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SUPPLY CHAIN PROJECT MANAGEMENT

VOLUME 2 SUPPLY CHAIN PROJECT MANAGEMENT TOOLS

WYŻSZA SZKOŁA LOGISTYKI
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INTRODUCTION

Nowadays the scope of supply chain activities is changing very dynamically. New challenges appear in companies during everyday business execution. In order to meet the goal of competitiveness, companies need to apply new tools and methods to improve their logistics processes. The implementation of effective supply chain management solutions requires not only strictly logistics-related competences, but also project management competences. The combination of the two types of competences mentioned above is required for supply chain project managers. People working in this position should not only be fluent in the world of logistics, but they should also know perfectly well and be able to apply the tools used in project management. The purpose of this book is to provide an overview of selected issues that a supply chain project manager may encounter in the course of their daily work.

The material prepared by the authors was collected and presented as a two-volume monograph entitled SUPPLY CHAIN PROJECT MANAGEMENT. Volume II, which, Dear Reader, you are currently holding in your hand, contains a total of six chapters referring to the following scope:

- Controlling logistics and Supply Chain,
- Forecasting,
- Operations research and optimization theory,
- Problem solving techniques,
- Supply Chain Big Data analysis,
- Negotiations and business communication.

The first chapter focuses on the Operational Controlling in logistics. A conscious supply chain project manager should be able to assess the impact of proposed implementations. For this purpose, the key indicators for evaluating logistics processes, described in chapter six, can be used.

The second chapter focuses on the basic issues of forecasting in Logistics. Opinions about the usefulness of the forecasting process in a company are varied. Some authors claim that forecasting is like driving a car with a covered windshield. In this case, only the rear-view mirror remains at the disposal of the driver. The driver and passengers travelling with him/her have a chance to reach their destination happily only if the road ahead of them looks exactly the same as the road behind them! In other words, if the future is similar to the past, the forecast will be effective. However, the authors support another thesis, which states that the forecasting process is an essential element of the functioning of a modern enterprise. Even if we make mistakes in predicting the future then, being aware of their occurrence and their estimated size, we can protect ourselves against their consequences. The chapter defines the forecasting process and discusses basic forecasting methods. Issues related to forecasting efficiency and collaborative forecasting were also discussed.

The third chapter contains key issues related to operations research and optimization theory. The reader will find here basic definitions and notions related to operations research and optimization theory, but above all, examples of the application of the described methods in the field of logistics. The use of optimization algorithms in logistics processes may contribute to the improvement of their operational efficiency, thanks to which a company builds its competitive advantage on the turbulent market.

An efficient supply project manager should know basic methods and tools to identify and solve problems in logistics processes. He should also be able to move around in a thicket of data. And this is what chapters four and five are dedicated to. Chapter 4 presents the application of the following methods: Failure Mode and Effects Analysis (FMEA), Ishikawa Fishbone Diagram and 5 Why to identify and solve business problems.

The fifth chapter contains basic information about the application of Big Data analysis logic in supply chain.

The last chapter is dedicated to soft skills that should be demonstrated by the supply project manager. Competences related to the negotiation process have been identified as particularly important. This chapter defines the concept and types of negotiation. It also discusses negotiation strategies used among partners interacting with each other in the supply chain.

The authors would like to especially thank the reviewer prof. Marek Fertsch who provided his specialist experience and knowledge, as well as valuable comments, which helped create the final version of the present work.

We hope that this book will be a useful reference material to students and practitioners who are interested in the area of effective supply chain project management.

The Authors

1. CONTROLLING LOGISTICS AND SUPPLY CHAIN

1.1. Controlling definition

The main objective of any company's business is to generate profits. In a highly competitive economy, most companies limit their strategy to a survival strategy, i.e. to staying on the market by reducing costs and setting short-term goals. Controlling is a tool supporting the effective management of a company in the conditions of a dynamically changing market. It is common knowledge that controlling is a tool which increases the efficiency of enterprises. It also improves the results of enterprises and increases their competitive advantage . Controlling is being constantly improved. That is why, it is difficult to find a complete definition of its importance in a enterprise. Controlling is often treated as a part of management or a subsystem of the management process. From the literature on the subject we can infer that controlling is[1]:

- a system which supports management,
- enterprise management, which is oriented on its financial result,
- a process performed through planning, control and reporting,
- a general tool supporting a traditional management process,
- a modern method of enterprise management concentrated on carrying out the assigned strategic goals.

It can therefore be concluded that the main functions of controlling are coordination, planning, control, regulation, control and access to up-to-date information. The integration of these functions with the management activities is an important element of the company's management. The management activities used in controlling are shown in Figure 1.1.

[1] Sliwczynski B., Kolinski A., Logistics controlling in enterprises, in: Kolinski A. (ed.), Logistics Management - modern development trends, Poznan School of Logistics Press, Poznan 2016, p. 87-88.

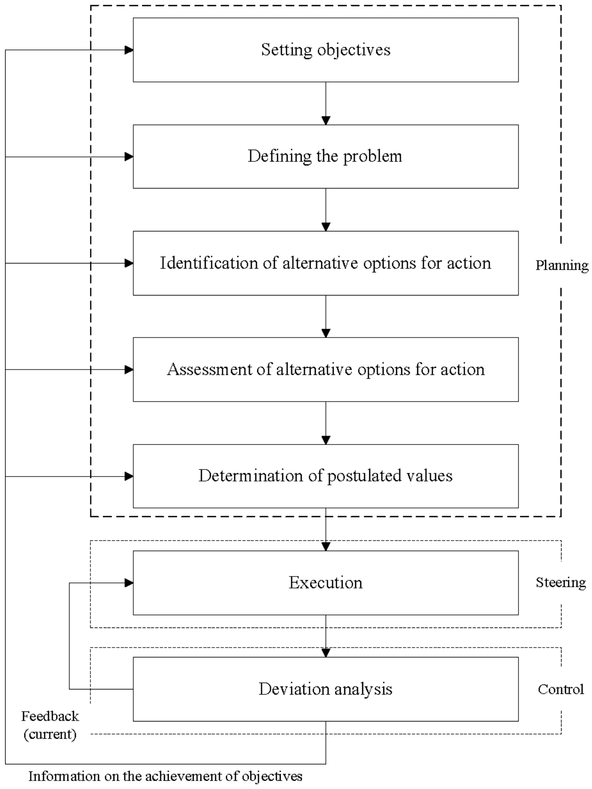

Figure 1.1. The role of controlling in the company's management system

Source: own study based on: Horváth P., Gleich R., Seiter M., Controlling, Vahlen Verlag, Munchen 2015, p. 59.

The basic task of controlling is to enable an enterprise its long-term existence. Because of a hierarchy of enterprise management and a time horizon, operational and strategic controlling can be identified. Strategic controlling is based on strategic planning which ensures achieving long-term results, whereas operational controlling is treated as a system of managing the enterprise's results during a short period. This is intended to enable achieving present goals regarding generating a profit thanks to the tools designed by strategic controlling.

It needs to be pointed out that the idea of controlling is very often mistakenly associated with already known concepts of management. Controlling is supposed to compare the real state of things with plans and aims of an enterprise and to implement necessary corrections whenever any abnormalities occur in those plans[2]. For this reason, controlling is very often wrongly associated with control only, whereas controlling processes deal not only with control but also with disposal, governing, planning and navigation.

The difference between the scope of traditional control and controlling activities is shown in the Figure 1.2.

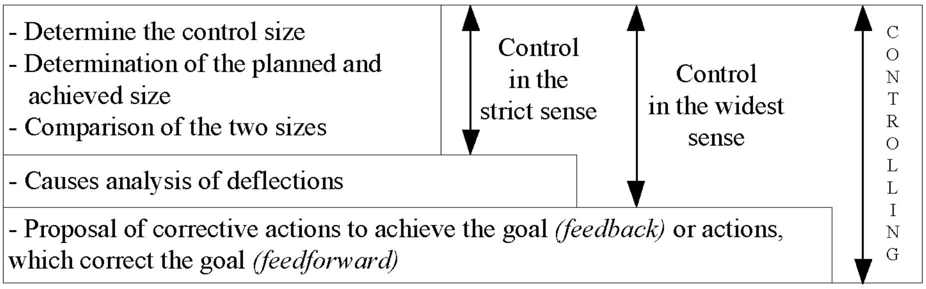

Figure 1.2. Difference between the scope of traditional control and controlling activities

Source: Sliwczynski B., Kolinski A., Controlling Supply Chains: Theory and Practice, Nova Science Publishers, New York 2016, p. 10.

The task of controlling is to control the processes taking place in the company in such a way that the employees control themselves. The difference between controlling and control concerns not only the scope of responsibility, but also the time taken into account. It should be remembered that control is aimed at events that occurred in the past. On the other hand, controlling refers to avoiding problems that may occur in the future[3].

The comparison of control and controlling from the point of view of substantial scope is presented in Table 1.1.

Table 1.1. Difference between the scope of traditional control and controlling activities

Controlling		Control	
Future	coordination	Past	detection of errors
	supervision		reasoning for correcting errors

[2] Powell J. D., Kelley C. A., Management, McGraw-Hill, New York 1981, p. 291.

[3] Sierpińska M., Niedbała B., Controlling operacyjny w przedsiębiorstwie, Wydawnictwo Naukowe PWN, Warszawa 2003, s. 21.

	counselling		finding guilty parties
	substantive support		claiming compensation for damage
	proposing solutions and remedial measures		proposing the imposition of penalties
	relying on external experience		proposing personnel and organizational changes
	inspiration		referring cases to the competent administrative or law enforcement authorities
	respecting		

Source: Sliwczynski B., Kolinski A., Controlling Supply Chains: Theory and Practice, Nova Science Publishers, New York 2016, p. 10.

Therefore, the controlling system is not only used to control processes, but mainly to prevent the occurrence of possible deviations from the assumed plan. Possible and probable deviations should be detected before they occur.

The idea of controlling is also often mistakenly associated with business management. Differences between them result mainly from their mutual relations. Two variants can be accepted. In the first variant, presented in Figure 1.3.a, controlling is a subsystem of business management in company, one of its instruments It does not function independently, but constitutes one of the elements of business management, which directly affects the company's activities.

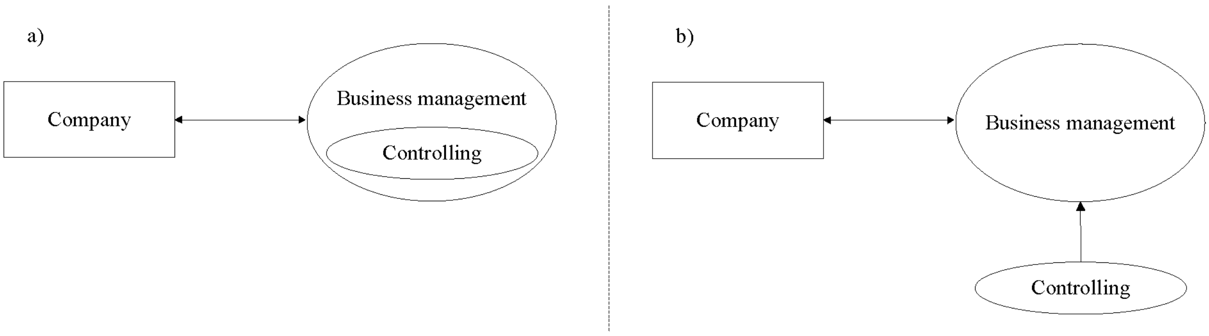

Figure 1.3. The relation between business management and controlling

Source: own study.

In the second variant (Figure 1.3.b) controlling is a separate system, which aims at supporting business management procedures, and only then influence the processes taking place in the company. Another important difference between controlling and management is that business management process occurs in almost every economic unit, while controlling (i.e. a management support system) is not compulsory and its application depends on the needs and strategy of the company.

Controlling is a system that assists the management of an organization in achieving objectives (Figure 1.4) by coordinating the processes of planning, organization, management and steering, controlling, as well as collecting and processing information[4].

Controlling integrates and coordinates the following areas in an enterprise (Figure 1.4):

- management functions – planning, organization, management and steering, control, response, and correction,
- activity areas – sales, distribution, manufacturing, purchasing and supply, marketing, research and development, customer service, warehousing and inventory, transportation, human resources management, outsourcing,
- management levels and stages of developing management decisions (strategic, tactical and operative) in the long, medium and short-term,
- value chains – integrating the needs of the market and the customer, products, processes and resources, as well as business performance (financial and operational), affecting the improvement of efficiency and eliminating waste (including bottlenecks).

[4] Sliwczynski B., Kolinski A., Controlling Supply Chains: Theory and Practice, Nova Science Publishers, New York 2016, p. 1.

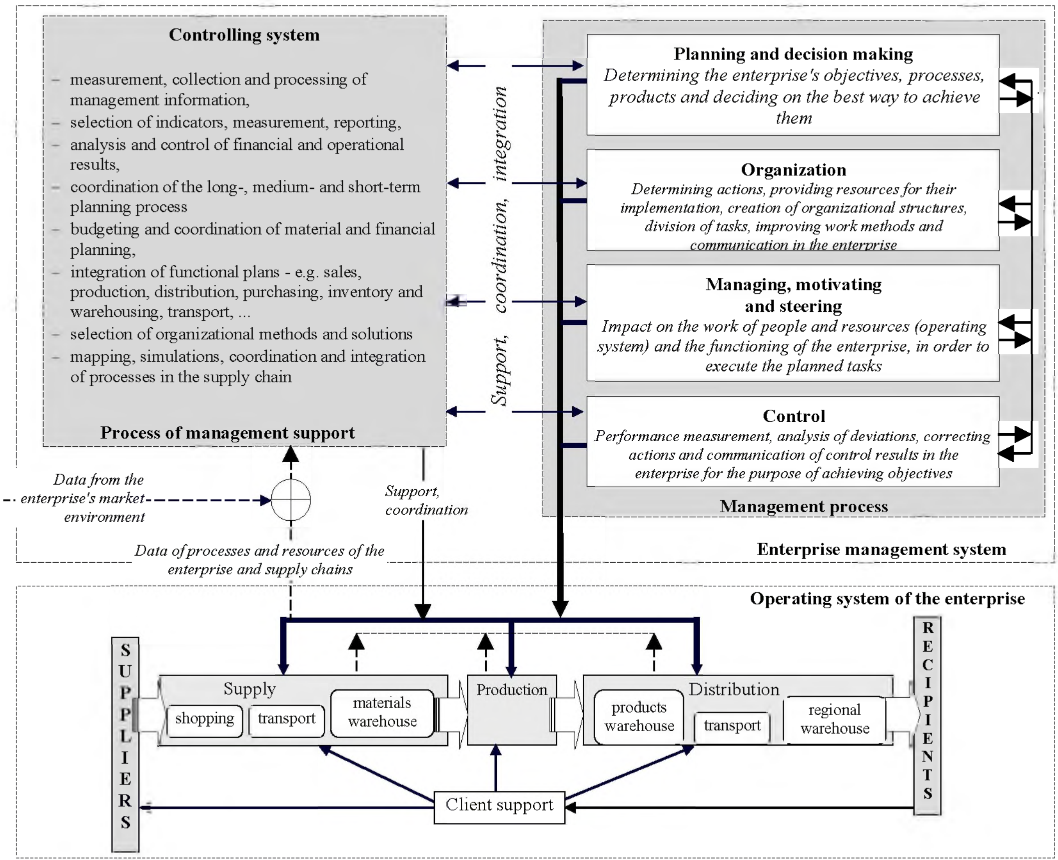

Figure 1.4. The relation between business management and controlling

Source: Sliwczynski B., Kolinski A., Controlling Supply Chains: Theory and Practice, Nova Science Publishers, New York 2016, p. 2.

In a complex enterprise, operating system processes integrate the work of many organizational entities and their resources, as well as suppliers, buyers and subcontractors in the supply chain. The ability to raise the value and competitiveness of a product depends on the possibility of establishing the complex connection (operational and economic) of performance analysis and selection of methods for steering processes and resources in the chain.

1.2. Controlling functions in a logistics system

Due to the hierarchy of business management, as well as the time horizon, there is a distinction between operational and strategic controlling. Strategic controlling is based on strategic planning, which ensures long-term results. Operational controlling is a system that assists operational management in achieving goals through the integration and coordination of planning, organization, steering, and control, as well as the collection and processing of information in relation to the product, processes and resources in the full supply chain[5]. Planning levels and the hierarchy of decisions are shown in Figure 1.5.

Figure 1.5. Planning levels and decision-making hierarchy

Source: Sliwczynski B., Kolinski A., Controlling Supply Chains: Theory and Practice, Nova Science Publishers, New York 2016, p. 2.

Operational controlling is a subsystem in which short-term decisions related to the current business activity of the company are made. The aim of operational controlling is to transform the most important strategic plans of the company into operational plans. Operational plans should be adjusted to the part of the company to which they refer. The transformation of the company's master plans into business plans, which are adapted to the structure of the company's management system, takes place in the budgeting process. The budgeting process is used in the management of the company. Budgeting can also be said to involve a certain way of organizing

[5] Sliwczynski B., Operational controlling - a tool of translating strategy into action, LogForum, 2011, Vol. 7, Issue 1, No 5, p. 56-57.

work in the company. The features distinguishing strategic from operational controlling are presented in Table 1.2.

Table 1.2. Operational and strategic controlling

Designators	Operational Controlling	Strategic Controlling
Objectives	profitability, profit, liquidity and economic performance	ensuring the long-term existence and development of the company and the necessary factors for success
Orientation	use of existing resources in the company, economization and regulation of internal processes	taking into account the external conditions of the enterprise and shaping the objectives and potential resources on their basis, as well as adjusting the enterprise's activity to changes
Dimensions considered	income/expenditure, cost/efficiency/profitability	opportunities, threats - Strengths and weaknesses
Structuring problems	the objectives and targets expressed in terms of in quantity sizes, high data precision	low degree of structuring of problems, more qualitative than quantitative nature of objectives and tasks
Degree of planning and control	planning and control on an equal footing	first of all, planning
Planning level	tactical, operational and budgeting	strategic
Time horizon	average up to 3 years and usually short periods (year, quarter)	long or very long periods, usually unlimited
Persons engaged in controlling activities	top-management and line units	top-management and staff
Degree of controller autonomy	autonomous task fields and cooperation	the need for close cooperation with other functions

Source: own study.

The objectives of logistics management in an enterprise are perceived as ensuring product availability on the market, an agreed level of customer service, continuity of material flows, reliability and efficiency of deliveries, cost reduction, as well as increase in the effectiveness of the enterprise's business activity. Logistics controlling is aimed at achieving the presented objectives both at the strategic and operational level. However, logistics controlling should not be interpreted as a separate subsystem of company controlling, since it also uses information and tools obtained from other controlling subsystems. Due to the complexity of the logistics management process in an enterprise, logistics controlling concerns a very complex area of tasks. Figure 1.6. shows the position of logistics controlling in the company's controlling system, taking into account the basic area of logistics controlling.

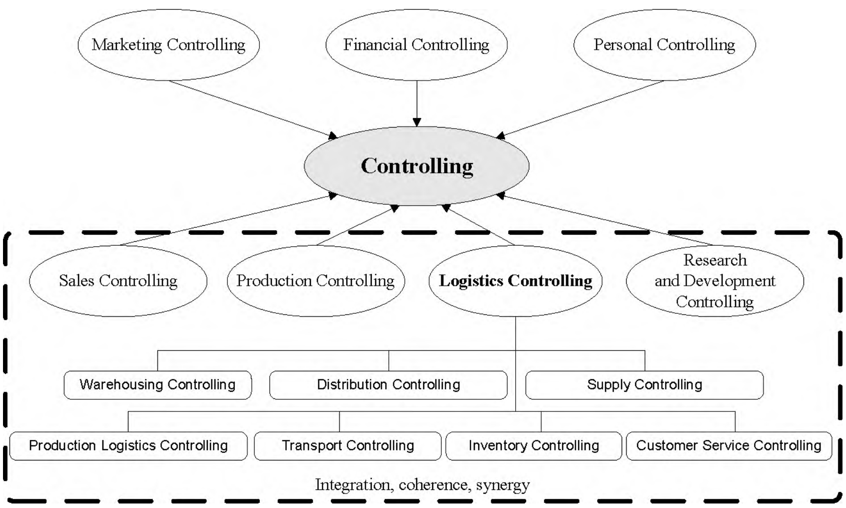

Figure 1.6. Location of logistics controlling in the company's structures

Source: Kolinski A., Trojanowska J., Pająk E., Theory of Constraints as supporting element of logistics controlling, in: Badzinska E. (ed), Sources of Competitive Advantage for Enterprises, Publishing House of Poznan University of Technology, Poznan 2010, p. 73.

The basic difference between logistics and controlling in the aspect of coordination is that logistics play a cross-sectional part in the service system and controlling plays the same part in the management system[6]. The following assumptions of logistics controlling should be distinguished as an effective tool supporting business management[7]:

- goal orientation – an advisory form of controlling, concerning the support of the company's management board in the formulation and implementation of the company's goals,

[6] Pfohl H., Logistikmanagement: Konzeption und Funktionen, ESE. Springer, Berlin Heidelberg 2004, p. 200-204.
[7] Vollmuth H. J., Controlling-Instrumente von A-Z: Die wichtigsten Werkzeuge zur Unternehmenssteuerung, Haufe-Lexware 2007, p. 17-20.

- future orientation – controlling focuses its activities on the future in order to provide accurate information on the future development of the company,
- orientation on bottlenecks – one of the basic tasks of controlling is to find all limitations to business activity; limitations may include both external factors (business environment, demand) and internal factors (e.g. limitations resulting from insufficient production capacity of the position),
- market orientation – appropriate identification of market needs may significantly improve the competitive position of the company; the controlling task is to identify opportunities and threats (external constraints) affecting the competitiveness of the company,
- customer orientation – a company can only survive in a competitive market if it maintains a high level of customer service; controlling is aimed at providing the necessary information to help maintain and improve the quality of customer service and customer satisfaction.

As can be seen in the assumptions presented above, controlling as a management subsystem uses tools of planning, control, and information processing. Due to the fact that decisions made by the management in the field of logistics are aimed at the effective use of the entire logistics supply chain, controlling logistics may turn out to be a useful tool supporting logistics management. The use of logistics controlling tools in the management of a company has many advantages:

- the logistics activities are strategically targeted,
- support of the decision-making leading to the achievement of the company's objectives,
- increase in the efficiency of the company's activity through the cooperation of logistics controlling with other company’s controlling subsystems,
- increase in the effectiveness of logistics process management,
- increase in the importance of logistics in the overall business activity of the company.

1.3. Logistics and supply chain controlling

Supply Controlling

Supply can be defined as the entire system, including its own supply of, external suppliers and their relationships (logistics system approach) or as the delivery, or a set of activities leading to the delivery of goods to the place at the right time, and in the right quantity, as well as condition. The definition of supply is often considered synonymous to the concept of procurement (Table 1.3.).

Table 1.3. The differences between supply logistics and procurement

Supply logistics	Procurement
ensuring optimal quality of products	Specifying the type of purchase
minimizing the total cost	determining the necessary level of investment
acquisition and maintenance of reliable and competitive suppliers	implementation of the procurement process
minimum inventory level and smooth flow of raw materials	evaluation of procurement process efficiency
cooperation and integration with other areas of enterprise	

Source: Domański R., Adamczak M., Cyplik P., Modele planowania przepływu materiałów w zaopatrzeniu w modelu SCOR, Gospodarka Materiałowa i Logistyka, 2012, no. 2, p. 12.

In this context, supply is the process of acquiring the business of goods and services (intake process, procurement), or a range of supply operations, including the step acquisition i.e.an aspect of the transaction and the physical flow of products: transportation, receipt and storage of intermediate materials, as well as other actions necessary to conduct everyday business functions in the area of acquisition of goods and services. The subject of supply logistics are goods (raw materials, auxiliary materials and consumables, parts purchasing and goods purchased in the trade) to be made available to a business in accordance with its needs. Strategic decisions in the supply logistics include:

- make or buy,
- rules for the selection and evaluation of suppliers,

- selection rules and control of material inventories,
- the area of computerization of supply processes.

A key aspect of the sphere of supply are decisions in the area of purchasing and delivery of materials and raw materials. The instruments of procurement policy include: product policy, contracting policy, communication policy and purchasing policies[8].

Carrying out a detailed analysis requires looking at the process of material management using the SCOR[9] reference methodology of process approach, and taking into consideration the following component elements[10]:

- S&OP planning – makes it possible to plan operations in a supply chain, including transposing the needs of sales into the level of planning the stream of goods from production process,
- material requirements planning – includes material structure of a product, necessary for material count, technologies and production itineraries, necessary for scheduling material needs and store stock; simulation is carried out with the net values of material needs,
- the procedure of commission – makes it possible to simulate individual variants according to estimated net material needs,
- the generator of real consumption and the algorithm of updating prognoses, which should be treated as auxiliary simulation models of real consumption for examined material indices; they are necessary for simulating the real environment of material supplies realization, transport processes and supplies availability at the stage of verifying the commission,

[8] Kolinski A., Kolinska K., Influence of supply process on the business management efficiency, in: Kolinski A. (ed.), Logistics Management - modern development trends, Poznan School of Logistics Press, Poznan 2016, p. 12.
[9] SCOR – Eng. Supply-Chain Operations Reference Model – Model Overview Version 9.0. – a referential model of supply chain operations integrating five basic processes– planning, supplies, realisation, distribution and service of the turning streams, developed by managers and academics associated in a global organisation Supply-Chain Council. The model consists of representative methods of describing supply chain processes, a set of standards for the assessment of processes and their results as well as the best practical actions of managing processes in a supply chain.
[10] Sliwczynski B., Kolinski A., Efficiency analysis system of material management, LogForum, 2012, Vol. 8, Issue 4, p. 300.

- commission procedure verifying – facilitates a multi-criteria analysis and choice of satisfactory models according to set criteria values,
- transport system and the model of verifying that system, including the model solution for a multi-criteria load and routes planning, as well as load and transit scheduling,
- warehouse process, which is also an auxiliary model necessary for defining the capability of receiving and servicing transport processes and maintaining supplies.

Controlling supports planning and organization of the supply process, control of results and correcting deviations, by[11]:

- mapping client's needs regarding materials in the final product to the requirements of the supply process (e.g. scope and methods of material quality control),
- classifying materials, suppliers, supply channels in accordance with the current ABC/XYZ classification as well as selecting of methods and algorithms for supply management in classification groups,
- support in determining methods and procedures of steering and operational norms - for purchasing, orders, deliveries and inventories,
- support in developing effective and safe methods of qualifying suppliers and coordinating periodic control of suppliers (technological, financial, trade, logistics, qualitative),
- support and coordination to conclude purchase contracts, negotiate terms of cooperation, payment and execution of deliveries,
- controlling and managing the ordering process, monitoring deliveries, integration with the storage process in order to effectively support delivery acceptance, exchange of information and handling complaints and returns,
- support for material requirements planning as well as controlling conversion formulas and MRP system scheduling (Material Requirements Planning),analysis of working capital - liability cycle and inventory cycle,
- control of delivery parameters - timeliness, completeness, quality compliance of materials,

[11] Sliwczynski B., Kolinski A., Controlling Supply Chains: Theory and Practice, Nova Science Publishers, New York 2016, p. 76-77.

- developing a material safety map covering rational scenarios and variants of deliveries as well as analysis of supply risk, downtime and changes in production plans, sales shortages
- integration of delivery, production, transportation, warehousing and sales plans,
- supply and materials management cost accounting, setting and controlling limits on the value of purchases,
- developing and controlling the budget of purchases and supply, analysis of deviations and implementing corrections and budgets conversions,
- reporting on the supply and materials management process.

Production Controlling

Production controlling should be considered as a comprehensive concept that is functionally, institutionally and personally integrated and supports the management of production processes. Production controlling complements the shaping and current functioning of the production activity management system. Production controlling focuses on[12]:

- productivity planning and controlling (input-output relation in a production process) aiming at its increase (also through shortening production time),
- optimization of the production program in terms of costs (management of fixed production costs), duration of the production process and storage (production volume, number of reinforcements),
- defining capital involvement (exploitation of owned fixed assets) and minimizing it.

It should be noted that controlling also supports production and material flow planning at tactical and strategic levels, achieving the following objectives:

- the assumed level of customer service (sales, final products warehouse),
- the lowest total production costs (minimum level of capital freezing, costs of changes in production plans),
- the highest efficiency in the use of production and logistics resources involved in the production process,

[12] Peemöller V. H., Controlling. Grundlagen und Einsatzgebiete, Verlag Neue Wirtschaft – Briefe, Herne – Berlin 1990, p. 291.

- the lowest possible level of inventories in the production process, which guarantees liquidity and planned implementation of production processes,
- stability of production plans, efficient production and even distribution of production and logistics resources,
- elimination of bottlenecks in the production process.

Too many small orders can minimize sales, increase costs, decrease coverage margin and lower financial result. Small orders constitute most of the orders and also a burden to production process. Productivity decreases due to frequent rearrangement of machines. The task of controlling is to evaluate the scale and size of orders and set a plan of actions improving future structure of orders. Table 1.4 presents division of aims of production controlling.

Table 1.4. Division of aims of production controlling

Criterion	Aims of production controlling
financial	margin cover (maintaining low variable costs)
	maximum utilization of production capacity (maintaining low fixed costs per production unit)
Time	short delivery times
	short production process time
quantity and quality	small size of waste
	high standard of quality (small number of complaints)
	quality aims adapted to ISO norms
flexibility	easy adaptation to changes in the environment and demand
	improving workers' qualifications
	flexible equipment with work resources
social	fair division of work
	ergonomic shape of the workplace
	work safety
ecological	low emission of hazardous substances into the environment
	low exploitation of natural resources

Source: Own study based on: Witt F. J., Controlling 1 – Ganzheitliches Controlling, edition 2, Verlag C. H. Beck, München 2000, p. 251.

Production controlling supports production planning and navigation on each level of management. Short life cycles of products and technologies and the pressure to lower costs and increase quality are the main reasons why the main task of production controlling on a strategic level is to support the choice of a proper technology (adapt production to changing needs of customers) and assess regularly whether the decisions which are made are compatible with present strategic aims[13].

From the point of view of production processes, controlling is not only about controlling the production process, but also about participating in the planning and control of production. Figure 1.7 shows the links between production controlling functions.

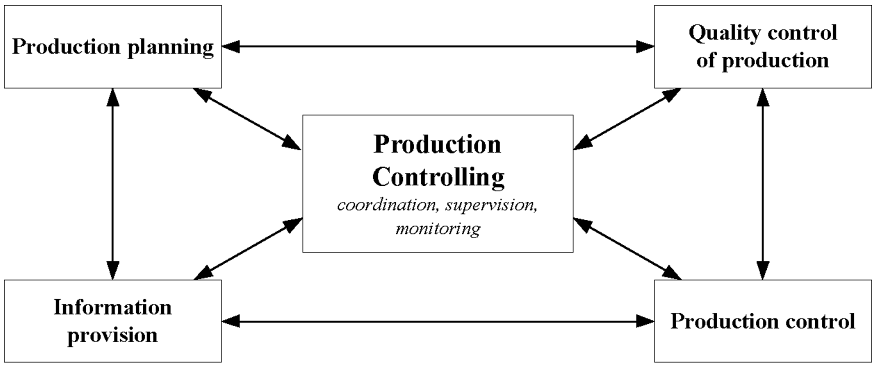

Figure 1.7. Production controlling functions

Source: own study.

It needs to be remembered that production controlling concentrates on the operational level. Production controlling on the operational level is closely connected with production logistics and the flow of materials. It is advisable to consider the role of production controlling in achieving the following goals[14]:

- maintaining the earlier established level of customer service (sales, finished goods store),

[13] Steinle C., Heike B., Controlling. Kompendium für Controller finnen und ihre Ausbildung, Schäffer-Pöschel Verlag, Stuttgart 1998, p. 730.
[14] Sliwczynski B., Kolinski A., Controlling Supply Chains: Theory and Practice, Nova Science Publishers, New York 2016, p. 81-88.

- obtaining the lowest total costs of production (minimum level of funds frozen, costs of changing production plans),
- obtaining the highest effectiveness of production and logistics resources engaged in a production process,
- maintaining a reasonable level of supplies in a production process which ensures fluency and planned performance of production processes,
- maintaining stability of production plans and effective production as well as constant loading of production and logistic resources,
- elimination of bottlenecks in the production process.

