for wages for employees at certain power stations.

Since the actual power consumption by a power station is still necessary whether it is occupied by employees or not, this part of the cost will not be considered. In other words, if the power station is not the operational administration, its power consumption will not be zero as power will be still be needed to run the station, so its own power consumption is not included in this criterion. Only the wage item is to be considered. A station that has low wage costs and a large amount of energy flowing through it is favourable.

Employee wages per year are used for the calculation of points for wage costs for particular power stations. The costs of the particular stations are arranged from the lowest to the highest. The lower the cost of a power station per year, the greater points rating is assigned to it, since the sensitivity of the evaluation scale is in the range of 0 to 100 points. The number of points received by each station is multiplied by the weight assigned to the economic criterion.

Strategic criterion – the amount of transferred energy

One of the evaluated criteria is the total transferred energy in MW per hour for particular power stations over a certain period. The amount of energy transferred for each power station will be arranged from the highest to the lowest. The higher the amount of energy flowing through a station, the higher the evaluation. The sensitivity of scale is set from 0 to 100 points. The number of points received by each station is multiplied by the weight that is assigned to the criterion. This gives a points-based evaluation of the particular electric power station for the amount of energy transferred.

Technical safety criterion

Each power station manages a number of transformers. The stations ensure their safe operation and eliminate any malfunctions that may occur during operation. This criterion assumes that the more fields administered, the greater the probability of a failure, so it is advisable to place administration in locations where most of these transformer fields are.

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This is reflected in the points-based evaluation of particular stations. The more transformer fields administered by a station, the more points it gets. The cardinal scale must be the same as in the previous criteria; it is between 0 and 100. The number of points is multiplied by the weights selected and the total number of points for this criterion is obtained for the particular evaluated stations.

Technical condition criterion

The evaluation for this factor is based on statistics of failure occurrence over a certain period and operating times. The breakdown probability is determined depending on the age of a device under this criterion. The probability of failure occurrence is Q, and the probability that a failure does not occur is F (16.1):

$$Q = 1 - e^{-\lambda.t} \qquad F = 1 - Q = e^{-\lambda.t} \tag{16.1}$$

λ – intensity of the disorders,
t – operation time of a device.

The older the technical equipment of a station, the greater the probability of failure occurring. It is advisable to locate administration in those places where the longest-running facilities are located.

The greater the probability of failure due to the length of operation time of the device, the more points are obtained for the evaluation of the station. The number of points is again in the range ⟨0;100⟩. The number of points is multiplied by the weights selected and the total number of points for this criterion is obtained for the particular station evaluated.

Time criterion

It is necessary to select sites to perform the function of operational administration in the future from the given number of electric power stations. The best stations are those that have the best position relative to subordinate stations. Their position should enable subordinate stations to be accessed as quickly as possible, if necessary. It takes about 1–1.5 hours by car in this case, 90 km distance (Figure 166).

Each station needs to be evaluated using points that reflect which station is accessible in what time, so it is necessary to begin by preparing a time table. The times represent the length of the route between each station. The station with the smallest sum of times is the best located relative to the others. The individual power stations are evaluated using points based on the total sum of times. The sensitivity of the points range

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is again from 0 to 100 points, whereby the station with the smallest sum of times gets the most points, and the stations with the highest sum of times get the fewest points. Stations are ranked by these points obtained, from the highest number of points to the smallest. The number of points for each station is multiplied by the selected weight of time criterion.

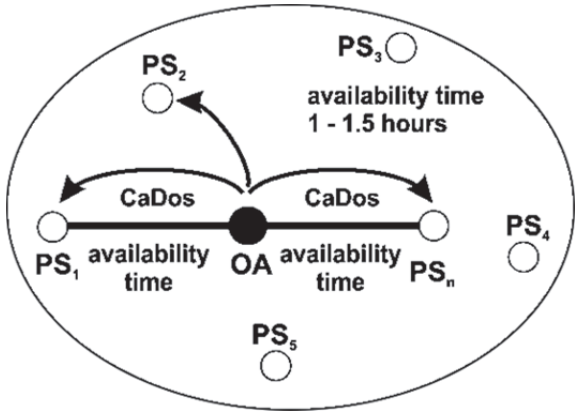


Figure 166 – CaDos – access time

16.4.2 Determination of the PS Structure and their Subordinate Stations

The procedure to define the structure of distribution stations, is determined by the Method of Distribution Potential MDP (Straka 2004):

1) The application of a direct approach to evaluation by applying the weighted sum method – the ratio index method. Power stations are rated according to defined criteria and they are sorted from the point with the largest distribution potential to the point with the smallest distribution potential.

2) The first site for operational administration will be the PS with the highest potential (Table 135), in this case PS4. Any electrical power stations which fulfil the *CaDos* access criterion are assigned to it (Table 136). These stations are not considered in later steps.

3) The power station with the highest potential out of the power stations that were not assigned to the administration range in point 2 is selected, and the procedure is repeated as in point 2. This procedure is repeated until the overall structure of operational administration is created.

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The operational administration sites and their subordinate stations are defined (as they were determined) in this way.

Note: After determining the structure of the OA-PS (points 2, 3), it may happen that some electrical power stations have the property that the access time from each of the designated operational administration sites will be greater than the specified *CaDos* access time. These stations would not be added to any OA group.

Table 135 – Arrangement of power stations by service potential

		Economic criterion		Strategic criterion		Technical safety criterion		Technical condition criterion		Time criterion		
	Weights	20		20		20		20		20		
	Power stations	Points	Weight x Points	Points	Weight x Points	Points	Weight x Points	Points	Weight x Points	Points	Weight x Points	SUM Weights x Points
1	PS4	53.31	1066.20	90.91	1818.20	67.74	1354.80	100.00	2000.00	56.68	1133.60	7372.80
2	PS19	53.31	1066.20	71.63	1432.60	38.71	774.20	99.95	1999.00	51.63	1032.60	6304.60
3	PS3	48.75	975.00	16.48	329.60	90.32	1806.40	99.99	1999.80	52.52	1050.40	6161.20
4	PS6	53.31	1066.20	63.65	1273.00	22.58	451.60	99.58	1991.60	49.11	982.20	5764.60
5	PS16	53.21	1064.20	32.39	647.80	41.94	838.80	100.00	2000.00	51.63	1032.60	5583.40
6	PS17	51.54	1030.80	35.78	715.60	19.35	387.00	97.92	1958.40	41.39	827.80	4919.60
7	PS1	61.94	1238.80	25.66	513.20	16.13	322.60	89.62	1792.40	48.66	973.20	4840.20
8	PS10	44.54	890.80	40.91	818.20	19.35	387.00	98.19	1963.80	33.68	673.60	4733.40
9	PS5	9.09	181.80	30.78	615.60	54.84	1096.80	100.00	2000.00	38.43	768.60	4662.80
10	PS7	51.54	1030.80	19.02	380.40	22.58	451.60	99.42	1988.40	34.12	682.40	4533.60
11	PS2	53.65	1073.00	11.27	225.40	19.35	387.00	92.46	1849.20	45.70	914.00	4448.60
12	PS15	53.31	1066.20	13.25	265.00	12.90	258.00	90.22	1804.40	45.25	905.00	4298.60
13	PS8	53.65	1073.00	8.01	160.20	16.13	322.60	98.65	1973.00	36.35	727.00	4255.80
14	PS13	62.08	1241.60	10.44	208.80	9.68	193.60	85.37	1707.40	44.07	881.40	4232.80
15	PS14	45.73	914.60	12.78	255.60	16.13	322.60	98.17	1963.40	26.41	528.20	3984.40
16	PS18	50.98	1019.60	13.45	269.00	25.81	516.20	99.17	1983.40	9.05	181.00	3969.20
17	PS12	55.76	1115.20	15.60	312.00	16.13	322.60	86.15	1723.00	21.66	433.20	3906.00
18	PS9	27.89	557.80	10.81	216.20	12.90	258.00	96.26	1925.20	36.20	724.00	3681.20
19	PS11	49.44	988.80	5.52	110.40	16.13	322.60	57.75	1155.00	49.11	982.20	3559.00
20	PS20	53.16	1063.20	8.17	163.40	9.68	193.60	9.09	181.80	23.44	468.80	2070.80

4) The procedure is repeated again from point 2, but first it is determined whether any of the stations that did not join any operational administration group because they were out of range have the minimum distance to a defined operational administration site. If so, the station will be under the structure of the created OA. The procedure is repeated until all PS are included.

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Table 136 – Table of times needed to overcome the distance between particular places

minutes	PS1	PS2	PS3	PS4	PS5	PS6	PS7	PS8	PS9	PS10	PS11	PS12	PS13	PS14	PS15	PS16	PS17	PS18	PS19	PS20
PS1	0	80	117	50	287	114	174	148	272	104	61	188	63	230	92	119	110	377	101	335
PS2	80	0	54	92	245	78	132	93	218	146	77	134	117	188	134	78	93	326	79	294
PS3	117	54	0	108	227	57	114	64	188	169	114	104	156	171	156	85	128	296	60	276
PS4	50	92	108	0	317	88	204	153	278	66	96	194	53	260	54	154	145	386	69	366
PS5	287	245	227	317	0	262	150	178	45	346	227	127	334	75	367	167	204	94	269	74
PS6	114	78	57	88	262	0	153	103	222	143	153	138	130	210	131	125	168	330	17	312
PS7	174	132	114	204	150	153	0	91	172	263	114	154	222	93	251	54	92	240	157	199
PS8	148	93	64	153	178	103	91	0	155	214	141	92	196	121	202	89	131	263	106	227
PS9	272	218	188	278	45	222	172	155	0	338	248	87	320	100	326	189	226	108	230	90
PS10	104	146	169	66	346	143	263	214	338	0	150	255	97	319	50	208	199	294	130	303
PS11	61	77	114	96	227	153	114	141	248	150	0	184	109	170	138	59	50	317	147	276
PS12	188	134	104	194	127	138	154	92	87	255	184	0	236	118	242	152	195	195	146	177
PS13	63	117	156	53	334	130	222	196	320	97	109	136	0	278	55	167	158	424	117	383
PS14	230	188	171	260	75	210	93	121	100	319	170	118	278	0	307	110	147	164	213	123
PS15	92	134	156	54	367	131	251	202	326	50	138	242	55	307	0	196	187	400	118	408
PS16	119	78	85	154	157	125	54	89	189	208	59	152	167	110	196	0	50	257	127	216
PS17	110	93	128	145	204	168	92	131	226	199	50	195	158	147	187	50	0	294	170	253
PS18	377	326	296	386	94	330	240	263	108	294	317	195	424	164	400	257	294	0	338	52
PS19	101	79	60	69	269	17	157	106	230	130	147	146	117	213	118	127	170	338	0	318
PS20	335	294	276	366	74	312	199	227	90	303	276	177	383	123	408	216	253	52	318	0

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The result of the application of the distribution potential method is the division of the distribution space into smaller parts with groups of electric power stations (Figure 167).

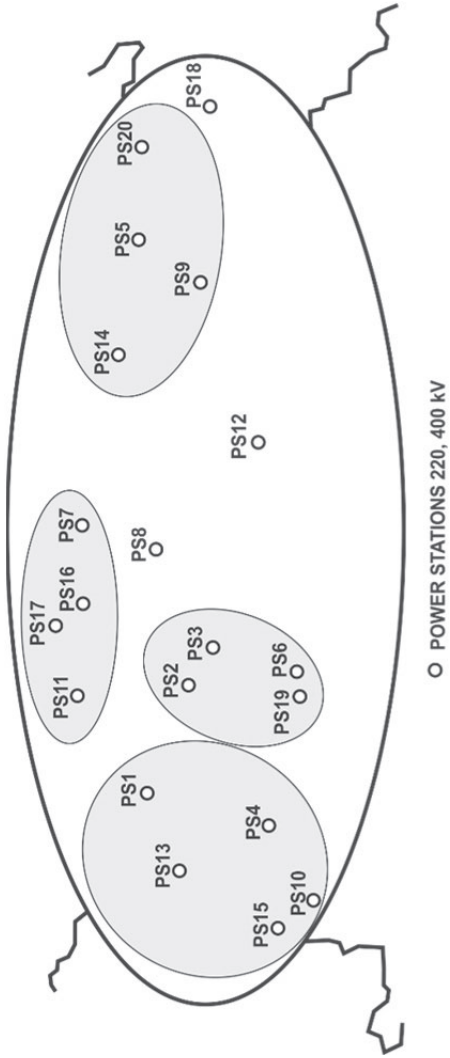


Figure 167 – Initial definition of power station groups and their operational administration sites

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Because some electrical power stations remain unassigned, namely PS8, PS12 and PS18, it is important to decide whether they are to be assigned to an existing group or to remain with separate operational administration. Based on queries and consultations with the company which set this task to the assignor, it was decided to assign the remaining PSs and to create the final proposal for the operational administration structure with power stations (Figure 168).

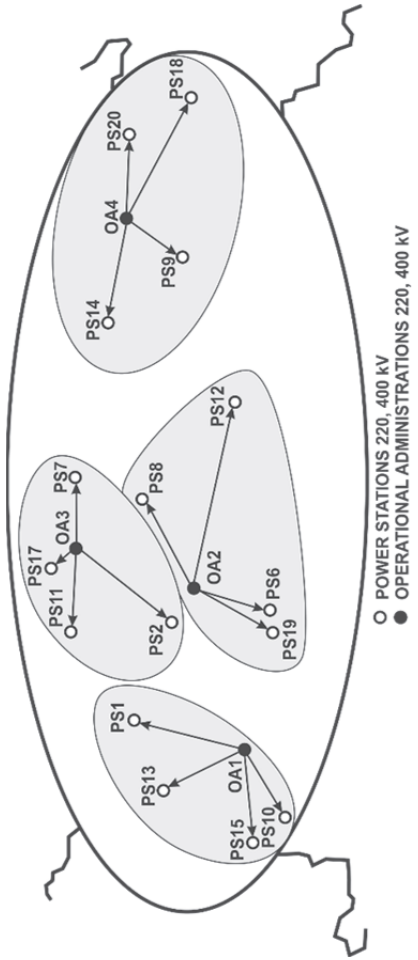


Figure 168 – Proposal for optimized operational administration regions according to multifactor analysis

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16.5 Applying the Geometric approach for the Location of Operational Administration in the Power Transmission System

When applying the geometric approach to find the location of operational administration, the solution procedure is as follows:

- creation of appropriate clusters, groups of electric power stations,
- calculation of the coordinates for the operational administration in each cluster using Cooper's iteration method.

The breakdown of the Power Transmission area into regions is based on the geographical location of electricity distribution stations in the area. Their locations suggest three or four areas for operational administration groups (Straka 2004).

During the breakdown of the researched region into areas, it is necessary to maintain the condition of access time from operational administration to subordinate stations in the event of a failure. This access time $CaDos \leq 90$ minutes means that the stations that comprise the area of operational administration are a maximum of 1.5 hours away from the operational administration site.

The Eastern Power Transmission area has such an arrangement that logically a maximum of two operational administration sites could be in this territory. If two operational administration sites were placed in the Eastern Power Transmission area, then there would be up to eight operational administration sites in the whole Power Transmission area while maintaining the condition of the number of distribution stations under an operational administration $PR_i = PR_j$. This is too many in terms of economy and operation. This shows that one operational administration site is best for covering whole Eastern Power Transmission area.

The operational administration site (OA) will be one of the current stations that takes care of the safe operation of subordinate power stations within a certain area. It manages the maintenance, repairs, and overall operation of the electrical power stations in the area under its control. It provides materials, people and equipment needed for the maintenance, repairs and operation of the electrical power stations.

The location of the operational administration site within an area is based on the idea of Cooper's iterative method (Straka 2004, Takala et al. 2007), i.e. to find such a location for operational administration that will have the minimum cost of transport to the power stations. Since the calculations results in optimal PS coordinates on a "green field", the power

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station that is closest to the calculated coordinates becomes the operational administration site.

The method is based on a geometric principle, the aim is to calculate the coordinates of the operational administration and its optimal location within a certain area. Once the area is determined with its power stations and respecting the access time, it is possible to calculate the coordinates for the operational administration sought.

It is assumed that the following are known:

- electric power stations PS_i,
- coordinates of power stations $PS_i\,(x_i, y_i)$,
- amount of energy transferred by particular stations M_i.

The map of the region is assigned coordinates on the x and y axes (Figure 169). The coordinates $[x_i,y_i]$ are determined for each PS_i. This is based on the idea of determining the absolute maintenance cost MC, which takes into account the following factors:

- the quantity of transferred and transformed energy,
- the unit cost of transferred and transformed energy,
- the distances of el. power stations from the operational administration site.

The objective function is defined as the product function of these variables (16.2). The variables are as follows, from the point of view of the PS_j location:

$$MC=\sum_{i=1}^{n} M_i.C_i.d_i \tag{16.2}$$

M_i – quantity,
C_i – price,
d_i – distances,
n – number of stations in the calculation.

The equation for MC is: $MC = \sum_{i=1}^{n} M_i.C_i.\sqrt{(x-x_i)^2+(y-y_i)^2}$.

The aim is to find the optimal coordinates x, y for the operational administration site using Cooper's iteration method (Figure 169, Figure 170), which has already been described.

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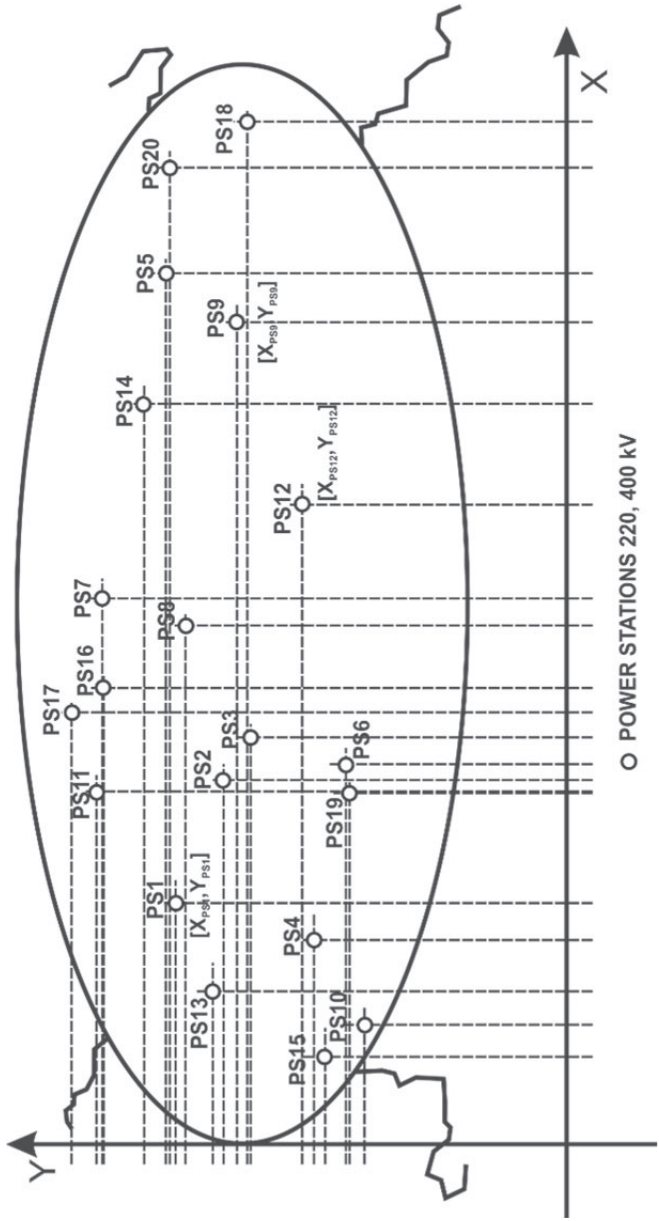


Figure 169 – Describing the region using X and Y coordinate axes

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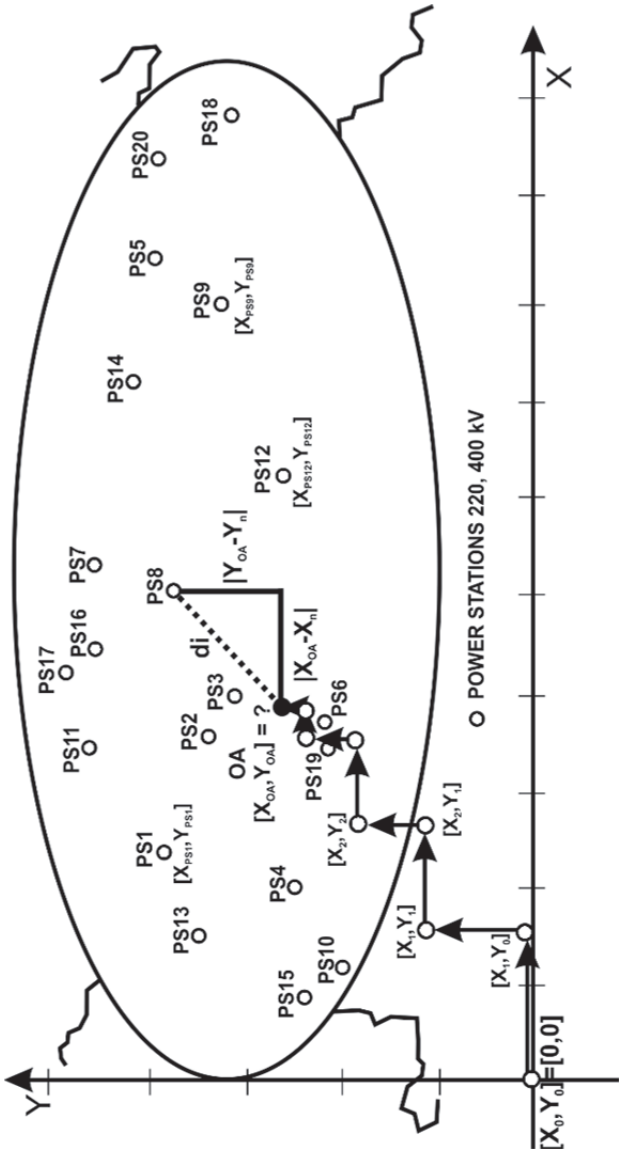


Figure 170 – Progress of the location of the operational administration site with optimal coordinates

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16.5.1 Calculation of the Coordinates of the Operational Administration Site

Before the calculation itself, it is necessary to prepare a table with the amounts of energy transferred for each station. The transferred amount of energy is a significant factor for the strategic position of the station in the system. Two types of energy are considered in the calculations:

- energy transmitted, the unit price is assigned to this,
- transformed energy, this has a fixed price set by the regulator in utility network industries.

The sum of the energy amount transferred with the relevant price used in the calculation for the operational administration location is shown in Table 137.