Distribution Logistics Controlling

In process terms, distribution is based on the movement of materials, usually products and elements for the service, from manufacturer to consumer. These activities include transport, warehousing, inventory management, material handling, order preparation, location analysis, packaging management, information processing and communication necessary to effectively coordinate all activities. The distribution process can also be analyzed as analogous to the procurement process, changing only the perspective of the analysis.

The analysis carried out indicates the diversity and multifacetedness of the issues raised. The results of the analysis of theoretical (scientific and specialist) and practical knowledge (research, consultations and observations in enterprises) indicate that the analysis of the distribution process effectiveness should include both a set of indicators to assess the current situation, as well as the consideration of various factors causing difficulties in the effective implementation of the process. The basic scope of distribution controlling is presented in Figure 1.8.

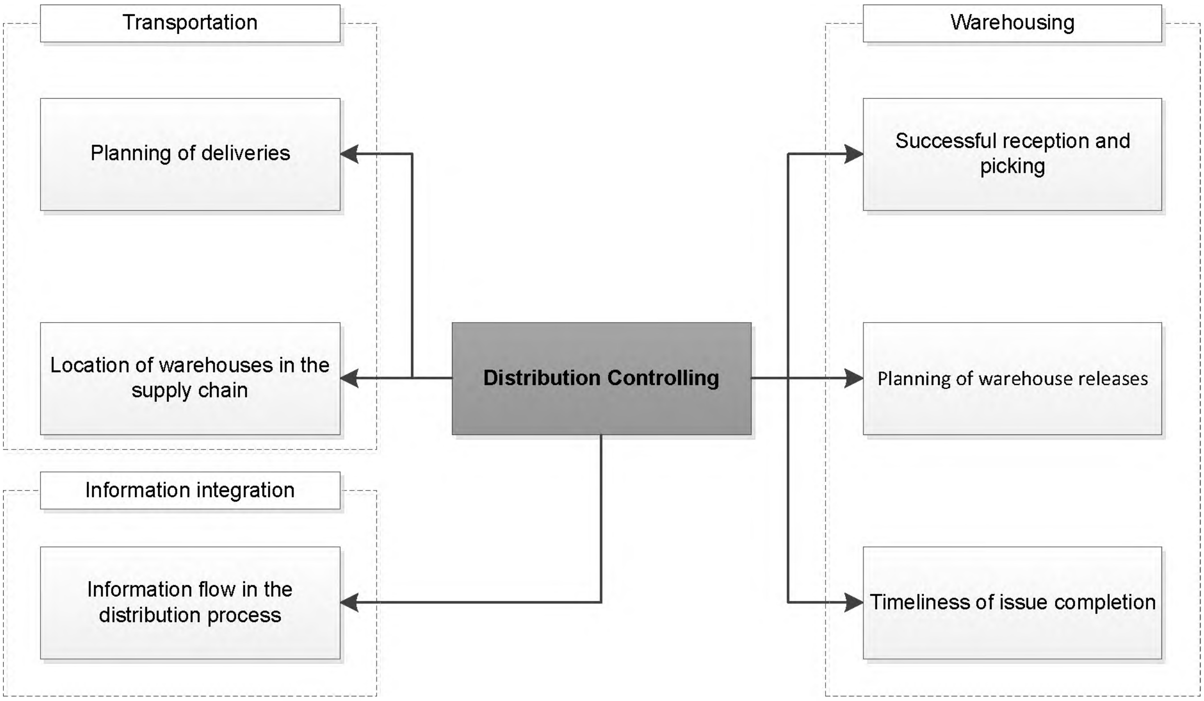

Figure 1.8. The basic scope of distribution controlling

Source: own study.

Controlling analysis of the supply chain at the strategic level depends on the location of individual business partners and their customers. The main problem identified in terms of transposing strategic objectives was the impact of warehouse location on distribution efficiency in the supply chain.

The analysis of delivery planning issues should include a planning system consisting of MRP (Material Requirement Planning) and DRP (Distribution Requirement Planning). The systems provide demand planning balanced with demand forecasts, while achieving shorter delivery cycles and lower inventory levels. MRP and DRP used simultaneously form an integrated Logistics Requirement Planning (LRP) system, which includes planning logistics needs in the area of supply, production and distribution processes.

The following potential benefits stemming from the application of supply planning for distribution should be identified:

- minimization of errors made during the completion of picking for dispatch,
- minimizing downtime in the release zone caused by waiting for the means of transport,

- elimination of release stacks at the same time,
- optimization of the use of warehouse workers' working time in the release zone,
- the possibility of joint organization of work in the reception and issue areas.

Delivery planning also has an impact on the last one from the identified processes directly affecting distribution effectiveness, i.e. planning and execution of warehouse releases. This process is one of the basic stages of cargo flow through the warehouse and is crucial in terms of distribution. This is because of its impact on the performance of loading on the means of transport, i.e. on the efficiency of delivery to the customer.

Information is necessary for the effective functioning of the supply chain, but it is also an organizational problem and a factor that has a negative impact on the market position. Lack of up-to-date and reliable information leads to erroneous and costly decisions that halt the implementation of operational activities related to the flow of goods throughout the supply chain.

1.4. Logistics and supply chain controlling in terms of logistics functions

Warehouse Management Controlling

Warehouse processes concentrate on those factors that have a crucial impact on the continuity of material flow throughout the supply chain. Scientific studies related to logistics management indicate various factors - the processes and resources that affect the whole warehouse process. It is, therefore, clear that the warehouse management should focus on ways to improve the efficiency of processes, both internal and external in the supply chain and continuous monitoring and evaluation of results.

Warehouse management is a very important element of business activity of every company. Warehouse management can be examined in three areas:

- procurement - the aim of warehouse management is to receive consumables and raw materials for the production from suppliers, their storage and issuing to production,
- production - where the task of warehouse management is reduced to an optimal allocation of materials and resources to the appropriate areas and production stages,

- distribution - where to store, complete and deliver finished goods in such a way so as to meet the expectations of customers (right product, at the right time, the right place, at the right price).

Analyzing the warehouse process in terms of controlling and efficiency can determine the objectives and tasks of effective warehouse management. This is shown in Table 1.5.

Table 1.5. Objectives and tasks of effective warehouse management

Objectives	Tasks
maximize the use of storage space, achieved through appropriate measures in the design, construction and commissioning of the magazine and responding to current changes;	ensuring the availability of technical and personal resources to achieve the planned level of activity - only possible with close coordination with the leadership of the company;
	ensuring the flow of goods corresponding to the requirements for deliveries and shipments - requires the cooperation of warehouse with procurement and sales departments;
minimize the use of manipulating operations - the first step eliminates redundant operations, and the second seeks to reduce the execution time of necessary activities	Solid planning, controlling and maintaining the use of all available resources - performed at the operational level and can be based on production schedules and orders placed with suppliers or sales plans and orders from customers;
	continuous monitoring, evaluation and improvement of the warehouse process according to established criteria - should be based on selected indicators and gauges reflecting the process

Source: Kolinski A., Sliwczynski B., Evaluation problem and assessment method of warehouse process efficiency. In Proceedings of The 15th International Scientific Conference, Business Logistics In Modern Management, Osijek 2015, p. 178.

Owing to the fact that warehouse management has a significant impact on the functioning of the company, companies should strive to continuously improve the functioning of the warehouse. The most important factors affecting the improvement in functioning productivity of the warehouse are[15]:

- adjustment of flow into the warehouse capacity - the starting point should be to determine the warehouse capacity. On this basis, in cooperation with companies, it

[15] Niemczyk A., Warehouse processes in enterprises, in: Kolinski A. (ed.), Logistics Management - modern development trends, Poznan School of Logistics Press, Poznan 2016, p. 74-78.

should establish a schedule of deliveries and shipments to avoid the accumulation of work during the day and excess loading units flowing through the warehouse,

- the use of storage space - refers to the efficient management of the available amount of storage area,
- rationalization of routes traveled by employees and the goods - this factor is most important for the process of completion, except that you should strive to eliminate or shorten the routes traveled by employees without the goods,
- use of staff - when analyzing this factor, one should pay attention to three criteria: full-time employees, they have competences and stability of employment,
- effective information flow - has a key impact on the implementation of all phases of the warehouse process. Any disruption in the flow of information (especially at the stage of completion and issuance) may result in delays in the performance of contracts.

Warehouse processes need to be carefully analyzed in terms of operational controlling to evaluate the following components:

- the efficiency of warehouse resources and their utilization,
- performance and reliability of warehouse operations,
- load handling from the time of accepting the goods until the release from the warehouse capacity, taking into account downtime, queues and bottlenecks in the flow of goods.

Inventory Controlling

Inventory management in terms of the whole supply chain should take into account the distinct character at different stages of material flow. Support for planning and managing inventory requires the selection of methods and parameters of inventory management, and controlling of inventory results.

When conducting controlling analysis, one may encounter a more precise approach to the determination of inventory standards, in which the decision on the development of inventory levels can be based on answers to three questions[16]:

- which goods should be stored,
- how much one needs to order to restore their stock levels,

[16] Cyplik P., Przegląd metod sterowania zapasami, Logistyka 1/2003, p. 23.

- when to order from suppliers to replenish stocks.

The process of inventory optimization should be preceded by the selection of the strategy of product availability management, that is, the indication of how and in compliance with what rules, the availability of respective products must be ensured in order to fulfill the expectations of customers, and also to strive for optimization of costs in the enterprise. Based on such a selection, products which are kept in the inventory at the enterprise and are managed by it, are identified, therefore, they can be covered by the inventory optimization process. Inventory optimization is a complex process and requires a number of analyses carried out by the enterprise, as well as preparation of rules for inventory replenishment, parameterization, and ultimately implementation of the developed solutions. The inventory optimization process consists of the following elements[17]:

- the development of rules for product classification, i.e. the use of the ABC, XYZ and 123 methods, etc.
- the development of the rules for the S&OP process functioning (Sales and Operation Planning),
- the selection of inventory replenishment methods for the respective products and parameterization of the selected algorithms,
- the development of inventory monitoring and control system, i.e. the set of reports and indicators, rules of their determination and responsibility,
- the selection of the IT functionalities necessary to implement the developed issues,
- the preparation of manuals and procedures.

Analysis of the results of inventory management allows to determine the tasks and responsibilities of operational controlling, including[18]:

- analysis of data concerning the level, structure (cyclical inventory, security inventory) and location of inventory and quantity of consumption (including the average size, dynamics and instability, trend, seasonality),

[17] Kolinska K., Cudzilo M., Analysis and optimisation o inventory in enterprises, in: Kolinski A. (ed.), Logistics Management - modern development trends, Poznan School of Logistics Press, Poznan 2016, p. 32.
[18] Sliwczynski B., Kolinski A., Controlling Supply Chains: Theory and Practice, Nova Science Publishers, New York 2016, p. 104-105.

- classification of product range groups according to ABC and XYZ methods, which enable the selection of methods for managing inventory for particular classification groups,
- assessment of methods used and parameters for restoring the inventory,
- controlling and correcting the selection of parameters and formulas for calculating the level of security inventory in the context of current instability of supplies and consumption, as well as requirements of the level of support,
- defining the inventory structure (production, operational - current and emergency, repair, investment inventory) in the context of conducted business and location in the internal and external supply chain,
- controlling inventory values and costs, including: the costs of maintaining and restoring inventory, costs of frozen capital, warehousing and depreciation of inventory, as well as the share of inventory costs in total costs of the enterprise,
- reporting the value and quantity of inventory (management reports, operational reports) and orders (restoring inventory) and outflow (consumption),
- analysis of the impact of inventory management on the results of the enterprise.

Transportation Controlling

Transport processes in a company result from the need to transport finished products, goods, materials, as well as machines and equipment. To ensure the availability of resources at all times and, at an acceptable cost level, the transport process occurs at every link in the logistics supply chain. One of the most frequently used logistics controlling tools is the planning of transport routes for both deliveries and shipments. The main goal of transport route planning is to achieve the highest possible level of use of means of transport, with the shortest possible route and in the shortest possible time. The main principles of savings in transport route planning include:

- increasing the load carried within the limits of the vehicle's capacity,
- planning normal delivery days and avoiding ad hoc (emergency) deliveries,
- extending the time taken for the total use of vehicles for freight transport,
- elongating the load path in both directions,
- minimizing downtime for drivers and delivery delays.

It should therefore be remembered that the task of controlling logistics in the transport process include:

- planning of loading and transporting of means of transport,
- scheduling of available means of transport,
- scheduling of shipments for dispatch
- route and loading planning,
- the allocation of appropriate loads to the route, the means of transport and the consignee group.

Transport management in the strict sense of the word, as well as measures aimed at improving the efficiency of the use of transport resources, are the basis for consideration by many specialists and experts in the field. Theoreticians and practitioners discuss the role of transport management, as well as significance, efficiency and effectiveness of transport processes facing the needs of the present and the challenges of the future.

The creation of a competitive advantage is, therefore, based on cost minimization or qualitative differentiation of the transport offer. However, actions related to the pursuit of these objectives result from the methodology based on Porter's value chain. In addition, it should be emphasized that building a competitive advantage refers to the fight against competition on the market of final products, where each player fights for the largest possible share in it and is based on activities related to building a proper image of the company and positioning the product in the consciousness of the target audience (market).

In this context, creating a competitive advantage in transport management can play a significant role through the following actions:

- the coordination of processes, procedures and activities at any stage in the process of creating offer diversity. The aim of such a procedure should be to optimize the so called usefulness of time and space of a given offer for transport services. These actions may be conducive to building higher value perceived by the customer in relation to competitors' proposals. In addition, they strengthen the level of customer confidence in a given company, which ensures the delivery of the right product in the right quantity, in the right condition, at the right time, and to the right place,

- integration of functions and organizational structures responsible for or connected with the flow of information, products or finance.

The task of controlling in the area of supporting transportation management and coordination of cooperation with other processes in the supply chain include[19]:

- the collection, processing and analysis of data on transportation needs and cargo streams in the supply chain, as well as the available transportation services,
- the collection, processing and analysis of data on transportation potential (fleet), current realization of transit operations, level of use of fleet and client support.
- the selection of methods of planning transportation routes, loading and modes of transportation, as well as scheduling of transit operations, and also the size and structure of the transportation fleet - helping to achieve high effectiveness, efficiency, capacity and reliability of transportation processes, and adapting them to the needs of the enterprise and the market of recipients,
- analysis of the effectiveness of the transportation process according to the terms of the purchase/supply/sales contract and applied formulas of INCOTERMS,
- supporting the organization of the transportation system - including the principles of procedures for operations, development decisions or exchanging the transportation fleet, qualifications of contractors of transit services,
- supporting the organization of the IT system for transportation management,
- calculation and updating of operational, cost and revenue norms,
- controlling the costs and results of transportation activities in the enterprise (including an analysis of the deviations of results and costs from the plans and their interpretation),
- supporting the budgeting process of transportation and control of the implementation and deviations of the budget,
- elimination of bottlenecks in the processes of transportation and deliveries,
- controlling the quality of transportation operations and their compliance with procedures and transportation instructions (including the control of: vehicle time sheets, operation documents, reports on tasks),

[19] Sliwczynski B., Kolinski A., Controlling Supply Chains: Theory and Practice, Nova Science Publishers, New York 2016, p. 110-111.

- reporting on transportation activities.

1.5. Key Performance Indicators (KPI's)

The measurement of logistics processes is extremely important for logistics controlling, as successful monitoring of logistics processes has a direct impact on the efficiency of the entire supply chain. Monitoring is, therefore, based on financial and non-financial indicators, used as a measurement in the process of analyzing the extent to which strategic objectives in the supply chain have been achieved.

KPIs support a company's achievement of its operational and strategic goals. They are of great importance for building a results-oriented organizational culture, as they are a source of objective feedback for employees on their work, costs and quality[20]. KPIs are also a tool for managerial control, allowing for quick decision making, planning and prioritizing of activities and responding to emerging problems. They also support the processes of continuous improvement and effective use of resources possessed by the organization.

An analysis of logistics controlling should be based not only on operational indicators, which are directly connected with logistics process, but also on financial indicators. Aims and indicators used in an analysis of logistics controlling should result from the company's vision and strategy. An analysis of logistics controlling can be thought of as complete when it does not only refer to indicators which apply to past results, but also when it allows to monitor what affects future results.

Complete logistics efficiency assessment has still not been polished in the subject literature. Taking into account the supply chain aspect, the problem of logistics controlling assessment can be based on the assumptions of Balanced Scorecard developed by R. Kaplan and D. Norton. The authors proposed the analysis of efficiency from four perspectives: financial, customer, internal business process, and learning and growth. Many companies already have performance measurement systems that incorporate financial and nonfinancial measures. What is new about a call for a "balanced" set of measures? While virtually all organizations do indeed have financial and nonfinancial measures, many use their nonfinancial

[20] Parmenter D., Key performance indicators: developing, implementing, and using winning KPIs, John Wiley & Sons, New Jersey 2015, p. 7-11.

measures for local improvements, at their front-line and customer facing operations. Aggregate financial measures are used by senior managers, as if these measures could summarize adequately the results of operations performed by their lower and mid-level employees. These organizations are using their financial and nonfinancial performance measures only for tactical feedback and control of production process in short-term[21].

Carrying out an analysis of logistics controlling from four perspectives, we can develop a set of indicators[22], which take into account the basic characteristics of efficiency defined by the model[23]. Table 1.6 presents chosen indicators of assessing logistics efficiency from the financial perspective.

Table 1.6. Selected measures for assessing the logistics processes efficiency in the financial

Scope	No.	Measuring name	formula	Description	unit
Supply	1.	Indicator of complaints and returns	$\frac{a}{b}$	a - value/cost of complaints and returns b - value/cost of all supplies of materials and raw materials	%
	2.	Index of value incompleteness of deliveries		a - value of incomplete deliveries b - value of all deliveries	%
	3.	Material Stock Turnover Ratio		a - costs of materials consumption b - average stock of material stocks	%
	4.	Average value/cost of the order		a - value/cost of completed orders b - number of completed orders	zł
Production	1.	Share of defective production		a - costs of materials consumption b - average stock of material stocks	%
	2.	Profitability rate of work		a - net sales b - salaries and wages	%

[21] Kaplan R. S., Norton D., The balanced scorecard: translating strategy into action, Harvard Business Press, 1996, p. 8.
[22] Corbett T., Throughput Accounting, North River Press, New York 1998; Meier H., Lagemann H., Morlock F., Rathmann Ch., Key Performance Indicators for Assessing the Planning and Delivery of Industrial Services, Procedia CIRP, 2011, Vol. 11, pp. 99-104; Sliwczynski B., Kolinski A., Controlling Supply Chains: Theory and Practice, Nova Science Publishers, New York 2016.
[23] In economic aspect efficiency is the result of company's activity, which is a proportion of the achieved effect to borne spending.

	3.	Material Stock Turnover Ratio		a - costs of materials consumption	%
				b - average stock of material stocks	
	4.	Employee productivity rate		a - net sales	%
				b - salaries and wages	
Distribution	1.	Indicator of complaints and returns		a - value/cost of complaints and returns	%
				b - value/cost of all supplies of materials and raw materials	
	2.	Cost intensity index of transport fleet I		a - the cost of the kilometres travelled	zł/car
				b - number of means of transport	
	3.	Cost intensity index of transport fleet II		a - value/cost of transported cargo	zł/car
				b - number of means of transport	
	4.	Transport costs per tonne-kilometre		a - transport costs	zł/tkm
				b - tonne-kilometre data (tkm)	

Source: own study.

The presented list includes only selected financial indicators, which, in the author's opinion, are the most frequently used to assess the logistics processes efficiency. There may be many more indicators useful in business practice, but it should be remembered that the greater the number of indicators used in the analysis, the greater the risk of dilution of the main goal of the analysis.

Table 1.7 presents selected measures of evaluation of logistics processes efficiency in the customer perspective.

Table 1.7. Selected measures for assessing the logistics processes efficiency in the customer

Scope	No.	Measuring name	formula	Description	unit
Supply	1.	Successful order processing	$\frac{a}{b}$	a - number of completed orders	%
				b - total number of orders	
	2.	Quantitative and valuable market share		a - the size of the target customer group	%
				b - total market size	
	3.	Average delivery time		a - total delivery time	h

				b - number of deliveries	
	4.	Share of incomplete material deliveries		a - number of incomplete deliveries	%
				b - total number of deliveries	
Production	1.	Successful order processing		a - number of completed orders	%
				b - total number of orders	
	2.	Quantitative and valuable market share		a - the size of the target customer group	%
				b - total market size	
	3.	Average delivery time		a - total delivery time	h
				b - number of deliveries	
	4.	Share of incomplete product deliveries		a - number of defective deliveries	%
				b - total number of deliveries	
Distribution	1.	Timeliness index of transport operations		a - number of time-saving journeys	%
				b - total number of trips	
	2.	Index of cargo damage during transport		a - number of damaged transport units	%
				b - number of all transport units transported	
	3.	Reactivity of delivery		a - number of elements delivered before time	%
				b - total number of elements	
	4.	Share of incomplete deliveries to the customer		a - number of incomplete deliveries	%
				b - total number of deliveries	

Source: own study.

Some of the above mentioned measures are often reduced to a single indicator - OTIF (On Time and In Full delivery). This indicator should be treated as a level of customer service seen from the customer (retail) perspective - "on-time, in-full" - full orders delivered on time. In practice, OTIF has been developed with the element "error-free" - taking into account picking errors (it is quantitatively correct, but a different variant of the product has been delivered than ordered). OTIF has become a key factor for process improvement initiatives within the organization. Organizational orientation and integration planning as a result of process optimization throughout the supply chain leads to a higher level of service related to inventory reduction[24].

Table 1.8 presents selected measures of evaluation of logistics processes efficiency in the internal process perspective.

Table 1.8. Selected measures for assessing the logistics processes efficiency in the internal process perspective

Scope	No.	Measuring name	formula	Description	unit
Supply	1.	Successful material collection	$\frac{a}{b}$	a - average time of receipt of materials	h/person
				b - number of employees	
	2.	Delivery reliability		a - number of deliveries in accordance with the parameters of the contract	%
				b - total number of deliveries	
	3.	Share of defective deliveries of raw materials		a - number of defective deliveries of raw materials	%
				b - total number of deliveries of raw materials	
	4.	Delivery delays		a - number of late deliveries	%
				b - total number of deliveries	
Production	1.	Production continuity		a - downtime in the production process	%
				b - total working time	
	2.	Capacity utilisation		a - the capacity utilised	%
				b - total production capacity	
	3.	Share of waste in the production process		a - the value of raw materials classified as production process defects	%
				b - total value of raw materials	
	4.	Electricity efficiency		a - non-productive time using electricity	%
				b - total operating time of the machine	
Distribution	1.	Transport fleet load indicator		a - number of kilometres travelled	kg/car
				b - number of means of transport	
	2.	Index of transport capacity utilisation		a - the weight of the cargo transported	kg/car

[24] Sehgal S., Sahay B.S., Goyal S.K., Reengineering the supply chain in a paint company, International Journal of Productivity and Performance Management, 2006, Vol. 55 Issue: 8, pp. 668.

				b - number of means of transport	
	3.	Indicator for cargo planning		a - freight transported (mass or volume)	%
				b - the capacity or capacity of the transport fleet	
	4.	Transport-intensiveness index		a - transport time	h/ delivery
				b - total number of deliveries	

Source: own study.

The inclusion of the logistics process efficiency is most visible in the comparison of measures from the perspective of the internal process for companies. Such a state of affairs should not be surprising, as it is the processes occurring at the operational level that make the greatest contribution to the evaluation of the logistics processes efficiency.

Table 1.9 presents selected measures of evaluation of logistics processes efficiency in the learning and growth perspective.

Table 1.9. Selected measures for assessing the logistics processes efficiency in the learning and growth perspective

Scope	No.	Measuring name	formula	Description	unit
Supply	1.	Share of defective deliveries of raw materials	$\frac{a}{b}$	a - number of defective deliveries of raw materials	%
				b - total number of deliveries of raw materials	
	2.	Flexibility of deliveries		a - number of deliveries meeting special requirements	%
				b - total number of deliveries	
	3.	Reliability of deliveries		a - number of deliveries in accordance with the parameters of the contract	%
				b - total number of deliveries	
	4.	Standardization of cargo		a - number of items contained in unified consignments	%
				b- number of items contained in all loads	
Production	1.	Share of spare parts in the product		a - number of interchangeable components	%
				b - total quantity of components in the product	
	2.	Flexibility of the production process		a - number of special orders executed	%

				b - total number of special orders	
	3.	Successful design of new products		a - number of completed projects of new products	%
				b - total number of projects of new products	
	4.	Share of defective deliveries of raw materials		a - number of defective deliveries of raw materials	%
				b - total number of deliveries of raw materials	
Distribution	1.	Share of defective deliveries		a - number of defective deliveries	%
				b - total number of deliveries	
	2.	Flexibility of deliveries		a - number of deliveries meeting special requirements	%
				b - total number of deliveries	
	3.	Transport reliability		a - number of transport operations carried out on time	%
				b - total number of transport operations	
	4.	Share of damage during transport		a - number of damaged transport units	%
				b - number of defective deliveries	

Source: own study.

Measuring the logistics process efficiency from the perspective of learning and growth is the most desirable form of efficiency evaluation, and also the most difficult to develop. It is important to remember about the threats posed by development measures, which may contradict not only the business and supply chain management, but also the basic strategic objectives.

When preparing a list of measures for evaluation of logistics processes efficiency, we should remember about close relations between particular perspectives. Analyzing and developing performance evaluation measures for each of the perspectives separately may lead to the opposite situation than the expected one - one can obtain a set of indicators that exclude each other.

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2. FORECASTING

2.1. Forecast and simulation in logistics

According to APICS forecasting can be thought of as: *"...attempting to predict or project future statistics—typically, demand or sales. It requires that all factors surrounding the decision-making process are recorded. Factors that affect forecasting include sales demand patterns, economic conditions, competitor actions, market research, product mixes, and pricing and promotional activities. Forecasts can be made at strategic, tactical, and operational levels"*[25].

Forecasting constitutes the input element for planning. Taking into account management functions, it can be clearly stated that forecasting is one of the key tasks in business management and supply chains. Figure 2.1. shows a typical structure of planning processes in a production enterprise. The place of forecasting is also underlined in the structure.

[25] www.apics.org/apics-for-individuals/apics-magazine-home/resources/ombok/apics-ombok-framework-table-of-contents/apics-ombok-framework-5.4 [10.06.2019]

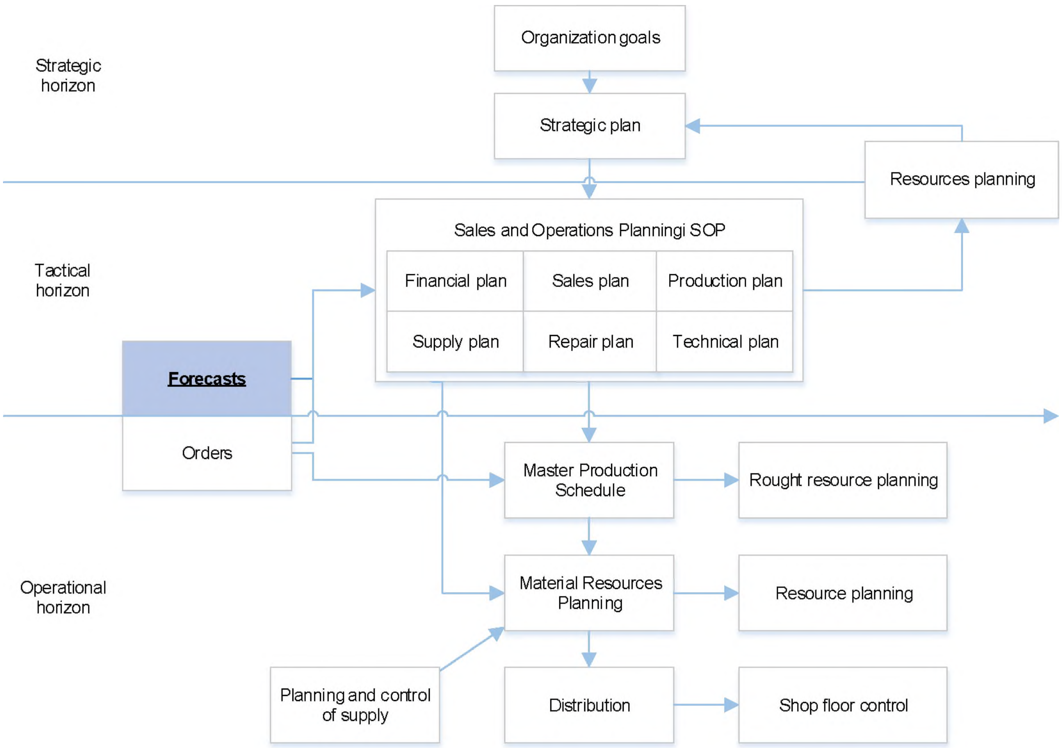

Figure 2.1. Localization of forecasts in a typical planning process structure

Source: Chapman S.N., Fundamentals of Production Planning & Control, Prentice Hall, New Jersey, 2005, p.11.

Forecasts on the presented planning structure (see Figure 2.1) are input data for both tactical and operational planning. Forecasts, as a contribution to sales and operations planning (S&OP), constitute an important element of calculating the requirements for enterprise resources in medium-term horizon (usually of one year). The importance of forecasts for the development of a S&OP is crucial. Thanks to them it is possible to plan the requirements for resources and make decisions about earlier production and to build a seasonal stock for the purpose of sales in the period of increased seasonal demand (in case of limited availability of resources). Forecasting in S&OP also allows to estimate the value of financial parameters such as planned revenues, planned costs and, as a consequence, the planned profit. Without sales forecasts, it would not be possible to develop a S&OP. Forecasts also include input data at the operational planning level (see Figure 2.1). At this level, forecasts mainly constitute input data to Master Production Schedule. Usually, Master Production Schedule is developed in companies on the basis of a mixture of customer orders (with confirmed date of delivery) and sales forecasts. Mainly it is a result of diversified customer service strategies and diversified lead time for production processes and supplies of particular parts, materials and raw materials. Without sales forecasts, it would be impossible to maintain the continuity of production and continuity of availability of finished products for customers. Forecasts are also used to control stocks of both: purchased items and finished goods for which the 'make to stock' strategy is implemented.

As can be seen above, the forecasts can play different roles in companies. These roles are particularly visible in planning processes. Forecasts can be classified in accordance with various criteria, but the most popular one is based on the time horizon for which forecasts are prepared, as it is the case in the classification of planning process. Figure 2.2 presents forecasts classified on the basis of time horizon related to organizational levels. In addition, they indicate the main tasks of these forecasts and on the level of granularity on which they focus.

Figure 2.2. Forecasting on organizational levels

Source: own study based on: apicsr.org/downloads/APICS_2013_Conference_Presentation_Materials_Perspectives/the_intricacies_of_forecasting_simplified.pdf.

Forecasting is widely used in logistics. As shown in Figure 2.2, the purposes of forecast are different at different organizational levels. Table 2.1 presents examples of decisions that may be supported by forecasting at various organizational levels.

Table 2.1. Forecasts as an input to decision making process

Type of a forecast	Decisions in the supply chain - examples
Operational forecast **Short-term forecast**	▪ calculating order quantity from supplier ▪ calculating inventory levels ▪ calculating the time to send an order to the supplier ▪ calculating the number of part-time employees
Tactical forecast **Mid-term forecast**	▪ calculating financial indicators ▪ calculating the number of full time employees ▪ calculating parameters for replenishment systems ▪ calculating resource and infrastructure needs
Strategic forecast **Long-term forecast**	▪ entering other markets ▪ entering another branches ▪ merging with another company ▪ purchasing shares in other companies

Source: own study.

In a forecasting process, simulation can also be used. Checking many variants based on historical data allows to determine the way in which the variable (i.e. demand or sales) can be shaped in the future. Simulation is a technique in which systems are modeled using a computer program designed to mimic a real system. One can run simulations before a real system becomes operational to aid in design, to see how the system might react to changes in operating rules, and to evaluate the system's response to changes in its structure[26].

According to A. Greasley, the main areas in which simulations are used include: production along with logistics and transport, as well as all investment decisions, queuing systems and customer service in a broad sense[27].

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[26] www.apics.org/apics-for-individuals/apics-magazine-home/resources/ombok/apics-ombok-framework-table-of-contents/apics-ombok-framework-6.6 [12.06.2019]
[27] Greasley A., Simulation Modelling for Business, Asgate Publishing Company, Aldershot, 2004, pp.8-10.

S. Robinson states and acknowledges that simulation support is possible with virtually any queuing system, in which the individual elements go through a series of processing steps, which in turn changes their state or state of the entire system. As part of the simulation, the system status is saved in the form of process attributes [28].

It is really important to forecasting process that according to S. Mitchell, computer simulations are an alternative for analytical solution of mathematical models. They are characterized by much greater flexibility than mathematical models, among others due to the smaller number of required assumptions and limitations with the same usefulness of the result[29].

2.2. Forecasting process

Developing a forecast is not only about determining its value based on historical data. Creating a forecast is a sequence of tasks that should be performed. Thus, forecasting is a process. According to the APICS Operations Management Body of Knowledge Framework, forecasting: *"...process predicts demand and the use of products and services so that the right quantities are ordered in advance. In forecasting, either historical demand data are transformed into future projections or a subjective prediction of the future is made or some combination of the two*"[30]. Typical tasks done in the forecasting process are presented in Figure 2.3.

[28] Robinson S., Simulation: The Practice of Model Development and Use, John Wiley & Sons, Chichester, 2004, p.10.
[29] Mitchell S., Unsimple truths: Science, complexity, policy, University of Chicago Press, Chicago, 2009, p.46.
[30] www.apics.org/apics-for-individuals/apics-magazine-home/resources/ombok/apics-ombok-framework-table-of-contents/apics-ombok-framework-5.4 [03.06.2019]

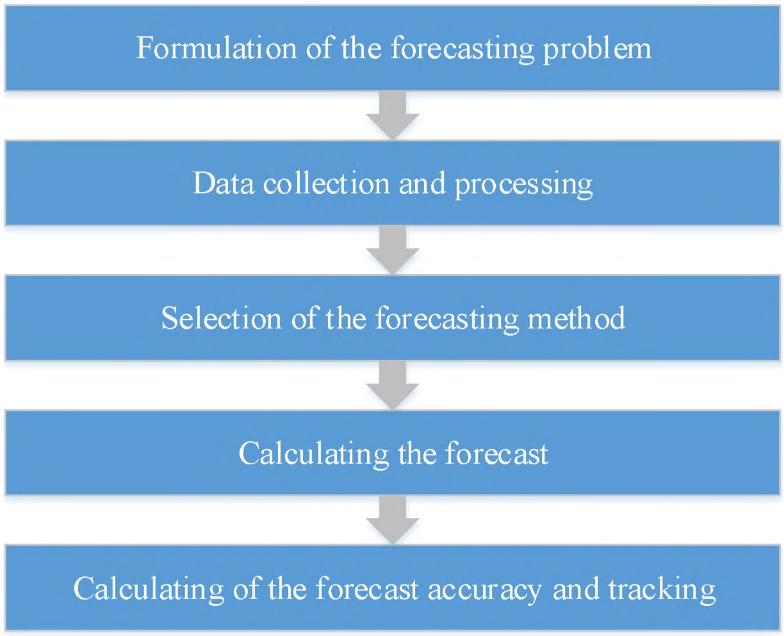

Figure 2.3. Forecasting process.

Source: own study based on: dashboardstream.com/the-6-steps-in-business-forecasting/.

Step 1

Before calculating the forecast, it is necessary to precisely define the scope of the forecast, including:

- phenomena that are forecast (e.g. sales volumes),
- the purpose in which the forecast is calculated (e.g. production planning),
- the level of aggregation which the forecast concerns (e.g. forecasting for SKU or product family),
- the forecasting period and time horizon (e.g. forecasting for months in the next year horizon),
- criteria for the acceptability of the forecast (e.g. assumed forecast accuracy, to allow making business decisions).

At this stage, it is also possible to determine the variables that may have an influence on the forecasted phenomenon. This can be illustrated by the influence of temperature and overcast on the sales of mineral water in summer periods.

Step 2

Forecast data may be broken down in an attempt to uncover the components of demand, such as trend, seasonality, as well as cyclical and random patterns. The base component reflects the demand for an item without applying the patterns. Trend is the general upward or downward movement of demand over time. Seasonality is a cyclical pattern of demand, where some in periods of the year, it is higher or lower than in others. An illustration of components of demand is shown in Figure 2.4.

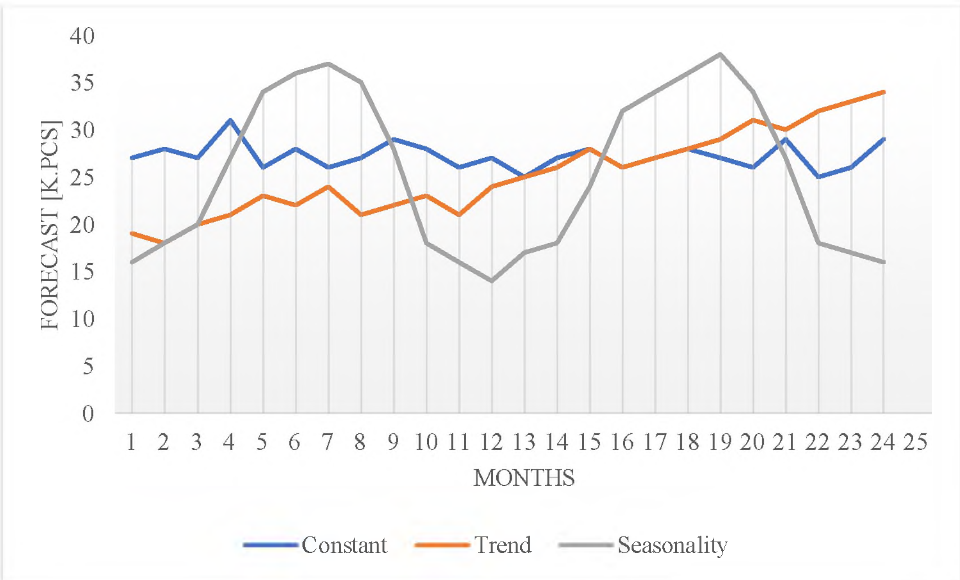

Figure 2.4. Types of demand patterns

Source: own study.

Data collection consists mainly of:

- identifying the sources of data,
- determining the periods of data collection and the person responsible for this,

- checking the quality of the data, including data completeness and reliability,

Data processing consists mainly of:

- aggregation of data to the required granularity (the degree of aggregation of data is determined in step 1),
- supplementing possible gaps in the data,
- elimination of atypical data (e.g. sales during the period of a special promotion),
- combining data (e.g. sales data from the previous model with the currently used one).

The analysis of accumulated data allows the identification of components of demand and better selection of the forecasting method in step 3. The collection and processing of data has a very large impact on the result of the entire forecasting process. Most forecasting models are quantitative models, also the quality of collected data as an input to the model directly determines the quality of the results obtained.

Step 3

In this step, the forecast should be calculated using several preferred models (due to the characteristics of historical data - see step 2). Many models are used to predict demand, such as: baseline methods, time series methods, exponential smoothing, regression analysis, the Delphi method, and brain storm or some combination of these quantitative and qualitative methods.

Baseline methods. Baseline demand is the percentage of a company's demand derived from continuing contracts with existing customers. It is usually a predictable component of demand. Time series is a technique that projects historical data patterns by looking at past forecasts and forecast errors. A time series may contain seasonal, cyclical, trend, and random components. Exponential smoothing is a forecasting technique using a weighted moving average, where past observations are adjusted according to their age. The most recent data typically are weighted the heaviest. A smoothing constant is applied to the difference between the most recent forecast and critical sales data, avoiding the necessity to maintain historical sales data. As an alternative to exponential smoothing, moving average and weighted moving average models can be employed.

Regression models. Regression models are statistical techniques used to determine the best mathematical expression that describes the relationship between a dependent variable, such as demand, and one or more independent variables[31].

After calculating forecasts with selected models (forecasts also for historical periods), forecast accuracy for historical periods can be calculated (more on this topic in Chapter 7.4). This allows for optimizing the values of the model parameters and choosing the model that has the smallest errors in historical data.

Step 4

In this step, the forecast is calculated for subsequent periods in the forecast horizon. To calculate the forecast, the model that was selected in step 3 is used.

Step 5

Step 5 consists of constant monitoring of the forecast accuracy in subsequent periods of the forecast horizon and calculation of forecasts for subsequent periods based on updated data. A frequently used solution is to determine the maximum forecast error value that is acceptable from the point of view of the process of making business decisions. If the error limit value is exceeded, it is necessary to verify the values of the forecasting model parameters or change the model itself.

2.3. Forecasting methods

Time Series Forecasting Models[32]

A time series is a set of data sorted according to the time criterion. From the logistics point of view, the time series may be: sales from the last year, aggregated in months and arranged in time order. Time series forecasting models are quantitative models of short-term forecasting. The most popular time series forecasting models are: naive model, average model,

[31] www.apics.org/apics-for-individuals/apics-magazine-home/resources/ombok/apics-ombok-framework-table-of-contents/apics-ombok-framework-5.4 [04.06.2019]
[32] Chapter based on: www.analyticsvidhya.com/blog/2018/02/time-series-forecasting-methods/ [04.07.2019]

moving average, weighted moving average, Brown model, Holt model, Winters model and analytical models.

Naive model

The naive model is the simplest of time series forecasting models. The formula used in the naive model is as follows:

$$\hat{x}_{t,r} = x_{t-1} \tag{2.1}$$

where:

$\hat{x}_{t,r}$ - forecast quantity,

x_t - real quantity.

Therefore, the naive model assumes that the forecasted value does not change. This model is suitable for forecasting stable demand.

Average model

The average model assumes that the forecast for the next period shall be equal to the average value of empirical data. The formula used in the average model is presented below:

$$\hat{x}_{t,r} = \frac{\sum_{i=1}^{n} x_t}{n} \tag{2.2}$$

where:

n - number of periods in empirical data.

An example of an average model use is presented in Table 2.2. The forecast was rounded up to an integer. It is needed due to sales data, which is always an integer. In all examples, the forecast will be rounded in the same way.

Table 2.2. Average model – an example

Period	Sales	Forecast
1	27	
2	28	**27**
3	27	(27+28)/2≈**28**
4	31	(27+28+27)/3≈**28**
5	33	(27+28+27+31)/4≈**29**

6	36	(27+28+27+31+33)/5≈**30**
7	32	(27+28+27+31+33+36)/6≈**31**
8	37	(27+28+27+31+33+36+32)/7≈**31**
9	41	(27+28+27+31+33+36+32+37)/8≈**32**
10	42	(27+28+27+31+33+36+32+37+41)/9≈**33**
11	41	(27+28+27+31+33+36+32+37+41+42)/10≈**34**
12	43	(27+28+27+31+33+36+32+37+41+42+41)/11≈**35**
13		(27+28+27+31+33+36+32+37+41+42+41+43)/12≈**35**

Source: own study.

The disadvantage of the average model is that it takes into account all data in time series and averages it. This means that the model does not detect the trend and seasonality. This model is used only in case of stable demand.

Moving average

Moving average model assumes that the forecast for the next period will be equal to the arithmetic mean of the last k observations. The formula used in moving average model is presented below:

$$\hat{x}_{t,r} = \frac{\sum_{i=t-k}^{t-1} x_t}{k} \tag{2.3}$$

where:

k - number of periods.

The example of the moving average model is presented in Table 2.3. It assumes that the value of parameter k is 3. So the average is calculated from the last three periods.

Table 2.3. Moving average model – an example

Period	Sales	Forecast
1	27	
2	28	
3	27	
4	31	(27+28+27)/3≈**28**
5	33	(28+27+31)/3≈**29**
6	36	(27+31+33)/3≈**31**
7	32	(31+33+36)/3≈**34**

8	37	(33+36+32)/3≈**34**
9	41	(36+32+37)/3≈**35**
10	42	(32+37+41)/3≈**37**
11	41	(37+41+42)/3≈**40**
12	43	(41+42+41)/3≈**42**
13		(42+41+43)/3≈**42**

Source: own study.

Moving average model is a model that can be used to calculate forecasts for trend demand. The smaller the value of parameter k, the better the reflection of the trend.

Weighted moving average

Weighted moving average model is an extended version of the moving average model. As in the moving average, the forecast is calculated as the average of the last observations, with the difference that each of these observations may have a different weight. The formula used in weighted moving average model is presented below:

$$\hat{x}_{t,r} = \sum_{i=t-k}^{t-1} x_t \cdot w_{i-t+k+1} \qquad (2.4)$$

where:

$w_{i-t+k+1}$ - weight in the i-th period

An example of using a weighted moving average model is presented in Table 2.4. It assumes that the value of the parameter k is 3 and the weights for individual data are w1 (for the oldest data) = 0.1, w2=0.3 and w3=0.6.

Table 2.4. Weighted moving average model – an example

Period	Sales	Forecast
1	27	
2	28	
3	27	
4	31	(0,1·27+0,3·28+0,6·27)/(0,1+0,3+0,6)≈**28**
5	33	(0,1·28+0,3·27+0,6·31)/(0,1+0,3+0,6)≈**30**
6	36	(0,1·27+0,3·31+0,6·33)/(0,1+0,3+0,6)≈**32**
7	32	(0,1·31+0,3·33+0,6·36)/(0,1+0,3+0,6)≈**35**

8	37	(0,1·33+0,3·36+0,6·32)/(0,1+0,3+0,6)≈**34**
9	41	(0,1·36+0,3·32+0,6·37)/(0,1+0,3+0,6)≈**36**
10	42	(0,1·32+0,3·37+0,6·41)/(0,1+0,3+0,6)≈**39**
11	41	(0,1·37+0,3·41+0,6·42)/(0,1+0,3+0,6)≈**42**
12	43	(0,1·41+0,3·42+0,6·41)/(0,1+0,3+0,6)≈**42**
13		(0,1·42+0,3·41+0,6·43)/(0,1+0,3+0,6)≈**43**

Source: own study.

Due to the use of weights, it is possible to control the influence of data from particular periods on the value of the forecast. The sum of the weights does not have to be equal to 1 (if we use dividing by the sum of weights in the formula). However, it should be remembered that the weight values are not the most important. The most important are the proportions between them.

Brown model

The Brown model is an exponential smoothing model, which means that the weights of individual observations decrease with age exponentially. The formula used in the Brown model is presented below:

$$\hat{x}_{t,r} = \alpha \cdot x_{t-1} + (1-\alpha) \cdot \hat{x}_{t,r-1} \tag{2.5}$$

where:

α - exponential smoothing coefficient with a value between [0;1].

An example of using the Brown model is presented in Table 2.5. It assumes that the parameter value α = 0.3.

Table 2.5. Brown model – an example

Period	Sales	Forecast
1	27	
2	28	
3	27	
4	31	(27+28+27)/3≈**28**
5	33	0,3*31+(1-0,3)*28≈**29**
6	36	0,3*33+(1-0,3)*29≈**31**

7	32	0,3*36+(1-0,3)*31≈**33**
8	37	0,3*32+(1-0,3)*33≈**33**
9	41	0,3*37+(1-0,3)*33≈**35**
10	42	0,3*41+(1-0,3)*35≈**37**
11	41	0,3*42+(1-0,3)*37≈**39**
12	43	0,3*41+(1-0,3)*39≈**40**
13		0,3*43+(1-0,3)*40≈**41**

Source: own study.

The Brown model is suitable for forecasting stable demand (without trend and seasonality). The model can be optimized according to the criterion of maximum forecast accuracy. Optimization is made by changing the value of parameter α, looking for a value that will maximize forecast accuracy (more on forecast accuracy in Section 2.4).

Holt model

The Holt model is a modification of the Brown model. It takes into account the trend. The formulas used in Holt model are presented below:

$$\hat{x}_{t,r} = F_n + (t-n) \cdot S_n \tag{2.6}$$

$$F_t = \alpha \cdot x_t + (1-\alpha) \cdot (F_{t-1} + S_{t-1}) \tag{2.7}$$

$$S_t = \beta \cdot (F_t - F_{t-1}) + (1-\beta) \cdot S_{t-1} \tag{2.8}$$

where:

α - exponential smoothing coefficient with a value between [0;1],

β - trend strength coefficient with a value between [0;1],

n – number of data in time-series.

An example of using the Holt model is presented in Table 1.6. It assumes that the parameter values are: α = 0.3; β = 0.6.

Table 2.6. Holt model – an example

Period	Sales	F	S	Forecast
1	27	27	28-27=1	
2	28	0,3·28+(1-0,3)·(27+1)=28,00	0,6·(28-27)+(1-0,6)·1=1,00	27+1=**28**
3	27	0,3·27+(1-0,3)·(28+1)=28,40	0,6·(28,4-28)+(1-0,6)·1=0,64	28+1=**29**
4	31	29,63	0,99	28,4+0,64≈**30**
5	33	31,33	1,42	29,63+0,99≈**31**
6	36	33,73	2,01	31,33+1,42≈**33**
7	32	34,61	1,33	33,73+2,01≈**36**
8	37	36,26	1,52	34,61+1,33≈**36**
9	41	38,75	2,10	36,26+1,52≈**38**
10	42	41,20	2,31	38,75+2,10≈**41**
11	41	42,75	1,86	41,20+2,31≈**44**
12	43	44,13	1,57	42,75+1,86≈**45**
13				44,13+1,57≈**46**

Source: own study.

The Holt model is suitable for forecasting trend demand. As in the case of the Brown model, values of α and β parameters can be optimized to maximize forecast accuracy.

Winters model

Winters model is a modification of Holt model. It takes into account the seasonality of the demand. It occurs in two variants: additive and multiplicative. The general formulas of the multiplicative Winters model are presented below:

$$\hat{x}_{t,r} = (F_n + (t-n) \cdot S_n) \cdot C_{t-1-r} \tag{2.9}$$

$$F_{t-1} = \alpha \cdot \frac{x_{t-1}}{C_{t-1-r}} + (1-\alpha) \cdot (F_{t-2} + S_{t-2}) \tag{2.10}$$

$$S_{t-1} = \beta \cdot (F_{t-1} - F_{t-2}) + (1-\beta) \cdot S_{t-2} \tag{2.11}$$

$$C_{t-1} = \gamma \cdot \frac{x_{t-1}}{F_{t-1}} + (1-\gamma) \cdot C_{t-1-r} \tag{2.12}$$

where:

α - exponential smoothing coefficient with a value between [0; 1],

β - trend strength coefficient with a value between [0; 1],

γ - seasonality coefficient with a value between [0; 1].

An example of using the Winters model is presented in Table 2.7. It assumes that the parameter values are: $\alpha = 0.4$; $\beta = 0.6$; $\gamma = 0.8$..

Table 2.7. Winters model – an example

Period	Sales	F	S	C	Forecast
1	27			27/(27+28+34+39)=0,92	
2	28			28/(27+28+34+39)=0,95	
3	34			34/(27+28+34+39)=1,15	
4	29			29/(27+28+34+39)=0,98	
5	29	29,00	(29+31+37+32)/4-(27+28+34+29)/4=2,75	0,8·(29/29,00)+(1-0,8)·0,92=0,98	
6	31	0,4·(31/0,95)+(1-0,4)·(29,00+2,75)=32,11	0,6·(32,11-29,00)+(1-0,6)·2,75=2,97	0,8·(31/32,11)+(1-0,8)·0,95=0,96	(29,00+2,75)·0,95≈ **31**
7	37	33,89	2,25	1,10	(32,11+2,97)·1,15≈ **41**
8	32	34,71	1,39	0,93	**36**
9	32	34,68	0,54	0,93	**36**
10	35	35,68	0,82	0,98	**34**
11	41	36,76	0,97	1,11	**41**
12	36	38,05	1,17	0,94	**36**
13					**37**

Source: own study.

Winters model is suitable for forecasting demand with the trend and seasonality. It is, therefore, the most comprehensive model from all models presented so far. As in the case of Brown and Holt models, the values of α, β and γ parameters can be optimized to maximize forecast accuracy.

Analytical models

Analytical models are regression models, for which the independent variable is the number of the period for which the forecast is calculated (dependent variable). The most popular analytical models include: linear, exponential and polynomial models. In Figure 1.5. an example of a linear analytical model is presented.

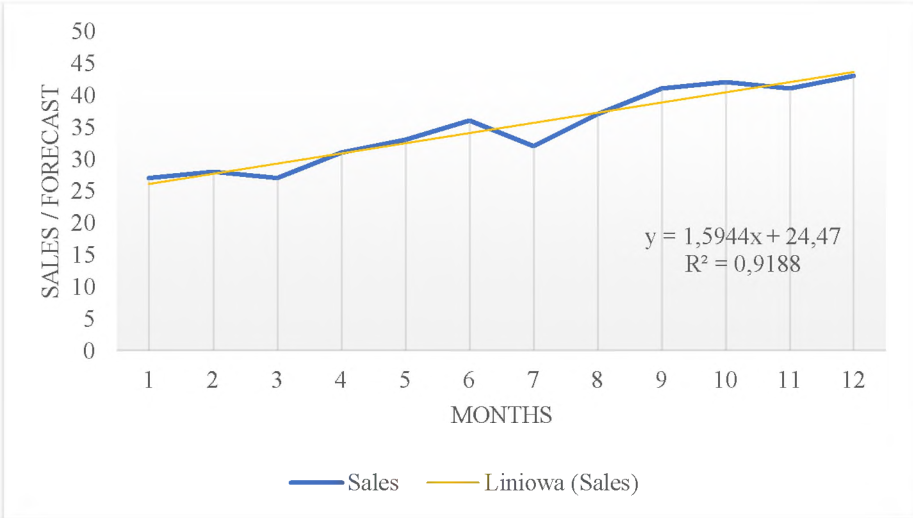

Figure 2.5. Analytical model.

Source: own study.

The presented linear analytical model is characterized by a good adjustment to empirical data, (the high value of the R2 coefficient - above 0.9). Calculation of the forecast for consecutive periods takes place by substituting in the linear function argument x by number of the period, for which the forecast is calculated.

Econometric Models

Econometric methods describe relationships between economic phenomena. The tool used in these methods is the econometric model. Econometric model is a function describing the connection of a dependent variable with independent variables. In an econometric model, parameter values are calculated using statistic methods. Regression analysis is the standard method for estimating parameter values usually of base metals which takes into account leading factors (independent variables; e.g. temperature, expenditures for promotions etc.). Therefore, a multiple regression model can be formulated as follows[33]:

$$x_t = z_0 + z_1 \cdot w_{1t} + z_2 \cdot w_{2t} + \cdots \tag{2.13}$$

As the data requirements for linear regression models are much higher than for simple time series models, it is obvious that this effort is only cost-effective if the models are used for aggregate mid-term or long-term forecast or for a few important end products.

Figure 2.6 presents an example of an econometric forecasting model. Dependent value is sales. Independent value that affects the sales volume is the average daily air temperature and the average daily overcast.

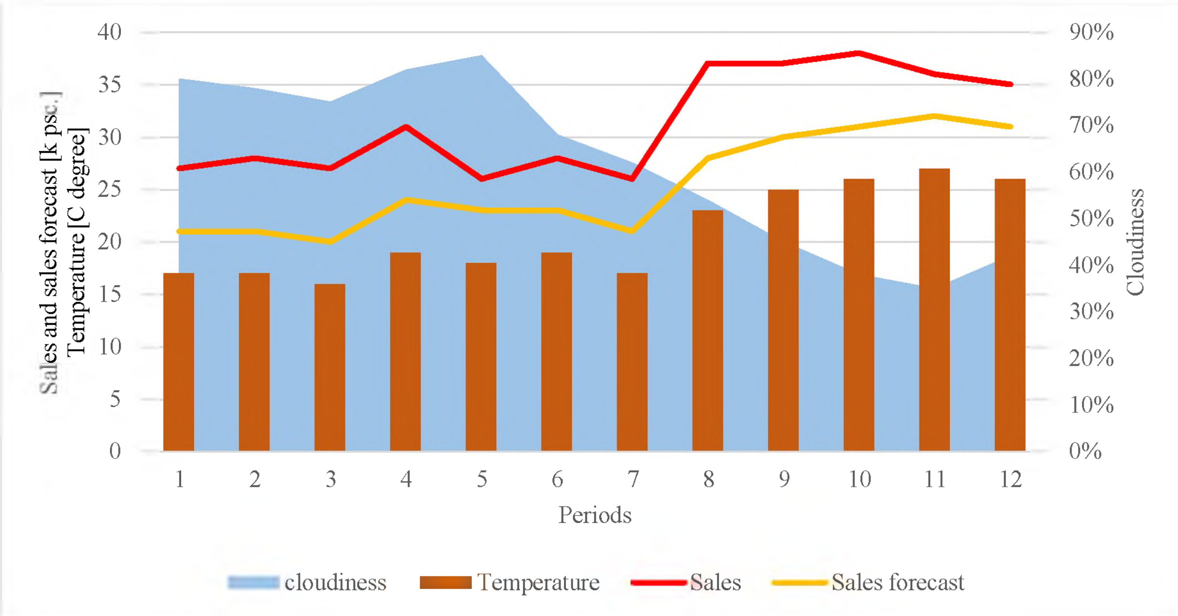

Figure 2.6. Example of regression model

Source: own study.

[33] Hanke J., Wichern D., Business forecasting (9th ed.), Pearson Education Limited, Harlow, 2014, p.84.

In the forecasting model presented in Figure 2.6., sales forecast is a function of which the arguments are: temperature and overcast. The parameters of this function have been calculated using the regression method. The formula of the function that allows to calculate the forecast sales is as follows:

$$x_t = 6{,}3655 + 1{,}7391 \cdot cloudiness_t + 1{,}1467 \cdot temerature_t \tag{2.14}$$

In the case of econometric methods, it should be underlined that forecasts are based on forecasts of other phenomena. To sum up, in the example presented above, to forecast the sales, it is necessary to forecast the values of dependent variables, i.e. temperature and overcast.

Other Models

In addition to quantitative methods, quantitative-qualitative and quality methods can also be used in forecasting. One of the groups of these methods are analog models. Analog models in forecasting have been known for many areas, for example, in weather forecasting or predicting water levels in rivers[34]. Analog models try to search for analogies between the forecasted phenomenon and other phenomena, or the same phenomenon in a different environment or in the past. For logistics purposes, analog models are used for:

- introducing of a new product to the market - sales of a similar product (fulfilling similar needs) in the past, when it was introduced on the market, as input data enabling the forecasting of sales of a new product,
- introduction of the product to another market - forecasting demand is based on data collected during the introduction of this product to another market with similar characteristics (population, wealth, needs structure).

The two methods presented below, due to labor-intensity of their implementation, apply only to long-term forecasts. The first of these methods is brainstorming, which can be used to

[34] Horton P., Obled C., Jaboyedoff M., The analogue method for precipitation prediction: finding better, Hydrology and Earth Systems Sciencess, 21, 2017: 3307–3323, p. 3314

generate opinions about the forecasted phenomenon. The brainstorming method is characterized by[35]:

- team work - during the session, each person taking part in it can express their own opinions about the forecasted phenomenon;
- people taking part in the session should be prepared for it or have knowledge on the discussed issues;
- separating the phase of generating opinions from the phase of its evaluation - which allows session participants to express themselves in an unrestrained manner.

Brainstorming can be used in logistics to predict long-term trends, which can be used in the development of company's strategy.

Another method used in long-term forecasting is the Delphi method. The Delphi method differs from the brainstorming because only experts in a given field are invited to the group of people expressing their opinion on a given topic. These experts do not meet. The survey form is delivered to them (by post or by email) thanks to which they retain full anonymity (they do not know who else participates in the study). In this method, the opinion of the majority of experts is treated as a forecast[36].

2.4. Forecast efficiency

Forecasting can be thought of as predicting the future based on historical data. The domain of prediction is that one has to assume its imperfection. Thus, forecasts also have errors. Main factors which have influence on forecast errors include[37]:

- the time delta between forecast and reality - forecasting is aiming at providing information about future shipments, sales etc. Under normal circumstances, it is easier to determine near future than the far away future. Thus, the forecast accuracy strongly

[35] Wilson C., Brainstorming and Beyond, A User-Centered Design Method (1st Edition), Morgan Kaufmann, Burlington, 2013, p. 24.
[36] Okoli C., Pawlowski S.D., The Delphi method as a research tool: an example, design considerations and applications, Information & Management, 42(1), 2004: 15-29, p. 19.
[37] Stadler H., Kilger C., Meyr H. (Eds.) Supply chain Management and Advanced Planning, Concepts, Models, Software and Case Studies, 5th edition, Sprnger-Verlag, Berlin Heilderberg, 2015, p.142.

depends on the time between the forecast creation and the time that is being forecasted. For example, consider a forecast for the sales volume in June this year. The sales forecast for the month of June that has been created in March has a lower a accuracy then a forecast created in May,

- the forecast granularity - the level of aggregation also has a strong impact on the forecast accuracy. Take sales forecasts again as an example. It is easier to forecast the total sales volume for all products for all geographic areas and for a complete fiscal year than to forecast on a weekly basis lower-level product groups for all regions individually. Thus, the forecasts accuracy normally decreases if the forecast granularity increases.

Forecasts efficiency can be assessed using a variety of methods. The most popular of them include:

- measure of overall fitness of forecasting model to historical data,
- analysis of the forecasts accuracy.

R-squared metric can be use to measure overall fitness of forecasting model in relation to historical data. R-squared is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determination for multiple regression[38]. R-squared can be calculated as follows:

$$R^2 = \frac{\Sigma(\hat{x}_{t,r} - \bar{x}_t)^2}{\Sigma(x_t - \bar{x}_t)^2} \tag{2.15}$$

where:

$\hat{x}_{t,r}$ - forecast quantity,

x_t - real quantity,

$\bar{x}_t$- average value of quantity.

R-squared is always between 0 and 100%:

[38] blog.minitab.com/blog/adventures-in-statistics-2/regression-analysis-how-do-i-interpret-r-squared-and-assess-the-goodness-of-fit [03.07.2019]

- 0% indicates that the model does not explain any variability of the response data around its average,
- 100% indicates that the model explains all the variability of the response data around its average.

An example of how the forecasting model can fit historical data is presented in Figure 2.7.

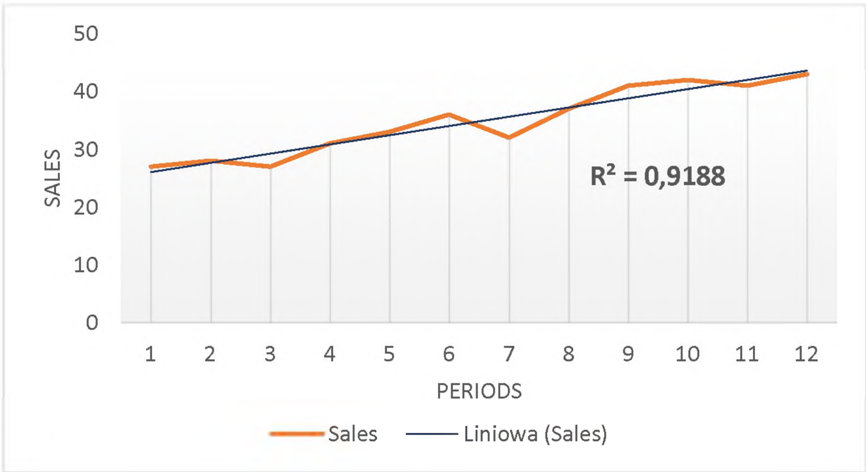

Figure 2.7. Adjustment of linear forecasting model to historical data

Source: own study.

Forecast accuracy is the second method which can be use to asses forecasts efficiency. The first step is to define a basic metric for the accuracy of the forecast at the same level of demand planning structures. Based on basic metrics, aggregated metrics can be computed. Note that the aggregate measures cannot be computed directly on the aggregated level of the demand planning structures as in this case shortage and excess planning would level out[39]. A basic metric used to measure the forecast accuracy must have the following properties[40]:

[39] Stadler H., Kilger C., Meyr H. (Eds.), Supply chain Management and Advanced Planning, Concepts, Models, Software and Case Studies, 5th edition Springer-Verlag, Berlin Heilderberg, 2015, p.142
[40] Eickmann L., Bewertung und Steuerung von Prozessleistungen des Demand Plannings Supply chain Mangement, 4(3), 2004: 37-43, p.41.