Table 137 – Coordinates of electric power stations and relevant amounts of transferred and transformed energy

Power stations	(m)		
	Xi	Yi	(M1.C1)+(M2.C2)
PS1	57 307	74 320	40 155 183
PS2	105 806	55 284	43 579 417
PS3	123 498	44 629	186 201 149
PS4	41 839	18 809	342 431 363
PS5	308 947	77 112	192 469 129
PS6	112 493	5 859	120 187 394
PS7	179 658	103 961	99 615 266
PS8	168 364	69 426	91 295 411
PS9	289 562	49 691	86 431 951
PS10	8 167	-1 479	90 657 574
PS11	101 938	106 005	70 957 249
PS12	216 815	23 874	128 905 555
PS13	21 605	59 290	102 738 739
PS14	256 788	87 031	103 280 257
PS15	-4 519	14 652	39 713 883
PS16	142 144	103 807	130 790 770
PS17	133 029	115 116	60 925 457
PS18	369 110	45 680	2 130 986
PS19	100 473	4 476	11 349 738
PS20	351 683	77 605	59 475 422

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This is based on the determination of the optimal number of areas and the number of electrical power stations in particular areas. The best means is the cluster that divides the area into the eastern region, the western region, the northern region and the southern region (Table 138).

Table 138 – Segmentation by area with stations in four regions

Western region	Southern region	Northern region	Eastern region
PS1	PS3	PS2	PS5
PS4	PS6	PS7	PS9
PS10	PS8	PS11	PS14
PS13	PS12	PS16	PS18
PS15	PS19	PS17	PS20

The optimal location of operational administration is calculated by iteration using Cooper's iteration method for each group of power stations, the calculated coordinates respect the transformed amount of energy (Table 139, Table 140).

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Table 139 – Calculation of the optimal coordinates for operational administration for the Western and Southern regions

	Power stations	Western group		
		Xi (m)	Yi (m)	(M1.C1)+(M2.C2)
1	PS1	57 307	74 320	40 155 183
2	**PS4**	**41 839**	**18 809**	342 431 363
3	PS10	8 167	-1 479	90 657 574
4	PS13	21 605	59 290	102 738 739
5	PS15	-4 519	14 652	39 713 883

Iteration	X[m]	Y[m]	ΔX	ΔY
X0,Y0	0.00	0.00		
X1,Y1	19 515.97	15 812.99	-19 515.97	-15 812.99
X2,Y2	30 961.96	20 387.62	-11 445.99	-4 574.63
X3,Y3	36 900.48	19 954.70	-5 938.52	432.92
X4,Y4	39 575.76	19 396.45	-2 675.28	558.26
X5,Y5	40 796.80	19 088.16	-1 221.04	308.28
X6,Y6	41 358.33	18 938.86	-561.54	149.30
X7,Y7	41 617.14	18 868.98	-258.81	69.87
X8,Y8	41 736.48	18 836.61	-119.34	32.38
X9,Y9	41 791.51	18 821.65	-55.03	14.96
X10,Y10	41 816.88	18 814.75	-25.38	6.90
X11,Y11	41 828.59	18 811.56	-11.70	3.18
X12,Y12	41 833.98	18 810.10	-5.40	1.47
X13,Y13	41 836.47	18 809.42	-2.49	0.68
X14,Y14	41 837.62	18 809.11	-1.15	0.31
X15,Y15	41 838.15	18 808.96	-0.53	0.14
X16,Y16	41 838.39	18 808.90	-0.24	0.07
X17,Y17	41 838.50	18 808.87	-0.11	0.03
X18,Y18	41 838.56	18 808.85	-0.05	0.01
X19,Y19	41 838.58	18 808.85	-0.02	0.01
X20,Y20	41 838.59	18 808.84	-0.01	0.00
X21,Y21	41 838.60	18 808.84	-0.01	0.00
X22,Y22	41 838.60	18 808.84	0.00	0.00
X23,Y23	41 838.60	18 808.84	0.00	0.00
X24,Y24	41 838.60	18 808.84	0.00	0.00
OA1	**X25,Y25**	**41 838.60**	**18 808.84**	0.00	0.00

	Power stations	Southern group		
		Xi (m)	Yi (m)	(M1.C1)+(M2.C2)
1	**PS3**	**123 498**	**44 629**	186 201 149
2	PS6	112 493	5 859	120 187 394
3	PS8	168 364	69 426	91 295 411
4	PS12	216 815	23 874	128 905 555
5	PS19	100 473	4 476	11 349 738

Iteration	X[m]	Y[m]	ΔX	ΔY
X0,Y0	0.00	0.00		
X1,Y1	140 652.04	28 854.92	-140 652.04	-28 854.92
X2,Y2	136 692.36	36 076.06	3 959.68	-7 221.13
X3,Y3	134 047.07	38 811.55	2 645.29	-2 735.49
X4,Y4	132 169.88	39 979.27	1 877.19	-1 167.72
X5,Y5	130 835.55	40 611.52	1 334.33	-632.25
X6,Y6	129 876.30	41 034.98	959.25	-423.46
X7,Y7	129 170.95	41 352.44	705.35	-317.45
X8,Y8	128 638.17	41 602.46	532.78	-250.02
X9,Y9	128 225.14	41 804.21	413.03	-201.74
X10,Y10	127 897.55	41 969.55	327.59	-165.35
X11,Y11	127 632.65	42 106.76	264.90	-137.21
X12,Y12	127 414.94	42 221.85	217.70	-115.09
X13,Y13	127 233.58	42 319.30	181.36	-97.45
X14,Y14	127 080.76	42 402.52	152.82	-83.22
X15,Y15	126 950.72	42 474.11	130.04	-71.59
X16,Y16	126 839.15	42 536.11	111.58	-62.00
X17,Y17	126 742.72	42 590.11	96.43	-54.00
X18,Y18	126 658.85	42 637.39	83.86	-47.28
X19,Y19	126 585.52	42 678.98	73.34	-41.59
X20,Y20	126 521.07	42 715.70	64.44	-36.72
X21,Y21	126 464.21	42 748.25	56.87	-32.55
X22,Y22	126 413.84	42 777.19	50.37	-28.94
X23,Y23	126 369.08	42 803.00	44.76	-25.81
X24,Y24	126 329.18	42 826.08	39.90	-23.07
OA2	**X25,Y25**	**126 293.51**	**42 846.75**	35.66	-20.68

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Table 140 – Calculation of the optimal coordinates for the operational administration for the Northern and Eastern regions

	Power stations	Northern group		
		Xi (m)	Yi (m)	(M1.C1)+(M2.C2)
1	PS2	105 806	55 284	43 579 417
2	PS7	179 658	103 961	99 615 266
3	PS11	101 938	106 005	70 957 249
4	**PS16**	**142 144**	**103 807**	130 790 770
5	PS17	133 029	115 116	60 925 457

Iteration	X[m]	Y[m]	ΔX	ΔY
X0,Y0	0.00	0.00	0.00	0.00
X1,Y1	134 771.74	97 223.72	-134 771.74	-97 223.72
X2,Y2	139 222.47	103 860.20	-4 450.73	-6 636.48
X3,Y3	141 153.88	103 940.16	-1 931.41	-79.97
X4,Y4	141 843.93	103 850.81	-690.04	89.35
X5,Y5	142 058.53	103 819.67	-214.61	31.14
X6,Y6	142 120.04	103 810.68	-61.51	8.99
X7,Y7	142 137.17	103 808.19	-17.12	2.50
X8,Y8	142 141.89	103 807.50	-4.72	0.69
X9,Y9	142 143.19	103 807.31	-1.30	0.19
X10,Y10	142 143.55	103 807.25	-0.36	0.05
X11,Y11	142 143.65	103 807.24	-0.10	0.01
X12,Y12	142 143.67	103 807.24	-0.03	0.00
X13,Y13	142 143.68	103 807.24	-0.01	0.00
X14,Y14	142 143.68	103 807.24	0.00	0.00
X15,Y15	142 143.68	103 807.24	0.00	0.00
X16,Y16	142 143.68	103 807.24	0.00	0.00
X17,Y17	142 143.68	103 807.24	0.00	0.00
X18,Y18	142 143.68	103 807.24	0.00	0.00
X19,Y19	142 143.68	103 807.24	0.00	0.00
X20,Y20	142 143.68	103 807.24	0.00	0.00
X21,Y21	142 143.68	103 807.24	0.00	0.00
X22,Y22	142 143.68	103 807.24	0.00	0.00
X23,Y23	142 143.68	103 807.24	0.00	0.00
X24,Y24	142 143.68	103 807.24	0.00	0.00
OA3	**X25,Y25**	**142 143.68**	**103 807.24**	0.00	0.00

	Power stations	Eastern group		
		Xi (m)	Yi (m)	(M1.C1)+(M2.C2)
1	PS5	**308 947**	**77 112**	192 469 129
2	PS9	289 562	49 691	86 431 951
3	PS14	256 788	87 031	103 280 257
4	PS18	369 110	45 680	2 130 986
5	PS20	351 683	77 605	59 475 422

Iteration	X[m]	Y[m]	ΔX	ΔY
X0,Y0	0.00	0.00		
X1,Y1	296 420.15	70 856.54	-296 420.15	-70 856.54
X2,Y2	301 669.74	74 292.12	-5 249.59	-3 435.58
X3,Y3	304 974.29	75 773.16	-3 304.55	-1 481.04
X4,Y4	306 876.22	76 446.45	-1 901.93	-673.29
X5,Y5	307 897.31	76 778.39	-1 021.09	-331.94
X6,Y6	308 423.01	76 945.79	-525.70	-167.40
X7,Y7	308 687.44	77 029.84	-264.43	-84.05
X8,Y8	308 818.83	77 071.68	-131.39	-41.84
X9,Y9	308 883.72	77 092.38	-64.89	-20.70
X10,Y10	308 915.67	77 102.59	-31.95	-10.21
X11,Y11	308 931.38	77 107.61	-15.71	-5.02
X12,Y12	308 939.10	77 110.08	-7.72	-2.47
X13,Y13	308 942.89	77 111.29	-3.79	-1.21
X14,Y14	308 944.75	77 111.89	-1.86	-0.60
X15,Y15	308 945.66	77 112.18	-0.91	-0.29
X16,Y16	308 946.11	77 112.32	-0.45	-0.14
X17,Y17	308 946.33	77 112.39	-0.22	-0.07
X18,Y18	308 946.44	77 112.43	-0.11	-0.03
X19,Y19	308 946.49	77 112.44	-0.05	-0.02
X20,Y20	308 946.51	77 112.45	-0.03	-0.01
X21,Y21	308 946.53	77 112.46	-0.01	0.00
X22,Y22	308 946.53	77 112.46	-0.01	0.00
X23,Y23	308 946.54	77 112.46	0.00	0.00
X24,Y24	308 946.54	77 112.46	0.00	0.00
X25,Y25	**308 946.54**	**77 112.46**	0.00	0.00
OA4				

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16.5.2 Analysis of the Results Obtained

The optimal coordinates for operational administration are: OAx_1, OAy_1 = *[41 838.50; 18 808.84]* for the western group of electrical power stations, these coordinates are nearest to station PS4. After drawing the calculated coordinates from the application into this map (

Figure), the same result was obtained, station PS4. Power station PS4 is OA1.

The optimal coordinates for operational administration are: OAx_2, OAy_2 = *[126 293.51; 42 846.75]* for the southern group of electrical stations, these coordinates are nearest to station PS3. Power station PS3 is OA2.

The optimal coordinates for operational administration are: OAx_3, OAy_3 = *[142 143.68; 103 807.24]* for the northern group of electrical power stations, these are closest to station PS16. Power station PS16 is OA3.

The optimal coordinates for operational administration are: OAx_4, OAy_4 = *[308 946.54; 77 112.46]* for the eastern group of electric power stations, these are closest to station PS5. Power station PS5 is OA4.

The results of both approaches for finding the locations of operational administration sites by means of logistics approaches are identical. This suggests that the choice of four power stations for promotion to operational administration sites is correct.

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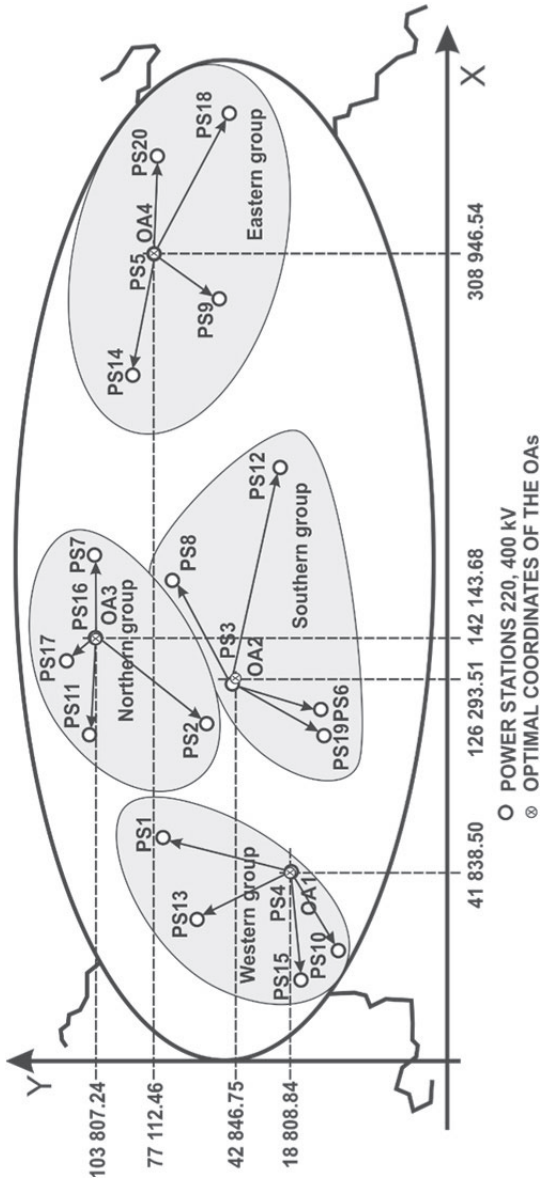


Figure 171 – Proposal for the location of operational administration structures for the Power Transmission System

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VII.

Case Studies from the Field of Distribution and Collection of Goods, Circular Tasks

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CHAPTER SEVENTEEN

APPLICATION OF CLARKE-WRIGHT'S SAVING ALGORITHM FOR INCREASING THE EFFICIENCY OF DISTRIBUTION FOR DELTA WAREHOUSES, INC. PRESOV

17.1 Definition of the Problem and Objective of the Task

The problem consists of reducing the costs of product distribution within the networks of Delta Warehouses, Inc. Presov (Delta) in Eastern Slovakia while maintaining flexibility of distribution and customer satisfaction. The goal is to find a systemic solution that saves costs and saves time to distribute company products by applying a quantitative distribution logistics method.

In times of global competition, the issue of increasing process efficiency in companies is being given considerable attention. There is an increasing interest from various businesses in the implementation of logistical principles in their overall strategy. Logistics is becoming crucial in the search for possibilities for effective business management and increasing business competitiveness. The entry of international commercial chains into the Slovak market and the competitive struggle for customers has brought the necessity to set up logistics and distribution centres in Slovakia and therefore the optimization of distribution within the micro and macro view of the company is a current topic.

The distribution of goods is one of the main functions of a distribution centre (Bancroft 1991). Therefore, in Presov within Delta Warehouses, Inc. (DW) in Slovakia, optimization of the distribution of goods is one of the possibilities for reducing the costs of activities related to the distribution of goods from producers to final consumers and customers. The aim of the solution is to create a design concept for optimizing the distribution of goods from the DW distribution centre in Presov in terms of the planning and subsequent implementation of distribution from a distribution centre to the particular units of Delta Warehouses, Inc. within the region that fall under this distribution centre. To achieve this goal, it is

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necessary to design a procedure for compiling daily distribution plans for a given distribution region, based on Clarke-Wright's saving algorithm principle, which is used to solve distribution tasks (Greskovicova, Straka 2009). Regarding analysis, it is appropriate to apply a systemic approach (Figure 172) to understand the activity of DW's distribution and to highlight deficiencies that may occur in this activity.

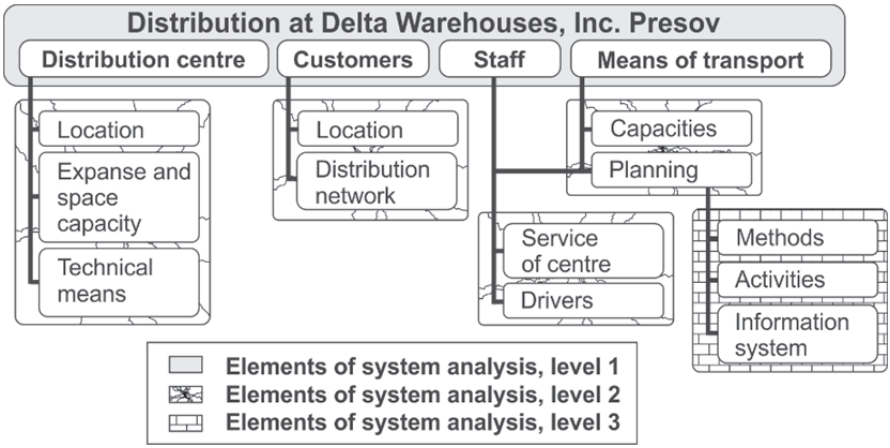


Figure 172 – Definition of the distribution system of Delta Warehouses, Inc.

17.2 Characteristics of the Delta Warehouses, Inc. Distribution Centre in Presov

Delta Warehouses, Inc. entered the Slovak market in 1996 when the company bought a network of department stores from the German company Ashop. Since 1996, it has built a wide network of its own facilities. Delta Warehouses, Inc. has maintained a leading position among its competitors in the Slovak market. The distribution centre (DC) in Presov was established due to the necessity for more efficient supply of Delta shop units in Eastern Slovakia and especially because the distribution centre in Trencin is no longer able to fulfil the needs of all Delta shop units in Slovakia. The Presov DC supplies Eastern Slovakia with food and goods called *Fresh Goods* and confectionery and drugstore products, known as *Sweet Stuff* (Mihalic, Straka 2008).

Logistics processes are part of the network of logistics chains that form the supply chain network. The supply chain is understood as a sequence of events focused on satisfying particular shop units (SU) (Figure 173). The

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controlling element in this chain is the Supply Chain department, with its headquarters in Bratislava. Shop units send their orders to the Supply Chain department. This department sorts orders according to the range of goods delivered from particular suppliers. It gives complete orders to the relevant suppliers. Suppliers delivers their goods to the DC, where goods are accumulated from all suppliers. Workers at the DC prepare goods with the required assortment and quantity as per the order of the SU and distribute it directly to each SU.

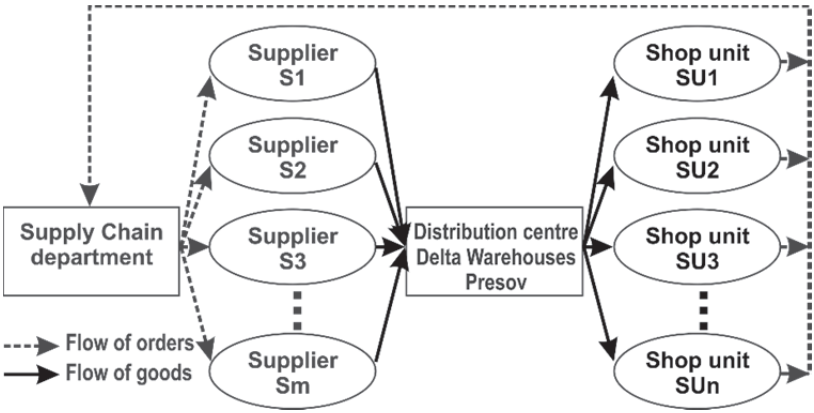


Figure 173 – Flow of orders and flow of goods at Delta Warehouses, Inc.

17.3 Presov DC Distribution Region

The distribution centre in Presov was built to supply shop units in eastern Slovakia. The distribution area (Figure 174) which falls under the Presov DC consists of 19 shop units (retail units) namely:

- Kosice 1,
- Kosice 2,
- Kosice 3,
- Michalovce,
- Humenne,
- Presov 1,
- Presov 2,
- Presov 3,
- Poprad,
- Kezmarok,
- Vranov nad Toplou,
- Velke Kapusany,
- Moldava nad Bodvou,
- Kralovsky Chlmec,
- Roznava.
- Stropkov,
- Krompachy,
- Svidnik,
- Medzilaborce,

Delta uses road vehicles to distribute goods. The Delta Presov Distribution Centre has five trucks of up to 18 tons with a capacity of 18 pallets and 10 conventional trailers with a capacity of 33 pallets each.

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Cargo Zeta Slovakia, Ltd. provides carriage of goods to the SUs and it also offers drivers and road tractors to pull the trailers.

The Delta distribution warehouse uses the standardized euro-pallet size of 800×1200×140 *mm* and a carrying capacity of 1000 *kg* as the basic transport unit, because it is the most suitable for the handling of piece goods. It is suitable for storage, handling and transporting throughout the process of circulation of goods. The pallet is a means for transporting things with a loading and handling floor for fork lift handling and it is adapted for stacking (Mihalic, Straka 2008; Greskovicova, Straka 2009).



Figure 174 – Distribution region map for Delta Warehouses, Inc. Presov in East Slovakia

17.4 Distribution of Goods from the Presov DC

Distribution of goods and planning deliveries of prepared goods from the Presov DC to a particular SU is provided by the department of transport of the Presov DC. This distribution plan, i.e. the travel plan, is compiled daily and the decisive criterion is the SU orders, the number of boxes or pallets per day.

Effective implementation of all warehouse activities requires proper and understandable marking of pallets. Each pallet in the DC must be

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marked with pallet labels, and a pallet that is currently being transported must also contain a shipping note. Pallet labels contain a barcode, so it is necessary to work with the scanner when handling the pallet so that all changes and movements of goods and pallets are directly recorded in the warehouse (from receipt through storage to loading) and sent to the DC information system linked to the system of the Supply Chain department (Greskovicova, Straka 2009).

The pallet label contains the following information:

- name of the distribution centre,
- name and shop unit number for which the pallet is intended,
- order number, pallet number and bar code,
- number of shipping note.

The schedule of transport to each SU is determined by the Supply Chain department. The schedule of transport includes the times when the goods for the given SU should leave the distribution centre and the times when they should be delivered to that SU. The maximum numbers of deliveries for a given SU are set the with the appropriate frequency per day in this schedule. When planning daily haulage of goods, it is necessary to create a travel plan in accordance with this transport schedule. This means that the goods are to be delivered to an SU at any of the listed times for that SU. This is related to the organization of the work of the department of goods receipt for the given SU (Greskovicova, Straka 2009).

Process of planning goods delivery

The rules, actions and procedures in planning goods dispatches performed by the department of transportation at the Presov DC are summarized in the following points:

1) Information;

Ascertaining and confirming information about the number of cartons and pallets for deliveries to shop units for the next day.

2) Processing information;

Processing information about the planned numbers of cartons and pallets. Recalculation and determination of the number of deliveries.

3) Planning;

Planning trips, direct and combined deliveries. Planning as economically as possible in collaboration with the transport company. Keeping the schedule of transport when planning. Determining the order of which SU will be served first and which subsequently for combined deliveries.

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4) Proposal of the plan;

Decision and proposal for a solution involving combined deliveries for particular SUs and determination of delivery routes.