- It must be certain that the domain of the metric is positive (otherwise positive and negative values would compensate when being aggregated). The metric must be standardized (values between 0 and 100%);
- All key figures (time series) required for the computation of the basic metric and for its aggregation must be available for all instances off the planning structures, all products, customers, time baskets etc., for example, in time series representing historic values might be not available for all instances of the planning structures because new products may not have historic prerequisites;
- It must be possible to get the buy-in of all involved departments in the organization regarding the definition of the basic metric. For example, if the "delivered quantity ex-works" is used as a reference to measure that forecast accuracy, sales might not commit to this metric as sales cannot be made responsible for a low delivery service of production.

All accuracy measures based on a forecast error which is defined as a difference between forecast quantity $\hat{x}_{t,r}$ and real quantity x_t:

$$e_{t,r} = \hat{x}_{t,r} - x_t \tag{2.16}$$

To measure the forecasts accuracy for individual periods, the following measures are used:

Squared error:

$$SE_{t,r} = e_{t-r}^2 \tag{2.17}$$

Absolute deviation:

$$AD_{t,r} = |e_{t,r}| \tag{2.18}$$

Absolute percentage error:

$$APE_{t,r} = \frac{|e_{t,r}|}{x_t} \cdot 100\% \tag{2.19}$$

The basic forecast accuracy metrics must be aggregated in order to enable the controlling of the demand planning process. One can distinguish between aggregation along time dimension and aggregation along the products and geography dimension. In that chapter only aggregation along time dimension will be presented. There are many methods to aggregate the forecast accuracy or the forecast error by time. Each measure is calculated for fixed horizon n (in the past) which has to be defined by the planner. If the horizon is short, then the value reacts fast to deviations from the average. However, it also may fluctuate heavily due to random demand variations[41]. The following measures are common in practice[42].

Mean squared error:

$$MSE_r = \frac{1}{n}\sum_{t=1}^{n} e_{t-r}^2 \quad (2.20)$$

Mean absolute deviation:

$$MAD_r = \frac{1}{n}\sum_{t=1}^{n} |e_{t,r}| \quad (2.21)$$

Mean absolute percentage error:

$$MAPE_r = \left[\frac{1}{n}\sum_{t=1}^{n} \frac{|e_{t,r}|}{x_t}\right] \cdot 100\% \quad (2.22)$$

Root mean square error:

$$RMSE_r = \sqrt{\frac{1}{n}\sum_{t=1}^{n} e_{t-r}^2} \quad (1.23)$$

In Table 1.8 examples of calculation of forecast accuracy indicators are presented. The values for both: individual periods and the values for aggregated indicators are presented.

Table 2.8. Example of forecasts accuracy

Period	Sales	Forecast	e	SE	AD	APE
1	27	27	0	0	0	0%
2	28	28	0	0	0	0%
3	27	30	3	9	3	11%
4	31	31	0	0	0	0%
5	33	33	0	0	0	0%
6	36	35	-1	1	1	3%
7	32	36	4	16	4	13%
8	37	38	1	1	1	3%

[41] Stadler H., Kilger C., Meyr H. (Eds.), Supply chain Management and Advanced Planning, Concepts, Models, Software and Case Studies, 5th edition Springer-Verlag, Berlin Heilderberg, 2015, p.143
[42] Stadler H., Kilger C., Meyr H. (Eds.), Supply chain Management and Advanced Planning, Concepts, Models, Software and Case Studies, 5th edition Springer-Verlag, Berlin Heilderberg, 2015, p.143

9	41	39	-2	4	2	5%	
10	42	41	-1	1	1	2%	
11	41	43	2	4	2	5%	
12	43	44	1	1	1	2%	
				MSE	**MAD**	**MAPE**	**RMSE**
				3,08	1,25	4%	1,76

Source: own study.

Interpretation of the values of forecast accuracy presented in Table 2.8 needs to be clarified. While the values of indicators of the accuracy of individual forecasts are clear, many difficulties are connected with the interpretation of aggregate measures. MSE determines the average square error. The use of a square measure means that larger errors have much more weight on the value of aggregate errors than in the case of MAD where the measure of absolute value is used. The selection of the aggregate forecast accuracy measure depends on the company's needs. It is impossible to objectively indicate better and worse measures. In case of inventory management, the RMSE is a frequently used measure. This meter, due to its characteristics, is used in the formula for safety stock, alternatively with the standard deviation of demand (calculated from historical data). It should be remembered that the values of various indicators cannot be compared with each other.

Analysis of forecast accuracy is very important in the context of improvement of forecasting models. Many of the forecasting models are parametric models. The values of parameter of these models have a key impact on the result and, thus, on the value of the forecast. Analysis of forecast accuracy allows to choose parameter values for which the forecast errors are minor. Forecast accuracy analysis, of course, goes back to the past. However, in the forecasted process, it should be assumed that if, for a given parameter values, the errors were minor in the past, it should be assumed that the same parameter values will be the best in the future. Therefore, the current tracking of forecast error values and the correction of the values of forecasting model parameters allows for maintaining high efficiency of the forecasting process understood as providing reliable data for planning processes.

2.5. Collaborative forecasting

CPFR (ang. Collaborative Planning, Forecasting and Replenishment) was developed by practitioners in the mid-1990s as Collaborative Forecasting and Replenishment (CFAR), being defined at that time as a "new" interorganizational system that enabled retailers and manufacturers to jointly forecast demand and schedule production, allowing exchange of complex decision support models and manufacturing/retailer strategies. Later the concept was renamed into CPFR to emphasize the main role of planning. The first CPFR pilot project was conducted by Wall-Mart, Warner-Lambert, SAP, Manugistics and Benchmarking Partners[43].

CPFR helps improve the quality of forecasting and cooperation between companies in the supply chain. It is based on intensive cooperation between companies in the supply chain and is a modern tool that supports their activities, in particular by improving their demand planning, order forecasting and resource planning and decision making processes in the area of stock replenishment[44].

The need for joint action in planning, forecasting and replenishing is justified by the fact that different parties in the supply chain tend to build up their own safety stock. This results in a significant increase in the level of stocks throughout the supply chain, often disproportionately to the needs. It is also connected with a significant increase of costs of long-term maintenance of inventories, which, in turn, is the reason for the increase in prices of offered products. Establishing cooperation between co-operators in the supply chain, based on mutual exchange of information on production forecasts and plans, sales and stocks, helps to reduce or even eliminate such undesirable situations.

Therefore, the primary goal of implementing and using CPFR is to increase the productivity of supply chains mainly by reducing the total level of inventory, while ensuring an increase in customer service level. In order to achieve this goal one needs to significantly improve the accuracy of demand forecasting. It is possible thanks to the mutual exchange of

[43] Hollmann R.L., Scavarda L.F., Tavares Thomé A.M., Collaborative planning, forecasting and replenishment: a literature review, International Journal of Productivity and Performance Management, 64(7), 2015: 971-993, p. 984.
[44] Danese P., Designing CPFR collaborations: insights from seven case studies, International Journal of Operations & Production Management, 27(2), 2007: 181-204, p. 183.

data between cooperating companies and providing them with easy access to information, in particular to:

- forecasts of demand (for material and final goods) made by partners in the supply chain,
- promotion schedules with individual forecast for an each promotional event (for each stock keeping unit – SKU),
- current sales data (from electronic cash terminals - EPOS) used in updating forecasts and replenishment plan,
- current level of stock (for each SKU).

Main areas in which CPFR is described in scientific literature are[45]:

- relationships in the supply chain,
- increase in performance,
- information sharing,
- information technology,
- lead time reduction,
- reduction of bullwhip effect,
- collaborative forecasting,
- inventory management.

The tasks of cooperation in CPFR should be divided by partners in the supply chain. Figure 2.8. shows the dedicated tasks for manufacturers and retailers.

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[45] Demiray A., Akay D., Tekin S., Boran F.E., A holistic and structured CPFR roadmap with an application between automotive supplier and its aftermarket customer,International Journal of Advance Manufacturing Technology, 91, 2017:1567–1586, p. 1569.

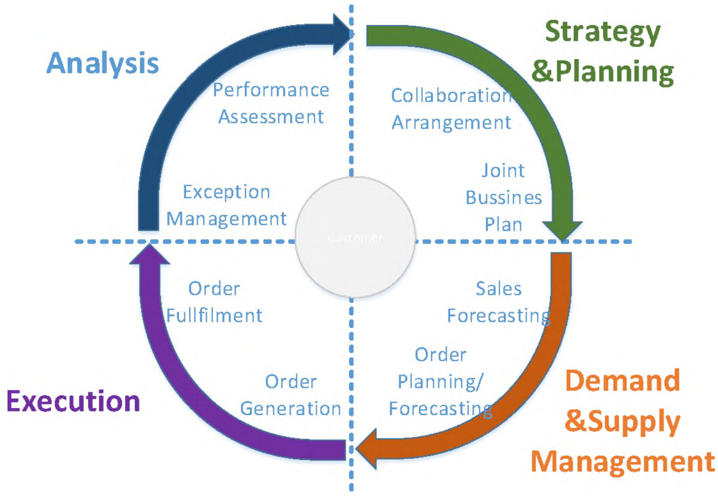

Figure 2.8. Manufacturer and Retailer Tasks

Source: Voluntary Interindustry Commerce Standards (VICS) VICS, Collaborative Planning, Forecasting and Replenishment (CPFR) - An overview, 2004 https://www.gs1us.org/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=492&language=en-US&PortalId=0&TabId=134 [10.06.2019].

Figure 2.8.shows four main areas of cooperation between manufacturer and retailer in the CPFR model[46]:

- Strategy & Planning – establish the ground rules for the collaborative relationship, determine product mix and placement and developed event plans for them,
- Demand & Supply Chain Management – project consumer (point-of-sale) demand as well as order and shipment requirement over the planning horizon,
- Execution – place orders, prepare and deliver shipment received and stock products on the retail shelves, record sales transactions actions and make payments,
- Analysis – monitor planning and execution activities for the exception conditions.

[46] Voluntary Interindustry Commerce Standards (VICS) VICS, Collaborative Planning, Forecasting and Replenishment (CPFR) - An overview, 2004 https://www.gs1us.org/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=492&language=en-US&PortalId=0&TabId=134 [10.06.2019]

The implementation of the joint planning method for forecasting and restocking requires a structured process. This allows partners in the supply chain to work together. In accordance with the guidelines, the CPFR process was divided into 9 steps[47]:

1. Develop a front-end agreement.
2. Create a joint business plan.
3. Create sales forecast.
4. Identify Exceptions for the Sales Forecast.
5. Resolve/Collaborate on Exception Items.
6. Create Order Forecast.
7. Identify Exceptions to the Order Forecast.
8. Resolve/Collaborate on Exception Items.
9. Order Generation.

The companies that operate in accordance with the CPFR technique are satisfied with the results of the outlays made and achieve many benefits, among which one should mention:

- information sharing has limited impact on the profitability, and the majority of benefits derived are related to the collaborative practices rather than information sharing, especially for the manufacturers above industry-average increase in sales[48],
- CPFR process can modify the common processes with the consideration of engineering change control, and achieved a significant decrease at inventory levels, lead times, and shortages[49],
- CPFR can be more beneficial than VMI (Vendor Manage Inventory) since CPFR produces lower supply chain cost, while it achieves higher customer service[50],

[47] Collboration Synergis Inc., Collaborative Planning, Forecasting and Replenishment CPFR, Vancuver, p. 9.
[48] Kulp S.C., Lee H.L., Ofek E., Manufacturer benefits from information integration with retail customers. Manag Sci 50(4), 2004: 431–444, p.442.
[49] Chung W.W.C., Leung S.W.F., Collaborative planning, forecasting and replenishment: a case study in copper clad laminate industry, Production Planning Control, 16(6), 2005:563–574, p.567.
[50] Sari K., On the benefits of CPFR and VMI: a comparative simulation study. International Journal of Production Economics, 113(2), 2008: 575–586, p.582.

- CPFR strategy is successful if the demand variability is high, production capacity is low, and backorder penalty cost and delivery lead time are high[51].

These effects have been achieved through the implementation of an institutionalized process of comprehensive exchange of relevant information between trading partners, ensuring the timely flow and timeliness of data and taking action, in particular, in the interest of consumers.

The CPFR technique allows for the application of specific solutions regulating the principles of cooperation in the area of stockpile management(like the VMI and the CMI Co-Managed Inventory methods.

[51] Kamalapurkar D., Benefits of CPFR and VMI collaboration strategies in a variable demand environment. Western Michigan University, Michigan, 2011, p. 127.

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[3] Collboration Synergis Inc., Collaborative Planning, Forecasting and Replenishment CPFR, Vancuver.

[4] Danese P., Designing CPFR collaborations: insights from seven case studies, International Journal of Operations & Production Management, 27(2), 2007: 181-204.

[5] Demiray A., Akay D., Tekin S., Boran F.E., A holistic and structured CPFR roadmap with an application between automotive supplier and its aftermarket customer,International Journal of Advance Manufacturing Technology, 91, 2017:1567–1586.

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[9] Hollmann R.L., Scavarda L.F., Tavares Thomé A.M., Collaborative planning, forecasting and replenishment: a literature review, International Journal of Productivity and Performance Management, 64(7), 2015: 971-993.

[10] Horton P., Obled C., Jaboyedoff M., The analogue method for precipitation prediction: finding better, Hydrology and Earth Systems Sciencess, 21, 2017: 3307–3323.

[11] Kamalapurkar D., Benefits of CPFR and VMI collaboration strategies in a variable demand environment. Western Michigan University, Michigan, 2011.

[12] Kulp S.C., Lee H.L., Ofek E., Manufacturer benefits from information integration with retail customers. Manag Sci 50(4), 2004: 431–444.

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[14] Okoli C., Pawlowski S.D., The Delphi method as a research tool: an example, design considerations and applications, Information & Management, 42(1), 2004: 15-29.

[15] Robinson S., Simulation: The Practice of Model Development and Use, John Wiley & Sons, Chichester, 2004.

[16] Sari K., On the benefits of CPFR and VMI: a comparative simulation study. International Journal of Production Economics, 113(2), 2008: 575–586.

[17] Silver E., Pyke D., Peterson R., Inventory management and production planning and scheduling (3rd edition), Willey, New York, 199.

[18] Stadler H., Kilger C., Meyr H. (Eds.) Supply chain Management and Advanced Planning, Concepts, Models, Software and Case Studies, 5th edition, Sprnger-Verlag, Berlin Heilderberg, 2015.

[19] Voluntary Interindustry Commerce Standards (VICS) VICS, Collaborative Planning, Forecasting and Replenishment (CPFR) - An overview, 2004.

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[3] dashboardstream.com/the-6-steps-in-business-forecasting/

[4] www.analyticsvidhya.com/blog/2018/02/time-series-forecasting-methods/

[5] www.apics.org/apics-for-individuals/apics-magazine-home/resources/ombok/apics-ombok-framework-table-of-contents/apics-ombok-framework-5.4

[6] www.apics.org/apics-for-individuals/apics-magazine-home/resources/ombok/apics-ombok-framework-table-of-contents/apics-ombok-framework-6.6

3. OPERATIONS RESEARCH AND OPTIMIZATION THEORY

3.1. Introduction to operations research and optimization theory

3.1.1. Operations research

According to the definition, operations research "(often referred to as management science) is simply a scientific approach to decision making that seeks to best design and operate a system, usually under conditions requiring the allocation of scarce resources."[52] Otherwise, operations research can be defined as "(…) is a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations their control."[53] Operations research (henceforth, OR) is most often used by managers of many enterprises to support the decision-making processes. Their major assumption is to enable decisions on the processes of assigning tasks to individual employees or route planning in such a manner so as to minimize transportation costs and maximize the use of company's resources. Operations research are methods that allow identification of any disturbances affecting the implementation of processes and enable their elimination. Their main objective is to analyze the current state and to propose decisions that provide opportunities primarily to increase the effectiveness of managerial decisions.

Operations research was first used by the British government during World War II, when the resources available to the British army were significantly reduced. Operations research has contributed to increasing the efficiency of resource use and to the greater effectiveness of problem solving. Modern methods of problem solving, at that time, were based on a tool known as 'brainstorming', performed by experts in specific fields and developed into linear programming methods that were used in the 1940s[54].

Operations research most often uses such problem solving methods as mathematical modeling, statistics or special algorithms, the use of which serves to solve decision problems by indicating

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[52] Winston W. L., Operations Research Applications and a algorithms, Brooks/Cole, Toronto 2004, p. 1.
[53] Morse P. M., Kimball G. E., Methods of Operations Research, Dover Publications, New York 2012, p. 2.
[54] Murthy P. R., Operations Research, New Age International (P) Ltd., New Delhi 2007, pp. 1-4.

decisions that result in pursuing a certain maximum (e.g. in case of profits or customer service level) or a minimum (e.g. in case of costs or level of risk)[55].

Operations research is very often employed as part of managerial processes to optimize the use of resources, which include both material and human resources. Management processes nowadays require making real-time decisions that determine not only the company's financial result, but also its position on the market. Decision-making processes, to a large extent, refer to the necessity of making decisions appropriate for a given organization and market conditions[56].

Operations research is not only focused on solving problems and developing solutions and decisions to be taken or management processes, but also refers to the effectiveness of the system used in a given enterprise. Operations research focuses mainly on showing the user of the system what an optimal solution is in decision-making processes. Individual tools in the field of OR, and optimization theory are frequently used to support systems in which the user plays a decisive role. In addition, OR supports systems in the identification of those areas of its activities that are characterized by low effectiveness of action and allow the development of tools of which the primary purpose is to increase the profits resulting from its application[57].

Operations research usage can be characterized by the possibility of supporting all processes and subprocesses performed within a given system, not only its individual parts, which is certainly one of its most important functionalities[58]. Operations research should be provided by an interdisciplinary team composed primarily of experts from various fields, whose cooperation should result in achieving the optimal solution for the system[59].

Speaking about operations research, it is necessary to clearly specify to what extent their methodology applies. Firstly, operations research, as the name suggests, relate to operations performed in a given organization. More specifically, OR refers to individual activities that are performed as part of many business processes performed both within enterprises and as part of entire supply chains cooperating in different activity areas. Operations research refers to storage

[55] Abid M., Operation Research for Management, Global India Publications, New Delhi 2008, p. 1.
[56] Winston W. L., Operations Research Applications and a algorithms, Brooks/Cole, Toronto, p. 1.
Abid M., Operation Research for Management, Global India Publications, New Delhi 2004, p. 1.
[57] Derigs U., OPTIMIZATION AND OPERATIONS RESEARCH – Volume I, EOLSS Publications, Oxford 2009, p. 5.
[58] Abid M., Operation Research for Management, Global India Publications, New Delhi 2008, p. 2.
[59] Derigs U., OPTIMIZATION AND OPERATIONS RESEARCH – Volume I, EOLSS Publications, Oxford 2009, p. 5.

processes, transport processes, production processes, financial and management aspects. In other words, operations research and optimization theory are most often used for production planning, transport planning, and planning or inventory management. Operations research is very often also used as part of purchasing activities, financial management of the enterprise, human resources management, marketing or analytical activities.

The name of the research refers to the use of mathematical models applied by many organizations to support the decision-making processes implemented by enterprises employing OR[60].

According to M. Abid, operations research use improves performance of the processes presented below[61]:

- designing effective arrangement of workplaces in the production hall,
- planning the flow of goods in the production process,
- planning the assignment of tasks to workstations,
- planning the allocation of tasks to employees,
- route planning due to the minimization of costs.

A. M. Natarajan and P. Balasubramani point out several areas of technological application of operational research in industry and logistics, which include[62]:

- optimization of system design processes,
- planning, organizing, scheduling and monitoring of production processes,
- management of the organization's inventory and the entire supply chain,
- planning the allocation of employees to workstations,
- planning workstations to carry out procedural tasks,
- allocation of resources to maximize profit or minimize costs,
- optimization processes of the design of transport supporting systems, resource management as well as control and monitoring processes.

[60] Hiller F. S., Lieberman G. J., Introduction to Operations Research, The McGraw-Hill, New Delhi 2001, p. 2. Jardine A. K. S., Operational Research in Maintenance, Manchester University Press, New York 1970, p. 9. Natarajan A. M., Balasubramani P., Operations Research, Pearson Education India, New Delhi 2006, p. 4.
[61] Abid M., Operation Research for Management, Global India Publications, New Delhi 2008, p. 2.
[62] Natarajan A. M., Balasubramani P., Operations Research, Pearson Education India, New Delhi 2006, p. 7-8.

Operations research very often practices various models, for example mathematical models, which allow essentially to reflect the existing system in order to verify its correctness, identify all system limitations, as well as problems preventing a satisfactory level of its effective application. As part of modeling processes, specific stages can be distinguished, the implementation of which allows not only effective recognition of system problems, but also their compensation[63]:

1) Identification of system problems.
2) Implementation of the model, within which system parameters, all elements and dependencies, which from the process point of view, influence its realization, should be determined.
3) Performing tests and analyzes that support identification and solving activities that do not add value to the process.
4) Analysis, evaluation of results and implementation of the model.
5) System control and conditional reuse of the model.

The most common techniques used in operational research should include[64]:

- linear programming – the most frequently used methods within OR, assume the possibility of presenting both the process and all problems that prevent the achievement of a satisfactory financial result of the enterprise in the form of a linear function,
- integer programming – constitutes a development of linear programming assuming the imposition of additional floating elements on the results of operations research; the main aspect here is the fulfillment of the condition of integers for the results of the objective function,

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[63] Panneerselvam R., Operations Research, PHI Learning Pvt. Ltd, New Delhi 2006, p. 3
[64] Mustafi C. K., Operations Research Methods And Practice, New Age International, New Delhi 2006, p. 5.
Panneerselvam R., Operations Research, PHI Learning Pvt. Ltd, New Delhi 2006, p. 4.
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Ravindran A. R., Operations Research and Management Science Handbook, CRC Press, New York 2016, p. 9-1.
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Lock D., The Essentials of Project Management, Gower Publishing , Hampshire 2007, p. 1.

- distance related network techniques – mainly used in transport issues by identifying and indicating the optimal transport route, so as to minimize costs or maximize profits; these techniques also apply to the traveling salesman problem,
- project management – used in the analysis of activities performed at subsequent stages of the process in order to identify their limitations, develop improvements, and later plan for the enforcement of these processes, implementation of solutions and control of all activities performed by the organization, the effective deployment of which results in reduction of the process cycle and the amount of costs generated,
- inventory control – used primarily for effective inventory management that guarantees an adequate level of service while minimizing maintenance costs and stockpiling,
- dynamic programming – used to simplify the processes performed in the organization by optimizing the subprocesses executed as part of the main process; a process is broken down into a sequence of subprocesses and the solutions to subprocesses are stored in case they need to be used later on
- queueing theory – used in system optimization processes in queue creation situations.
- replacement analysis – concerns the usability time of model employment defined in the context of minimizing costs policy,
- game theory – handles resolving conflict situations that occur as part of interaction events between users authorized to make decisions,
- simulation – reflecting the flow of the actual process with the use of simulation software to recognize all activities that do not generate added value and to eliminate them from the process,
- scheduling – planning the distribution of individual operations and activities necessary to implement the process over time,
- nonlinear programming – in contrast to linear programming, objectives functions are non-linear functions.

Operations research is very often used to optimize processes performed within supply chains. Most often, the procurement processes, production management, transport management and distribution management are optimized.

Within the OR use, six phases implemented by organizations, should be distinguished[65]:

1) Identification of the system environment – largely based on mapping the actual system with the aid of an appropriate tool to recognize its functionality and limitations.
2) Problem analysis – performed in order to identify the sources of problems, as well as their impact on the process. Proper recognition and analysis of problems is a prerequisite that needs to be accomplished in order to guarantee achieving such assumptions as increasing the efficiency of the system and eliminating distortions.
3) Creating a model – its purpose is to reflect the system and test solutions, as well as decisions that ensure process improvement. The model should include the system, all dependencies between its elements and users, as well as system interactions with the environment.
4) Selection of parameters and batch data – this phase is crucial from the point of view of the effective use of the created model . Only the deployment of appropriate data and parameters results in an effective application of the created model.
5) Control of introduced solutions – includes a test phase that allows to modify parameters and input data to effectively use the created model. This phase specifies the possibility of implementing the model in organizational conditions, and also verifies the possibility of achieving organizational objectives of the company.
6) Implementation of the system and its control – every time a new system is implemented, it is necessary to periodically monitor the implementation effects and, if necessary, take actions to improve.

3.1.2. Optimization theory

The concept of optimization focuses primarily on finding optimal, and therefore the best in given conditions, solutions that ensure the organization of the implementation of previously assumed strategic, tactical and operational aims. Optimization assumes finding specific parameter values (most often these are numerical parameters – values), the use of which

[65] Natarajan A. M., Balasubramani P., Operations Research, Pearson Education India, New Delhi 2006, pp. 7-8.

guarantees the achievement of assumptions of minimization or maximization (depending on the purpose) of the indicated objective function[66].
According to the definition, optimization is a "(...) discipline within applied mathematics that deals with optimization problems, or so-called mathematical programs."[67] In other words, optimization is "(...) the act of obtaining the best result under given circumstances."[68] The concepts of operations research and optimization theory are repeatedly used interchangeably, but they are not exactly identical. As described in the previous chapter, operations research is usually used to solve decision problems, compensation of which consists in creating an appropriate decision model and, if necessary, its periodic modification. Optimization theory, although its very similar by definition to the essence of operations research, it does not use ready-made schemes or algorithms. In operations research, those schemes and algorithms only require the introduction of data and parameters appropriate for the systems and thus, are ready to make a decision. Optimization theory focuses rather on solving problems, i.e. their optimization[69].

Many areas of business operations of enterprises and entire supply chains use solutions in the field of optimization theory. This is due to the increasingly rapid development of mathematical programming methods, more and more often using IT systems supporting optimization techniques. Tools used in the application of optimization theory include methods used also by operations research, however, in case of optimizing processes, the optimal value is always sought to guarantee the implementation of the assumed optimization purpose, thus, not using the calculation models created so far[70]. The most important of them will be presented in the next chapters.

Very often, to effectively optimize processes implemented in logistics companies, it is necessary to use both issues and computational methods in the field of operations research and optimization theory. Due to the scope of both concepts as well as blurring differences between

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66 Rangaiah G. P., Multi-Objective Optimization: Techniques and Applications in Chemical Engineering, World Scientific, Singapore 2009, p. 1.
67 Derigs U., OPTIMIZATION AND OPERATIONS RESEARCH – Volume I, EOLSS Publications, Oxford 2009, p. 2.
68 Rao S. S., Engineering Optimization: Theory and Practice, Wiley, New York 1996, p. 1.
69 Derigs U., OPTIMIZATION AND OPERATIONS RESEARCH – Volume I, EOLSS Publications, Oxford 2009, p. 2.
70 Hubertus Th. Jongen H. T, Meer K., Triesch E., Optimization Theory, Springer, Berlin 2007, p. X.

concepts, in most areas related to the decision problem one should consider both OR and OT issues. Operations research is used to build a model, often mathematical, as part of the decision-making process by systematically using computational methods in the field of optimization theory. ORs are based on created models, while optimization theory uses techniques developed on the basis of operations research, however their goal is to optimize the process. Therefore, although not such concepts as operations research and the optimization theory can not be used interchangeably, they should be treated as complementary concepts, especially in terms of methods and techniques used to optimize logistics processes.

Due to the high availability of publications in the field of operations research and optimization theory, it was decided to present in the following chapters the most frequently used tools and computational examples, the selection of which is justified primarily by the possibility of reference to problems that often appear in supply chain management processes. These examples include, first and foremost, an open and closed transport problem, a traveling salesman problem, and resources allocation for particular tasks. The authors of this handbook deem it appropriate to focus on the above-mentioned problems and the methods and tools most often used to calculate them because of the desire to present problems along with ways to optimize them in a clear and transparent manner, enabling the reader to understand the issues of operations research and optimization theory relating to the management of processes implemented within the supply chain.

3.2. Operations research and optimization theory in logistics

3.2.1. Linear programming

Decision problems that are solved with the use of linear programming methods which assume that both the form of the objective function and constraining conditions make linear function. Linear programming, which is one of the mathematical models, most often refers to the issues of optimal utilization of resources, which simultaneously translate into a solution fulfilling all the constraints. Usually, in linear programming one can get many different solutions, which, just like the optimal solution, meet the boundary conditions. A set consisting of such solutions is called ‘a set of acceptable solutions’. The optimal solution like every other one from the set of acceptable solutions, meets the restrictive conditions and is distinguished by the best implementation of the optimization goal (minimization or maximization). The aim of optimization aim is to minimize costs, maximize profit, minimize the duration of a specific activity and use available resources[71].

The general form of the objective function in the linear programming problems is reflected by the formula:

$$f(x_1, x_2, \dots, x_n) = c_1 * x_1 + c_2 * x_2 + \dots + c * x_n \rightarrow \max \tag{3.1}$$

when maximizing the objective function and:

$$f(x_1, x_2, \dots, x_n) = c_1 * x_1 + c_2 * x_2 + \dots + c * x_n \rightarrow \min \tag{3.2}$$

in the case of minimizing the purpose function, where:

$x_1, x_2, \dots, x_n$ – decision variables – the solution sought that fulfill the optimization purpose,

$c_1, c_2, \dots, c_n$ – factors of decision variables,

The general form of constraints limiting the objective function in the linear programming problems is reflected by the formula:

$$a_{j1} * x_1 + a_{j2} * x_2 + a_{j3} * x_3 + \dots + a_{jn} * x_n \leq b_1; \tag{3.3}$$

$$a_{j1} * x_1 + a_{j2} * x_2 + a_{j3} * x_3 + \dots + a_{jn} * x_n \geq b_2; \tag{3.4}$$

$$a_{j1} * x_1 + a_{j2} * x_2 + a_{j3} * x_3 + \dots + a_{jn} * x_n = b_k; \tag{3.5}$$

subject to:

$a_{j1}, a_{j2}, \dots, a_{jn}$ – factors of decision variables of the j-th limiting condition,

b_j – constant term of j-th constraint[72].

As part of linear programming, strictly defined steps should first be performed as their implementation enables the achievement of the previously assumed optimization purpose. The

[71] Gass S. I., Linear Programming: Methods and Applications, Dover Publications, New York 2003, pp. 3-4.
[72] Vanderbei R. J., Linear Programming: Foundations and Extensions, Springer, Berlin 2008, pp. 6-7.

first and the most relevant step is to identify the problem to be solved. A problem that is properly located in the process constitutes a condition for the increase of the company's efficiency. Usually, one of the most important problems that can be identified in decision-making processes, is minimization of expenditures without the need to lower the level of customer service. Reducing costs while ensuring customer satisfaction is sometimes associated not only with the overall growth in the efficiency of the company, but also increases in profits. However, the enterprise's focus on maximizing profits is a frequent organization purpose. A correctly identified decision problem requires appropriate formulation of all restrictions that directly and indirectly affect the result of the optimization process. All factors that must be intellectualized in the process of making the best decision for the organization should be taken into account. Based on the purpose of optimization and constraint conditions, it is necessary to determine whether the objective function is aimed at the minimum or maximum. The objective function should be presented as a linear function with an indicated optimization aim. Constraints are equations or inequalities depending on whether the constraint assumes a specific value or a specified range of values. The final stage is to solve the decision problem using one of many methods of linear programming optimization[73].

Linear programming methods are very often used in solving following issues[74]:

- problems related to the production subsystem, which include specification of production quantities, allocation of human and material resources, management of raw materials, maximization of revenue and minimization of costs,
- transport issue - transport routes related to route planning in order to minimize costs and fulfill customer needs related to the delivery of goods on time, the major purpose of solving transport issues is the allocation of transports and their volumes transported from many suppliers to many recipients,
- indication of the right proportions of raw materials in the production of various types of assortment items (blending problems),
- diet problem focusing on determining the right proportions of food to provide the right amount of nutritional value,

[73] Cheema C. D. S., Operations Research, Firewall Media, New Delhi 2005, p. 25.
[74] Cheema C. D. S., Operations Research, Firewall Media, New Delhi 2005, pp. 25-26.
Eiselt H. A., Sandblom C-L., Integer Programming and Network Models, Springer, Berlin 2007, pp. 67-129.

- investment decisions that indicate not only the potential of a given solution, and in which of them the decision-maker should invest, as well as the profitability of the investment being analyzed,
- task assignment, which specifies the activities that individual employees should perform, as well as the optimal number of employees necessary for the effective implementation of processes,
- scheduling tasks in production or storage subprocesses with regard to machine occupancy and human resources.