5) Creation of delivery plan;

Confirmation and creation of the table of deliveries for each SU for the next day.

6) Definite delivery plan;

The final closure of the delivery plan for the SUs. This delivery plan is announced on the intranet by the Presov DC to all shop units in the form of a table of deliveries by 5:00 pm the previous day.

7) Loading;

Loading goods for an SU. Communication between loading personnel and the transport department about completion of loading and combining deliveries. In the case of extraordinary or missed deliveries, the SU must be informed. Communication with Cargo Zeta dispatchers and drivers.

8) Documentation;

Delivery and shipping notes are prepared after the completion of goods loading.

9) Checking documents;

Checking the delivery notes and writing their numbers on the shipping notes. Checking driving numbers and completing times of departure from the Presov DC and arrival at an SU.

10) Monitoring;

Watching the weather and transport situation on the roads to SUs.

11) Verifying departures;

Confirming the shipment as sent in the table and reporting it on the intranet after the vehicle leaves.

12) Compliance with the delivery plan;

Each driver and SU are informed of the time of goods delivery to the SU. This means that if the delivery does not occur exactly at the specified time or no more than maximum 30 minutes later, the goods will be accepted but unjustified delay can lead to a penalty. Exceptions are accepted only in the cases of accident, failure, bad weather or other unforeseeable circumstances. Such an event must be reported immediately to the dispatcher, so that employees in the distribution centre and in the SU can be informed.

13) Goods reception at SU;

Goods at SU reception are picked up on pallets. The unloading time is up to 60 minutes maximum.

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14) Claims;

Any discrepancies need to be reported to a responsible person at the SU and to the department of transport in the distribution centre. Claims are dealt with under the Claims Procedure.

15) Summary;

Preparing summaries – the number of transfers, number of vehicles used, and possible delays after completing all trips within the given day. The completed delivery plan is published the next day on the intranet.

The distribution network

The connection of the Presov DC with Delta shop units within the distribution region that falls under this distribution centre can be characterized as a *1–m* connection type. This means the connection of one distribution centre with nineteen shop units, i.e. customers. The linkage may be straight or circular. It depends on the requirements of shop units and the capacity of the means of transport. The SU requirements are expressed in terms of the number of pallets and also the capacity of a vehicle.

If the requirements of some SUs are less than the capacity of a vehicle, a combined delivery may be considered. This means serving multiple shop units with one shipment. Then, it is possible to consider it as a circular journey.

However, if the requirements are almost equal to the capacity of the vehicle, it means that two SUs cannot be found which could be served with one shipment and it is a direct connection. In this case, there is a direct line connection.

Based on this, according to the theory of distribution logistics, it is possible to classify the Presov DC distribution network as a "FLOWER" type of network. It means that the beginning and end of the distribution of goods is at the Presov DC and it is not possible to serve all SUs from one shipment, i.e. in one circuit. There must be several shipments because of the limitation of vehicle capacity (Greskovicova, Straka 2009).

Trip planning

As has been already mentioned, the daily distribution plan (schedule), i.e. the travel plan, is compiled by a worker in the department of transport. He creates it manually, based on his knowledge and empirical experience. This means that the planning system is not automated.

When compiling the trip plan, the SU requirements for the number of pallets are the starting point. Requirements for *Fresh Goods* pallets have

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priority over *Sweet Stuff* pallets, so the trips are planned to cover the demands of fresh food for shop units first.

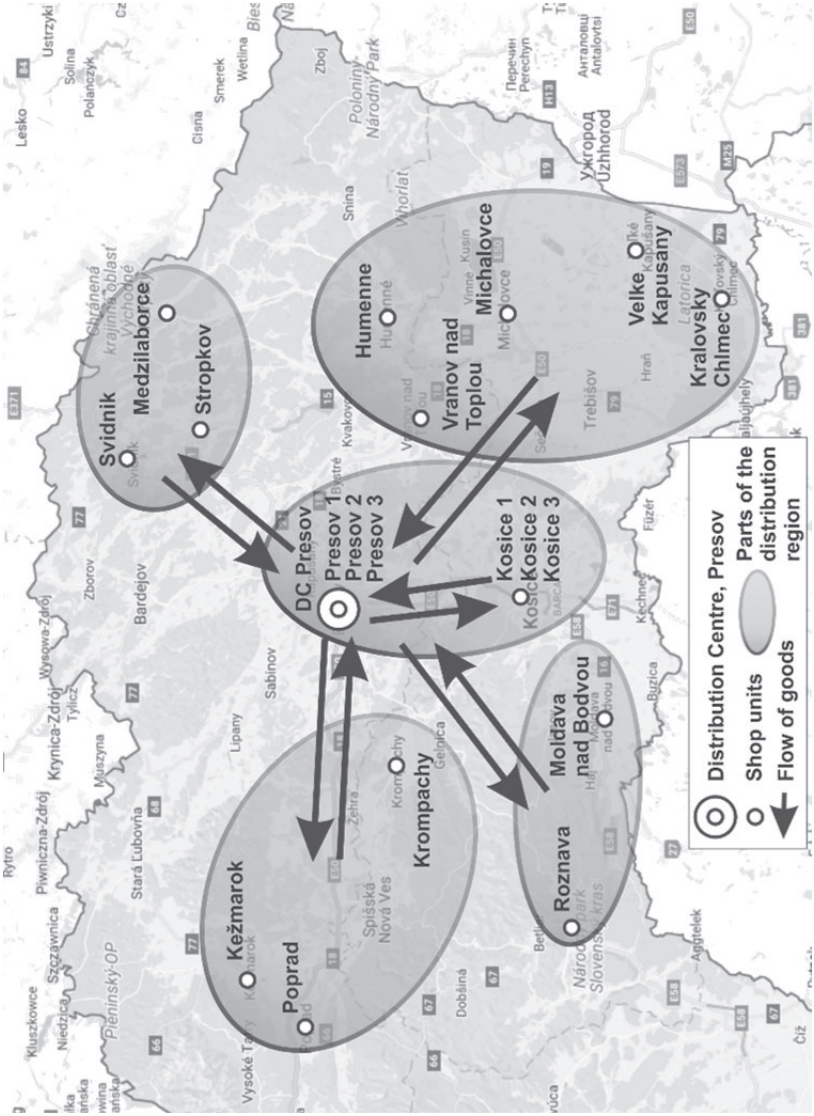


Figure 175 – Parts of the distribution region under the Presov DC

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In the case of unused capacity in a vehicle with the *Fresh Goods* pallets, either required Sweet Stuff pallets are added to the rear of a vehicle or a combined delivery is created between two or more shop units with the *Fresh Goods* pallets and the requirements for the *Sweet Stuff* pallets are covered in the next delivery, which will be either direct or combined again with other SUs, based on the remaining quantity requested.

The distribution area of Presov is divided into parts (Figure 175). When creating combined shipments, only circular trips between places within the same part are considered for creation. There is no plan to link two or more SUs across multiple or all parts of the region.

The shop units in the cities of Kosice and Presov have a specific position. They are perceived as the conjunction of other parts of the distribution region (due to three shop units at each point) and therefore they fall into each of the remaining parts of the distribution region. This means that in planning combined transport within one part, the possibility of assigning an SU in Kosice or Presov to the circular route in that part is considered (Greskovicova, Straka 2009).

17.5 Deficiencies Determined by Analysis of DC Delta Warehouses Presov

After analysing goods distribution at DC Delta Presov, the process of planning daily deliveries of goods from the Presov DC to particular shop units appears to be the main drawback. The daily distribution plan is compiled by a worker from the department of transport. One of his tasks is to plan the trips of trucks to distribute goods for shop units as economically as possible. However, this procedure for compiling the most economical deliveries of goods into SUs is not more specifically defined or determined by some standards and precise rules. The daily delivery plan is based only on the knowledge and experience of a certain worker without the use of appropriate computing techniques. This means that this planning system is not automated and it is dependent only on the ability of a certain worker to decide.

Another disadvantage that Presov DC distribution region is divided into parts and combined deliveries are subsequently planned only with the possibility of creating circular trips between places within one part of the distribution space. Supplying the distribution space as a whole is not considered. The division of the distribution region into smaller distribution groups is appropriate if distribution is limited by some distribution limiting criteria. When distributing goods from the Presov DC, the

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limiting criterion is the capacity of the distribution vehicle, but because the requirements of particular SUs are different every day and must be covered every time, it is inefficient to divide the distribution region this way in terms of costs (Greskovicova, Straka 2009).

17.6 Planning Distribution from Delta warehouses according to Clarke-Wright's Algorithm

One possible solution for removing the identified shortcomings is the possibility to focus on optimizing the planning process of daily deliveries of goods from the Presov DC to shop units, because the planning process is not defined in detail. It is assumed that a cost-effective reduction in kilometres driven can be achieved with an appropriate proposal for delivery and trip planning, which must also be reflected in the reduction of distribution costs, i.e. transport costs. To make the distribution of goods more efficient and to make daily plans of goods distribution from the Presov DC to a particular SU more effective, Clarke-Wright's saving algorithm will be used.

Numerical designation of the particular sale units and the distribution centre is introduced as shown in the table (Table 141) due to the large size of the distance matrix and this designation for SUs will be used throughout the proposal of optimization of goods distribution.

The Routeplanner expert system application was used for creation of a distance matrix (Table 142). It displays the route on the map as well as the length of the route after entering the starting and destination place. This application offers the choice of route type – either the shortest one, which is the shortest possible route between the selected cities, but many times it leads along secondary and even lower-quality roads, or the most advantageous route, which is the shortest possible connection of cities mostly through 1st class routes. For this reason, the option was chosen for determining the distance between cities which makes the most advantageous use of routes, in order to ensure that the routes are suitable for lorry traffic (Greskovicova, Straka 2009).

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Table 141 – Numerical designation of SUs

SU name	SU number	SU name	SU number
Presov DC	x	SU Poprad	10
SU Svidnik	1	SU Michalovce	11
SU Stropkov	2	SU Vranov nad Toplou	12
SU Velke Kapusany	3	SU Roznava	13
SU Moldava nad Bodvou	4	SU Humenne	14
SU Krompachy	5	SU Kezmarok	15
SU Kralovsky Chlmec	6	SU Presov 2	16
SU Medzilaborce	7	SU Kosice 2	17
SU Kosice 1	8	SU Kosice 3	18
SU Presov 1	9	SU Presov 3	19

Table 142 – Distance matrix (in km) between the Presov DC and Delta Warehouses shop units

i / j (km)	x	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
x		56	48	103	69	47	120	78	41	10	92	77	47	113	72	94	9	49	45	10
1			13	124	118	95	140	43	88	59	133	96	62	161	64	121	58	97	91	59
2				98	116	93	145	31	86	56	134	71	61	159	52	137	55	90	88	55
3					109	132	17	99	85	107	190	35	65	151	58	193	106	90	82	106
4						76	119	156	28	69	115	88	94	43	115	129	67	32	30	67
5							153	125	54	46	56	106	87	74	112	60	47	56	53	48
6								117	95	123	211	81	87	161	75	215	124	92	94	125
7									129	83	165	72	68	199	43	169	82	133	130	84
8										42	120	61	67	72	88	124	43	7	4	44
9											83	81	49	109	76	87	9	47	43	3
10												162	127	73	153	14	79	125	122	85
11													36	131	31	165	83	62	60	81
12														137	27	131	48	67	65	46
13															157	86	115	72	70	111
14																156	71	89	87	70
15																	89	124	126	90
16																		57	53	6
17																			3	47
18																				34
19																				

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17.7 Calculation of the Savings Matrix

The distance between two *SUs* is marked *(i,j)*, where *i* and *j* are shop units. The savings in km *u(i,j)* for each pair *SU (i,j)* are calculated according to the formula (17.1), where $i = 1, ..., 19$ and $j = 1, ..., 19$.

$$u(i,j) = d(x,i) + d(x,j) - d(i,j) \quad (17.1)$$

The calculated savings matrix must be sorted in descending order according to the size of the savings. Thus, the savings list is created (Table 143). The SU connections where *km* savings is equal to 0 or less than 0, are excluded from the savings list because it is unnecessary to consider a combined delivery for these SUs because there is no savings in kilometres driven. (Straka 2013).

A limited prerequisite for planning daily deliveries of goods from the Presov DC to a particular SU is the capacity of the means of transport. The capacity limit of a vehicle is set to 33 pallets in delivery planning. The Delta distribution centre has multiple vehicles available with a capacity of 33 pallets, and the priority in the proposal to optimize the distribution of goods is the number of kilometres driven rather than the number of trips for daily distribution of goods. For these reasons, 33 pallets per one vehicle trip is a limiting condition for delivery planning.

17.8 Requirements of Shop Units

The daily requirements of shop units for the quantity of pallets from the Presov DC vary. A larger SU requests a number of pallets many times larger per day than vehicle capacity. In this case, in the creation of a daily delivery plan, direct deliveries to these SUs are planned with maximum capacity utilization of the vehicle.

If the daily requirement of a certain SU cannot be fulfilled by direct deliveries only with the maximum capacity utilization of the vehicle, i.e. the SU requirement is not a multiple of 33 without remainder, then direct shipping to this SU is performed with a multiple 33 pallets and the remainder of its required pallets is added to the process of combined delivery planning.

Because there are days when some shop units have no pallet request from the Presov DC, it is necessary to exclude connections with these SUs from the *km* savings list (Table 143). Obviously, it is not necessary to visit the given SU on that day, nor to include it in planning delivery of goods.

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Table 143 – Savings list u_{ij} (in km) between the particular points

List of savings u_{ij} (km)														
Connection of the units		saved km	Connection of the units		saved km	Connection of the units		saved km	Connection of the units		saved km	Connection of the units		saved km
3	6	206	6	18	71	4	14	26	10	14	11	11	15	6
10	15	172	4	6	70	8	14	25	12	19	11	11	19	6
3	11	145	2	14	68	2	6	23	1	18	10	2	15	5
4	13	139	6	8	66	12	13	23	9	16	10	2	18	5
10	13	132	3	18	66	4	12	22	4	9	10	3	10	5
13	15	121	3	13	65	10	16	22	12	15	10	6	16	5
11	14	118	1	14	64	8	12	21	14	15	10	6	19	5
3	14	117	11	17	64	18	19	21	14	16	10	7	9	5
6	14	117	3	4	63	9	10	19	1	8	9	7	10	5
6	11	116	3	17	62	15	17	19	5	16	9	7	16	5
7	14	107	11	18	62	3	5	18	5	19	9	3	15	4
2	7	95	3	8	59	5	11	18	8	9	9	7	19	4
12	14	92	11	13	59	9	15	17	1	5	8	2	8	3
1	2	91	4	11	58	9	19	17	1	13	8	2	19	3
1	7	91	7	12	57	10	19	17	1	17	8	7	15	3
17	18	91	8	11	57	10	17	16	9	12	8	11	16	3
13	17	90	2	11	54	1	10	15	12	16	8	2	5	2
11	12	88	2	3	53	10	18	15	1	4	7	2	9	2
13	18	88	4	10	46	5	6	14	1	9	7	2	13	2
4	17	86	1	12	41	9	13	14	1	16	7	2	16	2
5	13	86	4	5	40	15	16	14	1	19	7	2	4	1
3	12	85	5	17	40	15	19	14	2	17	7	6	10	1
4	18	84	5	18	39	8	10	13	3	19	7	16	17	1
5	10	83	1	11	37	15	18	13	5	12	7	16	18	1
7	11	83	1	6	36	16	19	13	5	14	7	5	7	0
8	17	83	1	3	35	9	17	12	6	9	7	6	15	-1
3	7	82	2	12	34	9	18	12	8	16	7	7	17	-6
8	18	82	4	15	34	17	19	12	8	19	7	7	18	-7
4	8	82	5	8	34	14	19	12	10	11	7	7	13	-8
8	13	82	14	17	32	13	19	12	13	16	7	4	7	-9
6	7	81	14	18	30	4	19	12	2	10	6	7	8	-10
5	15	81	1	15	29	10	12	12	3	9	6			
6	12	80	12	17	29	5	9	11	3	16	6			
6	17	77	13	14	28	4	16	11	9	11	6			
6	13	72	12	18	27	8	15	11	9	14	6			

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17.9 Planning Combined Deliveries

After determining the number of direct loads with the maximum load capacity of the vehicle to SUs where pallet requirements are greater than 33 pallets and excluding connections to SUs with zero pallets required, it is appropriate to exclude from the list any savings from connections of two shop units where the sum of requirements exceeds 33 pallets, i.e. the capacity of a vehicle. Obviously, it is not possible to plan combined delivery to these two shop units.

This step has been specified because of the scope of the required task and it should simplify and accelerate the establishment of optimal combined deliveries by reducing the savings list, i.e. reducing the number of opportunities to create combined deliveries to shop units (Greskovicova, Straka 2009).

After reducing the savings list, the procedure for finding optimal combined deliveries is as follows:

1. The combined delivery will be planned between shop units that have the highest savings of km, *km*, *max* $u_{(i,j)}$, so it is the highest item in the savings list. These two relevant SUs, which are marked as SU_A and SU_B, will be included in one combined delivery.
2. The next SU connected to SU_A or SU_B with the highest savings and not exceeding the capacity of a vehicle is sought in the savings list.
3. a) If such an SU is not found, this combined delivery is closed. This means, that another SU cannot be added to the combined delivery $SU_A - SU_B$. All connections of other SUs with SU_A and SU_B will be removed from the saving list. Then we continue from step 1.
   b) If such an SU is found in the savings list, it will be assigned to this combined delivery, and it will be marked as SU_{NEW}. There are two cases of assignment that can occurred:

I. $SU_A - SU_B - SU_{NEW}$

or

II. $SU_{NEW} - SU_A - SU_B$.

Where all connections to an SU have already been defined, meaning that it is not possible to include another SU before or after it (in the case of I: this is SU_B, in the case of II: it is SU_A), connections to that SU will be removed from the savings list.

The SU marking with the index "NEW" is changed to the index with which the SU was labelled before. In the case of I: SU_{NEW} it will be

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changed to SU_B and, in the case of II: SU_{NEW} it will be changed to SU_A. Then we continue from step 2.

This algorithm for finding effective combined deliveries ends when the savings list is empty, all of its items have been excluded.

If there are still unassigned shop units that require less than 33 pallets, but it has not been possible to create a combined delivery between them, direct delivery will be planned for these shop units with lower capacity utilization of a vehicle than its maximum capacity after this algorithm for finding optimal combined deliveries is completed.

When planning combined delivery, it is possible to decide in what order the shop units will be served in this combined delivery. If, for example a circle of combined delivery has been found according to the proposed planning algorithm for combined delivery as follows:

Presov DC – SU_3 – SU_6 – SU_2 – Presov DC.

It is possible to serve shop units in this order or vice versa, that is:

Presov DC – SU_2 – SU_6 – SU_3 – Presov DC.

The number of kilometres travelled in combined delivery will not be changed, so the time to deliver goods will be the same. It is necessary to use the schedule of transport to decide the order of shop units in combined delivery and from this to determine which sequence of serving the SUs in the combined delivery is better (Greskovicova, Straka 2009).

17.10 Determination of the Order for Implementation of Planned Deliveries

After planning all shipments to shop units, both direct and combined, it is necessary to determine the order in which the deliveries are to be performed on the particular day. Since the schedules of delivery did not recognize the SU requirements of goods pallets with *Fresh Goods* and pallets for *Sweet Stuff* and the supplies of *Fresh Goods* pallets have priority, this fact will affect the determination of the order of planned deliveries to shop units on a certain day.

Scheduled deliveries are divided into two groups. There, all the planned combined shipments to SUs and direct deliveries to those SUs that are not included in any of the scheduled combined deliveries are in the first group. In this first group of deliveries there will be SUs with only one delivery planned for that day. Their requirements will be fulfilled in this

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one planned delivery, whether direct or combined, without the need to distinguish their requirements for the *Fresh Goods* pallets from the *Sweet Stuff* pallets. Subsequent to the first group of deliveries there will be one delivery to each of those shop units in which there are several shipments scheduled for the given day. Their requirements will be fulfilled at least in part depending on the capacity of the vehicle. For *Fresh Goods* pallets this is one delivery. The remaining repeated deliveries to these SUs will be included in the second group of deliveries, which will be performed just after the first group has been completed. The particular order of deliveries in the first group of deliveries will be determined with respect to the Transportation Schedule.

Deliveries will be scheduled to those SUs that have multiple shipments scheduled on a particular day in the second group of deliveries. The order will be determined with respect to deliveries and priority is given to those SUs which have to fulfil the remaining pallet requirements for *Fresh Goods*. These will be followed by deliveries to those SUs that have not already fulfilled their requirements for *Sweet Stuff* pallets. The exact order of deliveries within this second group of shipments will again be determined based on the Transportation Schedule.

17.11 Summary of the Procedure for the Daily Planning of Goods Deliveries

After the confirmation of requirements of shop units for the number of pallets for the following day, the planning of goods deliveries from the Presov DC to the individual SUs proceeds as follows:

1. Removing from the list of savings the connections of SUs that have 0 pallets required from the Presov DC on that day.
2. Determination of direct deliveries with maximum vehicle capacity utilization to those SUs for which the pallet requirement is greater than 33 pallets.
3. Including the remaining required pallets of these SUs in planning combined deliveries.
4. Elimination from the Savings List of connections of SUs where the sum of requirements exceeds 33 pallets.
5. Planning combined deliveries according to the procedure for finding optimal combined deliveries.
6. Determination of direct deliveries into SUs, where the requirement is less than 33 pallets, but it was not possible to schedule a combined delivery under the procedure for the finding the optimal combined delivery.

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7. Determination of the order of SUs in the planned combined deliveries according to the Transportation Schedule.
8. Determination of the order of implementation of the planned direct and combined deliveries.

17.12 Creation of a Goods Delivery Plan with the use of Algorithms

The proposed procedure for daily delivery planning from DC Delta Presov to shop units is difficult and time-consuming due to the size of the distribution region. If the daily deliveries to shop units are planned by a worker from the transport department without using any software application, the risk of mistakes due to human error would be very high. For this reason, it is appropriate to use an application that would at least partly automate the day-to-day planning process when creating goods delivery plans. The application will be represented by algorithms that can be converted to any computer program, e.g. Delphi, C ++, Visual Basic as well as the database application MS Access, or a web application using PHP scripts.

Creation of the program application consists of two areas, as follows:

1. Entering inputs – data about distances between shop units, distances between SUs and the Presov DC and the daily requirements of SUs for the quantity of pallets to be transported are entered in the distance matrix.
2. Calculation – where the cost savings matrix and the effective delivery routes are calculated.

Calculation of effective delivery routes works in three cycles (Greskovicova, Straka 2009):

The 1st cycle:

The algorithm (Figure 176) passes through all the requirements of each shop unit and for each requirement that is higher than or equal to the LIMIT value of a truck (33 pallets), it creates a direct delivery to the appropriate SU and it reduces the pallet requirement by the LIMIT value of a truck. The rest of the pallets required for the appropriate SU are saved as a new request in the table. The first cycle is repeated until all shop unit requirements are less than or equal to the LIMIT value of the truck.

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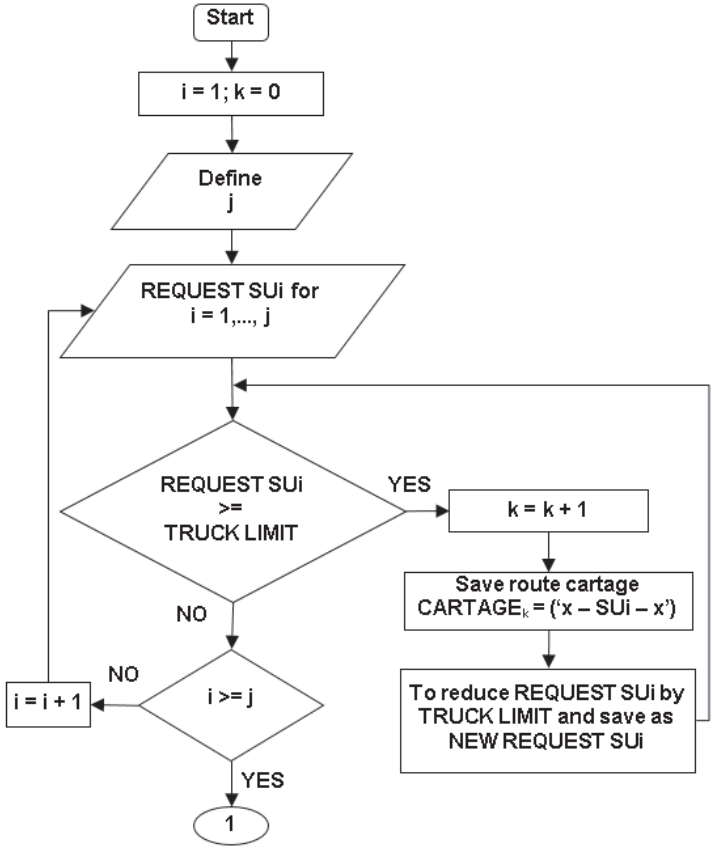


Figure 176 – Algorithm of the 1st cycle

The 2nd cycle:

The second cycle uses Clarke-Wright's saving algorithm to search for efficient delivery connections of SUs with requirements less than the LIMIT of trucks, with the fulfilment of following conditions:

- the connections with SUs with the largest savings of km have priority,
- the sum of the pallets in one delivery must not be greater than the LIMIT of a truck,
- SUs cannot be repeated in one delivery circuit,
- SUs cannot be repeated in particular created groups of deliveries.

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The algorithm (Figure 177) begins with sorting the calculated kilometre savings matrix for each pair of SUs in order from the largest to the lowest savings value. The algorithm sequentially searches the sorted savings matrix and for each pair of SUs with nonzero requirements it verifies the condition that either SU of that pair has been assigned to one of the previously created groups of deliveries. If not, the algorithm verifies whether one SU from the pair of shop units is in the currently-created circuit of delivery from the left or right side. If this is true, the algorithm tests whether the capacity limit of the vehicle exceeds the number of pallets. If the sum of the requirements for the number of pallets in a circuit is less than or equal to the LIMIT of a truck, the delivery group will be expanded to include the SU found and the status of the requirements for each SU will be updated in the table. The algorithm searches the sorted savings matrix from the start. If the sum of the requirements for the number of pallets is greater than the LIMIT of a truck, the algorithm continues searching the km savings matrix and it tests the order of the next SU pair in the savings matrix. The algorithm ends when, after searching the savings matrix, no suitable SU pairs can be found while maintaining all conditions. This means that it is no longer possible to create another group of delivery destinations.

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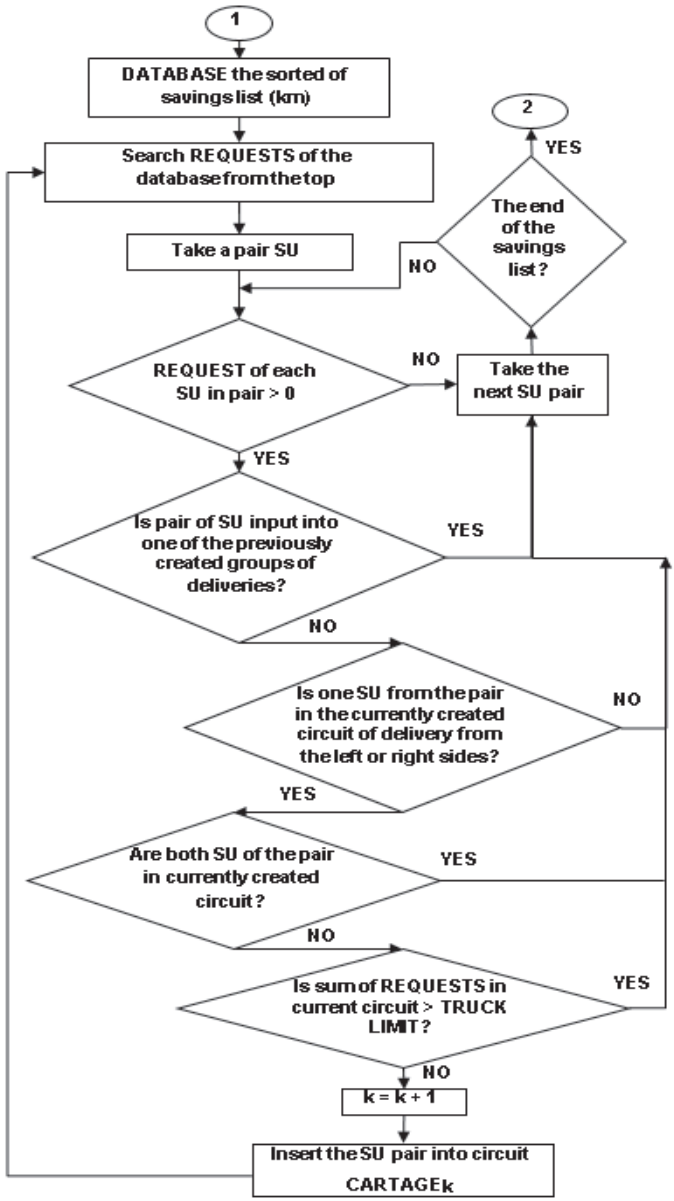


Figure 177 – Algorithm of the 2nd cycle

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The 3rd cycle:

The third cycle (Figure 178) checks the table of continuously created deliveries against each shop unit request that has not been assigned to any of the created circuits of the group of deliveries, and if the demand is greater than zero, a direct delivery will be created for the relevant SU.

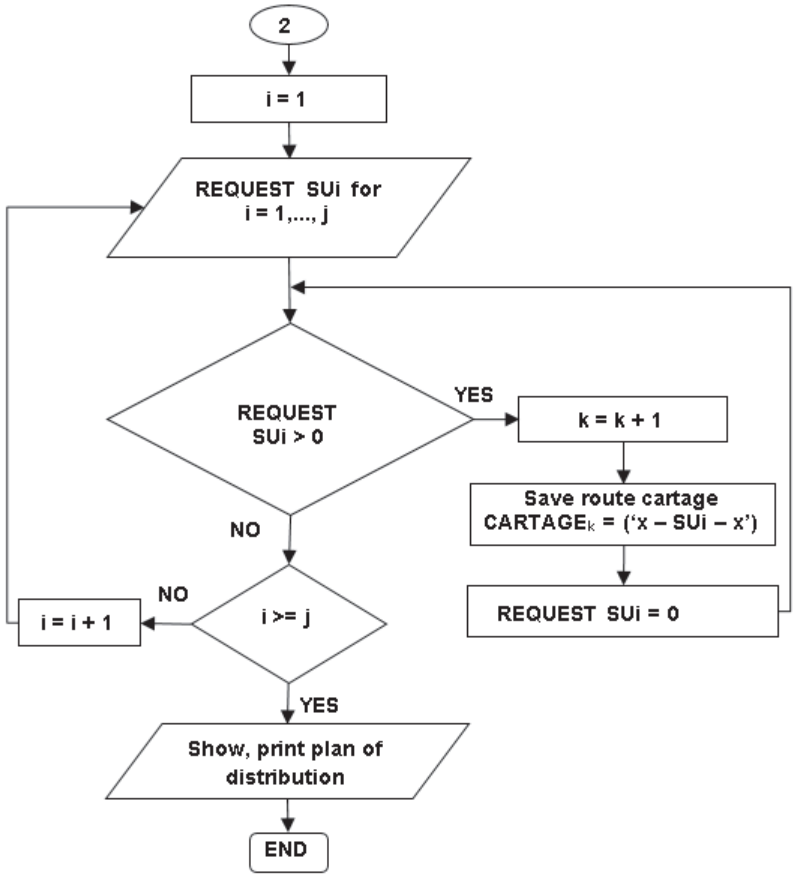


Figure 178 – Algorithm of the 3rd cycle

The proposed algorithm is the "automated" solution to the problem of manually calculating the optimal delivery routes to meet the requirements of shop units for a quantity of pallets while respecting the conditions for

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the maximum possible utilization of vehicles and achieving the largest savings in kilometres.

The whole procedure of planning daily deliveries of goods from the Presov DC to particular shop units is reduced from eight steps to three in comparison with planning optimal deliveries manually, as follows:

1. Planning optimal deliveries, both direct and combined, to particular shop units through the proposed software application.
2. Determining the order of SU in the planned groups of delivery routes based on the transport schedule.
3. Determining the order of the planned direct and group deliveries.

17.13 Evaluation of Optimization of Goods Distribution for DC Delta Warehouses, Inc. Presov

The main benefit of efficient distribution planning is the economic benefit. Transport costs are one of the largest cost items compared to other logistics activities at a distribution centre. Effective distribution planning has great importance in reducing the total transport costs due to economic factors such as fuel prices and labour.

Daily delivery plans for DC Delta Warehouses, Inc. Presov were monitored to quantify the economic benefits of the proposed concept for optimizing the distribution of goods. Subsequently, they were compared to daily delivery plans that were created according to the proposed daily delivery plans procedure for the same SU requirements for certain days. The quantification of economic benefits is summarized in the following table (Table 144).

The following daily averages can be achieved using the proposed concept for optimization of goods distribution with the daily planning of deliveries for DC Delta Warehouses, Inc. Presov:

- reduction of the number of trips by about 10%,
- reduction of the number of kilometres driven by about 7%,
- reduction of fuel consumption by about 7%,
- increase of utilization of capacity by about 9%.

Another benefit, which is not negligible, is saving time. The time needed for creation of an optimal daily delivery plan is shortened as is the time needed to transport goods from the DC in Presov to particular shop units. In terms of time, where 1 km travelled by a truck corresponds to 1 minute, if the average kilometres driven is reduced by 186 km per day, the time saving is about 3 hours per day.

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Last but not least, there is also an environmental benefit. Reducing the number of vehicle trips and the number of kilometres travelled will also help the environment by decreasing truck traffic.

Table 144 – Evaluation of the economic benefits

ID	Date	Savings in km	Percentage savings in km (%)	Reduction of the number of trips (quantity)	Percentage reduction of the trips (%)	Increase of a vehicle capacity utilization (%)
1	17.2	210	9	2	11	10
2	18.2	85	4	2	13	12
3	19.2	222	9	2	10	9
4	20.2	184	6	4	14	14
5	21.2	100	3	0	0	0
6	22.2	220	7	1	4	3
7	24.2	177	7	2	9	8
8	25.2	293	10	4	15	14
9	26.2	227	10	3	14	13
10	27.2	192	8	3	11	10
11	28.2	117	6	1	4	2
12	1.3	209	9	3	11	5
13	3.3	218	7	2	11	14
14	4.3	96	3	2	13	10
15	5.3	226	8	2	10	9
16	6.3	184	7	3	14	14
17	7.3	127	4	2	7	3
18	8.3	191	8	2	7	3
19	10.3	215	9	2	9	8
20	11.3	289	10	2	7	14
21	12.3	202	9	3	15	13
22	13.3	149	5	3	14	10
23	14.3	128	5	1	4	3
24	15.3	221	10	2	8	5
25	17.3	187	8	2	9	13
26	18.3	195	7	3	12	18
27	19.3	205	7	2	9	13
28	20.3	184	7	3	11	10
29	21.3	104	4	1	4	2
30	22.3	211	9	2	7	5
Daily average:		186 km	7%	2.2 trips	10%	9%

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17.14 Conclusion and Evaluation of the Results

Creating this plan for how to increase efficiency of goods distribution for Delta Warehouses, Inc. Presov led to more efficient planning and distribution of goods from the distribution centre to particular shop units within the distribution region, thereby fulfilling the defined target and reducing the costs associated with the distribution of goods.

The proposed plan for increasing the efficiency of goods distribution led the Delta distribution centre in particular towards a more effective process of planning distribution, especially in terms of the time needed to create daily delivery plans using appropriate computing technology such as a software application designed for the needs of the Delta Presov distribution centre. The increasing efficiency of daily delivery planning was also reflected in the economics of distribution by reducing the number of kilometres driven for daily deliveries of goods.

The proposal for increasing the efficiency of goods distribution is based on the conditions and possibilities of the Delta distribution centre in Presov, but with minor modifications to the proposal in order to increase the efficiency of goods distribution it can also be applied to make distribution more efficient in other distribution centres operated by Delta Warehouses, Inc. in the surrounding countries. Improving the efficiency of goods distribution is the first step towards comprehensive efficiency of operations in the distribution centres of Delta Warehouses, Inc., which should help the company to sustain and even strengthen its position in the market in these competitive times.

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CHAPTER EIGHTEEN

IMPROVING THE EFFICIENCY OF GOODS DISTRIBUTION AND COLLECTION IN A PARTICULAR REGION

18.1 Definition of the Problem and Objective of the Task

This is a distribution task that addresses the problem of distribution and collection of energy meters within a particular region. In order to shorten the time requirements for the distribution and collection of energy meters within the particular region, it is necessary to define new distribution circuits that will connect the metrology centre (MC) with the stations in which energy meters are collected for repairs (adjustments) and distribution.

18.2 Characteristics of the Metrological Centre

Metrology is the discipline concerned with how measurements of various physical values are expressed, the instruments needed to take measurements and procedures to ensure the accuracy of measurements. The Metrological Centre (later referred to as MC) is a part of the power plant (hereinafter referred to as PP) company, which provides operations in the field of production and transfer of electricity and provision of services to the population and companies related to this product. The consumption of electricity is closely related to the measurement of its consumption. Currently, energy meters (later referred to as EM) are used for the measurement of electricity consumption. PP in practice uses single-phase and three-phase meters. The measurement devices degrade and their accuracy decreases over their operation, therefore their regular maintenance is required. The Metrological Centre of PP provides collection, distribution and calibration of metrological facilities known as energy meters (EM). There are 43 external workplaces under the MC (Figure 179). These external workplaces (EW) collect and exchange

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energy meters for consumers, but they cannot maintain or calibrate energy meters (Straka, Malindzak 2002).

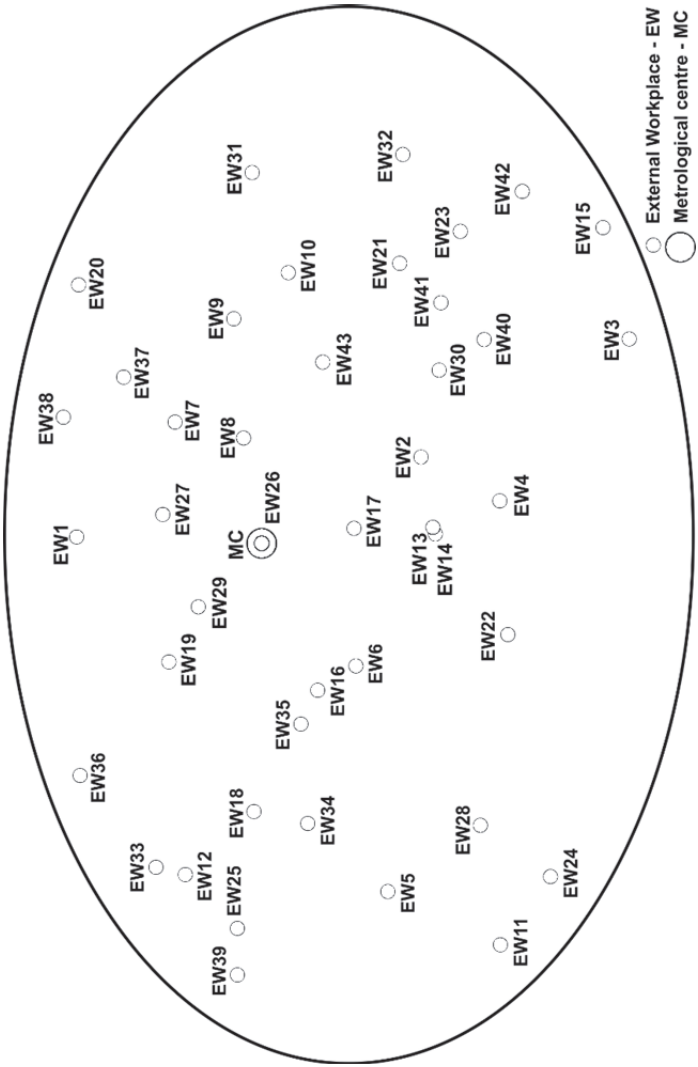


Figure 179 – Locations of the power plant workplaces

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18.3 Analysis of the Current Situation and Problems

The system for collecting and distributing energy meters developed into its present form over several years only on the basis of the operator's experience. The system for distributing and collecting energy meters from the metrology centre operates over a one-month period. This means that the distribution and collection plan for energy meters enables workplaces to serve the surrounding area once a month. In the case of extra delivery of energy meters to a workplace outside the established plan, it is very difficult to include this delivery in the distribution schedule. It is practically impossible to visit each workplace twice a month because there is only one vehicle available for collecting and distributing energy meters, which has to follow a distribution schedule. The only possibility would be for a workplace to use its own means of transport.

Each workplace passes on its energy meter delivery requirements five days before the planned date of distribution. During this time, according to the requirements of the workplace, energy meters are prepared in PVC crates. The day before the scheduled distribution day, these crates are loaded into the vehicle. On delivery day (DD), the delivery of required energy meters is provided to the relevant workplaces and when energy meters are unloaded at a workplace, malfunctioning energy meters or energy meters for which calibration is required are collected. These used energy meters are delivered to the MC, where they are serviced.

A worker has to load, distribute and collect used energy meters in about 8 hours, the length of one working shift. This distribution procedure is repeated every second day. The distribution and collection of energy meters takes place over the entire month because the surrounding workplaces consist of 14 distribution groups (Table 145, Figure 180). The vehicle travels over 2550 km each month.

This vehicle currently used for EM distribution and collecting is a truck with a load capacity of 3000 kg. The vehicle is also used for bringing EMs from the manufacturer and disposing of old EMs as scrap. One working shift takes about 8 hours. Loading and unloading the meters during one distribution day takes about 3 – 4 hours. Then, the time for transport is about 4 to 5 hours per one distribution day. A driver visits 3 to 5 workplaces during distribution. This means that about 40 – 60 minutes is needed to load and unload meters at present at one workplace during one distribution day (Straka, Malindzak 2002).

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Table 145 – The current status of distribution to workplaces

Rings	START	Distribution rings				END	There (km)	Back (km)	SUM (km)
1	MC	EW28	EW5	EW11	EW24	MC	196.7	118.7	315.4
2		EW25	EW39				90.1	89.4	179.5
3		EW12	EW33	EW36			117.6	62.8	180.4
4		EW17	EW29	EW19			65.4	29	94.4
5		EW8	EW9	EW43			85.3	45.2	130.5
6		EW10	EW31	EW20			153.5	84.8	238.3
7		EW21	EW32				111	110	221
8		EW41	EW23				102.7	102.7	205.4
9		EW30	EW40				79.5	79.5	159
10		EW3	EW15	EW42			153	114.6	267.6
11		EW34	EW18	EW35			100.4	49.2	149.6
12		EW6	EW16				56.3	41.3	97.6
13		EW13, EW14	EW2	EW4	EW22		108.7	62.4	171.1
14		EW27	EW1	EW38	EW37	EW7	115.1	27.2	142.3
							SUM (km)		2 552.1

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Annually, about 90,000 units of various meters are distributed around the PP workplaces. The average number of energy meters for distribution per workplace is 50 – 100 single-phase and 50–100 three-phase pieces per month. The same number of energy meters are brought back from the particular workplaces for maintenance. PP inspects and maintains approximately 600,000 meters, with about 40,000 units in store as a kind of reserve. The energy meters are freely loaded for transportation in PVC crates with a load capacity of 15 – 20 kg. For this reason, the PVC crates do not meet transport and storage requirements. The distribution network is of the flower type (Figure 180). As shown in the figure, this "flower" is degenerated and it can be stated that the network is unbalanced, i.e. it consists of circuits of varying lengths and with different numbers of places in a circuit.

The main distribution problems are:

- distribution and collection of EMs depends on the distribution restrictions,
- the vehicle has a capacity of 3000 kg, the working time is about 8 hours, the route consists of 14 distribution circuits,
- the vehicle travels a large number of inefficient kilometres near the MC,
- the high time requirement for distribution and collection of EMs,
- distribution and collection take one month, the transport time is about 5 hours and the time required for loading and unloading the crates of meters is about 3 hours,
- laborious and arduous loading and unloading of EMs,
- a worker must unload and load a large quantity of 15 – 20 kg of PVC crates,
- high time requirement for loading and unloading EMs,
- currently it takes from 40 to 60 minutes to load and unload EMs at one workplace,
- inappropriate manner of stowing energy meters in PVC crates,
- the PVC crates are open and do not enable EM to be fixed to protect against accidental tipping in the case of an accident and the EM are not protected against environmental influences.