Due to the subject matter of this book, which is largely related to process management in modern supply chains, the following sections focus only on issues that can be attributed to supply chain or process management, for instance, transport issues or allocation of tasks on the basis of methods used in operations research.
The main advantages of linear programming include[75]:

- a wide range of applications of linear programming methods and the ability to adapt them to solve various issues in the field of decision-making processes throughout the supply chain,
- the ability to analyze all acceptable solutions,
- being relatively simple thanks to the use of universal solution schemes.

One of the most commonly used methods of linear programming is the simplex method. The rules used in the simplex method are identical to the rules of linear programming, and thus, they concern the minimization or maximization of the objective function, while accomplish the limiting conditions. Simplex, in contrast to simple methods of linear programming, allows taking very complex decision problems characterized by a large number of variables, for which the optimization process is possible through the use of advanced computer applications[76].

The simplex method, developed by G. Dantzig, is an iterative method based on the implementation of subsequent steps and if necessary repeating them, starting from the analysis

[75] Tiwari N. K., Shandilya S. K., Operations Research, PHI Learning Pvt. Ltd. New Delhi 2006, p. 13.
[76] Sivarethinamohan R., Operations Research, Tata McGraw-Hill Education, New Delhi 2008, p. 58.

of the initial base solution, which is an acceptable but not optimal solution, up to the point of recognizing best solution in the established conditions[77].

The objective function striving for the minimum in the simplex method takes the value:

$$Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n \rightarrow min \tag{3.6}$$

subject to:

$$a_{11} * x_1 + a_{12} * x_2 + a_{13} * x_3 + \cdots + a_{1n} * x_n \leq b_1; \tag{3.7}$$

$$a_{21} * x_1 + a_{22} * x_2 + a_{23} * x_3 + \cdots + a_{2n} * x_n \leq b_2; \tag{3.8}$$

...

$$a_{m1} * x_1 + a_{m2} * x_2 + a_{m3} * x_3 + \cdots + a_{mn} * x_n \leq b_m; \tag{3.9}$$

and

$$x_1, x_2, x_3, \ldots, x_n \geq 0 \tag{3.10}$$

The canonical form of the objective function of the maximum objective assumes placing in the constraints slack variables with coefficients of 0, therefore they do not affect the restrictive condition values:

$$Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n \rightarrow max \tag{3.11}$$

subject to:

$$a_{11} * x_1 + a_{12} * x_2 + a_{13} * x_3 + \cdots + a_{1n} * x_{n+1} = b_1; \tag{3.12}$$

$$a_{21} * x_1 + a_{22} * x_2 + a_{23} * x_3 + \cdots + a_{2n} * x_n + x_{n+2} = b_2; \tag{3.13}$$

...

$$a_{m1} * x_1 + a_{m2} * x_2 + a_{m3} * x_3 + \cdots + a_{mn} * x_n + x_{n+m} = b_m; \tag{3.14}$$

and

$$x_1, x_2, x_3, \ldots, x_n, x_{n+1}, \ldots, x_{n+m} \geq 0 \tag{3.15}$$
[78]

[77] Gupta P. K., Operations research, Krishna Prakashan Media, Meerut 1992, p. 147.
[78] Gupta P.K. Hira D. S., Operations Research, S. Chand Publishing, New Delhi 1992, p. 155.

The simplex method assumes the implementation of the following steps on the way to the optimization process of linear programming:

1) Formulation of objective function and restrictive condition.
2) Determining the maximization / minimization of the objective function.
3) Finding the first, acceptable base solution.
4) Verification of the optimality of the base solution.
5) Finding the next base solution (if necessary) and repeating steps 3 and 4 until the optimal solution is found[79].

In the further part of this section an example of solving a linear problem using the simplex method is presented.

Due to the fact that the simplex method is one of the most frequently used methods of linear programming[80], the authors of the handbook decided to present a computational example using simplex tables as one of the most important elements in the field of operations research and optimization theory. Simplex method is most often used in the context of computer applications, however, due to the desire to better illustrate the reader process of optimization of the linear objective function, the authors decided to present an example implemented using simplex tables.

The simplex method is most often used by advanced computer applications in solving the problems of operations research. The following Example 3.1 shows a manual method of solving linear programming problems using simplex methodology. Tables 3.1-3.9 present the next steps of solving the problem of maximizing the objective function using the simplex method without using any computer application.

Example 3.1

The objective function has the form: $f(x) = 3x_1 + 2x_2 \rightarrow \max$ and is limited by the following inequalities:

1) $2x_1 + 2x_2 \leq 2000$

[79] Gupta P. K., Operations research, Krishna Prakashan Media, Meerut 1992, p. 147.
[80] Griva I., Nash S. G., Sofer A., Linear and Nonlinear Optimization: Second Edition, SIAM, Philadelphia 2009, p. 125.

2) $2x_1 + 1x_2 \leq 1400$

3) $x_1, x_2, x_3 \geq 0$

The first step is to bring the objective function to the base form, within which constraints are equations, not inequalities. It is essential to place artificial variables whose coefficients are equal to 0, and place new variables as a function of the objective:

1) $2x_1 + 2x_2 + 1x_3 + 0x_4 = 2000$

2) $2x_1 + 1x_2 + 0x_3 + 1x_4 = 1400$

3) $x_1, x_2, x_3, x_4 \geq 0$

$f(x) = 3x_1 + 2x_2 + 0x_3 + 0x_4 \rightarrow \max$

Step 2 enter the base form into the simplex table. In line x_B, there are coefficients of decision variables of the objective function, b_i is a constant term, and a_i is the ratio of the constant term and the coefficient of the indicated decision variable, and below two slack variables, added at the previous stage, are included.

	xj	x_1	x_2	x_3	x_4		
x_B	cj / cB	3	2	0	0	b_i	a_i
x_3	0	2	2	1	0	2000	
x_4	0	2	1	0	1	1400	

Figure 3.1. Step 2 – entering the base solution into simplex table and adding slack variables

Source: own study.

Step 3 Calculate the control coefficients:

$$Z_j = \sum_{i=1}^{m} c_B * a_{ij} \tag{3.16}$$

$$k_j = c_j - Z_j \tag{3.17}$$

	xj	x_1	x_2	x_3	x_4		
x_B	cj cB	3	2	0	0	b_i	a_i
x_3	0	2	2	1	0	2000	
x_4	0	2	1	0	1	1400	
Z_j	$\sum_{i=1}^{m} c_B * a_{ij}$	0*2+0*2	0*2+0*1	0*1+0*0	0*0+0*1		
k_j							

Figure 3.2.Step 3 – calculation of Zj coefficient

Source: own study.

	xj	x_1	x_2	x_3	x_4		
x_B	cj cB	3	2	0	0	b_i	a_i
x_3	0	2	2	1	0	2000	
x_4	0	2	1	0	1	1400	
Z_j	$\sum_{i=1}^{m} c_B * a_{ij}$	0	0	0	0		
k_j	$c_j - Z_j$	3-0	2-0	0-0	0-0		

Figure 3.3. Step 3 – calculation k_j coefficient

Source: own study.

In case of maximizing the objective function, the control factors k_j should reach nonpositive values, i.e. 0 or lower, then the solution should be considered optimal. When the objective function is minimized, the opposite occurs. Select the maximum positive value of the control factor, which in the analyzed example is 3. Then the absolute terms should be divided by the values of the coefficients a_{11} and a_{21}, in this case both are 2.

	xj	x_1	x_2	x_3	x_4		
x_B	cj / cB	3	2	0	0	b_i	a_i
x_3	0	2	2	1	0	2000	2000:2
x_4	0	2	1	0	1	1400	1400:2
Z_j	$\sum_{i=1}^{m} c_B * a_{ij}$	0	0	0	0		
k_j	$c_j - Z_j$	**3**	2	0	0		

Figure 3.4. Step 4 – choosing maximum of k_j

Source: own study.

To determine which decision variable should replace one of the basic solutions x_3 or x_4, find the lower of nonnegative values of the absolute term (**step 5**), in this case the value 700. The value at the intersection of the key column and row is called the solving element.

	xj	x_1	x_2	x_3	x_4		
x_B	cj / cB	3	2	0	0	b_i	a_i
x_3	0	2	2	1	0	2000	1000
x_4	0	**2**	1	0	1	1400	700
Z_j	$\sum_{i=1}^{m} c_B * a_{ij}$	0	0	0	0		
k_j	$c_j - Z_j$	3	2	0	0		

Figure 3.5. Step 5 – choosing variable to be replaced

Source: own study.

Step 6 is a construction of a new simplex table including the change of the base variable. In case of row x1, a new table will be created by dividing all values in the row by the solving element. In case of line x_3, the ratio between product of the elements of key row and key column and the solving element should be subtracted from the initial value.

	xj	x_1	x_2	x_3	x_4		
x_B	cj / cB	3	2	0	0	b_i	a_i
x_3	0	2	2	1	0	2000	1000
x_4	0	**2**	1	0	1	1400	700
Z_j	$\sum_{i=1}^{m} c_B * a_{ij}$	0	0	0	0		
k_j	$c_j - Z_j$	3	2	0	0		
x_3	0						
x_1	3	2:2	1:2	0:2	1:2	1400:2	
	xj	x_1	x_2	x_3	x_4		
x_B	cj / cB	3	2	0	0	b_i	a_i
x_3	0	2	2	1	0	2000	1000
x_4	0	2	1	0	1	1400	700
Z_j	$\sum_{i=1}^{m} c_B * a_{ij}$	0	0	0	0		
k_j	$c_j - Z_j$	3	2	0	0		
x_3	0	0	$2 - \frac{(1 * 2)}{2}$	1	$0 - \frac{(1 * 2)}{2}$	$2000 - \frac{(1400 * 2)}{2}$	
x_1	3	1	0,5	0	0,5	700	

Figure 3.6. Step 6 – determination of variable factors

Source: own study.

The optimality condition k_j should be checked again and (if required) another simplex table should be presented.

	xj	x_1	x_2	x_3	x_4		
x_B	cj / cB	3	2	0	0	b_i	a_i
x_3	0	2	2	1	0	2000	1000
x_4	0	2	1	0	1	1400	700
Z_j	$\sum_{i=1}^{m} c_B * a_{ij}$	0	0	0	0		
k_j	$c_j - Z_j$	3	2	0	0		
x_3	0	0	1	1	-1	600	
x_1	3	1	0,5	0	0,5	700	

Figure 3.7. Step 7 – creating new simplex table

Source: own study.

x_B	xj / cj / cB	x_1	x_2	x_3	x_4	b_i	a_i
		3	2	0	0		
x_3	0	2	2	1	0	2000	1000
x_4	0	2	1	0	1	1400	700
Z_j	$\sum_{i=1}^{m} c_B * a_{ij}$	0	0	0	0		
k_j	$c_j - Z_j$	3	2	0	0		
x_3	0	0	**1**	1	-1	600	600
x_1	3	1	0,5	0	0,5	700	1400
Z_j		3	1,5	0	1,5		
k_j		0	0,5	0	-1,5		

Figure 3.8. Step 7 – calculation of Z_j and k_j of second simplex table

Source: own study.

x_B	xj / cj / cB	x_1	x_2	x_3	x_4	b_i	a_i
		3	2	0	0		
x_3	0	2	2	1	0	2000	1000
x_4	0	2	1	0	1	1400	700
Z_j	$\sum_{i=1}^{m} c_B * a_{ij}$	0	0	0	0		
k_j	$c_j - Z_j$	3	2	0	0		
x_3	0	0	1	1	-1	600	600
x_1	3	1	0,5	0	0,5	700	1400
Z_j		3	1,5	0	1,5		
k_j		0	0,5	0	-1,5		
x_2	2	0	1	1	-1	600	
x_1	3	1	0	-0,5	1	400	
Z_j		3	2	0,5	1		
k_j		0	0	-0,5	-1		

Figure 3.9. Step 8 – creating another simplex table and checking optimality condition

Source: own study.

Finding the optimal solution is conditioned by the nonpositive of the coefficients of optimality k_j, then the objective function is calculated as a product of c_B coefficients and constant terms:

$$FC = 2 * 600 + 3 * 400 = 1200 + 1200 = 2400$$[81]

Closed Transportation Problem

Linear programming methods are very often used to optimize transport issues, both closed and open. The transport issue, from the point of view of the subject of the handbook, was considered one of the most important for the supply chain, hence the authors' decision to present ways of optimizing it.

The transport problem is one of the most-analyzed issues of linear programming that can be scrutinized with the help of optimization theory. The transport issue concerns the optimal allocation of routes to balance demand and supply. Therefore, transport issues refer to such a distribution of transport on individual routes, between the supplier and recipients involved in the process (participants in the supply chain), that makes it possible to ensure that the needs of customers are fulfilled, transport costs are minimized. When talking about transport issues, it should be pointed out that as part of route selection optimization, one needs to consider delivering the right cargo to individual customers as well as the distance and unit price for transport on individual routes. Algorithms used in route planning do not always refer to the criterion of minimum transport cost, but sometimes they take into account factors such as maximization of profit[82]. Achieving the optimization purpose depends on the well-formulated objective function, which under specific conditions and parameters indicates the cost or profit of the best solution at a given moment. The objective function is usually a character:

$$Max\ (Min)\ F(x_1, x_2, \dots, x_n) = \sum_{j}^{n} c_j x_j\ ; \tag{3.18}$$

subject to:

$F(x_1, x_2, \dots, x_n)$ – objective function that strives for a minimum or maximum,

$(c_1, c_2, \dots, c_n)$ – coefficients vector of the objective function,

[81] Cheema C. D. S., Operations Research, Firewall Media, New Delhi 2005, pp. 106-114.
[82] Sharma S. C., Operation Research: Theory Of Games And Travelling Root Problem, Discovery Publishing House, New Delhi 2006, p. 170.

$(x_1, x_2, \dots, x_n)$ – variables vector.

In case of optimization tasks of transport issues, the objective function usually seeks to a minimum taking the general form:

$$Z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}\, x_{ij}\,; \rightarrow min \tag{3.19}$$

subject to:

$$\sum_{j=1}^{n} x_{ij} \le a_i \qquad i = 1, 2, \dots, m \tag{3.20}$$

$$\sum_{i=1}^{m} x_{ij} \ge b_j \qquad j = 1, 2, \dots, n \tag{3.21}$$

and:

$x_{ij} \ge 0;$

$i = 1, 2, \dots, m;$

$j = 1, 2, \dots, n.$

where:

m – number of suppliers

n – number of recipients,

c_{ij} – single cost of transport on a given route,

x_{ij} – transport volume on a given route,

a_i – supply of the i-th supplier,

b_j – demand of j-th the recipient[83]

[83] Iyer, P. S., Operation Research, Tata McGraw-Hill Education, New Delhi 2008, p. 112. Panneerselvam R., Operations Research, PHI Learning Pvt. Ltd, New Delhi 2006, p. 73.

Two types of transport tasks can be distinguished. The first one is a closed (balanced) transport task, when demand on a given market is equal to supply and an open transport task, when demand is not equal to supply. It should also be noted here that in case of a closed transport task, the balance of demand and supply does not have to be synonymous with the same number of suppliers and customers in the supply chain[84].

One of the most commonly used methods used to solve transportation problems is the north-west corner method and the Vogel method known otherwise as the VAM method (Vogel Approximation Method)[85].

The North-west corner rule assumes the allocation of certain volumes of transported goods on routes starting from allocating the maximum number of transported products in the upper left corner of the matrix. If the supply of the first supplier is equal to the demand of the recipient number one, the next allocation takes place on the supplier's line 2. - recipient 2. If the supply of the first supplier is greater than the demand of the first recipient, the remaining supply is allocated in sequence to the other recipients starting from the second recipient, if the supply of the first supplier is lower than the demand of the first customer, then it's demand and products are covered by another supplier. The allocation of individual transport results in the indication of the first base solution, which requires subsequent optimization. For this purpose, it is necessary to calculate coefficients α, β and k_{ij}, which calculation formulas are presented as follows:

$$cij=\alpha i+\beta j \tag{3.22}$$

$$\alpha i= cij-\beta j \tag{3.23}$$

$$\beta j= cij-\alpha i \tag{3.24}$$

$$kij=cij-\alpha i-\beta j \tag{3.25}$$

The α and β coefficients are calculated on the basis of base routes, and the k_{ij} coefficient for non-base routes that is, routes to which no values have been assigned[86].

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84 Panneerselvam R., Operations Research, PHI Learning Pvt. Ltd, New Delhi 2006, p. 74.
85 Krishnaswamy K. N., Sivakumar A. I., Mathirajan M., Management Research Methodology: Integration of Principles, Methods and Techniques, Pearson Education India, New Delhi 2009, p. 246.
86 Sivarethinamohan R., Operations Research, Tata McGraw-Hill Education, New Delhi 2008, p. 189-190.

A base solution is a solution that in the matrix of suppliers and recipients runs through the cells in which the quantities of transport are placed. The schematic of the solution of the closed transport problem is shown in Example 3.2.

Example 3.2

Company X is a logistics operator of one of the largest brands in Europe. Company X, based on the amount of supply of its suppliers (S1, S2, S3, S4) and amount of demand in regional warehouses located in three locations (W1, W2, W3), plans to allocate individual routes between suppliers and recipients in order to minimize transport costs. The transport rate is shown in the Table 3.1. Please indicate the optimal location of transport on individual routes based on the north-west corner method.

Table 3.1. Input data

Transport pay rate (€/km)			
Warehouse j / Supplier i	W1	W2	W3
S1	0,03	0,04	0,02
S2	0,14	0,03	0,12
S3	0,07	0,03	0,08
S4	0,10	0,04	0,01

Distances between suppliers and warehouses (km)			
Warehouse j / Supplier i	W1	W2	W3
S1	358	471	611
S2	214	454	300
S3	276	500	457
S4	397	541	638

Subject	Quantity of supply/demand
Supplier 1	441
Supplier 2	248
Supplier 3	365
Suppiler 4	550
Warehouse 1	498
Warehouse 2	512
Warehouse 3	594

Source: own study.

Table 3.2.Calculation of transportation costs

Transportation costs depending on route			
Warehouse j / Supplier i	W1	W2	W3
S1	(Distance between S1 and W1) * (transport pay rate at the route linking S1 and W1)	(Distance between S1 and W2) * (transport pay rate at the route linking S1 and W2)	(Distance between S1 and W3) * (transport pay rate at the route linking S1 and W3)
S2	(Distance between S2 and W1) * (transport pay rate at the route linking S2 and W1)	(Distance between S2 and W2) * (transport pay rate at the route linking S2 and W2)	(Distance between S2 and W3) * (transport pay rate at the route linking S2 and W3)
S3	(Distance between S3 and W1) * (transport pay rate at the route linking S3 and W1)	(Distance between S3 and W2) * (transport pay rate at the route linking S3 and W2)	(Distance between S3 and W3) * (transport pay rate at the route linking S3 and W3)
S4	(Distance between S4 and W1) * (transport pay rate at the route linking S4 and W1)	(Distance between S4 and W2) * (transport pay rate at the route linking S4 and W2)	(Distance between S4 and W3) * (transport pay rate at the route linking S4 and W3)

Transportation costs depending on a route (€)			
Warehouse j / Supplier i	W1	W2	W3
S1	10	20	12
S2	30	15	36
S3	20	14	36
S4	40	19	8

Source: own study.

Table 3.3. Exemplary table of transportation problem solving.

Warehouse j / Supplier i	W1	W2	W3	α
S1	quantity c_{11} k11 +/-	quantity c_{12} k12 +/-	quantity c_{13} k13 +/-	0
S2	quantity c_{21} k21 +/-	quantity c_{22} k22 +/-	quantity c_{23} k23 +/-	
S3	quantity c_{31} k31 +/-	quantity c_{32} k32 +/-	quantity c_{33} k33 +/-	
S4	quantity c_{41} k41 +/-	quantity c_{42} k42 +/-	quantity c_{43} k43 +/-	
β				

Source: own study.

Step 1. The original allocation of tasks using the north-west corner method.

Table 3.4. Step 1 – the first allocation of tasks using the north-west corner method

Warehouse j / Supplier i	W1	W2	W3	α
S1	441 [10]	[20]	[12]	
S2	57 [30]	191 [15]	[36]	
S3	[20]	321 [14]	44 [36]	
S4	[40]	[19]	550 [8]	
β				

Source: own study.

For the presented solution, the objective function assumes a value:

$$Z = 10*441 + 30*57 + 15*191 + 14*321 + 36*44 + 8*550 = 19\ 463€$$

Step 2. Checking the optimality of the solution.

This step involves the calculation of the α and β coefficients according to the formula; α_1 is assumed at level 0.

ATTENTION! These coefficients should be calculated **only** for base routes. For non-base routes, the k_{ij} coefficients must be calculated.

Table 3.5. Step 2 – checking optimality of the first solution

Warehouse j / Supplier i	W1	W2	W3	α
S1	441 [10]	k12 = 20-0-(-5) = [20]	12-0-17= -5 [12]	0
S2	57 [30]	191 [15]	36-20-17 = -1 [36]	30-10=20
S3	20-19-10 = -9 [20]	321 [14]	44 [36]	14-(-5)= 19
S4	40-(-9)-10 = 39 [40]	19-(-9)-(-5) = 33 [19]	550 [8]	8-17=-9
β	c11 - 0 = 10-0 = 10	15-20= -5	36-19=17	

Source: own study.

If any coefficient k is negative, the solution presented is not the optimal one. In case of coefficient k reaching the value 0, the objective function has more than one optimal solution. In order to verify and change the allocation, it is necessary to transfer individual quantities of transported goods between routes. It should be indicated that the route characterized by the lowest coefficient k (in this case k31 = -9) and transfer the specified number of transported products to this route. The volumes of carried transport depend on the cycle determination in the presented matrix, which simultaneously constitutes **step 3**.

Step 4. The cycle presented in the table above requires the decision-maker to place alternating "+" signs on routes to which the goods should be moved and "-" signs on routes from which this transport should be removed or its size should be reduced. Each time the matrix cycle must be closed, that is, if the cycle has started with the "+" sign, it must end with the "-" sign in the vicinity of the first character placed in the cycle. The quantities transferred between routes are the lowest size in the cell with the "-" sign, in the example above this value is 57.

Table 3.6. Step 3 and 4 – indication of the cycle as part of changing the base solutions

Supplier i \ Warehouse j	W1	W2	W3	α
S1	441 [10]	k12 = 20-0-(-5) = [20]	12-0-17= -5 [12]	0
S2	57 [30] -	191 [15] +	36-20-17 = -1 [36]	30-10=20
S3	20-19-10 = -9 [20] +	321 [14] -	44 [36]	14-(-5)= 19
S4	40-(-9)-10 = 39 [40]	19-(-9)-(-5) = 33 [19]	550 [8]	8-17=-9
β	c11 - 0 = 10-0 = 10	15-20= -5	36-19=17	

Source: own study.

Table 3.7. Checking optimality of the second solution

Supplier i \ Warehouse j	W1	W2	W3	α
S1	441 [10]	k12 = 20-0-4=16 [20]	12-0-26= -14 [12]	0
S2	30-11-10 = 9 [30]	248 [15]	36-11-26 = -1 [36]	11
S3	57 [20]	264 [14]	44 [36]	10
S4	40-(-18)-10 = 48 [40]	19-(-18)-4 = 33 [19]	550 [8]	-18
β	10	4	26	

Source: own study.

The presented solution still does not fill the condition of optimality. In this case, steps 3 and 4 must be repeated.

Table 3.8. Indication of the cycle as part of changing the base solutions and checking optimality of the third solution

Warehouse j / Supplier i	W1		W2		W3		α
S1	441	10 -	k12 = 20-0-4=16	20	12-0-26= -14	12 +	0
S2	30-11-10 = 9	30	248	15	36-11-26 = -1	36	11
S3	57	20 +	264	14	44	36 -	10
S4	40-(-18)-10 = 48	40	19-(-18)-4 = 33	19	550	8	-18
β	10		4		26		

Warehouse j / Supplier i	W1		W2		W3		α
S1	397	10	k12 = 20-0-4=16	20	44	12	0
S2	30-11-10 = 9	30	248	15	36-11-12 = 13	36	11
S3	101	20	264	14	36-10-12 = 12	36	10
S4	40-(-4)-10 = 34	40	19-(-4)-4 = 19	19	550	8	-4
β	10		4		12		

Source: own study.

The solution shown above is the optimal solution, because value of the every k factor is non-negative, for which the objective function assumes a value:

$$Z = 10*397 + 20*101 + 15*248 + 14*264 + 12*44 + 8*550 = 18\ 334€$$

Solution Of Closed Transportation Problem Using A MS Excel Spreadsheet

In order to present various methods of optimizing a closed transport problem, the authors decided to develop the same example as above using both MS Excel and the VAM method. Solving a transport problem starts with assigning routes in the MS Excel spreadsheet according to the North-West Corner principle.

Due to the fact that the MS Excel add-in, which is Solver, creates unlimited possibilities for optimization not only of transport issues, but also many other problems that operations research includes, the authors decided to present the possibilities of using this tool in practice.

Table 3.9. Routes allocation in MS Excel

Routes allocation

Warehouse j / Supplier i	W1	W2	W3
S1	441		
S2	57	191	
S3		321	44
S4			550

Source: own study.

The objective function reaches the value:

$$Z = 10*441 + 30*57 + 15*191 + 14*321 + 36*44 + 8*550 = 19\,463€$$

Calculation of the objective function in Excel using the SUMPRODUCT formula which is the sum of products of the transport volumes on individual routes and transport costs:

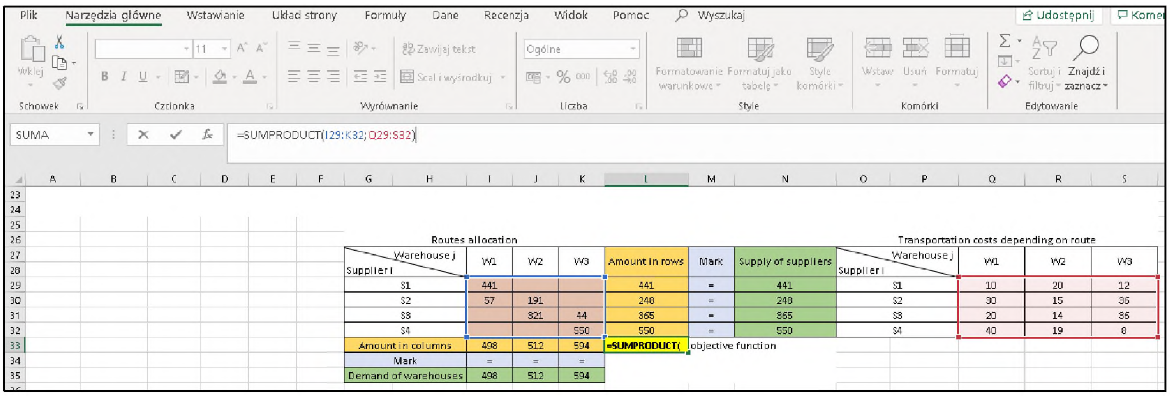

Figure 3.10. Defining the objective function in Excel by SUMPRODUCT formula.

Source: own study.

In order to be able to use the Excel tool, which is Solver, it is also necessary to take into account the limiting conditions assuming that the sum of values in individual columns must be equal to demand amounts, and the sum of values in the rows of suppliers must be equal to the supply amounts of each supplier, as shown in Figures 3.11 and 3.12.

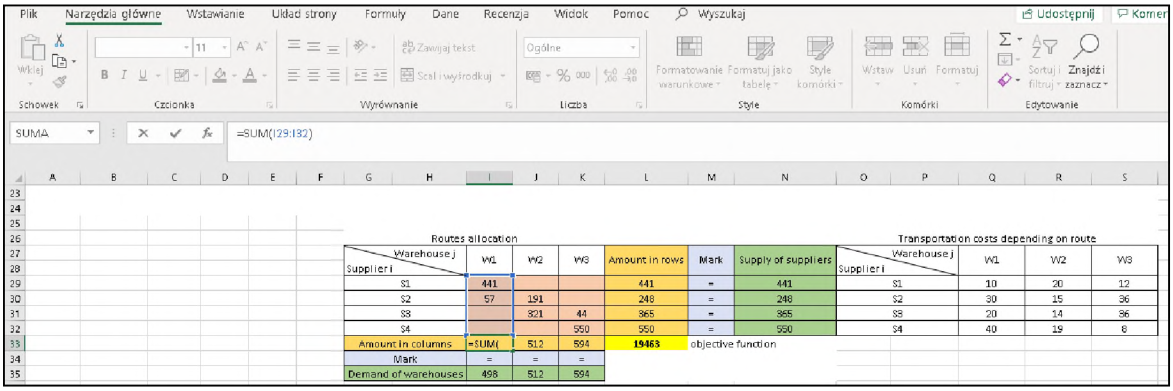

Figure 3.11. Consulting of constraints in columns

Source: own study.

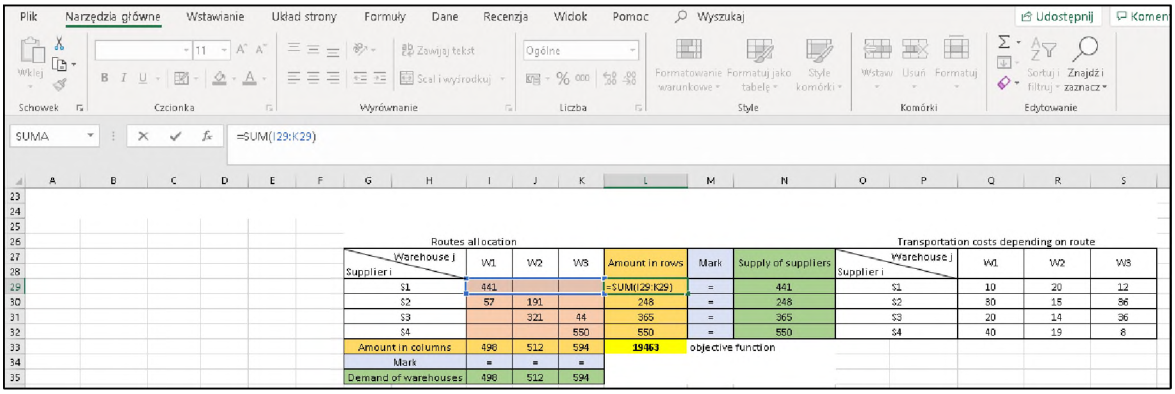

Figure 3.12. Consulting of constraints in rows

Source: own study.

If the Solver add-on is not available on the Data tab, it should be activated by clicking on: File→Options→Add-ins→Manage: Excel Add-ins and click Go→Check the box Solver add-in and click OK.

After a while the Solver plug-in is located in the Data tab.

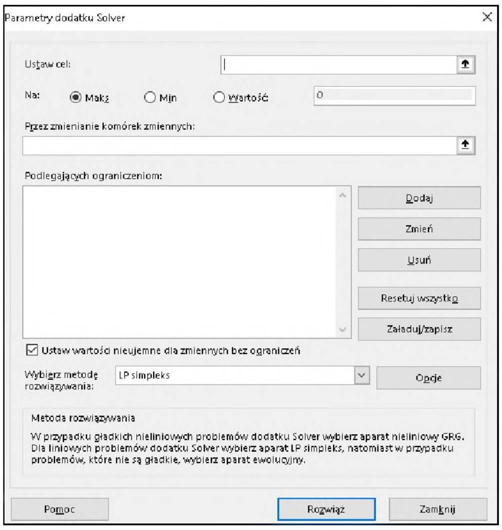

Figure 3.13. Query window of Solver

Source: own study.

In the Solver dialog box, place the cell in which the target function is located in the "Set Target" window and select "MIN" (the function tends to the minimum).