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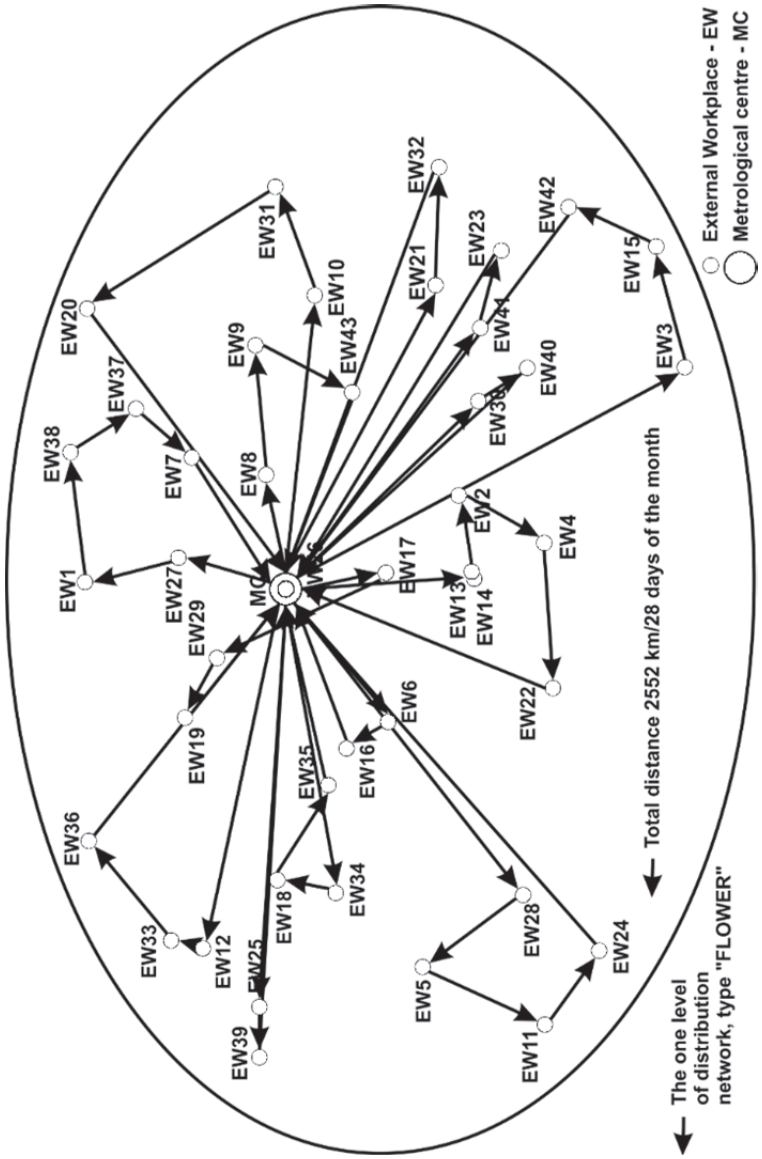


Figure 180 – Distribution circuits of PP workplaces, degenerated network of the flower type

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18.4 The Possibilities for Energy Meter Distribution

The possibilities for solution followed from the main problems:

- creation of small buffer stores forming a multi-level distribution network,
- optimization of distribution circuits and the length of their routes,
- using a vehicle that has a bigger capacity,
- dynamic route planning,
- simplification of the loading and unloading of EMs, shortening handling time,
- changing the manner of stowing EMs and transportation.

18.4.1 Creation of Buffer Stores, Multi-level Distribution Network

The creation of smaller buffer stores in some of the surrounding workplaces would reduce the time needed for the transport of goods and simplify the handling of goods during loading and unloading (Figure 181). The idea of these buffer stores is that the vehicle from the centre (MC) will distribute and pick up energy meters from only one workplace i.e. from a buffer store and will only travel between the centre and the buffer store. The distribution and collection of energy meters to particular workplaces is subordinated to the buffer store and will be provided by individual workplaces using their own vehicles. This form of distribution significantly reduces the route that the vehicle must travel from the centre and saves time as the vehicle delivers the energy meters only to a buffer store, where EMs are loaded and unloaded for maintenance and delivery and there is no need to deliver and collect EMs around all the other workplaces. As the EMs are unloaded and loaded in one place, it reduces and simplifies handling.

This is based on the current status of groups of workplaces that are subordinated to eight superior workplaces in terms of the created group buffer stores. These are the workplaces: EW28, EW26, EW13, EW10, EW30, EW21, EW25 and EW34. In our system, these workplaces form extra buffer stores. The distribution system is divided into a distribution route and distribution circuits. The distribution route consists of the sum of particular routes (MC – buffer stores). The distribution circuit consists of the sum of routes (buffer store – workplaces).

The advantage of buffer stores is that the centre is responsible for distributing and collecting energy meters only to a buffer store. Then workers from subordinated workplaces, come to the buffer store as they need to pick up new EMs as well as bring the EMs that need to be

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maintained. In this way, the vehicle from the centre travels 1031 km per 14 days, the vehicles that make deliveries to particular workplaces travel 1610 km per 14 days. The total distribution distance is 2641 km per 14 days.

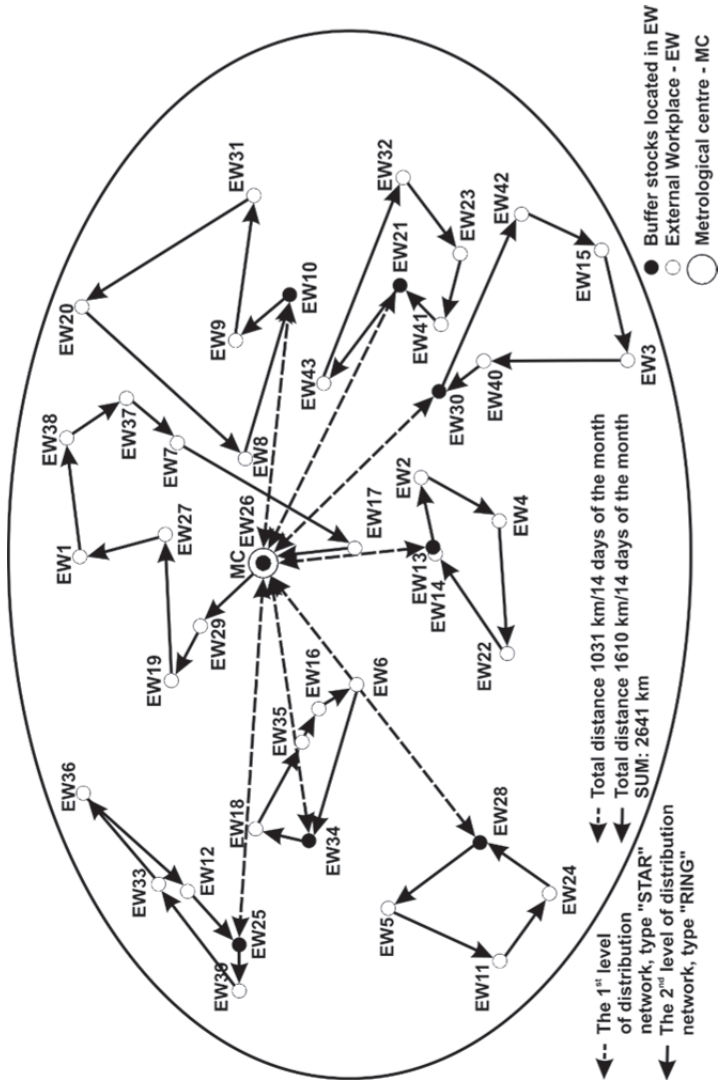


Figure 181 – Graphical representation of buffer stores and their distribution circuits

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18.4.2 Improving the Efficiency of Distribution Circuits and the Length of their Routes

Another possible solution is distribution based on the current mode of transport, with improved efficiency of distribution circuits, both in terms of the number of places in the circuit and the lengths of these circuits. The 43 external workplaces are effectively linked to new distribution circuits based on analysis that was made from the program results so that the vehicle travels as short a distance as possible. In this case, Clarke-Wright´s saving algorithm (Figure 182) and the Nearest Neighbour algorithm with total enumeration of positions were used for circuit design. The difference from the previous method is that the distribution circuits begin and end at the metrological centre. Therefore, buffer stores and other extra vehicles for transport of EMs are not needed. The results with this distribution method were proven to be the best.

It is necessary to use a vehicle with sufficient transport capacity to serve 8 to 10 workplaces in one distribution circuit. More than 10 workplaces cannot be served during one current working shift – 8 hours. For one distribution circuit it holds that (18.1) (Straka 2004):

$$t_T + \sum_{i=1}^{m} t_{LULi} + \sum_{i=1}^{m} t_{Ai} \leq t_{PS} \tag{18.1}$$

where:
t_T – total time for transport in circuit,
t_{LULi} – time of loading and unloading at position i, $i=1,2, \ldots, m$,
t_{Ai} – time for administration at position i, $i=1,2, \ldots, m$,
t_{PS} – time of one working shift,
m – number of external workplaces, positions in circuit.

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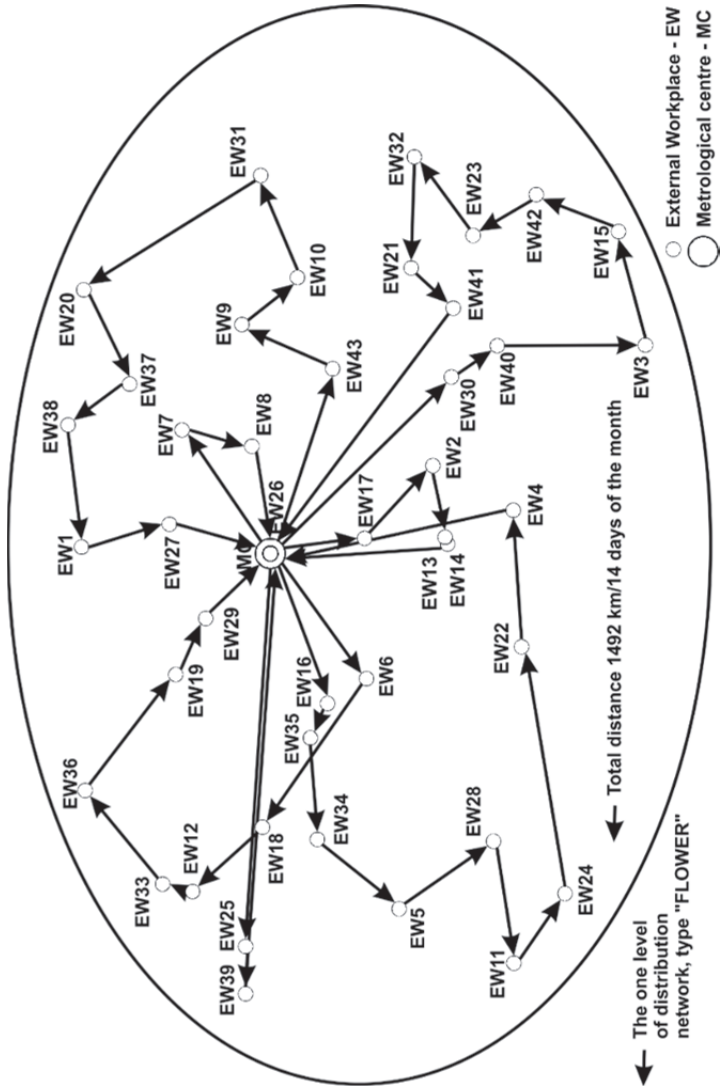


Figure 182 – Graphical representation of newly designed connections, the balanced distribution network type “NEW FLOWER”, Clarke-Wright´s approach

Distribution is not divided into outer and inner circuits in this type, but there are only 5 optimized, balanced distribution circuits (Figure 183). The

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distribution network is of the flower type, but with a balanced number of circuits and a balanced length per circuit (Straka, Malindzak 2002).

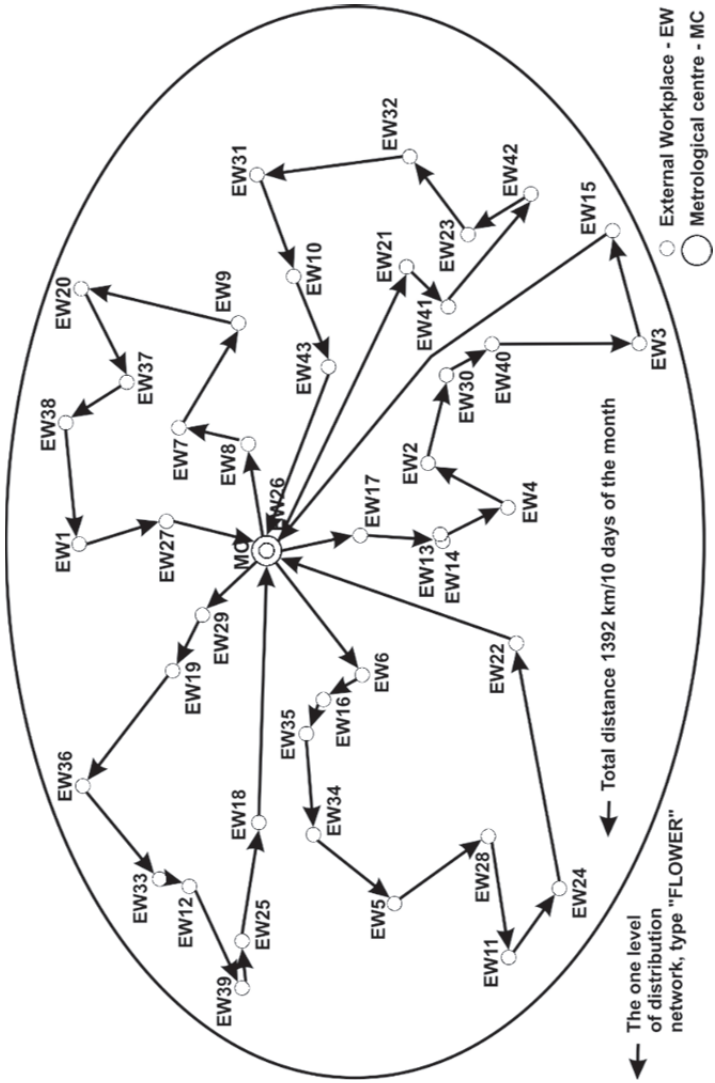


Figure 183 – Graphical representation of newly designed connections, balanced distribution network of the type “NEW FLOWER”, with the approach of total enumeration of positions

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If some of the external workplaces do not require enough meters that would ensure the shipping crates are full, it is necessary to make an estimate of consumption for next month for a particular workplace in order to utilise the space of crates and the vehicle to maximum. It is inefficient to carry crates filled to only 50%. If some of the workplaces do not have distribution requirements for a certain month, it is necessary to enable improvement of the efficiency of the distribution circuit by making it shorter, if possible.

Both approaches to the solution are appropriate for implementation in practice, but the approach with total enumeration of positions is a little bit better. The Nearest Neighbour algorithm with total enumeration of positions is better in terms of total distance and in terms of the total time needed for distribution of goods. The total length of distribution circuits is 1392 km. Loading and unloading meters should not take longer than 15 – 20 minutes compared to the current 40 – 60 minutes at each workplace. The rest of the time is needed for transporting meters in the distribution circuit.

The length of the distribution route is reduced by 1160 km per month with this distribution approach compared to the current state and the total distribution is done in 5 – 10 days compared to the current 14 – 30 days. There will be enough time for any unforeseen distribution circumstances after optimizing distribution.

18.4.3 Other Proposals for Improving Efficiency of Distribution and Collection

Usage of a vehicle with a greater carrying capacity

It was concluded by analysing the program results that there could be a maximum of 10 workplaces in one distribution circuit. Loading and unloading meters should not exceed 15 – 20 minutes compared to the current 45 – 60 minutes at each workplace. The rest of the time is needed for transporting meters in the distribution circuit.

It is necessary to use a vehicle with a higher load capacity in distribution when considering a smaller number of distribution circuits but with more workplaces. This vehicle must be capable of serving 8 – 10 workplaces per load. The weight of the distributed goods with this distribution approach is about 4500 kg. Vehicles that meet these requirements are available for example, from manufacturers like IVECO, MERCEDES, FORD and others.

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Dynamic planning of distribution routes

The previous distribution possibilities were based on the fact that each workplace had requirements for the MC to supply new EMs in the maximum quantity with each distribution cycle. In practice, a situation can arise where some workplaces may not have requirements to deliver new EMs at full volume, or new EMs are not needed at all. In such a case, especially with distribution based on the optimization of distribution routes, it is necessary to re-evaluate the route in which such a workplace is located. By optimizing each distribution route, its length may be shortened. In addition to shortening the distribution route, distribution time is shortened too, both for transport and for loading and unloading. It can be said then that the proposed routes are not the final distribution possibilities, rather each route is dynamically created before the "DD". However, it is necessary to set a deadline for workplaces to state their requirements for delivery of EMs. After that time, optimal distribution routes would be generated. The deadline for sending EM requirements depends on the ability to prepare the required amount in transport crates. Currently, this limit is five days ahead of the planned distribution.

Simplification of EM loading and unloading, shortening handling time

The difficulty of work and the expense of loading and unloading energy meters results from the way in which energy meters are currently transported, using PVC crates with a load capacity of 15 – 20 kg. The amount to be transported requires the use of a large number of PVC crates that make loading and unloading strenuous and time consuming. Loading and unloading PVC crates is currently performed manually. This manner of work determines the amount of time needed to load and unload the vehicle. Currently, this amount of time is around 40 – 60 minutes at one workplace. For this reason, it is not possible to serve more than five workplaces in one distribution circuit.

The entire EM loading and unloading system must not be based on loading and unloading PVC crates consecutively. This approach is laborious and time-consuming. It is necessary to unload and load the whole EM supply for each workplace as simply as possible. EMs would be loaded and unloaded more quickly if EMs were loaded in a separate closed container that would be equipped with a clip eye. These containers would be loaded and unloaded using mechanical equipment, which would be mounted in a vehicle. Each workplace should have one container for new EMs and one for used EMs. A service worker would unload the imported EMs using mechanical equipment and then load another container of used EMs into the vacant space in the vehicle. The container with new EMs

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would be emptied out by workers at a workplace as needed. Before the next delivery of new EMs, workers would load a container with malfunctioning EMs, and the procedure for replacing containers would be repeated. With such a container exchange system, the process time for distribution and collection is estimated at about 15 – 20 minutes.

This container distribution and collection approach of EMs would greatly facilitate work even in the current distribution circuits. The total EM loading and unloading time would be reduced to 1.5 – 2 hours from the current 3 – 4 hours per one distribution circuit with the current structure of workplaces in a distribution circuit. The advantage of containers is, in addition to simplifying the loading and unloading of EMs, that EMs are securely stored in closed containers that resist shocks and environmental influences. Each container contains the required number of EMs for particular workplaces.

Storage of energy meters and means of transport

Transporting energy meters in open plastic crates is very liable to lead to damage of transported instruments and it also does not protect EMs against the influence of weather. It would be very advantageous to use containers with a larger volume that would be closed during the transport of energy meters. The required number of energy meters for individual workplaces would fit into one container. Such a container would be unloaded simply using a pallet truck, and a container filled with energy meters for maintenance would be loaded. This system would save time on loading and unloading measuring instruments and by keeping the container closed, the meters transported would be protected from environmental influences.

18.5 Evaluation of Results and Conclusion of the Task

Results were compared with the current state using the direct approach to decision making, i.e. by the weighted sum method. At least 5 assessment factors were determined for the weighted sum method – time, cost, route length, etc.

The weighted sum method suggests that the most appropriate solution is to distribute from the MC with optimized distribution routes with a balanced number of workplaces in them.

After improving the efficiency of the current state, up to 60% of time and approximately 45% of the fuel costs needed to distribute and collect energy meters is saved.

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Improving the efficiency of the system for distributing and collecting energy meters will bring about better use of the vehicle, increased safety of the transported material and reduced time and handling work related to loading, unloading and transporting the energy meters. When switching to the new distribution system, it is necessary to make certain investments in both vehicles and new transport containers. Investments will return with time and money spent on distribution and collection of energy meters.

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VIII.

Case Studies from the Field of Inventory Management

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CHAPTER NINETEEN

DYNAMIC MODELS OF SUPPLY AND MANAGEMENT OF WAREHOUSES AT OMEGA, INC.

19.1 Definition of the Problem and Objective of the Task

The current economic situation leads companies to improve efficiency of costs incurred, while preserving or increasing the flexibility of the company. The flexibility of a company in crisis conditions is one of the factors that enable it to avoid losing customers, to keep long-term customers and acquire new customers. For this reason, the composition of input stock is very important, as this can greatly influence the flexibility of production and the early satisfaction of the requirements of the customer. The impact of the crisis on the activity of companies and the continual need for improvement of products and services offered has forced OMEGA, Inc. to reassess its activities related to procurement and warehouse management.

The economic situation in the market forces companies to accept most orders and deals that come from the market while preserving or increasing their flexibility and speeding up satisfaction of customer needs. Since the set of incoming orders varies, it is necessary to maintain quantities of different stocks in input warehouses to maintain the flexibility of the company and to comply with delivery dates. The requirements of customers lead to large variation in the requirements for input material, which requires high standards of the equipment and capacity of input warehouses and the range of different types of materials available, as well as faster, more accurate and better responses from the supply chain (Mikusova, Straka 2012). The problems of OMEGA, Inc's current supply system follow from the above. There is a large number of different types of input materials in warehouses and associated locked-up capital in materials that are not necessarily needed. There is a lack of a stock management system that would dynamically reflect market requirements and to a large extent the impact of the human factor. The aim of the

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solution is to design a modelling and purchasing system for the company to consider the dynamic behaviour of the market in terms of its conditions, customer requirements and the specific needs of the company itself. In terms of the solution, it is necessary to analyse the "current" state of the purchasing system at OMEGA, Inc. i.e. to identify the strengths and weaknesses of the existing system, to propose a new plan of the supply system, to propose the principles of material ordering relating to time and importance for the production process, to propose algorithms for purchasing.

19.2 Characteristics of Omega, Inc.

Omega, Inc. has been operating in the Slovak market for five years and is one of the youngest companies active in the field of paint and lacquer. The company is based on traditional values and good long-term relationships with its clients. Omega, Inc. is a company that is dynamically developing and it is customer-oriented. The range of products produced by the company is represented by the production of basic synthetic, nitrocellulose, water-soluble and ecological paints. The production programme of the company and the composition of products are oriented towards a wide range of customers across different sectors. There is high interest in the products and a 25% increase in turnover per year. The company has its own scientific research department, which ensures the long-term acquisition of invaluable knowledge in the field it operates in. Valuable knowledge and experience gained from its own research is perfectly matched with up-to-date technologies. Investments in modern, progressive technology in the company provide increased flexibility, competitiveness and, of course, better fulfilment of customer needs. Modern technological facilities fully meet the requirements of environmental legislation as they are equipped with emissions-eliminating devices which have clear environmental benefits in terms of prevention of air pollution (Mikusova, Straka 2012).

Omega, Inc. regularly invests in the development of human resources. It supports many projects in education, health, sports and culture.

19.3 The Organizational Structure of Omega, Inc.

The organizational structure of OMEGA, Inc. consists of the management and of four basic divisions (Figure 184):

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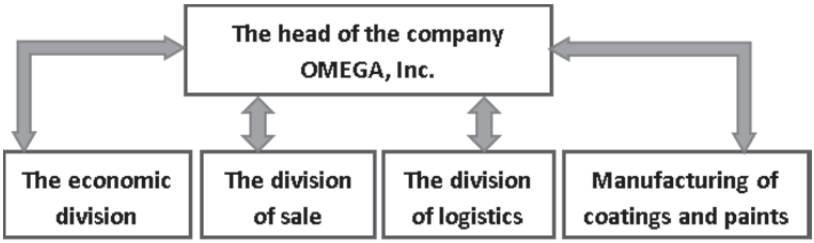


Figure 184 – Basic organizational structure of Omega, Inc.

All company processes are repeated (Figure 185). The activities of supply, storage, production, planning and transport are divided into separate departments, which causes problems with the coordination of material flow, production and product distribution. As a result, the logistics division has been created to take over organization and securing the necessary input materials and the distribution of products, which has proved to be beneficial for the management of the company itself making the production process much smoother.