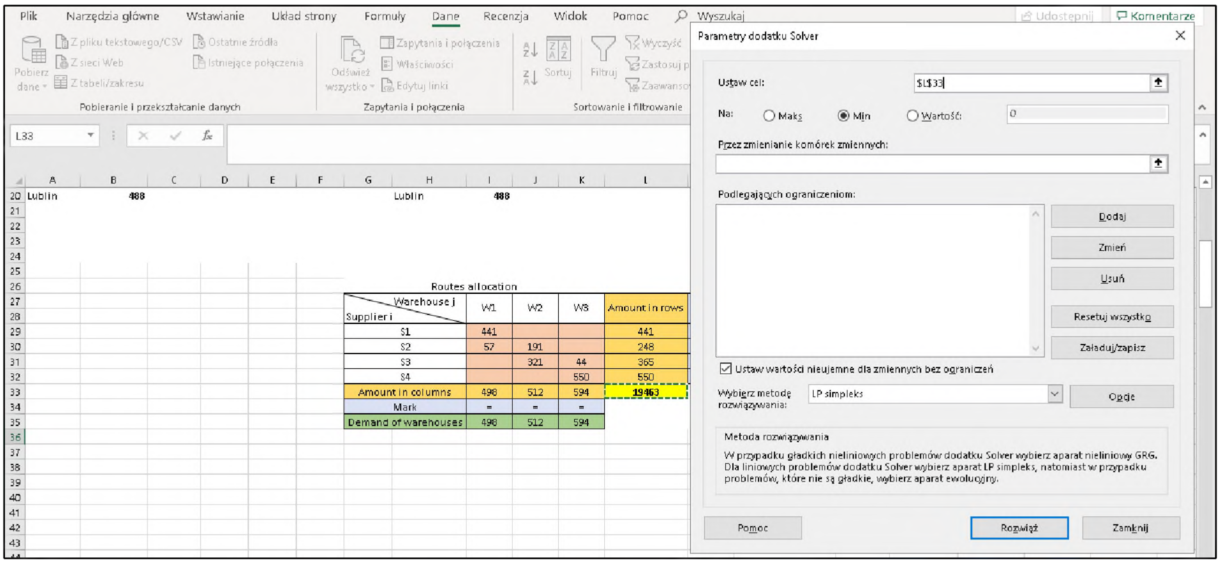

Figure 3.14. Objective function in Solver

Source: own study.

Then, in the line "By changing variable cells", mark the area on which the individual amounts allocated on routes are placed (marked in pink).

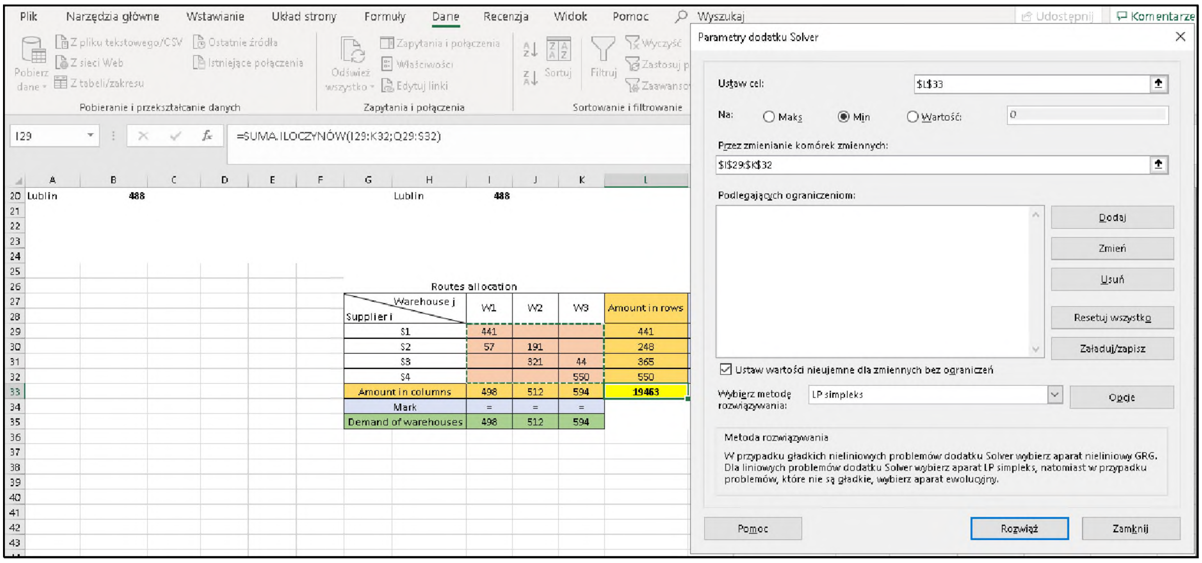

Figure 3.15. Indication of the variable area in Solver

Source: own study.

The next step involves adding constraints by clicking the Add button. In the first field, the user should place an area of totals in columns, which is to be equal to the demand of individual magazines (second field).

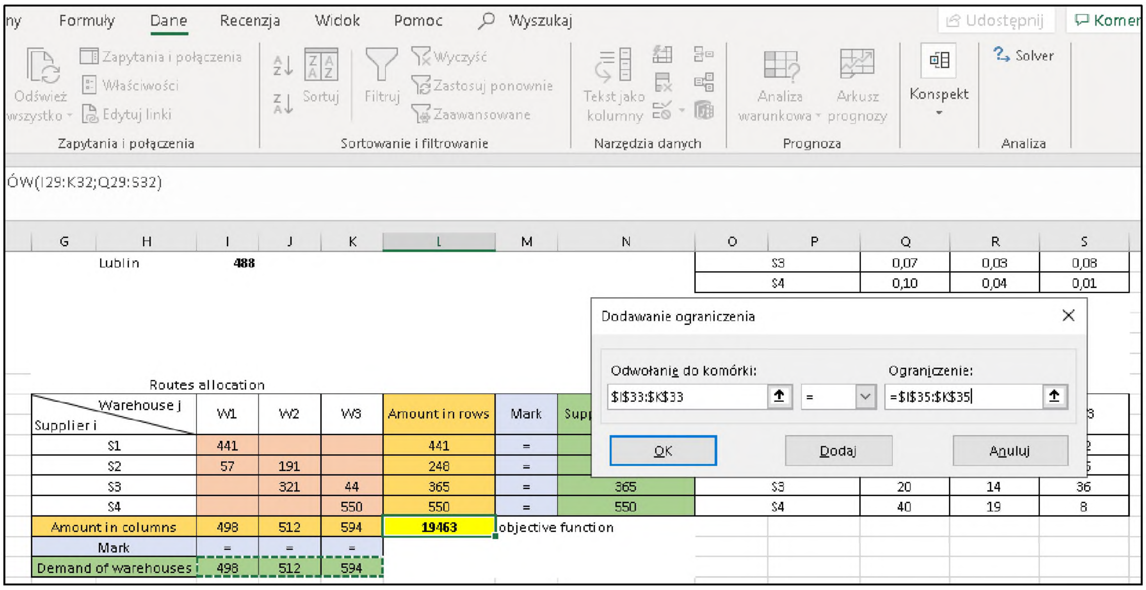

Figure 3.16. Adding the first constraint in Solver

Source: own study.

Another limiting condition is the sum in rows, which must be equal to the supply offered by individual suppliers.

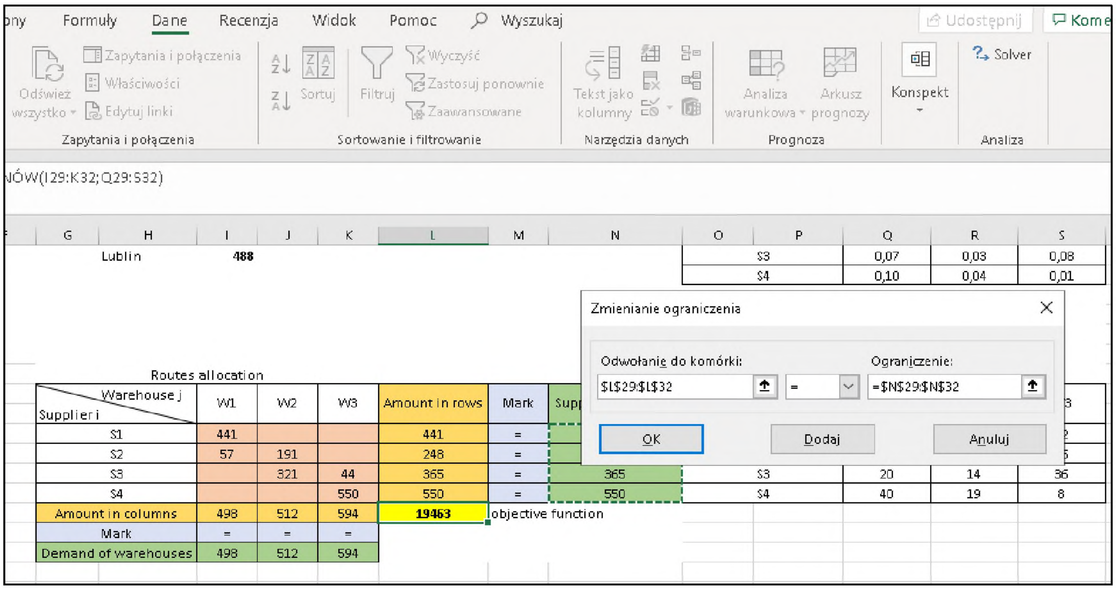

Figure 3.17. Adding the second constraint in Solver

Source: own study.

Then select the method of solving the problem on Simplex LP, approve and then accept the solution proposed by Solver.

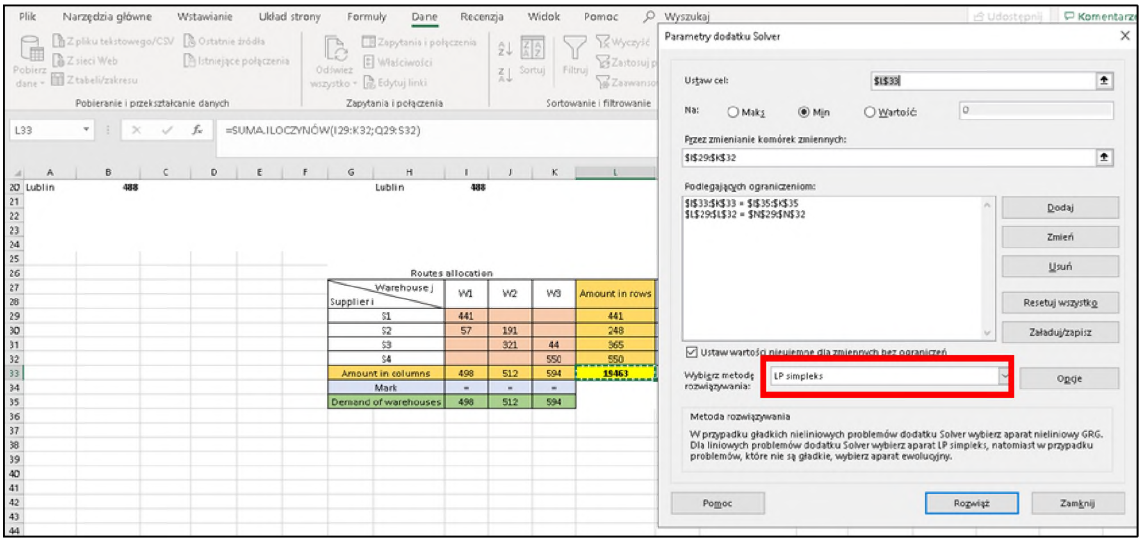

Figure 3.18. Choosing the calculating method

Source: own study.

Solver found the optimal solution based on the entered data and constraints.

Table 3.10. Solving the transportation problem using Solver

Routes allocation

Warehouse j / Supplier i	W1	W2	W3	Amount in rows	Mark	Supply of suppliers
S1	397	0	44	441	=	441
S2	0	248	0	248	=	248
S3	101	264	0	365	=	365
S4	0	0	550	550	=	550
Amount in columns	498	512	594	**18334**	objective function	
Mark	=	=	=			
Demand of warehouses	498	512	594			

Source: own study.

Then it is crucial to recalculated the objective function, which has reached the minimum value of 18 334€.

$$Z = 10*397 + 20*101 + 15*248 + 14*264 + 12*44 + 8*550 = 18\ 334€$$

The VAM method assumes such a route allocation, which is based on the minimum transport costs on individual routes. Example 3.2 calculated with this method is presented below.
This method assumes an analysis of costs on individual routes in order to find the minimum cost of transport.
Step 1. Calculation of minimum values between the two lowest costs in both rows and columns

Table 3.11. Input data - transportation costs

Transportation costs depending on route

Warehouse j / Supplier i	W1	W2	W3	Minimum in row
S1	10	20	12	2
S2	30	15	36	15
S3	20	14	36	6
S4	40	19	8	11
Minimum in column	10	1	4	

Source: own study.

In the first row the two lowest values are 10 and 12, and the difference between them is 2. In the first column, the two lowest values are 10 and 20, and the difference between them is 10. In this way, the minimum for all rows and columns should be calculated.

Step 2. Choose the maximum value among all minimum values, both from rows and columns.

Table 3.12. Choosing the maximum value of rows and columns

Transportation costs depending on route

Warehouse j / Supplier i	W1	W2	W3	Minimum in row
S1	10	20	12	2
S2	30	15	36	15
S3	20	14	36	6
S4	40	19	8	11
Minimum in column	10	1	4	

Source: own study.

Then, in the row or column with the highest of minimum values and then indicate the lowest cost. For the analyzed example, this is the value of 15.

Table 3.13. The minimum value of chosen column/row

Transportation costs depending on route

Warehouse j / Supplier i	W1	W2	W3	Minimum in row
S1	10	20	12	2
S2	30	15	36	15
S3	20	14	36	6
S4	40	19	8	11
Minimum in column	10	1	4	

Source: own study.

The next stage involves the allocation of the first transport on a given route, i.e. on the route from the second supplier to the second warehouse.

Table 3.14. Allocation of the first route

Routes allocation

Warehouse j / Supplier i	W1	W2	W3	supply	supply accomplished
S1				441	0
S2		248		248	248
S3				365	0
S4				550	0
demand	498	512	594		
demand accomplished	0	248	0		

Source: own study.

If the supplier's supply is fully depleted or the customer's supply is completely covered, it should be deleted from further cost analysis.

Steps 1 and 2 should be repeated until all demand is covered.

Table 3.15. Choosing the second maximum value of columns and rows

Transportation costs depending on route

Warehouse j / Supplier i	W1	W2	W3	Minimum in row
S1	10	20	12	2
S2				
S3	20	14	36	6
S4	40	19	8	11
Minimum in column	10	5	4	

Source: own study.

Table 3.16. Allocation of the second route

Routes allocation

Warehouse j / Supplier i	W1	W2	W3	supply	supply accomplished
S1				441	0
S2		248		248	248
S3				365	0
S4			550	550	550
demand	498	512	594		
demand accomplished	0	248	550		

Source: own study.

Table 3.17. Choosing the third maximum value of columns and rows

Transportation costs depending on route

Warehouse j / Supplier i	W1	W2	W3	Minimum in row
S1	10	20	12	2
S2				
S3	20	14	36	6
S4				
Minimum in column	10	6	24	

Source: own study.

Table 3.18. Allocation of the third route

Routes allocation

Warehouse j / Supplier i	W1	W2	W3	supply	supply accomplished
S1			44	441	44
S2		248		248	248
S3				365	0
S4			550	550	550
demand	498	512	594		
demand accomplished	0	248	594		

Source: own study.

Table 3.19. Choosing of the fourth maximum value of columns and rows

Transportation costs depending on route

Warehouse j / Supplier i	W1	W2	W3	Minimum in row
S1	10	20		2
S2				
S3	20	14		6
S4				
Minimum in column	10	6		

Source: own study.

Table 3.20. Allocation of the fourth route

Routes allocation

Warehouse j / Supplier i	W1	W2	W3	supply	supply accomplished
S1	397		44	441	441
S2		248		248	248
S3				365	0
S4			550	550	550
demand	498	512	594		
demand accomplished	397	248	594		

Source: own study.

Table 3.21. Choosing the fifth maximum value of columns and rows

Transportation costs depending on route

Warehouse j / Supplier i	W1	W2	W3	Minimum in row
S1				
S2				
S3	20	14		6
S4				
Minimum in column	0	0		

Source: own study.

Table 3.22. Allocation of the fifth route

Routes allocation

Warehouse j / Supplier i	W1	W2	W3	supply	supply accomplished
S1	397		44	441	441
S2		248		248	248
S3		264		365	264
S4			550	550	550
demand	498	512	594		
demand accomplished	397	512	594		

Source: own study.

Table 3.23. Choosing the last cost

Transportation costs depending on route

Warehouse j / Supplier i	W1	W2	W3	Minimum
S1				
S2				
S3	20			6
S4				
Minimum in column				

Source: own study.

Table 3.24. Allocation of the last route

Routes allocation

Warehouse j / Supplier i	W1	W2	W3	supply	supply accomplished
S1	397		44	441	441
S2		248		248	248
S3	101	264		365	365
S4			550	550	550
demand	498	512	594		
demand accomplished	498	512	594		

Source: own study.

Table 3.25. Final routes allocation

Routes allocation

Warehouse j / Supplier i	W1	W2	W3
S1	397		44
S2		248	
S3	101	264	
S4			550

Source: own study.

The objective function assumes a value:

$$Z = 10*397 + 20*101 + 15*248 + 14*264 + 12*44 + 8*550 = 18\ 334€$$

Open Transportation Problem

Open, unbalanced transport issues are characterized by an imbalance between demand and supply. This means that, depending on the situation, when a part of the demand may not be satisfied or the suppliers offer a number of products exceeding the demand, then the optimization purpose is not only to appropriately distribute transport on individual routes, but also to reduce lost sales costs, and in case of excess loads collected from suppliers, you should find a solution to optimize storage costs.

As part of solving open transport issues, each time a fictitious customer or supplier needs to be entered so that the problem can be balanced. The process of optimization of open transport issues is presented in detail in Example 3.3. As it was presented in case of closed transportation problem, the authors will present the methodologies of calculation object functions using most commonly used application, i.e. North-West Corner Principle. Calculation of open transportation problem using Solver in MS Excel and VAM method should be made by making the same steps as described in an Example 3.2.

Example 3.3

Company X is a logistics operator of one of the largest brands in Europe. Company X, based on the amount of supply of its suppliers (S1, S2, S3, S4) and amount of demand in regional warehouses located in three locations (W1, W2, W3), plans to allocate individual routes between suppliers and recipients in order to minimize transport costs. The transport rate is shown in the Table 3.26. Please indicate the optimal location of transport on individual routes based on the north-west corner method.

Table 3.26. Transportation costs in open transportation example

Transportation costs depending on route

Warehouse j / Supplier i	W1	W2	W3
S1	25	14	27
S2	32	38	40
S3	19	15	30
Fictional Supplier	32	14	20

Source: own study

Table 3.27. Quantities of supply and demand

Quantities of supply and demand

Supplier i \ Warehouse j		W1	W2	W3
		358	214	391
S1	250			
S2	368			
S3	311			
Fictional Supplier	34			

Source: own study.

In case of the example analyzed, the demand exceeds the supply, which means that part of customers' expectations remains unfulfilled. Therefore, it is necessary to indicate the warehouse, for which the non-fulfillment of the part of the demand is the least costly.

The solution of the unbalanced problem should start with the allocation of transport volumes according to the north-west corner method.

Table 3.28. The first allocation of transportation quantities

Supplier i \ Warehouse j	W1	W2	W3	α
S1	250 [25]	[14]	[27]	
S2	108 [32]	214 [38]	46 [40]	
S3	[19]	[15]	311 [30]	
Fictional Supplier	[32]	[14]	34 [20]	
β				

Source: own study.

Then, calculate the coefficients α, β and k_{ij}. The calculation of coefficients involves the necessity to change the base routes. This step should be repeated until all rates k of non-negative routes reach non-negative values (less than 0).

Table 3.29. Choosing the first cycle in order to change base solutions

Warehouse j / Supplier i	W1	W2	W3	α
S1	250 $\boxed{25}$ -	$\boxed{14}$ -17 +	$\boxed{27}$ -6	0
S2	108 $\boxed{32}$ +	214 $\boxed{38}$ -	46 $\boxed{40}$	7
S3	$\boxed{19}$ -3	$\boxed{15}$ -13	311 $\boxed{30}$	-3
Fictional Supplier	$\boxed{32}$ 20	$\boxed{14}$ -4	34 $\boxed{20}$	-13
β	25	31	33	

Source: own study.

Table 3.30. Choosing the second cycle in order to change base solutions

Warehouse j / Supplier i	W1	W2	W3	α
S1	36 $\boxed{25}$ -	214 $\boxed{14}$	$\boxed{27}$ -6 +	0
S2	322 $\boxed{32}$ +	$\boxed{38}$ 17	46 $\boxed{40}$ -	7
S3	$\boxed{19}$ -3	$\boxed{15}$ 4	311 $\boxed{30}$	-3
Fictional Supplier	$\boxed{32}$ 20	$\boxed{14}$ 13	34 $\boxed{20}$	-13
β	25	14	33	

Source: own study.

Table 3.31. Choosing the third cycle in order to change base solutions

Warehouse j / Supplier i	W1	W2	W3	α
S1	[25] 6	214 [14]	36 [27]	0
S2	358 [32] -	[38] 11	10 [40] +	13
S3	[19] -3 +	[15] -2	311 [30] -	3
Fictional Supplier	[32] 20	[14] 7	34 [20]	-7
β	19	14	27	

Source: own study.

Table 3.32. Final routes allocation

Warehouse j / Supplier i	W1	W2	W3	α
S1	[25] 6	214 [14]	36 [27]	0
S2	47 [32]	[38] 11	321 [40]	13
S3	311 [19]	[15] 0	[30] 3	0
Fictional Supplier	[32] 20	[14] 7	34 [20]	-7
β	19	14	27	

Source: own study.

The optimal solution assumes that the warehouse number 3can not be fully serviced, which guarantees minimization of the costs of lost sales. The objective function assumes a value 24 901€.

3.2.2. Non-linear programming

Operations research aimed at solving problems in the field of transport and resource allocation uses non-linear programming methods, in addition to linear programming methods. Both linear and non-linear programming, is based on the development of a mathematical model that is very often used in the decision-making process. The difference between linear programming and the problems of non-linear programming described in this subsection, is that the objective function assumes a non-linear form[87].

Non-linear programming assumes the possibility of presenting the objective function in many different forms, while linear programming allows for only presenting it in the form of a linear function. As optimization and decision processes are usually performed using simplex method, non-linear techniques can be characterized not only by a wide range of applications, but also the use of various types of optimization methods. Furthermore, it is not necessary to apply specific decision-making algorithms[88].

Non-linear programming is widely used in problems related to decision making processes. It allows to search for optimal solutions that simultaneously fill the constraints of very congeneric and complex decision problems related to such areas of economic activity as planning of technological processes, economics, as well as all economic issues related to technological and logistic processes, production planning or resource management[89].

In general, the form of a non-linear function can be presented as below:

$$\min/\max f(x_i) \tag{3.26}$$

$g_i(x_i) \leq 0$; $i = 1, 2, \ldots, m$;

$h_j\,(x_i) = 0$; $j = 1, 2, \ldots, p$[90].

As part of the use of non-linear programming, different types of optimization methods can be distinguished, as opposed to linear programming, which as the major technique uses the simplex

[87] Avriel M., Nonlinear Programming: Analysis and Methods, Courier Corporation, New York 2003, p. 1.
[88] Carter M. W., Price C. C., Operations Research. A Practical Introduction, CRC Press, New York 2001, p. 195.
[89] Avriel M., Nonlinear Programming: Analysis and Methods, Courier Corporation, New York 2003, p. 1.
[90] Fiacco A. V, McCormick G. P., Nonlinear Programming: Sequential Unconstrained Minimization Techniques, SIAM, Philadelphia 1990, p. 1.

method. The methods of non-linear programming are essentially divided into two types of tools, that is: limited and unlimited[91].

An example of a problem that is optimized using the non-linear programming method is portfolio analysis. It allows to analyze and point to a company that is worth investing in by purchasing its shares. Within this type of issues, the expected rate of return is calculated E(rj):

$$E(r_j) = \sum_{i=1}^{m} p(r_{ij}) * r_{ij} \tag{3.27}$$

subject to:

$p(r_{ij})$ – the probability that the return rate of the i-th reaches the value,

r_{ij} – i-th possible value of the rate of return.

Sometimes the value of the expected rate of return is insufficient to make an effective decision, so the standard deviation defining the deviation of the rates of return from the expected rate of return should be also calculated. The greater the deviation, the higher the risk. The risk can also be assessed on the basis of the variance being the square of the standard deviation value.

$$s = \sqrt{V} = \sqrt{\sum_{i=1}^{m} p(r_{ij}) * (r_{ij} - E(r_j))^2} \tag{3.28}$$

s – standard deviation,
V – variance[92].

Due to the possibility of using risk assessment methods and tools supporting the selection of the best option in terms of profitability, it was decided to present in this handbook a method of assessing various options due to the expected rate of return, which in the case of logistics

[91] Di Pillo G., Palagi L., Nonlinear Programming: Introduction, Unconstrained and Constrained Optimization in Pardalos P., Resende M. (eds.), Handbook of Applied Optimization, Oxford University Press, New York 2002, pp. 268-285.
[92] Gupta P.K. Hira D. S., Operations Research, S. Chand Publishing, New Delhi 1992, pp. 944-949.

companies and entire supply chains is an important element in terms of e.g. establishing cooperation with suppliers or business partners.

Example 3.4

The probability of a rate of return in four economic states for enterprises A and B are indicated in Table 3.33. Specify the shares of companies that should be invested in by assessing not only the expected value of the rate of return, but also the risk of investment.

Table 3.33. Input data to example

The state of the economy	Probability	Rate of return [%]	
		A j=1	B j=2
S1	0,1	25	10
S2	0,3	0	5
S3	0,2	10	-10
S4	0,4	-20	15

Source: own study.

According to the formula, the expected rate of return on investment in shares of company A is:

$E(r_A) = 0,1* 25 + 0,3*0 + 0,2*10 + 0,4*(-20) = -3,5$

The expected rate of return on investment in shares of company B is:

$E(r_B) = 0,1*10 + 0,3*5 + 0,2*(-10)+ 0,4*15 = 6,5\%$

Risk assessment:

$V(r_A) = 0,1*(25-(-3,5))^2 + 0,3*(0-(-3,5))^2 + 0,2*(10-(-3,5))2 + 0,4*((-20)-(-3,5))^2 = 230,25$

$S(r_A) = 15,77$

$V(r_B) = 0,1*(10-6,5)^2 + 0,3*(5-6,5)^2 + 0,2*((-10)-6,5)^2 + 0,4*(15-6,5)^2 = 85,25$

$S(r_A) = 9{,}23$

Due to the lower risk and higher rate of return, the shares of company B should be invested in.

3.2.3. Network programming

Network programming, sometimes called concepts of directed graphs (digraphs), is one of the tools increasingly used in operations research. Network programming focuses on the use of a graphical method, thanks to which it is possible to present, and fully analyze the problems of the organization[93].

Network programming within the framework of optimization processes performed with the use of operations research allows for planning, scheduling and monitoring of complex projects performed in the organization or the entire supply chain. Network programming techniques support the analysis and identification of irregularities in the implementation of the plan, as well as their subsequent impact on other processes introduced as part of the company's organizational activities. Network programming was first used in the 1950s in the United States[94].

The most commonly used within the network programming, in the field of operations research, tools are: Critical Path Method, Program Evaluation and Review Technique (PERT)[95]. **Critical Path Method (CPM)** was first used in the 1950s as a project management tool. CPM, which is a development of Gantt chart, enables illustration of activities that should be performed along the way of project implementation, and points to these activities, which if shifted in time, can result in a delay in the introduction of the entire project. The essence of the critical path method is identification critical activities and dependencies between them. Delaying any of them involves time shifts of the entire project. In order to end the project as scheduled, it is necessary to secure the restrictions and ensure their timely beginning and ending[96].

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[93] Foulds L. R., The Application Of The Theory Of Directed Graphs In Jackson M.C., Keys. P., Crooper S. A. The Social Sciences in Operational Research and the Social Sciences, Plenum Press, London 2012, p. 183.
[94] Sharma S. C., Operation Research: Pert, CPM & Cost Analysis, Discovery Publishing House, New Delhi 2006, p. 2.
[95] Sivarethinamohan R., Operations Research, Tata McGraw-Hill Education, New Delhi 2008, pp. 415-416.
[96] Hutchings J. F., Project Scheduling Handbook, CRC Press, New York 2003, p. 56.

CPM as part of project management enable specifying such elements of the process as[97]:

- the minimum duration of the project and the maximum time acceptable for its implementation,
- indication of activities that can be executed simultaneously,
- indication of critical activities, affecting the subsequent implementation of the entire undertaking.

The greatest benefits of using CPM include:

- the possibility of reducing costs through effective planning and project management,
- proper identification and implementation of individual activities,
- the possibility to determine the duration of the project,
- indication of the minimum and maximum start and end dates of activities,
- indication of critical activities, which affect the possibility of timely implementation of the project,
- the ability to change the organization's objectives if they are impossible to implement.

Disadvantages of CPM include[98]:

- high costs as creating CPM diagrams can be expensive. Therefore, the cost-effectiveness analysis of the use of CPM should be performed every time,
- the use of critical paths requires the employment of a suitably qualified manager as well as providing training of employees,
- in some cases, the method may be inflexible,
- it can sometimes be characterized by subjectivity related to inaccurate and unreliable scheduling of dates and durations of particular activities[99].

In the first stage of solving the problems of network programming with the use of CPM, it is necessary to determine the activities performed within the project, as well as to indicate the relations between them and their duration.

[97] Wisniewski M., Klein J. H., Critical Path Analysis and Linear Programming, Macmillan International Higher Education, New York 2017, pp. 120-121
[98] Hutchings J. F., Project Scheduling Handbook, CRC Press, New York 2003, pp. 57-58.
[99] Hutchings J. F., Project Scheduling Handbook, CRC Press, New York 2003, pp. 57-58.

As part of Example 3.5, the authors decided to present two methods of network programming supporting the solving of project management problems. Due to the subject of this handbook and the important role of project management in the context of supply chain efficiency, it seems reasonable to present these methods that are one of the most commonly used methods in the context of solving project management issues.

Example 3.5

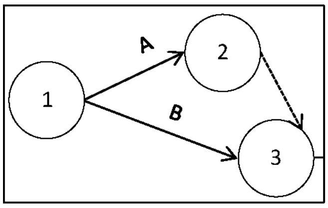
Based on the data collected in Table 3.34, specify the earliest and latest possible start and end date of the undertaking.

Table 3.34. Input data to CPM example

Activity	Activity Description	Previous activity	Duration [days]
A	Market analysis in search of a new supplier	-	20
B	An attempt to negotiate prices with the current supplier	-	15
C	Analysis of offers received from current and potential suppliers	A, B	3
D	Analysis of the possibility of using your own transport	A, B	7
E	Verification of the costs of own transport	D	3
F	The choice of the optimal one	C,E	1
SUM			49

Source: own study.

In case of two activities which are being performed in parallel, it is crucial to use the apparent activity in a diagram, the duration of which is 0.



instead of this:

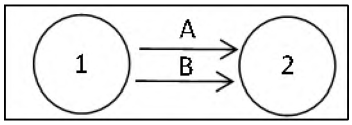


Figure 3.19. The correct representation of two simultaneous activities

Source: own study.

After accomplishing the activity, the events marked with consecutive numbers should be placed on the diagram. The CPM diagram looks as below:

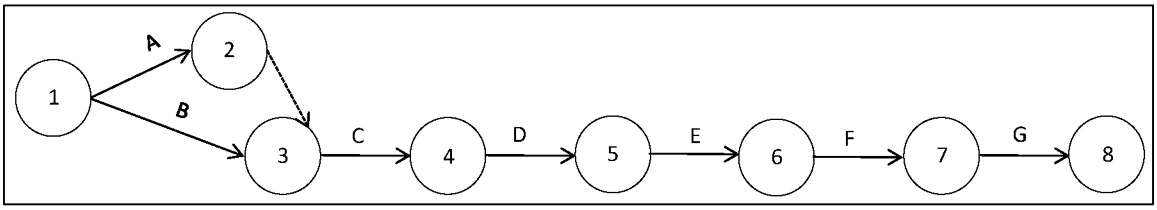


Figure 3.20. Initial diagram of CPM

Source: own study.

On the basis of the network diagram and the quantitative description, the basic network characteristics should be determined: the earliest possible moment of occurrence of the event, the latest acceptable date of the event, time stocks for events and activities, critical path and the deadline for the entire project. The characteristics describing the events are placed directly in the event:

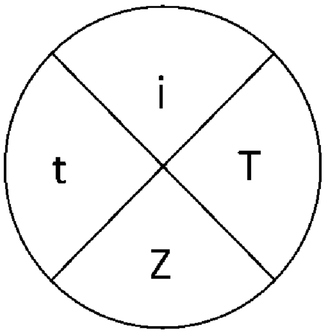


Figure 3.21. Event characteristics in CPM.

Source: Bise C. J. Mining Engineering Analysis, SME, Littleton, 2003, pp. 26-27.

i – event number,

t – the earliest possible moment of the event,

T – the latest acceptable moment of the event,

Z – stock of the event time.

In case of the first event, the earliest possible moment of the event is equal to 0, while the earliest possible moment of occurrence of the next event is equal to the sum of the earliest possible moment of occurrence of the previous event and the duration of the action leading to a given event.

$$\begin{gathered} t_1 = 0 \\ t_2 = t_1 + t_{1-2} \end{gathered} \tag{3.29}$$

If more than one action comes to the event, as in Figure 3.20 to Event 3, the earliest possible moment of occurrence of the event is the maximum value according to the formula:

$$\begin{aligned} &t_1 = 0 \\ &t_j = \max[t_i + t_{i-j}] \end{aligned} \tag{3.30}$$

$$\begin{aligned} &\text{t}_3 \text{ for activity B} \\ &t_3 = t_1 + t_{1-3} = 0 + 7 = 7 \\ &\text{t}_3 \text{ apparent activity} \\ &t_3 = t_2 + t_{2-3} = 15 + 0 = 15 \end{aligned} \tag{3.31}$$

The earliest possible time of occurrence of event 3 is 15. T, i.e. the latest acceptable moment of occurrence. It is determined by the value of the earliest possible date of occurrence of the event, and therefore, it is possible to minimize the duration of the project.

At the last stage, the time inventory should be determined as a difference between the latest acceptable date of occurrence of the event and the earliest possible date of its commencement.

time reserve for event:

$$Z_j = T_j - t_j \tag{3.32}$$

time reserve for activities:

$$Z_{i-j} = (T_j - t_{i-j}) - t_i \tag{3.33}$$

If the time reserve for a given event is 0, it means that the action leading to the occurrence of a given event is a critical activity. All critical activities create a critical path, so delaying any of these steps affects the delay of the entire process[100].

The above example of a project for which the critical path includes activities A-C-D-E-F-G lasts 23 days and can be presented as follows:

[100] Antill J. M., Woodhead R. W., Critical Path Methods in Construction Practice, Wiley, New York 1991, pp. 10-19.

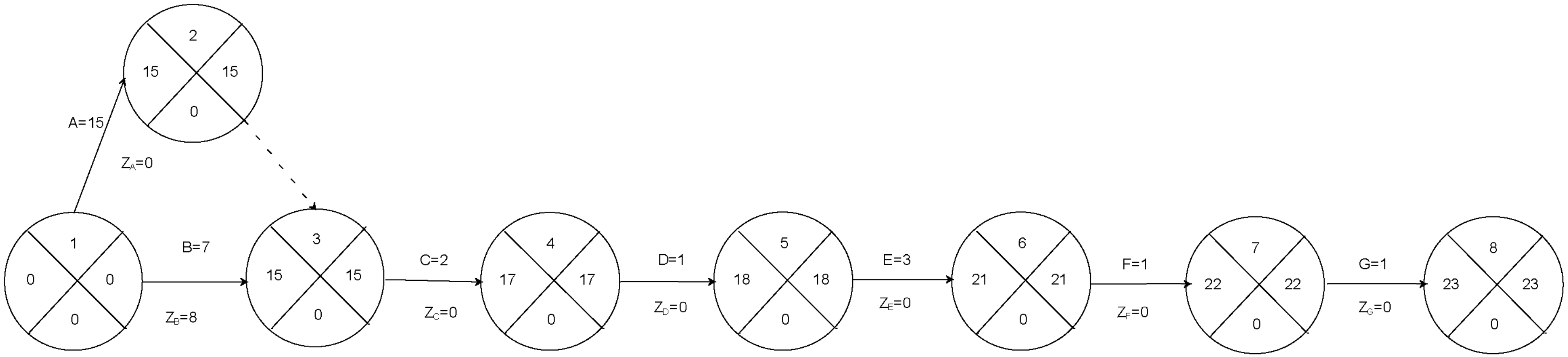


Figure 3.22. Example of Critical Path Method

Source: own study.

Program Evaluation and Review Technique (PERT) is a method very similar to CPM, although it was created independently in the 1950s. The difference between the tools is related to the valuation of data regarding the deadlines for the implementation of individual activities. In addition, CPM focuses on the duration of individual activities, while PERT refers to the dates of their start and end, and thus to events. PERT unlike CPM treats individual events as uncertain, therefore, it is necessary to specify three different durations, which translates into an indication of the scope of the analyzed event. PERT uses the durations specified in the previous step to determine the expected end time of the event, as well as the standard deviation or variance, used each time to calculate the difference between the expected and the actual end date of the event. PERT method assumes the determination of the following three times:

- optimistic end time T_o,
- the most probable end time T_m,
- pessimistic end time T_p.

The expected duration of the event (T_e) is calculated using the formula:

$$T_e = \frac{T_o + 4T_m + T_p}{6} \tag{3.34}$$

Next, it is necessary to calculate the standard deviation and variance, as well as their sum for the analyzed critical path.

$$\sigma_e = \frac{T_p - T_o}{6} \tag{3.35}$$

$$V_e = {\sigma_e}^2 \tag{3.36}$$

$$T_E = \sum_{i=1}^{n} (T_e)_i \tag{3.37}$$

$$V_E = \sum_{i=1}^{n} ({\sigma_e}^2)_i \tag{3.38}$$

$$\sigma_E = \sqrt{V_E} \tag{3.39}$$

where:

σ_e – standard deviation of the single event,

V_e – variance of the single event,

T_E – total expected time of event end,

V_E – variance calculated for the entire critical path,

σ_E – standard deviation calculated for the entire critical path.

At the final stage, the probability (Z) of completing the task at the indicated time or strictly specified time should be calculated.

$$Z = \frac{T_S - T_E}{\sigma_E} \quad (3.40)$$ [101]

Below is an example a diagram prepared using the PERT method.

For the example analyzed using CPM method, 3 different times of occurrence were determined, optimistic, the most probable and pessimistic.

Table 3.35. Indicating optimistic, most likely and pessimistic activity duration in PERT method

Activity	Activity Description	Previous activity	Optimimistic	Most likely	Pessimistic
A	Market analysis in search of a new supplier	-	17	20	24
B	An attempt to negotiate prices with the current supplier	-	12	15	17
C	Analysis of offers received from current and potential suppliers	A, B	1	3	4
D	Analysis of the possibility of using your own transport	A, B	5	7	12
E	Verification of the costs of own transport	D	1	3	9
F	The choice of the optimal one	C,E	1	2	4

Source: own study.

It is necessary to determine the expected time of event completion for all events, as well as their standard deviations and variances and also the expected duration of the entire project:

[101] Mubark S. Construction Project Scheduling and Control, Wiley, Hoboken 2015, pp. 292-295.
Bise C. J., Mining Engineering Analysis, SME, Littleton 2003, pp. 26-27.

Table 3.36. Expected time of realization all activities

Activity	Activity Description	T_e	σ_e	V_x	T_E
A	Market analysis in search of a new supplier	20	1,17	1,36	51
B	An attempt to negotiate prices with the current supplier	15	0,83	0,69	
C	Analysis of offers received from current and potential suppliers	3	0,50	0,25	
D	Analysis of the possibility of using your own transport	8	1,17	1,36	
E	Verification of the costs of own transport	4	1,33	1,78	
F	The choice of the optimal one	2	0,50	0,25	

Source: own study.

Then, with the assumed probability level of 0.8159, the date of project implementation (TS) should be indicated:

Table 3.37. Time of realization of whole project in relation to probability level

Activity	Activity Description	T_e	σ_e	V_x	T_E	σ_E	V_E	Z	T_S
A	Market analysis in search of a new supplier	20	1,17	1,36	51	5,50	5,69	0,816	56
B	An attempt to negotiate prices with the current supplier	15	0,83	0,69					
C	Analysis of offers received from current and potential suppliers	3	0,50	0,25					
D	Analysis of the possibility of using your own transport	8	1,17	1,36					
E	Verification of the costs of own transport	4	1,33	1,78					
F	The choice of the optimal one	2	0,50	0,25					

Source: own study.

Taking into account the optimistic, real and pessimistic deadlines for the implementation of individual events and their probability, project introduction time amounts to 56 days.[102]

The biggest advantages of using network programming tools include[103]:

- the possibility of using them in any organization in the planning and implementation of long-term projects,

[102] Moder J. J., Phillips C. R., Davis E. W., PROJECT MANAGEMENT with CPM, PERT and Precedence Diagramming, Van Nostrand Reinhold Company Inc., New York 1983, p. 270.
[103] Sharma S. C., Operation Research: Pert, CPM & Cost Analysis, Discovery Publishing House, New Delhi 2006, p. 4.

- creation of an appropriate project plan can be used to perform and later implement solutions in the form of ready algorithms,
- effective implementation of the project management tool allows to reduce costs, achieve greater profit and better allocation of resources,
- in particular, the tool supports decision-making processes and system control,
- they allow to identify restrictions and indicate ways to compensate them.

In addition, it should be pointed out that the use of both CPM and PERT methods should be implemented in three phases:

1) Planning.
2) Scheduling.
3) Monitoring.

During project **planning phase**, all the operations that must be carried out as part of a given project should be indicated, as well as resources required for their timely and effective implementation. In addition, project objectives and the parametric requirements for its implementation should be clearly defined. It is also necessary to estimate the costs during the project planning phase, as well as to specify each operation that needs to be performed as part of its implementation.

The scheduling phase focuses on determining lead time, start dates and end dates of individual stages as well as the entire project and also delegating employees responsible for the enforcement of individual project activities. The scheduling phase also refers to indicating interrelations between activities and identifying any operations that can delay the implementation of the entire project. In addition, this phase allows balancing the demand for resources including: materials, machines, costs and human resources.

The monitoring phase includes activities related to controlling the degree of performance of the project planned beforehand and, if necessary, updating the plan to enable timely implementation of scheduled activities that will be consistent with the previously estimated costs. As part of this stage, it is also possible to receive progress reports which, in the final phase, enable a full analysis of the effectiveness of the processes executed within individual projects. This phase also allows for the subsequent development of algorithms that can be used in the future by a given organization or other participants in the supply chain[104].

Due to the wide range of applications of network programming methods with particular emphasis on project management, the choice of these examples presented above seemed fully justified to the authors of this manual.

3.2.4. Multicriterial programming

Multicriteria programming is a mathematical modeling method used on a large scale as part of operations research, in relation to system analysis. It refers to the assessment of the effectiveness of system's functioning as an organization and the entire supply chain[105]. The main assumption of multicriteria programming is to support the decision process which requires verification and consideration of a set of factors affecting the company's activity in a direct and indirect way. Multicriteria programming, therefore, focuses on the development of tools suitable for use in various areas of activity of both enterprises and entire supply chains. Multi-criteria programming, which is often called multi-criteria decision making (MCDM) or multi-criteria decision analysis (MCDA), helps to compensate the problem related to the decision-making process, that is difficult to implement due to its complexity and high level of sensitivity to different types of factors conditioning the financial result of many companies or supply chains[106]. The general form of the objective function in multicriteria programming tasks is presented below.

$$f(x) = f_1(x), f_2(x), \ldots, f_p(x) \to max \tag{3.41}$$

subject to

[104] Sharma S. C., Operation Research: Pert, CPM & Cost Analysis, Discovery Publishing House, New Delhi 2006, pp. 7-10.
[105] Cohon J. L., Multicriteria programming: brief review and application in Gero J. (ed.), Design Optimization, Elsevier, Orlando 2012, p. 163.
[106] Tam C. M., Tong T. K. L, Zhang H., Decision Making and Operations Research Techniques for Construction Management, City University of HK Press, Kowloon 2007, p. 2.
Parlak B., Tolga A. C., Health Informatics in Kahraman C, Topcu Y. I. (ed.), Operations Research Applications in Health Care Management, Springer, Berlin 2017, p. 439.

$g_i(x) \leq b_i$ i = 1, …, m, (3.42)

$x_j \geq 0$ j = 1, …, n[107]. (3.43)

The only criterion used to assess organizational processes is the price or cost, as well as the quality parameter. The basis for making decisions within the scope of multicriteria programming issues is the sum of grades obtained due to the degree of fulfillement of individual criteria. In case of these parameters not being evaluated, (meaning that they are equally important for the decision maker), the assessment can be very subjective and inaccurate. A more reliable evaluation is guaranteed by using a weighted average in accordance with the following formula.

$$\sum_{k=1}^{p} w_k z_k(x) \to max \tag{3.44}$$

subject to

$g_i(x) \leq b_i$ i = 1, …, m, (3.45)

$x_j \geq 0$ j = 1, …, n[108]. (3.46)

The most commonly used multicriteria programming methods include:

[107] Cohon J. L., Multicriteria programming: brief review and application in Gero J. (ed.), Design Optimization, Elsevier, Orlando 2012, p. 166.
[108] Cohon J. L., Multicriteria programming: brief review and application in Gero J. (ed.), Design Optimization, Elsevier, Orlando 2012, p. 171.

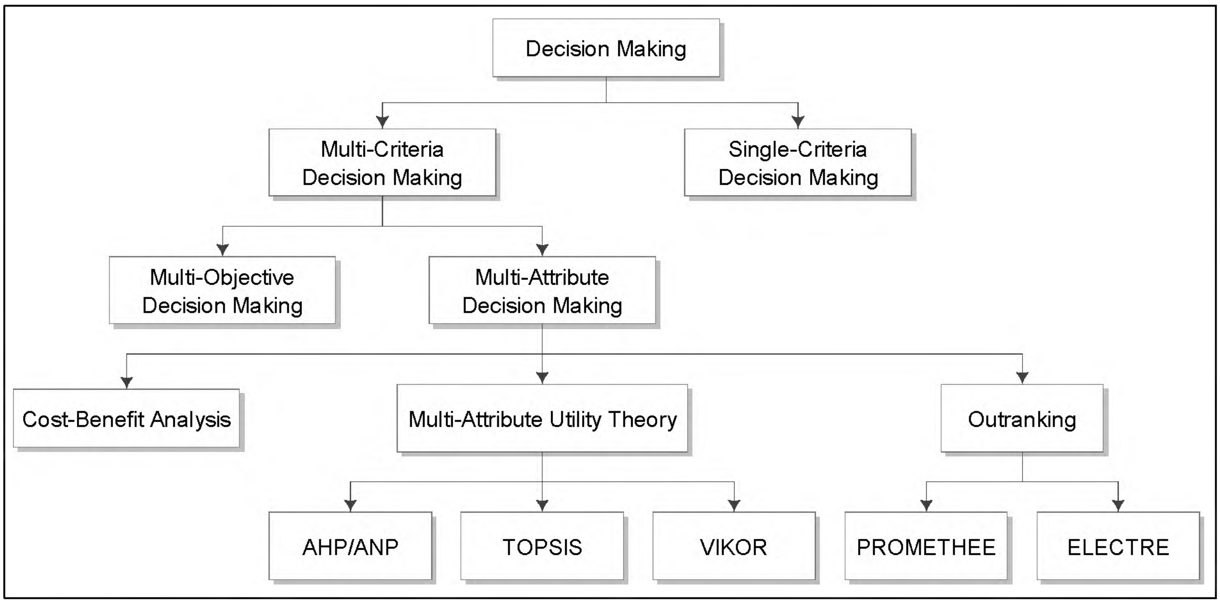


Figure 3.23. Multi-Criteria Decision Making Techniques

Source: Pattanaik L. N. Analytical Tools in Research, Educreation Publishing, New Delhi, 2017, p. 136.

Due to the fact that AHP is one of the most commonly used methods supporting multicriteria evaluation, this technique will be the subject of attention at this point.

AHP method (Analytic Hierarchy Process), created by T. Saaty, is a method used in decision-making processes., It allows for reliable verification of possible solutions by means of system optimization using specific criteria and mutual dependencies between processes. AHP method is characterized by a high level of reliability and complexity of decision support processes. It is most often used to optimize very complex and complicated problems that are affected by a wide set of many different criteria. AHP method is also supported by the modern ANP (Analytic Network Process) method as the expansion of AHP. ANP is applied to problems with a higher degree of complexity and deviates from the hierarchical structure of criteria in favor of a set of mutually interacting criteria[109].

[109] Jayaswal B. K., Patton P. C., Forman E. H., The Analytic Hierarchy Process (AHP) in Software Development, Pearson Education, Harlow 2007, p. 1.
Saaty T. L., Vargas L. G. Models, Methods, Concepts & Applications of the Analytic Hierarchy Process, Springer, Berlin, 2012, p. 4.
Saaty T., Theory and Applications of the Analytic Network Process: Decision Making With Benefits,

According to the assumptions of AHP, a decision-maker is obliged to take several steps, which include:

1) Identification of the problem to be optimized. Based on the analysis of the issue, one needs to create a hierarchical structure of criteria and alternatives and present them in the form of a tree, as shown in 3.24:

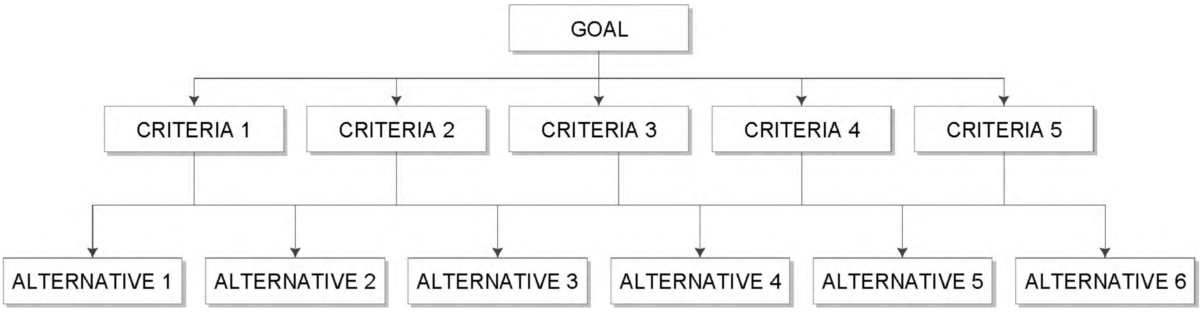


Figure 3.24. Tree diagram of criteria and alternative in solving decision problem

Source: Saaty T. L., Vargas L. G. Models, Methods, Concepts & Applications of the Analytic Hierarchy Process, Springer, Berlin, 2012, p. 3.

2) Creating a criteria comparison matrix according to the Saaty scale.

Table 3.38. Satty evaluation scale

Description	Satty's scale
Indifference	1
-	2
Moderate preference	3
-	4
Strong preference	5
-	6
Very strong or demonstrate preference	7

Opportunities, Costs, and Risks, RWS Publications, Pittsburgh 2013, p. 47.

-	8
Extreme preference	9

Source: Brunelli M. Introduction to the Analytic Hierarchy Process, Springer, Berlin, 2014, p. 15.

Using the comparison matrix, the criteria are evaluated in pairs according to the following pattern:

$$\begin{pmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \cdots & 1 \end{pmatrix} \tag{3.47}$$ [110]

On the main diagonal there are values 1, over which the individual assessment criteria assigned on the basis of significance and their reversals located below the main diagonal were placed.

3) Determining the weights of all criteria.

This stage assumes unification of the values assigned to criteria by summing the matrix values in the columns, and then dividing each value in the column by the sum of the given column. Then, it is crucial to calculate the average of the rows in the assessment matrix in order to indicate the weight of each.

As part of this stage, it is also necessary to assess the validity of using certain weights by using the Consistency Ratio (CR).

$$CR = \frac{CI}{RI} \tag{3.48}$$

subject to:

RI – random incompatibility index (Random Index) determined depending on the number of n criteria.

[110] Brunelli M. Introduction to the Analytic Hierarchy Process, Springer, Berlin, 2014, p. 5.

Table 3.39. Average random consistency index (RI)

n	1	2	3	4	5	6	7	8	9	10
Random consistency index (RI)	0	0	0,52	0,89	1,11	1,25	1,35	1,40	1,45	1,49

Source: Saaty T. L., Vargas L. G. Models, Methods, Concepts & Applications of the Analytic Hierarchy Process, Springer, Berlin, 2012 p. 9.

CI –Consistency Index calculated based on the deviation from compliance.

$$CI = \frac{\lambda_{max}-1}{n-1} \tag{3.49}$$

subject to:

n – number of criteria,

λ_{max} – eigenvalue of the matrix calculated from the following formula:

$$\lambda_{max} = \frac{1}{w_i}\sum_{j=1}^{n} a_{ij}w_{ij} \quad ^{111} \tag{3.50}$$

4) Comparison of the evaluations of the analyzed offers on the basis of the criteria.

As part of this stage, it is necessary to compare the scores awarded to individual solutions by creating for each criterion a separate comparison matrix (stages 1 and 2) and determining the absolute assessment criteria.

5) Determining the weighted assessment of all the analyzed offers and creating the final ranking[112].

[111] Lee J-H., Yeom K-W., Park J-H., A Development of Graphical Interference for Decision Making Process Including Real-Time Consistency Evaluation in Aykin N. (ed.), Usability and Internationalization. HCI and Culture: Second International Conference on Usability and Internationalization, UI-HCII 2007, held as Part of HCI International 2007, Beijing, China, July 22-27, 2007, Proceedings, Part I, Springer, Berlin 2007, pp. 132-133.

[112] Ssebuggwawo D., Hoppenbrowwers S., Proper E., Evaluating Modeling Sessions Using the Analytic Hierarchy Process in Persson A. (ed.), Lecture Notes in Business Information Processing (Book 39), Springer, Berlin 2010, pp. 74-80.

Due to the fact that the AHP method is one of the most commonly used multicriterial programming methods, it is used, for example, in the issues of supplier selection. From the point of view of this handbook as well as the topics taken up as part of its implementation, the reference of the method used in operations research and optimization theory to issues in the field of e.g. supply planning is an important element in the context of appropriate management of processes implemented within the supply chain. Hence the choice of the example implemented below using the AHP method was considered by the authors to be accurate.

Example 3.6

Two suppliers producing raw materials for company X received marks due to the degree to which they fulfilled the criteria of quality, price, timeliness and delivery time, which is presented in the following matrixes:

$$Q = \begin{bmatrix} 1 & 6 \\ \frac{1}{6} & 1 \end{bmatrix}$$

$$P = \begin{bmatrix} 1 & \frac{1}{9} \\ 9 & 1 \end{bmatrix}$$

$$OT = \begin{bmatrix} 1 & \frac{1}{3} \\ 3 & 1 \end{bmatrix}$$

$$DT = \begin{bmatrix} 1 & 7 \\ \frac{1}{7} & 1 \end{bmatrix}$$

The criteria linkage matrix is presented as follows:

Table 3.40. The criteria binding matrix

	Q	P	OT	DT
Q	1	4	6	9
P	1/4	1	3	2
OT	1/6	1/3	1	2
DT	1/9	1/2	1/2	1

	Q	P	OT	DT
Q	1	4	6	9
P	0,25	1	3	2
OT	0,17	0,33	1	2
DT	0,11	0,50	0,50	1

Source: own study.

Then, calculate the sum in columns and divide each value of the matrix in the column by sum.

Table 3.41. Calculating the sum in columns and dividing by each case the value from the column

	Q	P	OT	DT
Q	1	4	6	9
P	0,25	1	3	2
OT	0,17	0,33	1	2
DT	0,11	0,50	0,50	1
Sum	1,53	5,83	10,5	14

	Q	P	OT	DT
Q	1/1,53	4/5,83	6/10,5	9/14
P	0,25/1,53	1/5,83	3/10,5	2/14
OT	0,17/1,53	0,33/5,83	1/10,5	2/14
DT	0,11/1,53	0,5/5,83	0,5/10,5	1/14
Sum	1,53	5,83	10,5	14

Source: own study.

Then the values of the matrix should be normalized so that the criteria can be compared with each other by determining their weights.

Table 3.42. Normalized matrix of criteria weights

	Q	P	OT	DT
Q	0,6545455	0,685714	0,571429	0,642857
P	0,1636364	0,171429	0,285714	0,142857
OT	0,1090909	0,057143	0,095238	0,142857
DT	0,0727273	0,085714	0,047619	0,071429

Source: own study.

The weight of the criteria should be pre-determined by calculating the average value in each row:

Table 3.43. Criteria weights

	Q	P	OT	DT	Criteria weights
Q	0,6545	0,6857	0,5714	0,6429	0,6386
P	0,1636	0,1714	0,2857	0,1429	0,1909
OT	0,1091	0,0571	0,0952	0,1429	0,1011
DT	0,0727	0,0857	0,0476	0,0714	0,0694

$$\frac{0{,}6545 + 0{,}6857 + 0{,}5714 + 0{,}6429}{4} = 0{,}6386$$

Source: own study.

In the next stage, it is necessary to indicate the correctness of the established criteria and to calculate the Consistency Ratio for this purpose. However, before this occurs, the initial matrix must be multiplied by the obtained weights:

Table 3.44. Sum of weights and criteria ratio

	0,6386	0,1909	0,1011	0,0694
	Q	P	OT	DT
Q	1*0,6386	4*0,1909	6*0,1011	9*0,0694
P	0,25*0,6386	1*0,1909	3*0,1011	2*0,0694
OT	0,17*0,6386	0,33*0,1909	1*0,1011	2*0,0694
DT	0,11*0,6386	0,5*0,1909	0,5*0,1011	1*0,0694

	0,6386	0,1909	0,1011	0,0694	Sum of weights	Criteria	Sum of weights/Criteria
	Q	P	OT	DT			
Q	0,6386	0,7636	0,6065	0,6244	2,6331	0,6386	4,1230
P	0,1597	0,1909	0,3032	0,1387	0,7926	0,1909	4,1515
OT	0,1064	0,0636	0,1011	0,1387	0,4099	0,1011	4,0551
DT	0,0710	0,0955	0,0505	0,0694	0,2863	0,0694	4,1274

Source: own study.

The ratio of the sum of weights to the values of the criteria allows the calculation of the eigenvalues of the matrix λ_{max}

$$\lambda_{max} = \frac{4,1230+4,1515+4,0551+4,1274}{4} = 4,1143$$

Next, the consistency ratio and consistency index should be calculated:

$$CI = \frac{4,1143 - 4}{4 - 1} = 0,038$$

$$CR = \frac{0,038}{0,89} = 0,0427$$

If the value of the CR coefficient is less than 0.10, weights are allocated correctly.

Properly assigned weights allow suppliers to be evaluated in terms of criteria. For this purpose, in each comparison matrix for suppliers, the scores awarded should be normalized.

	Q	
	S1	S2
S1	1	6
S2	0,16667	1
Sum	1,17	7,00

	Q		Criteria weights
	S1	S2	
S1	0,8571	0,8571	0,8571
S2	0,1429	0,1429	0,1429

	P	
	S1	S2
S1	1	0,11111
S2	9	1
Sum	10,00	1,11

	P		Criteria weights
	S1	S2	
S1	0,1000	0,1000	0,1000
S2	0,9000	0,9000	0,9000

	OT	
	S1	S2
S1	1	0,33333
S2	3	1
Sum	4,00	1,33

	OT		Criteria weights
	S1	S2	
S1	0,2500	0,2500	0,2500
S2	0,7500	0,7500	0,7500

	DT	
	S1	S2
S1	1	7
S2	0,14286	1
Sum	1,14	8,00

	DT		Criteria weights
	S1	S2	
S1	0,8750	0,8750	0,8750
S2	0,1250	0,1250	0,1250

Figure 3.25. Indication weights value of all criteria

Source: own study.

In the last step a comparative assessment of both suppliers should be provided for all criteria:

$$S1 = 0{,}8571 * 0{,}6386 + 0{,}1 * 0{,}1909 + \ 0{,}25 * 0{,}1011 + 0{,}8750 * 0{,}0694 = \mathbf{0{,}6525}$$

$$S2 = 0{,}1429 * 0{,}6386 + 0{,}9 * 0{,}1909 + \ 0{,}75 * 0{,}1011 + 0{,}8750 * 0{,}1250 = 0{,}3475$$

The first supplier should be chosen.

AHP supports many areas of the economy, including management, supply, transport and manufacturing processes. Multicriteria programming methods is very often used in logistics in suppliers' evaluation processes in order to select the optimal source of supply for the organization and the entire supply chain. Effective evaluation is conducive to efficient decision-making processes which, in turn, have a direct impact on the subsequent implementation of processes within the organization and as part of cooperation with other links, as well as on efficiency and timeliness of delivering quality products that meet the expectations of final recipients of products[113].

3.2.5. Dynamic programming

Dynamic programming is one of the methods of mathematical models. It consists of processes supporting the making of successive decisions in a given time interval[114]. Dynamic

[113] Vaidya O. S., Kumar S., Analytic hierarchy process: An overview of applications in European Journal of Operational Research, Volume 169. 1, 2006, pp. 13-17.
[114] Radhakrishnan R., Balasubramanian S. (2008). BUSINESS PROCESS REENGINEERING: Text and Cases , PHI Learning Pvt. Ltd., New Delhi, p. 261.

programming methods were developed in the 1950s and are used to make decisions on many levels of a given process by solving complex decision problems little by little[115]. Dynamic programming is characterized by solving complex problems consisting of n variables, which are divided into less demanding issues and solved only within one n variable. In contrast to linear programming methods, dynamic programming is characterized by lack of specific algorithms used in problem solving. However, it also indicates the need to build a model in order to optimize unique decision problems each time[116]. Dynamic programming is used in production planning processes, inventory management and investment profitability analysis[117]. Solving the problems of dynamic programming requires solving problems from the end, that is, the first optimized problem is given the value of n, and the next, more complex problem reaches the value of n-1. To understand the essence of dynamic programming, it is necessary to explain the three concepts presented below:

- stage – it is part of a complex problem for which many decisions are allowed to be taken to select the optimal one,
- state – determines the state of the decision process at a given stage,
- return function – is the value of the decision made at a particular stage, allowing the system to reach a certain state and enabling the transition to the next stage of the decision-making process[118].

The decision process with the use of dynamic programming can be presented as below:

[115] Rao S. S., Engineering Optimization: Theory and Practice, Wiley, New York 1996, p. 544.
[116] Hiller F. S., Lieberman G. J., Introduction to Operations Research, The McGraw-Hill, New Delhi 2001, p. 533.
[117] Radhakrishnan R., Balasubramanian S., BUSINESS PROCESS REENGINEERING: Text and Cases , PHI Learning Pvt. Ltd., New Delhi 2008, p. 261.
[118] Murthy P. R., Operations Research, New Age International (P) Ltd., New Delhi 2007, p. 564. Radhakrishnan R., Balasubramanian S. BUSINESS PROCESS REENGINEERING: Text and Cases , PHI Learning Pvt. Ltd., New Delhi, 2008, p. 262.

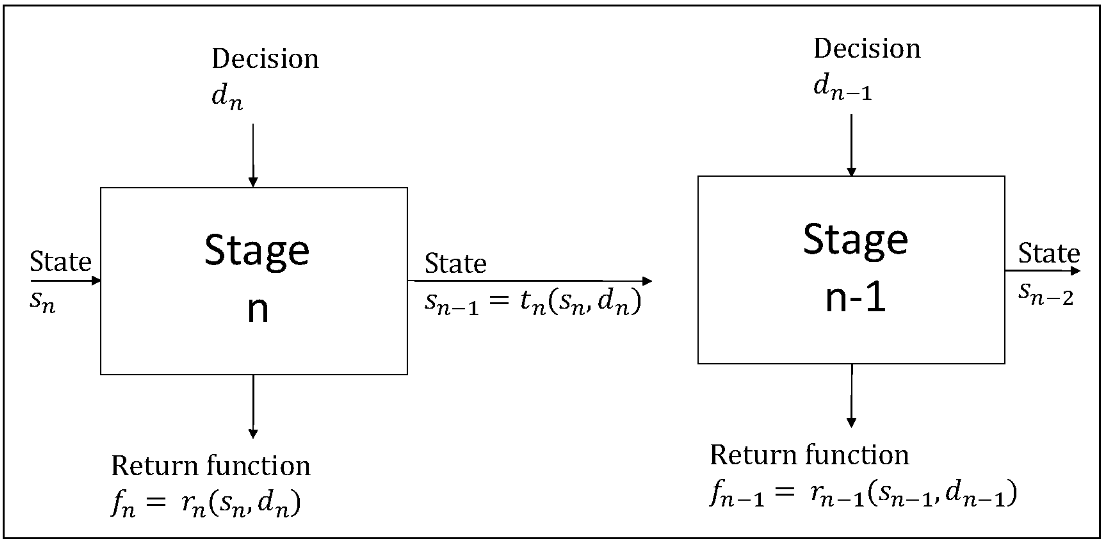


Figure 3.26. Dynamic programming Decision Process

Source: Radhakrishnan R., Balasubramanian S. BUSINESS PROCESS REENGINEERING: Text and Cases , PHI Learning Pvt. Ltd., New Delhi, 2008, p. 262.