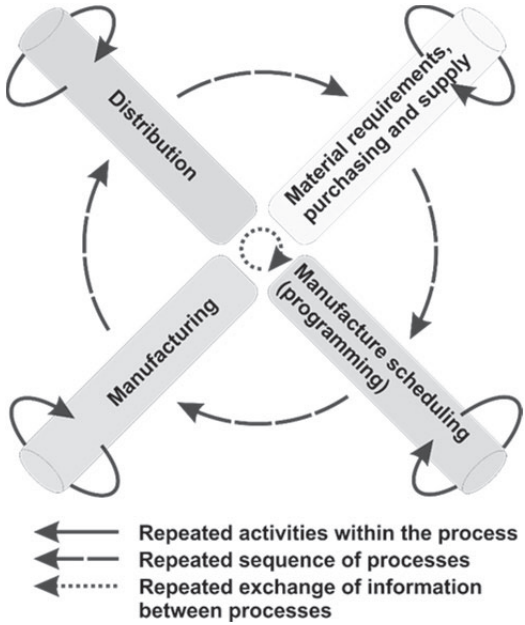


Figure 185 – Repeated processes of Omega, Inc., the process propeller

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19.4 Analysis of the Procurement and Supply System at Omega, Inc.

Customers and Order Receipt

The most important customers of the company are companies from the local automotive industry, building materials companies and a chain of shops selling paints and varnishes. The sales division is responsible for selling the products of Omega, Inc. Sellers carry out research on demand from business partners and monitor market developments to react to the ever-changing needs of customers. Their task, upon acceptance of an order, is also to agree all essentials regarding delivery terms and conditions. If a customer agrees to the delivery terms and conditions, the official order is prepared, which becomes a definite order for the company when the seller enters it, (uploads it) to the internal system of the company. Under the contract with the customer, the manner of preparation of the order is agreed. The delivery process begins from the day when the order is received. The delivery times are firmly bound and they depend on the type of customer, the type of order, whether the customer is priority or ordinary, whether the product is new or has already been produced. Sellers enter into the system the latest deadline for delivery of the required paint types to the shipping warehouse. When creating production plans or during purchasing, these terms may be changed to either to an earlier delivery or later delivery. In both cases, it is necessary to agree the terms with the customer (Mikusova, Straka 2012).

The Selection of a Material for Production Orders

Based on the information in the system, the sellers create pre-requirements for input raw materials needed to complete the orders. They are based on a database order that contains both contracted orders but also those that are in the process of being approved. The pre-requirements may be:

- contracted,
- statistical,
- new.

Contracted pre-requirements are material requirements for orders for which real contracts are approved and concluded. The contracted pre-requirement may be new, i.e. a completely new order for which the new contract is concluded, or statistical i.e. material for a long-term contract is ordered statistically.

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Statistical pre-requirements are material requirements for orders that are repeated on a regular basis where contracts are not yet concluded, however delivery dates are agreed.

New pre-requirements are material requirements for orders that are brand new where contracts are not yet concluded. In terms of production, they represent the riskiest group.

Working with statistical and new pre-requirements can be considered a risk, but it is very important for the flexibility of the company. Buying and ordering input raw materials and other materials is influenced not only by technological processes (production and mixing of colours), but also by the customers themselves, who can request special shades and colour types.

Purchasing Required Materials

Pre-requirements can be produced in two ways:

- using material that is in stock,
- ordering new material.

This means that the supervisor of the department of Production Preparation compares the inventories with the requirements and finds out if there is enough stock in the warehouse. If so, they reserve the required material in the warehouse system. If there is not enough inventory in stock, they prepare requirements for ordering the material and the pre-requirement becomes a requirement. The requirements are used for issuing orders for materials required for the execution of orders which have been approved and will be processed.

Supplier selection is made from the list of suppliers approved by a committee. Once a year, the committee has a meeting that reviews the proposal for selection of suppliers of raw materials for production. In this list are primary suppliers with other possible alternative suppliers.

Supplier selection is influenced by factors such as price, delivery time, and reliability of delivery. After the order is issued to the selected supplier and upon its confirmation, the Purchase Contract for delivery of input materials can be concluded. The purchaser of input materials, after agreement with the supplier, enters the agreed delivery date of the materials into the information system. Based on the agreed delivery time for input of raw materials into the warehouse, a production plan is created and the relevant customer is informed about the delivery date of products for him. At the present time, the purchaser of the input materials for production does not check whether the agreed delivery date of the input materials will be adhered to for a sufficiently long time before the

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production process starts and the system itself is not set up for an automatic notification of the interested parties in the event of the occurrence of inconsistency in the material in the warehouse with the production requirements at the given time (Mikusova, Straka 2012).

Securing production

The first step in securing production is procuring supplies, which is directly related to purchasing. According to the author *"Supply is the process of acquiring the materials, goods, products and produce of a varying nature and character for the purpose of securing the functioning of production, trade or consumption."*

The activity of purchasing influences customer service and customer satisfaction, because securing the correct quality of material for the right price at the right time has a direct impact on customer satisfaction. In purchasing it is necessary to address the following questions:

- where, from whom and how much to buy,
- how and with what to transport it,
- how to order,
- how and into what to package it,
- how and when to deliver,
- how to manage the movement of material,
- who carries the transport risk.

As stocks are related to finances, which are very important to the company, it is necessary to manage them. A balance needs to be sought between storage costs and the price of providing services at the level which the customer or consumer expects. Low costs and a high level of services are the ideal targets for stock management.

Six rules relating to stock management:

- stocks should be justified and minimized, with a target stock level of zero,
- for employees to be able to correctly place, determine and count all the stock they need training and motivation,
- emergency stocks should be available only for the purpose of securing customer service in the event of fluctuations in demand or supply,
- orders should be entered only if it is expected that stocks will be used,
- order only that which is needed to cover demand until the next shipment comes,

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- concentrate on fewer, important items rather than a lot of meaningless items.

Bad stock management is often accompanied by the following symptoms:

1. A growing number of unserved orders.
2. Growing investment costs tied up in stocks while the number of orders is not changing or falling.
3. High turnover of customers.
4. An increasing number of cancelled orders.
5. Regular repetition of a lack of storage space.
6. Large differences in turnover of the main storage items between the individual distribution centres.
7. Worsening relations with customers, typified by cancellations and reductions in orders on the part of the dealers.
8. A large number of obsolete items.

After the purchase agreement is confirmed, securing production begins. A worker from order logistics accepts the purchase agreement through the PEGAS information system, which they complete, i.e. they create a forecast of the mandatory end of production and compare it with the agreed date. In the event of any discrepancies they analyse production capacities and suggest the necessary changes and again they check the discrepancy with the terms. After confirmation, the purchase agreement can be released into production. This means the internal production order can be issued and included in production schedules.

Warehouse receipt, storage and transport to production

Omega, Inc. arranges transport to the warehouse through an external transporting company. The material delivered to the warehouse is received and checked by a worker using a scanner gun. Barcodes are scanned into the GENSKLAD storage system, which automatically assigns a new number and storage location in the warehouse to this material. Occasionally, the material passes directly into production without storage. However, this is not a planned event as in "just-in-time" supply.

Material is stored by forklift trucks. Removal takes place after the production requirement has been accepted. The warehouse keeper searches for the necessary material in the system, prepares it for removal from the warehouse and another worker physically transfers it to the place of processing using an appropriate means of transport.

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Omega, Inc. has three kinds of warehouses:

- finished products warehouses – located directly at the company site,
- consignment warehouse, in Slovakia,
- four warehouses for recipients.

In the finished goods warehouse, goods are directly intended for a customer, who orders them using references. Occasionally, the delivery date is already known when the order is received. In this warehouse, products are stored based on the customer's requirements for an average of three months, but no more than a maximum of nine months. By the expiration of this date, the customer has to collect the goods. Due to the need to respond quickly to customer requirements and to ensure the continuity of the production flow, part of input material is purchased statistically. This activity is performed by the supervisor of Technical Production Preparation, who follows trends, performs analyses for a certain period and uses his own assumptions as to whether the inventory will be needed or if it will be added for another reason. However, most raw materials and other materials are purchased based on customer requirements (Mikusova, Straka 2012).

19.4.1 Strengths and Weaknesses in Purchasing in the Company

The strengths of Omega, Inc., related to purchasing are:

- a fully mechanized warehouse that has been running successfully since 2008. Material placement is mechanized using a system of forklifts, software support has been introduced in collaboration with the Salomon Automation company from Austria, the leader in automation and software management of logistics processes. In addition, hardware devices from Motorola, Hewlett-Packard and the GENSKLAD software application are used,
- streamlining of materials deployment in the warehouse,
- the existence of a methodology, a way of selecting and considering criteria for materials selection for production requirements,
- objectification of the approach to the selection of raw materials and other input materials related to their purchasing,
- sufficient storage capacity,
- application of information systems,
- set up of SCM and EDI systems in cooperation with the major customers. These systems enable the optimization of production

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batches on the part of the supplier and smooth customer supply on the basis of requests,
- experienced workers that are employed in purchasing and storage positions,
- the effort of the company to introduce a Supply Chain Management (SCM) system within the supplier-producer-customer chain.

The weaknesses of OMEGA, Inc. related to purchasing are:
- the problem of the deputisation for the Technical Production Preparation employee,
- there is a lack of regular implementation and control of material analyses and the manner of stock purchase management (for example stock-based purchasing using statistics),
- statistical supply and inventory management are not systemic, workers do not use any methods to help them,
- some employees of the company do not use or they avoid the PEGAS and WebPEGAS information system. Purchasers do not check or verify the agreed delivery date of the raw materials needed for the production in the PEGAS system with input material suppliers with sufficient time in advance to enable compliance,
- purchasers are not informed by the production preparation workers about the dates by when input materials must be brought into the warehouse,
- during the preparation of an order there can be a loss of important information. The delivery date of input materials to the warehouse is entered by sellers in the PEGAS system,
- ordering means of transport for supply is not centralized,
- there are also materials in stock that have been purchased for reasons other than due to their need for orders (e.g. due to a favourable price) and they have not been used. This means that there is locked-up capital in the materials of the company.

19.5 Analysis of the Stock Inventories of Omega, Inc. using the ABC and XYZ Methods

The examination of stock inventories can be performed using a variety of methods. In this case there are two comprehensive analyses that divide material items into several groups depending on the percentage ratio of the total value of a selected parameter – ABC analysis and another based on

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the nature of material consumption – XYZ analysis (Mikusova, Straka 2012).

19.5.1 The Application of ABC Analysis in the Specific Business Environment

Using the ABC method, the *"Average annual cost of input materials"* data provided by OMEGA, Inc. from a certain period of time were used, which contain data about the total consumption of particular input materials and from the previous year also data about the prices of these materials. The criterion of evaluation was the value of annual turnover in EUR per item. 617 items were analysed and since this represents a large volume of data representing a quantity of attached sheets, the overall analysis was reduced (Mikusova, Straka 2012).

The ABC analysis application procedure is:

1) Calculation of the annual turnover in EUR for each input material using:

w_i = *annual consumption of material* × *price per unit*

w_i – annual turnover of material *i.*

For example, *Material 21*:
the annual consumption of the material: 66 213 kg,
the price of the material per kilogram: 0.22684 €,
the value of annual turnover of material 21:
w_{21} = 66 213 × 0.22684 = 15019.76 €.

2) Calculation of the total value of annual turnover using the formula: $W = \sum_{i=1}^{m} w_i$; meaning the sum of the turnover of 617 items for the whole year.

3) Calculation of annual turnover (19.1) as a percentage of the total per item using the formula:

$$r_i = \frac{w_i}{W} \times 100\ [\%] \tag{19.1}$$

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r_i – annual turnover of material i out of the total quantity expressed as a percentage.

For example, *Material 21*:
the annual turnover of material 21: w_{21} = 15019.76 €,
the total value of annual turnover of all materials: W = 1 802 639.39 kg,
the annual turnover in %:
r_{21} = (15019.76 /1 802 639.39) ×100 = 0.00833 ×100 = 0.833%.

4) Arrangement of the annual turnover as a percentage r_i of the particular items in descending order.

5) Calculation of the cumulative percentage ratio (i.e. the sum of all percentages from the first to the last item, so it all must sum to 100%).

6) Creation of *the Lorenz curve* graph (Figure 186) – the relation between the number of items and percentage of total turnover. The Lorenz curve represents a graphical interpretation of the results of the ABC analysis, which determines the boundaries between individual groups of input materials A, B and C.

7) Division of the items into groups A, B, C.

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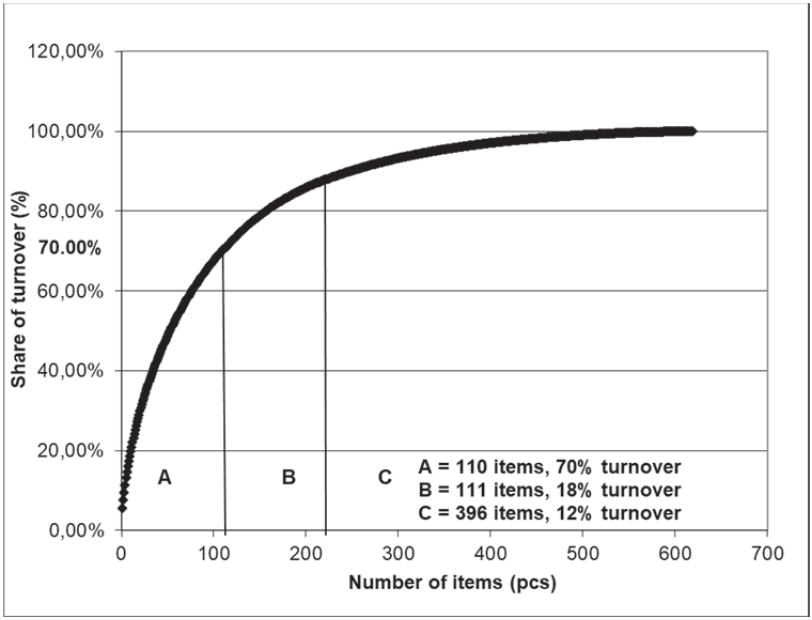


Figure 186 – Lorenz curve expressing the relationship between the ratio of input materials to the turnover of the company

Now it is possible to determine distribution further on the basis of the Lorenz curve and the information from the division of items based on the ABC method of data at Omega, Inc.:

- **"A" type items** – create about 70% of the total turnover and represent 17.83% of the total number of items, which means 110 items,
- **"B" type items** – create about 18% of the total turnover and represent 17.99% of the total number of items, which means 111 items,
- **"C" type items** – create about 12% of the total turnover and represent 64.18% of the total number of items, which means 396 items.

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19.5.2 Application of XYZ Analysis in the Specific Business Environment

Another method of inventory analysis applied was the XYZ method, where the data provided by OMEGA, Inc., *"Input materials movements for production"* was used. The data contains consumption of particular input materials and other materials from the previous year. The analysis was performed with 792 items (Mikusova, Straka 2012).

The XYZ analysis application procedure is:

1) Process data about the monthly consumption of all material items, where the observed period is 12 months, one year.

2) Determine the total consumption (19.2) of the *i-th* material item in the *j-th* month using the formula:

$$w_i = \sum_{j=1}^{n} W_{ij} \tag{19.2}$$

w_i – total material consumption within the observed period, expressed in kilograms,
W_{ij} – consumption of material item i in month j, expressed in kilograms,
i – analysed material,
j – monitored calendar month,
n – the number of calendar months for which the analysis was provided.

For example, *Material 5* (Table 146):

Table 146 – Data for material 5, consumption per 12 months in kg

Month	**1**	**2**	**3**	**4**	**5**	**6**
consumption (kg)	14 112	2 444	9 526	5 283	11 037	11 988
Month	**7**	**8**	**9**	**10**	**11**	**12**
consumption (kg)	10 609	18 606	23 023	19 588	2 711	4 346

$w_5 = 133\ 273\ kg$.

3) calculation of the average value $\overline{w}_i$ (19.3) of the consumption of the *i-th* material item in the *j-th* month, using the formula:

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$$\overline{w}_i = \frac{\sum_{j=1}^{n} W_{ij}}{n}. \tag{19.3}$$

For example, *Material 5*:
the total material consumption w_5 = 133 273 *kg,*
the number of months n = 12,

$\overline{w}_5$ = 133 273 kg / 12 = 11 106.08 kg.

4) calculation of the standard deviation using the formula:

$$s_i = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(W_{ij} - \overline{w}_i\right)^2}$$

while $s_i^2 = \frac{1}{n}\sum_{j=1}^{n}\left(W_{ij} - \overline{w}_i\right)^2$ is deviation. In Microsoft Excel, it is possible to use the VAR function to calculate variance and the STDEV function or SQRT (VAR) for the standard deviation.

5) determination of the variation coefficient V_i (19.4), for each item using the formula:

$$V_i = \frac{s_i}{\overline{w}_i} \cdot 100[\%]. \tag{19.4}$$

For example, *Material 5*:
the standard deviation s_5 = 6 505.65 kg,
the average consumption $\overline{w}_5$ = 11 106.08 kg,
the variation coefficient V_5 = 6 505.65 kg / 11 106.08 kg = 0.5858 × 100 = 58.58%. Material 5 is classed as an item of group *Y*.

6) Based on the value of the variation coefficient, it is possible to include particular items of material in the groups listed in Table 147.

Table 147 – Boundaries for classifying items into groups X, Y, Z

Group	Variation coefficient V_i
X	up to 50%
Y	from 50 to 90%
Z	over 90%

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It is possible to define the following groups of items by dividing items based on the value of the variation coefficient:

- 12 items are in group X,
- 62 items are in group Y,
- 718 items are in group Z.

The following figure (Figure 187) shows that only 1.52% of all material items show regular consumption (group X of items). On the contrary, items with sporadic consumption include the majority of all materials. Group Z has the largest percentage. This means that the company has more irregular paint consumption than regular consumption and it means that the company accepts every order for different types of paints, no matter what the consumption is.

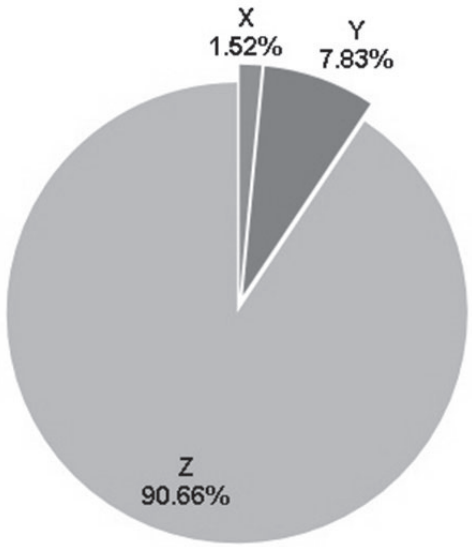


Figure 187 – Division of warehouse items into XYZ groups

19.5.3 Combination of Analysis Methods ABC and XYZ

Both analyses form a framework for determining the stock management approach. If only the ABC method was used, we would discover how particular items influence the turnover of the company, if only the XYZ method was used, the regularity of consumption of the input

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materials would be recognized during a certain period, which would make it impossible to manage the items effectively, that is why it makes sense to combine both methods (Mikusova, Straka 2012).

The combination of both methods resulted in classification of items as the following types AX, AY, AZ, BX, BY, BZ, CX, CY, CZ, where:

- the AX group consists of 10 items,
- the AY group has 38 items,
- the AZ group has 33 items,
- the BX group has 2 items,
- the BY group has 15 items,
- the BZ group has 67 items,
- and the CX, CY, CZ groups have 288 items.

There are 453 items of input materials where it is possible to determine how to manage their purchase. Combining ABC and XYZ analyses brings some benefits, e.g. in the case of using logistics technologies. Recommendations for managing the purchase of material items in particular groups are shown in Table 148.

Table 148 – Ways to manage the purchase of items in groups AX, AY, AZ, BX, BY, BZ, CX, CY, CZ

Material group	*A*	*B*	*C*
X	Just in time	Just in time	Warehouse
Y	Just in time	Warehouse	
Z	Individual purchases	Individual purchases	Warehouse

19.6 Graphical Assessment of Incoming and Outgoing Materials from the Warehouse to Production

It is necessary to analyse the quantity of input materials received into the warehouse over a certain period of time and the quantity of input materials going out to production over the same time period or with a certain time shift, from the point of view of the activity of a purchaser of input materials. This is because the system of input materials consumption works based on a certain degree of inertia. Based on the data analysed

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from OMEGA, Inc. several graphs can be created to identify correct or incorrect activities on the part of a buyer (Mikusova, Straka 2012).

A buyer buys materials based on their own evaluation, statistics and knowledge, which does not always have to be good for the company. Materials are always ordered with a certain margin. If the same input materials are needed for particular orders, they are combined. For clarity, a few graphs are selected that capture the activity of a buyer, with an appropriate review of the process.

Figure 188 shows that there was a supply of materials to the company in quantities that were identical with the amount of issued material with a small difference in April and May, which could not be identified. The buyer only purchased the quantity of material that was needed, which represents an efficient supply system. In the months of February, November and December no receipt or issued material was recorded. This stock management system is described as a Just in Time system, i.e. the material goes to the production process immediately after it is received and thus there is no useless storage.

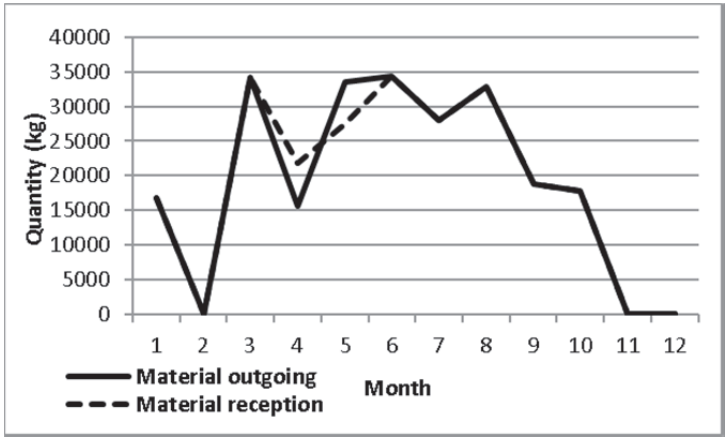


Figure 188 – Receipt and issue of the material UNI FERMEZ UF123

Figure 189 shows that there was continuous replenishment of inventory of around the amount of material consumed in accordance with orders received. In the months of February and July no material was received. Probably there was sufficient stock and only issuing was recorded. There is no long-term storage because the quantities required to

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supplement the stock had been ordered and this material had arrived a few days before it was needed for the production process.

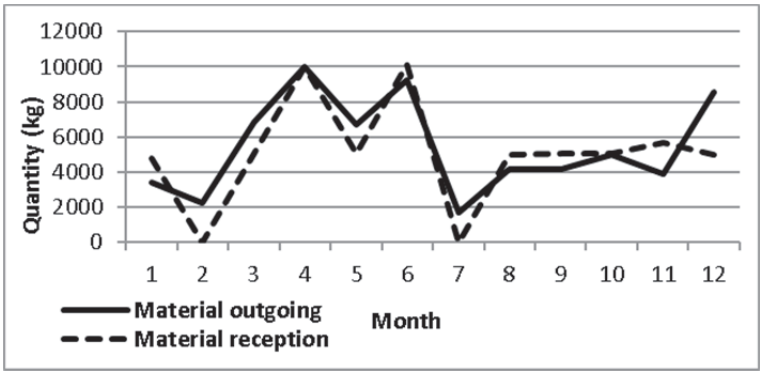


Figure 189 – Receipt and issue of the material NITRLAK C605

Figure 190 shows the resupply of stocks without major fluctuations in advance, where there is an average rotation of 4 – 6 weeks. In January, June, August, October, December no receipt was recorded in the warehouse, with a larger issue in September, which did not affect the production in the company because there was enough stock due to the regular replenishment of inventory. This may be periodic stock replenishment, when a stock is refilled by the same amount, with the same time interval.

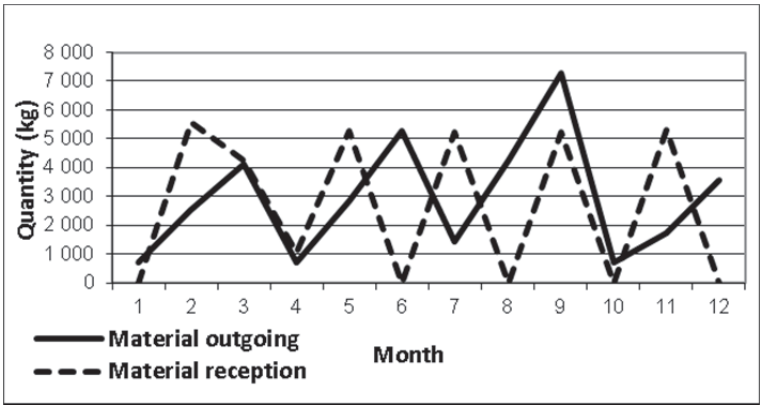


Figure 190 – Receipt and issue of the material SYNTETICBELOBA S236

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Figure 191 shows that this replenishment of material is of a constant stock size, in this case about 5 000 kg. This activity could be compared to inventory management, i.e. upon reaching or exceeding the ordering point, an order is generated to ensure stock levels are replenished to the planned level (Mikusova, Straka 2012).

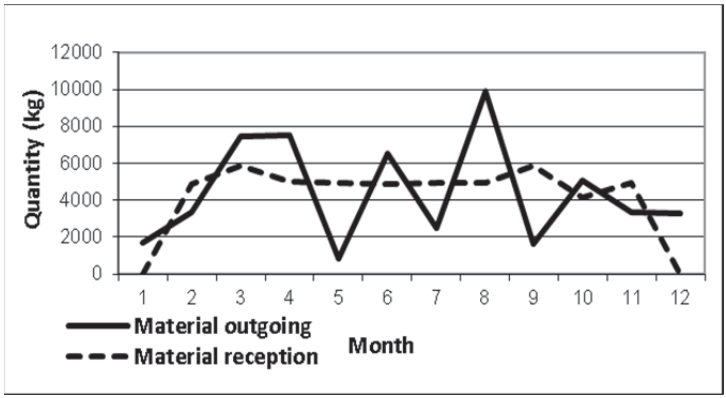


Figure 191 – Receipt and issue of the material EKOFHNEDA EFH356

Figure 192 shows that over 12 months, production required varying quantities, but purchasing was performed in large quantities, in batches, thereby increasing storage costs. Purchase was probably carried out under the appropriate financial conditions, at market prices, or purchasers ordered the entire requirement for a longer period of time even though they are not meant to do that.

Whether it would be better to purchase in smaller batches with higher prices, and not require long-term storage and locked-up capital in input materials, or to purchase in larger batches, which would increase storage costs, cannot be estimated from the figure because no precise circumstances are known and it is only in the hands of the buyer themselves to know what is best for the situation.

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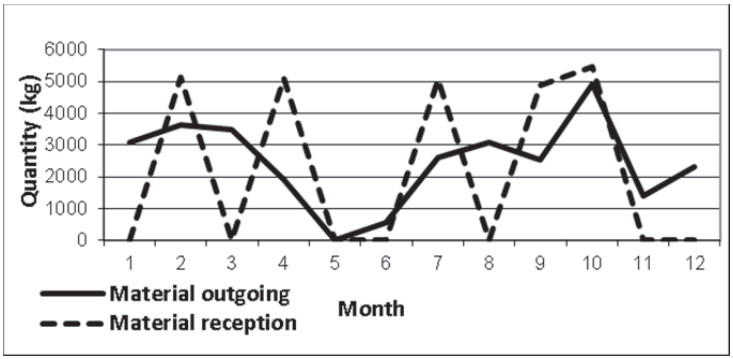


Figure 192 – Receipt and issue of the material EKOPBIELA EPB 012

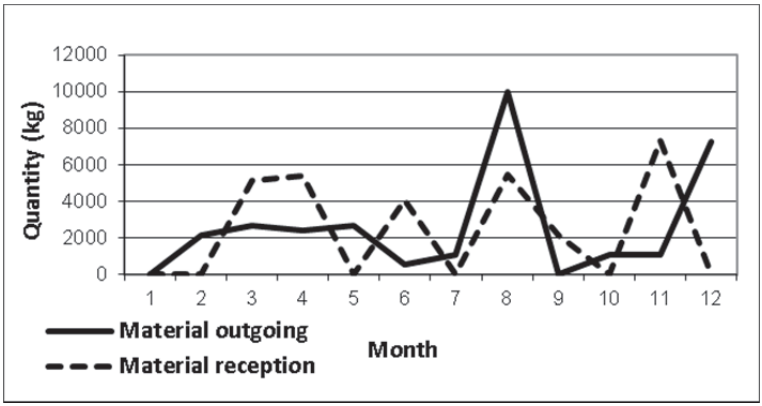


Figure 193 – Receipt and issue of the material SYNTETICRED S330

Figure 193 shows that the purchase of input materials was carried out in much larger quantities which did not correspond to the quantities consumed, while it was stored for almost one month. It is not possible to justify why the purchaser has done this and it is not effective in economic terms.

19.7 Definition of Deficiencies and Proposals for more Effective Solutions for Purchasing Activities at Omega, Inc.

Some deficiencies have been identified in the analysis of purchasing activities, however the solving of them does not require a considerable

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amount of finance, but particularly the willingness and the desire to do things that should be a regular part of the work of people in their positions. The identified deficiencies can be divided into three groups (Mikusova, Straka 2012):

1) Personnel deficiencies related to the Technical Production Preparation Department – TPPD:

- the problem of deputisation for the position of technician in the Technical Production Preparation Department.

2) Deficiencies related to a systemic solution for warehouse management:

- there is a lack of regular implementation and control of material analyses and management of stock purchasing (for example, stock-based statistics),
- statistical addition and inventory management are not systemic, workers do not use any methods to help them,
- there are also materials in stock that have been purchased for reasons other than being needed for orders (e.g. due to a favourable price) and have not been used. This means that they take up space and lock-up the financial capital of the company, even if they were obtained with favourable financial conditions.

3) Deficiencies related to entering, not entering and verifying a delivery date and planning a vehicle:

- purchasers do not check or verify with material suppliers, if the obligatory delivery date of the input materials required for the production in PEGAS system is kept,
- purchasers are not informed by the Technical Production Preparation Department of the dates by which input material must be brought into the warehouse,
- some employees of the company do not use or they avoid the PEGAS, WebPEGAS information systems and do not enter important data into these systems,
- there is a loss of important information entered by sellers in PEGAS system during the flow or execution of the order, such as the delivery date of basic input material at the warehouse,
- ordering means of transport for supply is not centralized.

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19.7.1 Possibilities for Solution of the Personnel Coverage of the TPPD Position

Since there is currently one technician working in the technical preparation of the production, there is a great risk of a potential stoppage and idle-time in system operations. This job of this worker is very important as they are in charge of assessing the material requirements, objective and effective material selection and determining possible stock management in the warehouse. From the point of view of ensuring seamless continuity in this position in the event of holidays or the unplanned absence of this worker, it is appropriate to support this position with one more worker. This employee could be more closely involved in inventory management and in determining the management strategy for each warehouse item (Mikusova, Straka 2012).

19.7.2 Warehouse System Management Solutions

Optimizing warehouse items leads to an increase in the flexibility of the company, a reduction in materials in stock and a reduction in locked-up funds in warehouse items. These finances can be used more efficiently somewhere else, where they are needed. As has been found by analysis, inventory management is not subject to any notion of inventory management models in the company. Inventories do not have specified base stocks and orders are based on intuitions and assumptions. In terms of warehouse management or the management of the input warehouse it is important regularly to apply methods that are helpful in deciding how to manage the warehouse and to replenish stocks statistically. Basic methods in this area are ABC and XYZ analysis. In terms of inventory management, it is appropriate to introduce the regular application of these methods. It is possible to create the software form of these analyses using the table editor, which would basically do all the time-consuming calculations for the user to simplify working with these methods. The user could verify whether a change in an item's management occurs and when it occurs, the reason is analysed to determine if it is not just a temporary phenomenon (Mikusova, Straka 2012).

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19.7.3 Possibilities to Address Entering / Not Entering, Verification of Delivery Date and Planning for Means of Transport

During the analysis of purchasing activities, a serious deficiency was found that, despite the agreed binding delivery time for stock which is also fixed in the PEGAS system, the material is not delivered at the required time. Because the production planning department creates plans for production with a material that should be in stock, but actually is not present, there is idle-time and a forced operation or it happens that transport is ordered for a time when the material is not yet available. However, these situations could be avoided by verifying the binding delivery date with suppliers before the final creation of production plans when these plans can be changed without any major problems. There are several possible solutions to minimize these situations:

- It is necessary to introduce the obligation for purchasers to verify the binding delivery date with suppliers before the final planning period and the delivery date needs to be updated in the PEGAS system. In the event of any change, the purchaser has to inform the responsible persons and delegate a person who is involved in ordering supply-side transport to verify the delivery date for material supply and in the event of any change to enter it in the PEGAS system.
- To strengthen the distribution department by adding an extra employee, who will be in charge of verifying the delivery time, ordering a vehicle and optimizing transport for supply to the company. Transport should be centralized, which should increase the efficiency of the use of the vehicle for distribution.

Another very serious deficiency is related to the functional disruption of company information flows, from a systemic perspective, from a programming perspective and from a personnel perspective. One systemic error appears to be the fact that buyers are not informed by TPPD workers about the dates on which the input material must be brought into the warehouse in order to fulfil the binding delivery dates of the products. Sometimes it happens that the ordered material comes into the warehouse after the latest possible date. At best, an order is made for production; at worst it is necessary to inform the customer that the delivery dates of products will not be kept to. In terms of solving this problem, it is sufficient for the information system (one of the order signs or prerequisites) to enter the latest possible date of delivery of a material to

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the warehouse, so that the purchasers are also informed about it and try to keep to it, to negotiate these terms or to allow this information to be retrieved by sellers. It appears that during the flow of order execution in the information system of the company, information entered by the sales staff about the latest possible delivery date to the production warehouse is lost; this is a programming error. Probably during the movement of an order, a purchase order or pre-order causes the loss of this important information. It is recommended to check this situation and to ensure this information is not lost. Once a seller has entered it, it should be there at least for verification. From a personnel point of view, it is unacceptable for TPPD staff to provide information for the logistics department about transport requirements in paper form in this age of information systems (subsequently it has to be entered into WebPEGAS) when it is sufficient to enter the information into the information system of the company. In this case, reinforcing the TPPD position would help to solve this problem, it would be possible to disburden some of the workers and it would make some extra time available for entering important information into the information system (Mikusova, Straka 2012).

19.8 The Proposal for the Purchasing and Logistics Model at Omega, Inc.

19.8.1 Main Algorithm of Purchasing Activities

Based on the analysis of purchasing activities at OMEGA, Inc., it was possible to create an algorithm (Figure 194), to model particular activities related to purchasing, shifting to production and statistical counting inventories that dynamically considers the market, customer and business requirements. The algorithm works with orders that are contractually agreed.

Description of main algorithm activity:

1) Loading the *"Orders"* file that is part of the business case database.

2) Based on the business case database and customer requirements, the input materials required for production are defined. The result of this activity is a database of prerequisites, which contains the file *"Input materials"* – i.e. prerequisites for sellers, what input materials, how much and at what time they will be needed.

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3) Sellers will check specified prerequisites for reliability, accuracy, and validity (functionality). The result of this activity is the file *"Non-compliant prerequisites"*, i.e. prerequisites that will not be executed for a specific reason and the file *"Prerequisites"* that will be further processed.

4) On the basis of agreed contracts, information from customers, production capacity control, sellers define the latest possible delivery dates for input materials and enter them into the PEGAS system.

5) Inventory control in the warehouse with the GENSKLAD system in the file *"Inventories"*.

6) Comparison of prerequisites with inventory status in the warehouse. Decision about whether the needed material is in stock or the material needs to be ordered. If a given prerequisite is fulfilled from the available material (in stock), the prerequisite remains and the file *"Warehouse prerequisites"* is created. If there is not enough stock available for a production prerequisite and material needs to be ordered, the prerequisite becomes a requirement and the file *"Requirements"* is created. In the case of decline of inventory in the warehouse, it is decided whether stocks need to be statistically replenished. If so, the file *"Inventory requirements"* is created.

7) Combination of requirements based on type, colour, producer, for supply efficiency and cost optimization. The result of this activity is the combined file of requirements.

8) Supplier selection for purchasing input materials.

9) Agreement of a mandatory delivery date for material, consultation of terms with sellers and the Production Program Department, conclusion of a purchase contract with a supplier. The result of this activity is the file *"Purchase contracts with the agreed delivery date"*.

10) Entering / Editing the delivery date of a material in the PEGAS/WebPEGAS system. In the event of modification of the due date because of suppliers' delivery times, it is immediately and unconditionally necessary to inform sellers about this change.

11) Verification and confirmation of the date of delivery of input material to the warehouse. A responsible worker (a purchaser or a person

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responsible for ordering the means of transport) sufficiently long before the creation of production plans (the period during which it is possible to change the production plan without any problems, e.g. one planning period) verifies and confirms the date of delivery of input materials to the warehouse.

12) Ordering the means of transport. After the verification and confirmation of the due dates, a responsible worker orders the means of transport necessary to bring the materials to the warehouse.

13) Receiving material at the warehouse. A member of warehouse staff accepts the material into the warehouse and enters the parameters of the accepted material in the warehouse information system GENSKLAD.

14) Issuing material and moving to production. Based on production requirements, a member of warehouse staff prepares sufficient time in advance to provide the necessary material for a smooth and planned production process.

15) Analysis and assessment of inventory stocks. Based on the production requirements for the following planning periods, inventory stock analysis needs to be performed using the ABC and XYZ methods, and then adjustments and management of stock need to be performed in the light of their results and the predictions formed.

16) Statistical addition of stocks. Based on the results of the warehouse item analyses and based on the predictions, it is necessary to apply the statistical replenishment of materials in stock.

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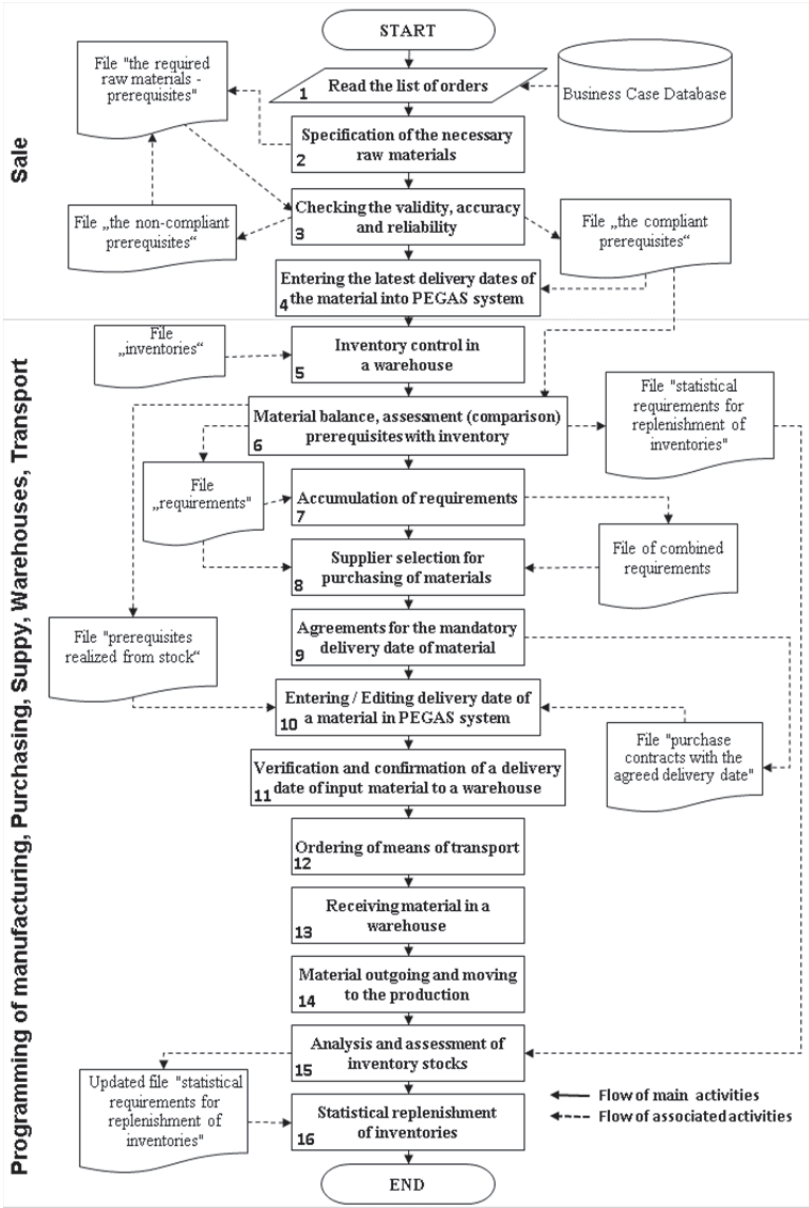


Figure 194 – The purchasing Algorithm at OMEGA, Inc.

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19.8.2 The Dynamic Model of Inventory Management - Application with a Fixed Order Quantity

When applying the dynamic inventory management fixed order quantity model, the data on group A items was used. This consisted of data about input material receipt and issue from the previous year. The current inventory management system of one of the group A items was analysed first, with a correlation between the issuing and the amount of balanced stock. Then, the new dynamic management system and mutual comparison of the average stocks and associated costs were applied.

The current management of inventory

The application of this model will be executed on *NITRLAK C610 (C610)*. As the issued and received *C610* material across the whole year represents a significant amount of data in the inventory management application, the sample (Table 149) will be limited to an abridged amount of data.

It is necessary to calculate the average daily consumption I_D and its standard deviation σ_{I_D} the estimated annual requirement I, the average stock size $\overline{Z}$, the average length of delivery time $\bar{t}$ a and its standard deviation σ_t from the above data (Table 149, Table 150).

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The average daily consumption:

$$\overline{I_D} = \frac{\Sigma consumption}{number\ of\ monitored\ days} = \frac{86718}{365} = 237.584\ kg/day.$$

The standard deviation of daily consumption:

$$\sigma_{I_D} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(I_{ij} - \overline{I_D}\right)^2} = \sqrt{\frac{381\,983\,085}{365}} = 1023\ kg/day$$

I_{ij} – the consumption of material item i in day j, expressed in pieces,
i – analysed material,
j – monitored day,
n – the number of days for which the analysis was provided.

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Table 149 – Current inventory management of material NITRLAK C610

Delivery cycles (days)	**29**					**28**		
Date	**1 Jan**	**7 Jan**	**16 Jan**	**23 Jan**	**30 Jan**	**11 Feb**	**17 Feb**	**27 Feb**
Order (kg)	6989	0	0	0	7788	0	0	4302
Delivery (kg)	0	0	0	0	6989	0	0	7788
Consum. (kg)	0	5368	810	4088	1077	797	2971	0
Stock (kg)	11000	5632	4822	734	6646	5849	2878	10666
Delivery cycles (days)	**17**			**18**		**17**	**3**	
Date	**10 Mar**	**16 Mar**	**27 Mar**	**31 Mar**	**3 Apr**	**7 Apr**	**20 Apr**	**23 Apr**
Order (kg)	0	5385	0	0	812	0	8126	6189
Delivery (kg)	0	4302	0	0	5385	0	812	8126
Consum. (kg)	1072	0	2955	2429	1347	799	812	0
Stock (kg)	9594	13896	10941	8512	12550	11751	11751	19877
Delivery cycles (days)	**1**	**17**		**3**			**46**	
Date	**24 Apr**	**30 Apr**	**11 May**	**13 May**	**14 May**	**26 May**	**12 Jun**	**17 Jun**
Order (kg)	4868	0	10270	0	9954	0	0	0
Delivery (kg)	6189	0	4868	0	10270	0	0	0
Consum. (kg)	0	5936	0	2456	0	1065	4053	2425
Stock (kg)	26066	20130	24998	22542	32812	31747	27694	25269
Delivery cycles (days)	**38**					**67**		
Date	**29 Jun**	**6 Aug**	**31 Aug**	**2 Sep**	**17 Sep**	**18 Sep**	**23 Sep**	**5 Oct**
Order (kg)	8210	6986	0	0	0	0	0	0
Delivery (kg)	9954	8210	0	0	0	0	0	0
Consum. (kg)	0	3244	5935	544	273	1094	9954	2433
Stock (kg)	35223	40189	34254	33710	33437	32343	22389	19956
Delivery cycles (days)				**49**			**21**	
Date	**6 Oct**	**12 Oct**	**23 Nov**	**24 Nov**	**25 Nov**	**30 Nov**	**16 Dec**	**21 Dec**
Order (kg)	0	15191	0	0	0	10388	0	7110
Delivery (kg)	0	6986	0	0	0	15191	0	10388
Consum. (kg)	4379	0	5926	1635	823	4000	6018	0
Stock (kg)	15577	22563	16637	15002	14179	25370	19352	29740

The estimated annual stock consumption:
$I = 237.584 \times 365 = 86\,718\ kg/year$.

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The average stock size:
$\bar{Z} = \frac{\Sigma inventories}{number\ of\ monitored\ days} = \frac{8\ 154\ 445}{365} = 22\ 341\ kg/day.$

Table 150 – Number and lengths of current delivery cycles

Cycle	Days from-to	Cycle length (days)	Cycle	Days from-to	Cycle length (days)
1	1 Jan–30 Jan	29	**8**	24 Apr–11 May	17
2	30 Jan–27 Feb	28	**9**	11 May–14 May	3
3	27 Feb–16 Mar	17	**10**	14 May–29 Jun	46
4	16 Mar–3 Apr	18	**11**	29 Jun–6 Aug	38
5	3 Apr–20 Apr	17	**12**	6 Aug–12 Oct	67
6	20 Apr–23 Apr	3	**13**	12 Oct–30 Nov	49
7	23 Apr–24 Apr	1	**14**	30 Nov–21 Dec	21

The stock rotation:
$O = \frac{\bar{Z}}{\overline{I_D}} = 22\ 341/237.584 = 94.03\ days.$

The average length of delivery time:

$\bar{t} = \frac{\Sigma lengths\ of\ delivery\ cycles}{number\ of\ delivery\ cycles} = \frac{354}{14} = 25.29\ days.$

The standard deviation of the delivery time:
$\sigma_t = 18.47\ days.$

The average order size:
$\bar{Q} = \frac{\Sigma quantity\ of\ ordered\ material}{number\ of\ orders} = \frac{112\ 568}{15} = 7\ 505\ kg.$

Because these input materials are in group A, among the most important in terms of company turnover, the coefficient of protection is determined at

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the level of 95% for order coverage. Annual maintenance costs are estimated as = 20% of its value (Table 151).

Table 151 – Basic values and quantile values for calculating the maximum inventory level

coefficient of protection for 95%, $k = 1.645$
cost of order implementation, $N_o = 150$ €
keeping goods in stock 20%, $\pi = 0.2$
unit price of the goods, $h = 2.66$ €/kg

Quantile values of standardized normal distribution					
Coefficient of the supply assurance *k*	**Level of service (%)**	**Risk of lack of supplies (%)**	**Coefficient of the supply assurance *k***	**Level of service (%)**	**Risk of lack of supplies (%)**
2.326	99	1	0.643	74	26
2.054	98	2	0.613	73	27
1.881	97	3	0.583	72	28
1.751	96	4	0.553	71	29
1.645	95	5	0.524	70	30
1.555	94	6	0.496	69	31
1.476	93	7	0.468	68	32
1.405	92	8	0.440	67	33
1.341	91	9	0.412	66	34
1.282	90	10	0.385	65	35
1.227	89	11	0.358	64	36
1.175	88	12	0.332	63	37
1.126	87	13	0.305	62	38
1.080	86	14	0.279	61	39
1.036	85	15	0.253	60	40
0.994	84	16	0.228	59	41
0.954	83	17	0.202	58	42
0.915	82	18	0.176	57	43
0.878	81	19	0.151	56	44
0.842	80	20	0.126	55	45
0.806	79	21	0.100	54	46
0.772	78	22	0.075	53	47
0.739	77	23	0.050	52	48
0.706	76	24	0.025	51	49
0.674	75	25	0.000	50	50

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The fixed order quantity Q and the signal level r for 95% service level can be determined as follows:

The fixed order quantity:

$$Q = \sqrt{\frac{2 \times 86\,718 \times 150}{0.2 \times 2.66}} = 6\,993\,kg\,.$$

Inventory management must ensure 95% service level coverage, i.e. the assurance coefficient $k = 1.645$.

The signal level for 95% service level coverage:

$$r = \overline{I_t} + PZ = \overline{I_D} \times \bar{t} + PZ = \overline{I_D} \times \bar{t} + k \times \sqrt{\bar{t} \times \sigma_{I_D}^2 + \overline{I_D}^2 \times \sigma_t^2} =$$

$$237.58 \times 25.29 + 1.645 \times \sqrt{25.29 \times 1023^2 + 237.58^2 \times 18.47^2} =$$

$$6\,008.4 + 1.645 \times \sqrt{45\,714\,039} = 6\,008.4 + 11\,122.2 \cong 17\,130\,kg.$$

The application of the fixed order quantity model is based on previous calculations which enable a significant reduction in inventory (Table 152). We simulate supplies of ordered materials under the new conditions and with the observation of delivery cycles as they were implemented in the previous period.

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Table 152 – New manner of inventory management of the material NITRLAK C610 using the fixed order quantity model

Delivery cycles (days)	**29**					**28**		
Date	**1 Jan**	**7 Jan**	**16 Jan**	**23 Jan**	**30 Jan**	**11 Feb**	**17 Feb**	**27 Feb**
Order (kg)	6993	0	0	0	6993	0	0	6993
Delivery (kg)	0	0	0	0	6993	0	0	6993
Consum. (kg)	0	5368	810	4088	1077	797	2971	0
Stock (kg)	11000	5632	4822	734	6650	5849	2882	9875
Delivery cycles (days)	**17**		**18**			**17**		
Date	**10 Mar**	**16 Mar**	**27 Mar**	**31 Mar**	**3 Apr**	**7 Apr**	**20 Apr**	**30 Apr**
Order (kg)	0	6993	0	0	6993	0	0	6993
Delivery (kg)	0	6993	0	0	6993	0	6993	0
Consum. (kg)	1072	0	2955	2429	1347	799	812	5936
Stock (kg)	8803	15796	12841	10412	16058	15259	21440	15504
Delivery cycles (days)	**3**			**1**			**17**	
Date	**3 May**	**13 May**	**26 May**	**12 Jun**	**13 Jun**	**17 Jun**	**6 Aug**	**23 Aug**
Order (kg)	0	0	0	6993	0	0	6993	0
Delivery (kg)	6993	0	0	0	6993	0	0	6993
Consum. (kg)	0	2456	1065	4053	0	2425	3244	0
Stock (kg)	22497	20041	18976	14923	21916	19491	16247	23240
Delivery cycles (days)		**3**						**46**
Date	**31 Aug**	**2 Sep**	**5 Sep**	**17 Sep**	**18 Sep**	**23 Sep**	**5 Oct**	**6 Oct**
Order (kg)	0	6993	0	0	0	6993	0	0
Delivery (kg)	0	0	6993	0	0	0	0	0
Consum. (kg)	5935	544	0	273	1094	9954	2433	4379
Stock (kg)	17305	16761	23754	23481	22387	12433	10000	5621
Delivery cycles (days)	**38**							
Date	**8 Nov**	**23 Nov**	**24 Nov**	**25 Nov**	**30 Nov**	**16 Dec**		
Order (kg)	6993	0	0	0	0	6993		
Delivery (kg)	6993	0	0	0	0	6993		
Consum. (kg)	0	5926	1635	823	4000	6018		
Stock (kg)	12614	6688	5053	4230	230	1205		

The average daily consumption:
$\overline{I_D} = 237.584\ kg/day$.

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The standard deviation of daily consumption:
$\sigma_{I_D} = 1023\ kg/day.$

The estimated annual stock consumption:
$I = 86\,718\ kg/year.$

The average stock size:
$\bar{Z} = \frac{4\,683\,086}{365} = 12\,830\ kg/day.$

The stock rotation:
$O = 12\,830/237.584 = 54.00\ days.$

The average length of delivery time:
$\bar{t} = \frac{217}{11} = 19.73\ days.$

The standard deviation of the delivery time:
$\sigma_t = 13.86\ days.$

The average order size:
$\bar{Q} = \frac{83\,916}{12} = 6\,993\ kg.$

By applying the fixed order quantity model, the average stock of material $\bar{Z}$ decreased by 9 511 kg and the number of ordering cycles dropped to eleven from fourteen. This clearly shows that inventory management is better than the current management methods.

19.8.3 The Dynamic Model of Inventory Management - Application with a Fixed Time Period

In the fixed time period method different amounts of stock Q_i are ordered at regular intervals t_d to reach the maximum required level of stock S in the warehouse. The quantity to be ordered is equal to the difference of the maximum required level of the stock and the actual state of the same stock in the warehouse at the time of issuing the order.

The size of the economic order quantity Q_{opt}, in the delivery order cycle t_d for 365 days in a year and the maximum inventory level S for the 95% service level can be determined as follows:

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The size of the order quantity:

$$Q_{opt} = \sqrt{\frac{2\times 86\ 718\times 150}{0.2\times 2.66}} = 6\ 993\ kg.$$

The delivery order cycle during 365 days in a year:

$$t_d = t_{d_{opt}} = \frac{365\times Q_{opt}}{I} = \frac{365\times 6\ 993}{86\ 718} \cong 29\ days.$$

The maximum inventory level:

$$S = \bar{I_D} \times \left(t_{d_{opt}} + \bar{t}\right) + k \times \sqrt{\left(t_{d_{opt}} + \bar{t}\right) \times \sigma_{I_D}^2 + \bar{I}_D^2 \times \sigma_t^2} =$$
$$237.58 \times (29 + 25.29) + 1.645 \times$$
$$\sqrt{(29 + 25.29) \times 1\ 023^2 + 237.58^2 \times 18.47^2} = 12\ 898.22 + 1.645 \times$$
$$\sqrt{76\ 071\ 503.84} = 12\ 898.22 + 14\ 347.5 \cong 27\ 246\ kg.$$

The application of the dynamic model with a fixed time period based on previous calculations enables a significant reduction in inventory (Table 153). We simulate supplies of ordered materials under the new conditions and with the observation of delivery cycles as in the previous period.

Table 153 – New method of inventory management of NITRLAK C610 using the fixed time period model

Delivery cycles (days)	**29**				**28**			
Date	**1 Jan**	**7 Jan**	**16 Jan**	**23 Jan**	**30 Jan**	**11 Feb**	**17 Feb**	**27 Feb**
Order (kg)	16246	0	0	0	11343	0	0	0
Delivery (kg)	0	0	0	0	16246	0	0	11343
Consum. (kg)	0	5368	810	4088	1077	797	2971	0
Stock (kg)	11000	5632	4822	734	15903	15106	12135	23478
Delivery cycles (days)	**17**				**18**			
Date	**28 Feb**	**10 Mar**	**17 Mar**	**27 Mar**	**29 Mar**	**31 Mar**	**3 Apr**	**7 Apr**
Order (kg)	3768	0	0	0	4027	0	0	0
Delivery (kg)	0	0	3768	0	0	0	0	0
Consum. (kg)	0	1072	0	2955	0	2429	1347	799
Stock (kg)	23478	22406	26174	23219	23219	20790	19443	18644
Delivery cycles (days)			**17**				**3**	

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Date	16 Apr	20 Apr	27 Apr	30 Apr	13 May	14 May	26 May	29 May
Order (kg)	0	0	5387	0	0	0	9457	0
Delivery (kg)	4027	0	0	0	0	5387	0	9457
Consum. (kg)	0	812	0	5936	2456	0	1065	0
Stock (kg)	22671	21859	21859	15923	13467	18854	17789	27246
Delivery cycles (days)			1					
Date	12 Jun	17 Jun	24 Jun	25 Jun	23 Jul	6 Aug	21 Aug	31 Aug
Order (kg)	0	0	6478	0	0	0	3244	0
Delivery (kg)	0	0	0	6478	0	0	0	0
Consum. (kg)	4053	2425	0	0	0	3244	0	5935
Stock (kg)	23193	20768	20768	27246	27246	24002	24002	18067
Delivery cycles (days)	17				3			
Date	2 Sep	7 Sep	17 Sep	18 Sep	19 Sep	22 Sep	23 Sep	5 Oct
Order (kg)	0	0	0	0	7846	0	0	0
Delivery (kg)	0	3244	0	0	0	7846	0	0
Consum. (kg)	544	0	273	1094	0	0	9954	2433
Stock (kg)	17523	20767	20494	19400	19400	27246	17292	14859
Delivery cycles (days)				46				
Date	6 Oct	18 Oct	16 Nov	23 Nov	24 Nov	25 Nov	30 Nov	3 Dec
Order (kg)	0	16766	16766	0	0	0	0	0
Delivery (kg)	0	0	0	0	0	0	0	16766
Consum. (kg)	4379	0	0	5926	1635	823	4000	0
Stock (kg)	10480	10480	10480	4554	2929	2096	0 (-1904)	14862
Delivery cycles (days)	38							
Date	15 Dec	16 Dec	24 Dec					
Order (kg)	12384	0	0					
Delivery (kg)	0	0	16766					
Consum. (kg)	0	6018	0					
Stock (kg)	14862	8844	25610					

The average daily consumption:
$\bar{I_D} = 237.584\ kg/day$.

The standard deviation of daily consumption:
$\sigma_{I_D} = 1023\ kg/day$.

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The estimated annual stock consumption:
$I = 86\,718\ kg/year$.

The average stock size:
$\bar{Z} = \frac{6\,522\,299}{365} = 17\,869\ kg/day$.

The stock rotation:
$O = 17\,869/237.584 = 75.21\ days$.

The average length of delivery time:
$\bar{t} = \frac{217}{11} = 19.73\ days$.

The standard deviation of the delivery time:
$\sigma_t = 13.86\ days$.

The average order size:
$\bar{Q} = \frac{113\,712}{12} = 9\,476\ kg$.

By applying the fixed time period model, the average stock of material $\bar{Z}$ decreased by 4 472 kg and the number of ordering cycles dropped to eleven from fourteen. This clearly shows that it is better to use this kind of inventory management than to use the current management approach.

This model includes order placement in a regular ordering cycles, whereby the amount to be ordered depends on the maximum stock level, i.e. the stocks are always brought back to the maximum level. This amount of material will cover all received orders until a new ordering cycle occurs. If a new ordering cycle occurs and the stock has reached its maximum level, no order will be issued.

By comparing the "current" and new inventory management (Figure 195), it can be ascertained that stocks are much lower, they are around the defined inventory level and there is no surge of material in stock with the new inventory management system. With warehouse inventory management, the fixed order quantity model or the fixed time period model are more acceptable and better than the current management system.

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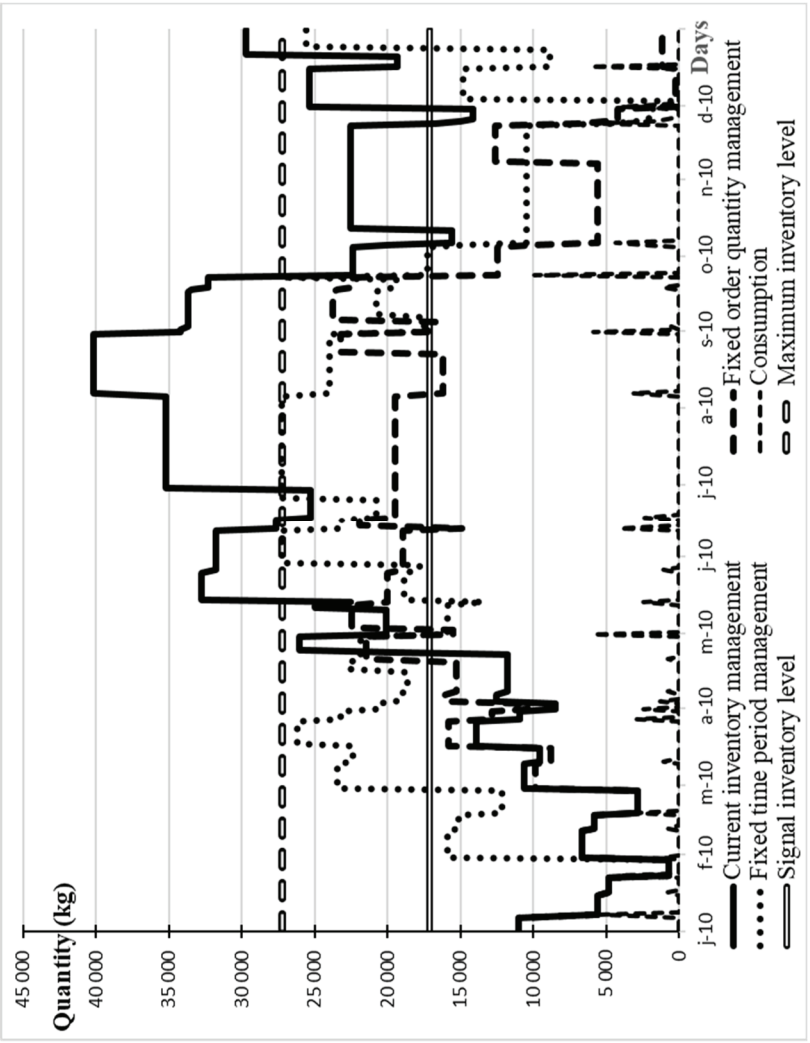


Figure 195 – Graphical comparison of current and new inventory management systems

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19.8.4 Economic Calculation

The total costs monitored and associated with the current inventory management methods and the "new" methods of inventory management can be determined as follows:

The total costs related to the current management of inventories can be calculated using the values in Table 154:

Table 154 – Basic values for calculating the current inventory management cost

keeping goods in stocks 20%, $\pi = 0.2$
unit price of the goods, $h = 2.66$ €/kg
average stock size, $\bar{Z} = 22\,341$ kg/day
annual stock consumption, $I = 86\,718$ kg/year
average order size, $\bar{Q} = 7\,505$ kg
number of delivery cycles $I / \bar{Q} = 11.6$, performed in practice 14
cost of order implementation, $N_o = 150$ €

$Ncr(cur) = \pi \times h \times \bar{Z} + \frac{I}{\bar{Q}} \times No = 0.2 \times 2.66 \times 22\,341 + 14 \times 150 \cong 13\,985\ EUR/year.$

The total costs related to the fixed order quantity inventory management method can be calculated using the values in Table 155:

Table 155 – Basic values for calculating the cost of fixed order quantity inventory management

keeping goods in stocks 20%, $\pi = 0.2$
unit price of the goods, $h = 2.66$ €/kg
average stock size, $\bar{Z} = 12\,830$ kg/day
annual stock consumption, $I = 86\,718$ kg/year
average order size, $\bar{Q} = 6\,993$ kg
number of delivery cycles $I / \bar{Q} = 12.4$, performed in practice 11
cost of order implementation, $N_o = 150$ €

$Ncr(foq) = \pi \times h \times \bar{Z} + \frac{I}{\bar{Q}} \times No = 0.2 \times 2.66 \times 12\,830 + 11 \times 150 \cong 8\,476\ EUR/year.$

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The total costs related to the fixed time period inventory management can be calculated using the values in Table 156:

Table 156 – Basic values for calculating the cost of fixed time period inventory management

keeping goods in stocks 20%, $\pi = 0.2$
unit price of the goods, $h = 2.66$ €/kg
average stock size, $\bar{Z} = 17\,869$ kg/day
annual stock consumption, $I = 86\,718$ kg/year
average order size, $\bar{Q} = 9\,476$ kg
number of delivery cycles $I / \bar{Q} = 9.2$, performed in practice 11
cost of order implementation, $N_o = 150$ €

$$Ncr(ftpo) = \pi \times h \times \bar{Z} + \frac{I}{\bar{Q}} \times No = 0.2 \times 2.66 \times 17\,869 + 11 \times 150 \cong 11\,157\ EUR/year.$$

It is clear that from the economic point of view, that a new means of inventory management with a fixed order quantity or with a fixed time period is better, as there is a significant reduction in the financial costs of managing inventory.

With the fixed time period there is a reduction in financial costs of up to about 20.2%, but for three days the system is in inventory deficit which increases costs.

With the fixed order quantity there will be a reduction of financial costs by up to about 39.4%.

19.9 Conclusion and Summary

Underestimating the value of warehouse inventory management and the ineffective spending of funds to secure it often brings companies into economically unviable situations and ends with bankruptcy, distrainment and shut-down. For these reasons, it is necessary to perform careful consideration of the level of stock items in which a significant amount of capital is tied-up. Buyers and purchasers of input materials should regularly evaluate inventory items and, if necessary, dynamically change the system under which the input of materials into a company will be managed. Such a system can bring considerable savings for the company and the whole of society and it can ensure the long-term competitiveness and flexibility of a company, and thus its survival and existence in a highly competitive market.

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CONCLUSION

In terms of problem solving, the advantage of logistics is in its applicability to all areas of industry, trade, services and everyday life, whereby logistics enables the unconventional application of different problem-solving approaches with the possibility of combining different methods to achieve the desired target.

Participants in the tasks addressed, both active and passive, are trying to achieve their own targets and logistics is just the tool that is able to define the balance between the subjects and to subordinate individual requirements to global optimization. Optimizing distribution and supply systems, or the proposal of new distribution and supply systems, is dependent on information where sources represent a wide range of data on different qualitative and quantitative levels.

Defining the basic structures of distribution and supply systems mainly leans on the experience and knowledge of researchers, but accurate "tuning" of the system is not possible without adequate data from different levels of the distribution and supply system.

The aim of this monograph has been to describe possible structures of distribution and supply systems and to identify areas that can influence their functioning. According to Pareto's rule, small and medium-sized industrial concerns and other companies are the majority of the market in practice. Companies need their own simple and practical solutions for distribution and supply, which they are able to tackle only within their own internal resources. For this reason, this publication is oriented towards practice and application.

Distribution and supply logistics are all the more important as they form an active link between "a company and its surroundings", whereby interdependence with the environment in most cases goes beyond the borders of companies, regions, countries and continents through information, material and financial flows.

The problems that occur in distribution and supply are identical on every continent, in every part of our planet, and therefore the means of distribution and supply logistics are "the Lingua Franca, the Bible and the Law" in one place, for all the professionals in this field.

I believe that using examples of the application of methods and approaches to solving practical tasks is the best way to understand the

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importance of making distribution and supply more efficient in companies, in order to increase their competitiveness in the market. I hope that, for this reason, this publication will also help many people, not only in the field of logistics but also people who work and deal with similar problems in practice every day.

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
AIS	Automatic Identification Systems
APICS	American Production and Inventory Control Society
BOA	BelastungsOrientierte Auftragsfreigabe (Load-oriented order release)
C	Consumer
C-W	Clarke-Wright's saving algorithm
CIM	Cooper's Iteration Method
CONWIP	CONstant Work in Process
CSCMP	Council of Supply Chain Management Professionals
DBR	Drum Buffer Rope
DC	Distribution centre
DD	Delivery Day
DG	Distribution Group
EAN	European Article Numbering
ECR	Efficient Consumer Response
EDI	Electronic Data Interchange
EDIFACT	Electronic Data Interchange for Administration, Commerce and Transport
ELA	European Logistics Association
EM	Energy Meters
EOQ	Economic Order Quantity method
EPCC	Energy Process Control Centre
ERP	Enterprise Resource Planning
ES	Expert Systems
EW	External Workplace
FIFO	First in First out
FOQ	Fixed Order Quantity model
FTP	Fixed Time Period model
FZ	FortschrittsZahlenkonzept (Progress number concept)
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
GPSS	General Purpose Simulation System
ISO	International Organization for Standardization
JIT	Just in Time

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MC	Metrological Centre
MCQS	Multichannel Queuing System
MDP	Method of Distribution Potential
MODI	Modified Distribution method
MPC	Method of Pair-Wise Comparison
MRP 1	Material Requirements Planning
MRP 2	Manufacturing Resource Planning
MRP 3	Money Resource Planning
MRP 4	Material Requirements Planning fourth generation
OA	Operative Administration
OAS	Office Automation Systems
OCR	Optical Character Recognition
OPT	Optimized Production Technology
PDS	Project of Distribution Stock
PP	Power Plants
PQS	Parallel Queuing System
PS	Power Station
PTS	Power Transmission System
QR	Quick Response
RFID	Radio-frequency identification
S	Source of distribution
SAP	Systems Applications Products
SCM	Supply Chain Management
STN	Slovak Technical Standard
SU	Shop Unit
SWOT	Strengths, Weaknesses, Opportunities, Threats
TPPD	Technical Production Preparation Department
VAM	Vogel's approximation method
XML	eXtensible Markup Language

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