The most frequently solved problems using dynamic programming are the issues of the traveling salesman and the allocation of tasks that are presented below. Due to the possibility of using methods in the field of operations research and optimization theory in the field of supply chain management, it was decided to present examples of salesman optimization problem as an issue often identified with the problems of choosing the right route, guaranteeing the lowest transport costs and resource allocation, which is applicable even in the case of planning the delegation of resources to specific processes performed as part of the supply chain management activities.

The Traveling Salesman Problem

The traveling salesman problem as one of the most common optimization problems relates to the indication of the optimal order of transportation, starting and ending with the same location. Depending on the restrictions, the salesman can visit a given town only once. The traveling salesman problem first appeared in the 1930s[119]. Very often, the traveling salesman

[119] Gutin G., Punnen A.P. (eds.), The Traveling Salesman Problem and Its Variations, Springer, Berlin 2007, p. 1.

problem, concerns logistic aspects, and thus the whole supply chain, within which one can distinguish, for example, route optimization related to the delivery of goods between individual links in the supply chain, e.g. from the central warehouse to regional warehouses and delivery of cargo to final customers located in different locations of the served area.[120] The following is an example of the traveling salesman problem
To solve the problem of the traveling salesman from Example 3.7 is presented below.

Example 3.7

The salesman sets off from town X and should visit the four-location only once and return to the starting place. The distance matrix contains the values of the number of kilometers between individual tows. The plan containing the shortest possible route allocation for the traveling salesman should be indicated.
when:
i – the number of the town in which the route begins,
j – the number of the town in which the route ends,
subject to:
i, j € N <1, …4>.

Table 3.45. Distance matrix in salesman problem

Distance matrix

j i	1	2	3	4
1	0	150	200	110
2	150	0	90	130
3	200	90	0	120
4	110	130	120	0

Source: own study.

Applegate D. L., Bixby R. E., Chvátal V., Cook W. J., The Traveling Salesman Problem: A Computational Study, Princeton University Press, Princeton 2006, p. 1.
Applegate D. L., Bixby R. E., Chvátal V., Cook W. J., The Traveling Salesman Problem: A Computational Study, Princeton University Press, Princeton 2006, p. 59.

Initial order of visited towns presented below:

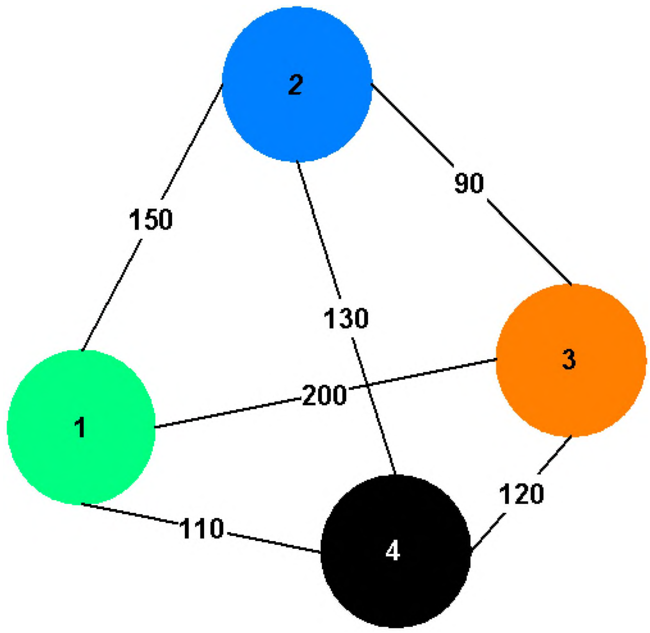


Figure 3.27. Distances between locations

Source: own study.

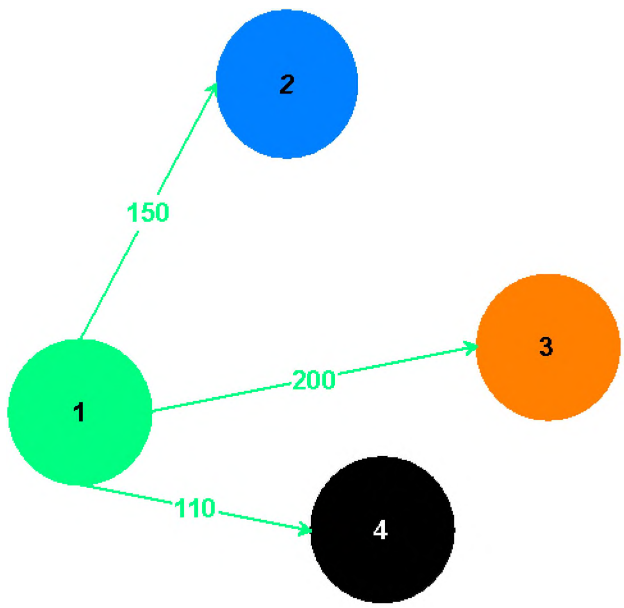


Figure 3.28. Indicating the first route

Source: own study.

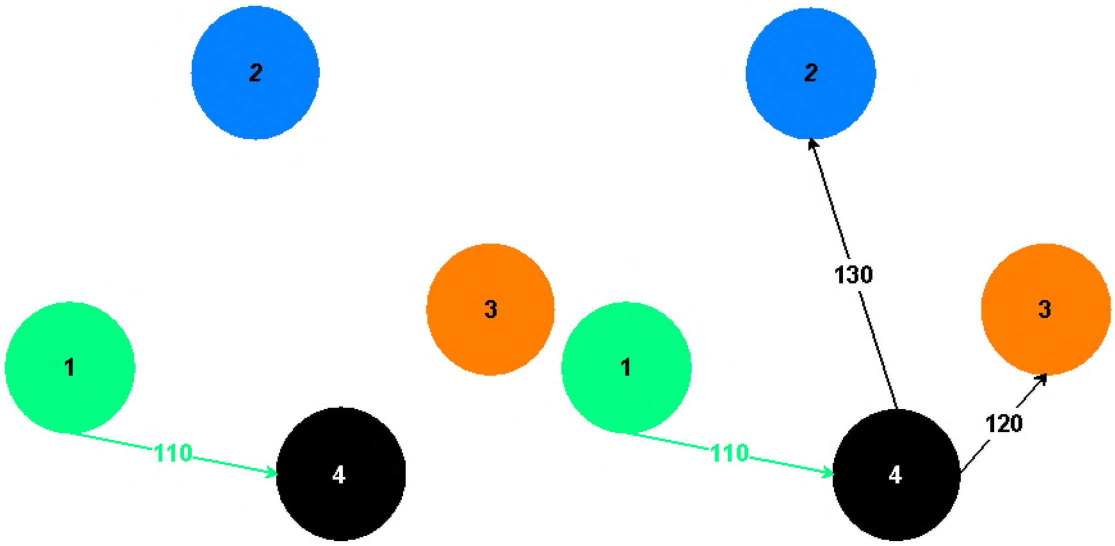


Figure 3.29. Indicating the second route

Source: own study.

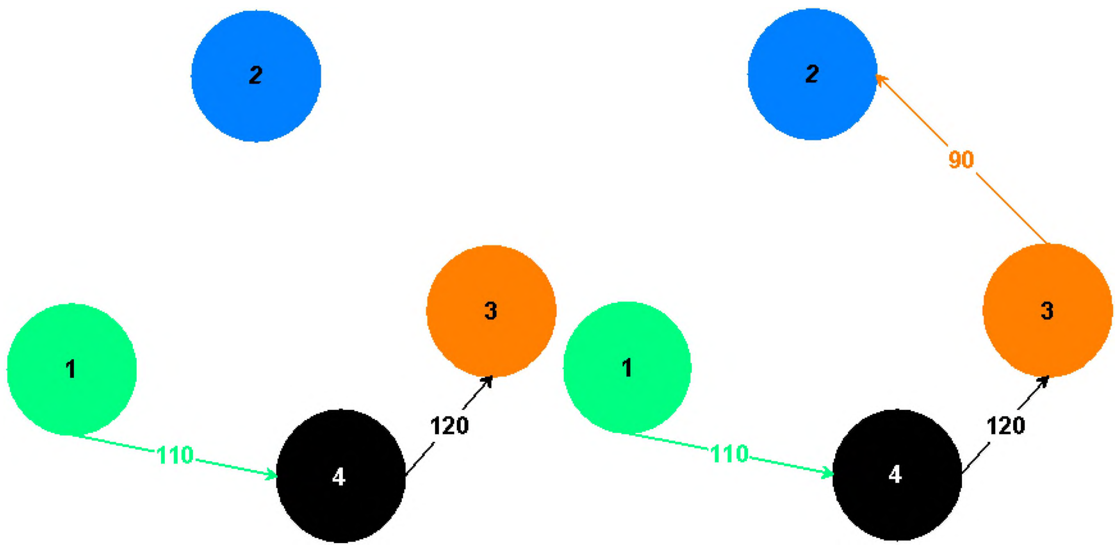


Figure 3.30. Indicating the third route

Source: own study.

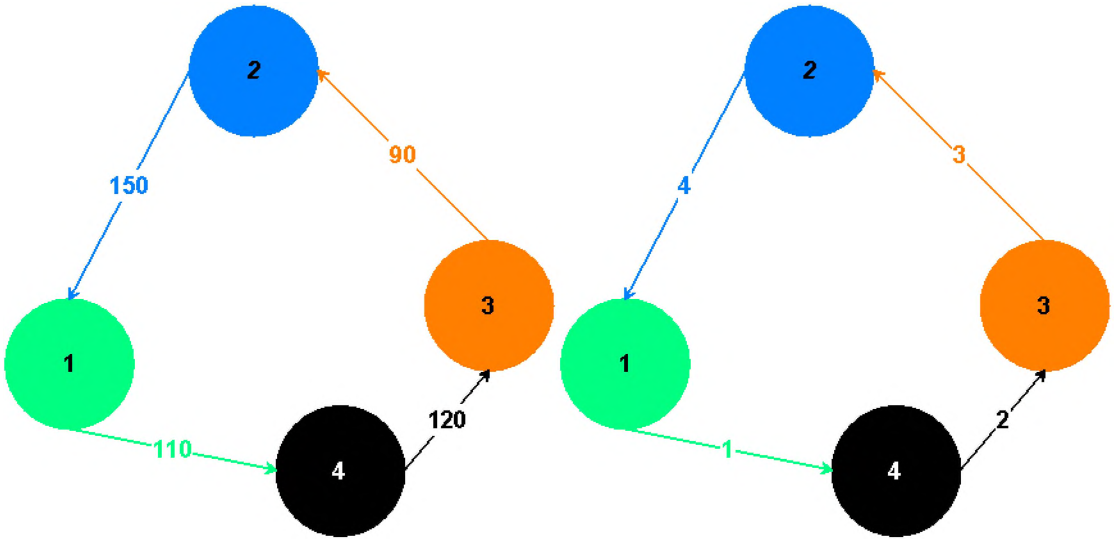


Figure 3.31. Final route allocation

Source: own study.

1-1 = 0

1-2-1 = 150 + 150 = 300

1-2-3-1 = 150 + 90 + 200 = 440
1-3-2-1 = 200 + 90 + 450 = 440

1-2-3-4-1 = 150 + 90 + 120 + 110 = 470
1-2-4-3-1 = 150 + 130 + 120 + 300 = 700
1-4-2-3-1 = 110 + 130 + 90 + 200 = 530
1-3-2-4-1 = 200 + 90 + 130 + 110 = 530
1-3-4-2-1 = 200 + 120 + 130 + 150 = 600
1-4-3-2-1 = 110 + 120 + 90 + 150 = 470

Starting from town 1, the route should be performed in the following order: 1-4-3-2-1. The alternative route for generating the same costs which route presented above is the 1-2-3-4-1 route.

Task Allocation Problem

The problem of allocating tasks or otherwise allocating resources to tasks was initiated in the 1960s by the American army in order to optimally allocate resources to tasks. Optimal allocation of employees to tasks, as well as allocation of resources requires, above all, the of the need to maximize the organization's effectiveness and profits, and minimize costs, service time and employment levels while fulfilling the conditions, e.g. the possibility of assigning only one task to an employee etc.[121]. Currently, this problem concerns not only military issues, but also, to a large extent, logistics and supply chain management through optimal allocation of vehicles to the routes used by the organization, allocation of tasks to production workers to ensure that the tools and machines used achieve maximum performance levels, and to reduce employment to a minimum[122].

Due to the wide scope of application of the tool, which is the addition to MS Excel, Solver, the authors decided to present its use in the allocation of resources required for the process. This is an issue that finds application even in resources allocation, for example in the field of production planning or the selection of appropriate means of transport, hence its presentation in this manual has been found to be fully justified.

The following example illustrates how to solve the problem of resource allocation using the Solver tool.

Example 3.8

A transport company deals with the distribution of goods throughout the city. Depending on the time of day, there is a demand for vehicles from 6 a.m. to 8 p.m. The company operates from Monday to Friday from 8:00 to 4:00 p.m. and has 8 own vehicles at its disposal. In case of increased demand, it uses the services of subcontractors. Its employees can have one hour break, half of them at 1 p.m. and the other half at 2 p.m. Subcontractor drivers working as subcontractors work a maximum of 5 hours without interruption. The cost of the employee's

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[121] Sharma S. C., Operation Research: Pert, CPM & Cost Analysis, Discovery Publishing House, New Delhi 2006, p. 200.
Murthy P. R., Operations Research, New Age International (P) Ltd., New Delhi 2007, p. 16.
Shrader C. R., History of operations research in the United States Army, V. 3 1973-1995, Government Printing Office, Washington D.C. 2009, p. 271.
[122] Winston W. L., Operations Research Applications and a algorithms, Brooks/Cole, Toronto 2004, pp. 393-395.

remuneration is 100 € and the subcontractor 80 € for 5 hours of work. It is necessary to plan the allocation of human resources in order to minimize costs, assuming that there is no possibility to change the number of permanently employed drivers.

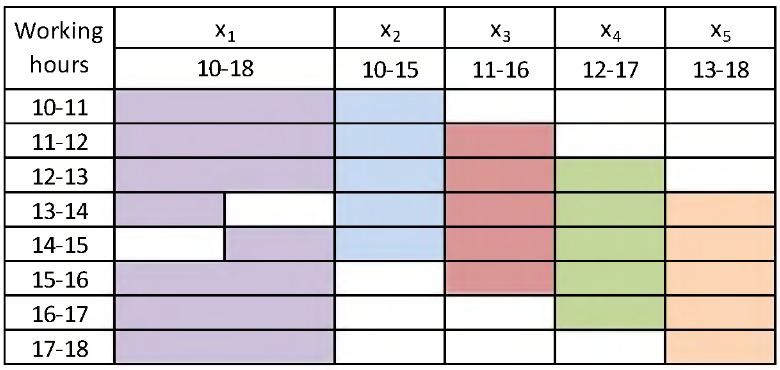
Table 3.46. Number of employees required depending on the working hours

Working hours	Number of employees required
10-11	20
11-12	15
12-13	17
13-14	9
14-15	6
15-16	12
16-17	16
17-18	19

Source: own study.

In this optimization task, the most difficult stage is to define the limitations of the objective function, which tends to the minimum. It can be facilitated by the following table:

Table 3.47. Allocation of employees to working hours



Source: own study.

When considering the company's employees, it is also necessary to indicate an obligatory, one-hour break. In the next step, the objective function and constraints must be determined.

$$f(x) = 100x_1 + 80x_2 + 80x_3 + 80x_4 + 80x_5 \rightarrow min$$

1. Employee + 1 subcontractor. $x_1 + x_2 \geq 20$
2. Employee + 2 subcontractors. $x_1 + x_2 + x_3 \geq 15$
3. Employee employed + 3 subcontractors. $x_1 + x_2 + x_3 + x_4 \geq 17$
4. Half of the employees employed + 4 subcontractors. $0{,}5x_1 + x_2 + x_3 + x_4 + x_5 \geq 9$
5. Half of the employees employed + 4 subcontractors. $0{,}5x_1 + x_2 + x_3 + x_4 + x_5 \geq 6$
6. Employee + 3 subcontractors. $x_1 + x_3 + x_4 + x_5 \geq 12$
7. Employee + 2 subcontractors. $x_1 + x_4 + x_5 \geq 16$
8. Employee + 1 subcontractor. $x_1 + x_5 \geq 19$
9. The company employs 8 driver. $x_1 = 8$

In the next step the objective function and constraints formulas should be placed in Solver so as to solve the problem and perform optimal decision variables values.

Table 3.48. Constraints of task allocation example

Variables	Employee	Subcontractor 1	Subcontractor 2	Subcontractor 3	Subcontractor 4
Hours	10-18	10-15	11-16	12-17	13-18
Symbol	x_1	x_2	x_3	x_4	x_5
Number of drivers required					
Costs of employment	100	80	80	80	80
Constraints					
Constraint 1	1	1			
Constraint 2	1	1	1		
Constraint 3	1	1	1	1	
Constraint 4	0,5	1	1	1	1
Constraint 5	0,5	1	1	1	1
Constraint 6	1		1	1	1
Constraint 7	1			1	1
Constraint 8	1				1

Source: own study.

=SUMPRODUCT(G4:K4;G5:K5)

F	G	H	I	J	K	L	M	N
Variables	Employee	Subcontractor 1	Subcontractor 2	Subcontractor 3	Subcontractor 4			
Hours	10-18	10-15	11-16	12-17	13-18			
Symbol	x_1	x_2	x_3	x_4	x_5			
Number of drivers required						=SUMPRODUCT(	OBJECTIVE FUNCTION	
Costs of employment	100	80	80	80	80			
Constraints						Constraint value		No. of drivers required
Constraint 1	1	1				0	>=	20
Constraint 2	1	1	1			0	>=	15
Constraint 3	1	1	1	1		0	>=	17
Constraint 4	0,5	1	1	1	1	0	>=	9
Constraint 5	0,5	1	1	1	1	0	>=	6
Constraint 6	1		1	1	1	0	>=	12
Constraint 7	1			1	1	0	>=	16
Constraint 8	1				1	0	>=	19

=SUMPRODUCT($G$4:$K$4;G7:K7)

F	G	H	I	J	K	L	M	N
Variables	Employee	Subcontractor 1	Subcontractor 2	Subcontractor 3	Subcontractor 4			
Hours	10-18	10-15	11-16	12-17	13-18			
Symbol	x_1	x_2	x_3	x_4	x_5			
Number of drivers required						0	OBJECTIVE FUNCTION	
Costs of employment	100	80	80	80	80			
Constraints						Constraint value		No. of drivers required
Constraint 1	1	1				=SUMPRODUCT(	>=	20
Constraint 2	1	1	1			0	>=	15
Constraint 3	1	1	1	1		0	>=	17
Constraint 4	0,5	1	1	1	1	0	>=	9
Constraint 5	0,5	1	1	1	1	0	>=	6
Constraint 6	1		1	1	1	0	>=	12
Constraint 7	1			1	1	0	>=	16
Constraint 8	1				1	0	>=	19

Figure 3.32. Definition of objective function and constraints in Excel

Source: own study.

The limitation should also include the condition that decision variables must take integer values.

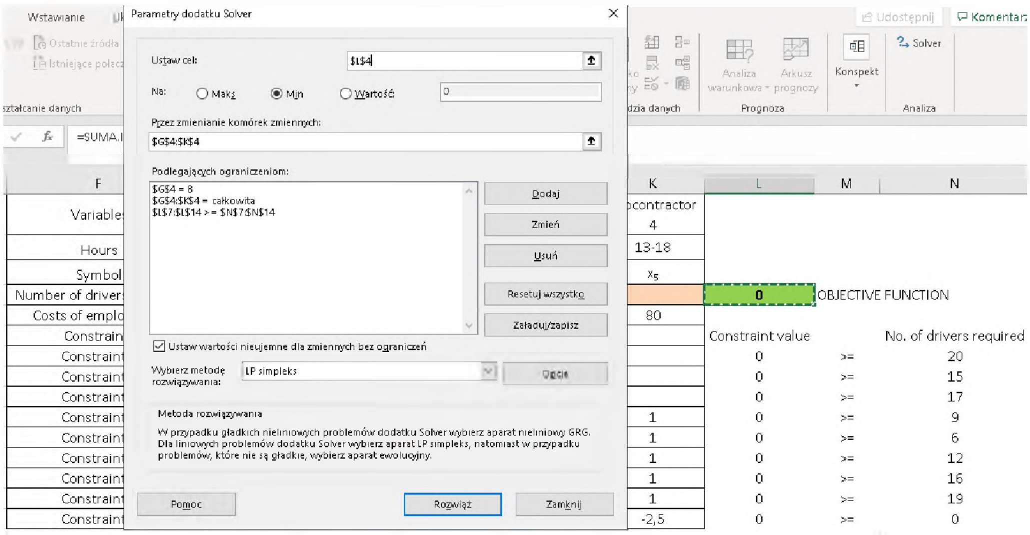


Figure 3.33. Implementation of example parameters in Solver

Source: own study.

After solving the problem, the decision variables assume values[123]:

Variables	Employee	Subcontractor 1	Subcontractor 2	Subcontractor 3	Subcontractor 4	
Hours	10-18	10-15	11-16	12-17	13-18	
Symbol	x_1	x_2	x_3	x_4	x_5	
Number of drivers required	8	12	0	0	11	**2640**
Costs of employment	100	80	80	80	80	OBJECTIVE FUNCTION
Constraints						
Constraint 1	1	1				
Constraint 2	1	1	1			
Constraint 3	1	1	1	1		
Constraint 4	0,5	1	1	1	1	
Constraint 5	0,5	1	1	1	1	
Constraint 6	1		1	1	1	
Constraint 7	1			1	1	
Constraint 8	1				1	

Figure 3.34. Final task allocation

Source: own study.

[123] Hiller F. S., Lieberman G. J., Introduction to Operations Research, The McGraw-Hill, New Delhi 2001, pp. 386-391.

The objective function assumes the form:

$$f(x) = 100 * 8 + 80 * 12 + \ 80 * 0 + \ 80 * 0 + 80 * 11 = 2\ 640$$

The daily cost of employment of 8 employees and the rental of 12 subcontractors from 10am till 3pm and 11 between 1pm and 6pm is 2 640€.

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4. PROBLEM SOLVING TECHNIQUES

4.1. Problem identification

A turbulent environment affects the changes taking place in the organization and causes the emergence of new management problems. These issues can be related to the area of logistics or even the functioning of the entire supply chain[124]. In order to adapt to changes taking place in a changing environment, these problems need to be identified with the aim of solving them and adjusting accordingly[125].

Management problems and the process of solving them are among the main areas of scientific research, both for theoreticians as well as management practitioners. Management issues are analyzed from different perspectives (e.g., strategic management, human resources management, finance, production marketing and logistics).

Defining the term “problem" in terms of management sciences is a semantic challenge (in terms of theory and practice). This is because in their day-to-day business, managers solve various problems and tasks. To distinguish between tasks and problems, various criteria are used to analyze their structural differences. One of these criteria is whether or not there is a subjective feeling of mental difficulty, which also means that tasks are treated as cognitively easy situations and problems are treated as situations connected with the feeling of greater difficulty[126].

A problem can be defined as an accepted goal, which has been set by someone else (or assigned). On the other hand, a management problem is always related to a specific problem situation, i.e., an element of the organization's reality that needs to be repaired[127]. Management problems, as pointed out earlier, take different forms and concern single or multiple areas of an organization.

[124] Szarucki M., *Evolution of managerial problems from the perspective of management science*, Business: Theory and Practice, Vol. 16, No. 4/2015.
[125] Isaksen S. G., Dorval K. B., Treffinger D.J., *Creative Approaches to Problem Solving. A Framework for Innovation and Change*, 3rd edition, Publishing House: Sage, Washington DC 2011.
[126] Nosal C. S., *Umysł menedżera. Problemy, decyzje, strategie*, Wydawnictwo: Wrocławskie Wydawnictwo Przecinek, Wrocław 1993.
[127] Szarucki M., Bugaj J., *Metody identyfikacji problemów zarządzania w organizacji - próba typologii*, Journal of Management and Finance, vol. 14, no. 2/2/2016, p. 435-447.

Problems related to management and logistics should, therefore, be seen as a discrepancy between what is and what should (or potentially could) be present in an organization, regardless of its legal form and the type of business conducted The existence of a problem requires those exercising formal authority, i.e., holding managerial positions in the organization's hierarchy, to take some actions in order to resolve it[128].

In logistics processes of companies, it is possible to identify different types of problems, the occurrence of which has negative effects. In order to classify them appropriately, a right criterion for their allocation should be adopted. It should also be noted that from the point of view of logistics processes, the most important are both internal (endogenous) disturbances, on which the company has influence, so that a manager can control them, as well as external (exogenous) disturbances - independent of the company.

It bears significance that the same determinants of problems in different organizations occur with different probability and cause a different scale of potential effects, so the identification of potential causal factors should be considered individually in a given company[129]. The subject literature mentions problems that occur in particular areas of logistic processes functioning (Table 4.1).

Table 4.1. Problems of enterprise logistics processes (supply chain)

Area	Problems
Supply	- incorrect evaluation of the quality of materials. - error of assessment of suppliers, - incorrect selection of suppliers, - delays in delivery dates, - breach of contract by carriers, logistics operators, etc, - lack of close cooperation with suppliers, - lack of overall assessment of all basic suppliers, - volatility of material prices,

[128] Ibidem, s. 435-447; Nazemi, A., Omidi F., *An efficient dynamic model for solving the shortest path problem*, Transportation Research Part C: Emerging Technologies, vol. 26/2013, pp. 1-19.
[129] Gaschi-Ucieha A., *Zakłócenia w procesach logistycznych przedsiębiorstw produkcyjnych - badania literaturowe*, Zeszyty Naukowe Politechniki Śląskiej, Seria: Organizacja i Zarządzanie, z. 78, nr kol. 1928/2015, pp. 131-140.

	- failure on the part of the suppliers to comply with technical standards, - punctuality of deliveries, - changes in the terms of supply, - relations with business partners, - inadequate supply of materials in terms of quantity, quality, time, place and cost, - information flow problems, - qualifications and experience of employees, - mistakes of office workers, - wrong information system, - staff shortage.
Production	- large production stocks, - lack of knowledge of all production bottlenecks, - long flow paths for materials and products, - lack of appropriate packaging, - lack of modern planning and control instruments, - no instant access to production department data, - bad production planning, - lack of flexibility in the production process, - malfunctions of machinery and equipment, - qualifications and experience of employees, - staff shortage, - imbalance in the production system, - restrictions on product transformation, - shortages of production factors, - inadequate organization of workstations, - lack of flexibility of production lines, - failure to meet the delivery time of orders, - failure to adapt the conditions of contract performance to the company's capabilities, - decrease in the number of orders,

	- defect in order processing. - lack of knowledge of market niches, - lack of financial resources for marketing research, - problem with identifying key customers or groups of customers, - misplaced anticipation of customer needs, - inadequate service provision, - error in estimating the customer's profitability, - error in selecting a strategy for managing distribution channels, - Imbalance between customer expectations and the capabilities of all links in the supply chain, - fashion, - variability in demand, - misunderstanding of market needs, - lack of integration with customers.
Distribution	- lack or insufficient flow of information on demand from points of sale and from key customers, - inadequate forecasting methods, - competitive forces in the market, - the impact of promotion and advertising measures, - market potential, - inflation, - substitution of products, - variability of legal regulations, - structure and strength of the recipients, - qualifications and experience of the employees, - staff shortage, - failure to meet the delivery time of orders, - relations with business partners, - a mismatch in terms of tastes of the employees, - decrease in the number of orders.
Transport	- lack of adequate means of transport,

<table>
<tr><td></td><td colspan="2">- damage during transport,
- downtime due to waiting for the means of transport,
- lack of a system for organizing in-house transport,
- car breakdowns,
- working time of drivers,
- qualifications and experience of the drivers,
- driver shortage,
- accidents,
- lack of available drivers</td></tr>
<tr><td>Warehousing</td><td colspan="2">- no division of the warehouse into fast and slow-moving materials,
- inadequate material management,
- lack of appropriate marking of the marking fields,
- lack of classification of materials,
- lack of detailed information regarding particular data,
- occurrence of insufficient material,
- material quality control system,
- possession of redundant supplies,
- damage during storage,
- hidden defects in materials,
- qualifications and experience of employees,
- staff shortage.</td></tr>
<tr><td rowspan="4">Supporting processes</td><td>analysis and forecast of market logistics situations</td><td>Supporting processes</td></tr>
<tr><td>identification of customer preferences and expectations in the area of logistics services</td><td>- problem with identifying key customers or groups of customers,
- misplaced anticipation of customer needs.</td></tr>
<tr><td>identification of logistics market segments</td><td>- maladjustment of the offer of logistics services to the segment,
- lack of integration of all activities related to the given logistics segment.</td></tr>
<tr><td>preparation and development of logistics strategies</td><td>- error in selecting a strategy for managing distribution channels,</td></tr>
</table>

		- too long a time for a new product to appear.
	development of the set and structure of the mix logistics components	- decisions concerning the service level, - Planning of material requirements, - issuing orders, - forecasting supply - location of depots and warehouses.
	securing and developing staff qualifications concerning competence in designing and implementing logistics processes	- bad production planning.
	securing the quality of service provision processes	- inadequate service provision.
	securing the quality of the processes of purchase and sale of products	-deficient control assessment of the quality of finished products.
	controlling the flow of products by developing the processes of transport, handling, storage, packaging and marking of goods	- lack of internal and external integration in supply chain management.
	issuing instructions concerning the execution of orders from customers	- too long a time to pass on the information, - illegibility of the information, - Misinterpretation of commands.
	identification of objectives and development of a framework for the implementation of logistics customer service	- insufficient capacity of partners to respond to unexpected procurement (low flexibility, too slow adaptation to requirements).
	securing the capacity and potential for added value	- lack of innovative solutions, - no strategy, no plans to be put into practice, - limiting oneself to announcing slogans - no implementation, - the impact of promotion and advertising.
	research and development of logistics infrastructure	- changes in the terms of supply, - bad production planning, - lack of flexibility in the production process.

	development of information and communication technology	- lack or insufficient flow of information on demand from points of sale and from key customers, - inadequate demand forecasting methods, information flow problems.
	shaping and maintaining relationships and relations with the environment	- Imbalance between customer expectations and the capabilities of all links in the supply chain, misunderstanding market needs, - lack of integration with customers, - variability of demand, relations with business partners, - competitive forces in the market, - market potential.
	management of waste, packaging, permanently damaged products	- lack of regulation of waste recirculation, - insufficient environmental awareness, - lack of a hazardous waste collection system, - lack of landfills meeting legal requirements, - no separate collection of waste.
	securing sales and turnover	- errors in planning material requirements, - possession of redundant supplies.
	securing financial aspects of logistics (execution of customer accounts)	- error in estimating the customer's profitability, - too high a service cost, - volatility of material prices, - underestimation of expected costs.

Source: Gaschi-Ucieha A., *Zakłócenia w procesach logistycznych przedsiębiorstw produkcyjnych - badania literaturowe*, Zeszyty Naukowe Politechniki Śląskiej, Seria: Organizacja i Zarządzanie, z. 78, nr kol. 1928/2015, pp. 131-140; Pavlenko V., Pavlenko T., Morozova O., Kuznetsowa A., Voropai O., *Solving transport logistics problem in a virtual enterprise through artificial intelligence methods*, Transport Problems, vol. 12(2)/2017, pp. 31-41.

The list of problems in logistics processes described in Table 4.1 is not a closed list, but it gives an initial picture of the scale of the problem, which is the need to manage disruptions in logistics processes. In each company the scope of particular problems may differ. The same problems in different organizations occur with varying degrees of probability, and thus, cause a different scale of potential impact.

4.2. Problem identification process

In order to solve problems, it is necessary to first be able to notice them. The notion of identification, commonly referred to as recognition, refers to the information process. The process of identifying problems can be seen as an element of the information needs analysis, of which methods and techniques are a very important component. Therefore, the identification of a management problem can be described as[130]:

- searching for the most important problems,
- problem formulation,
- gathering information about the problem,
- investigation of the causes of the problem.

Proper identification of a problem in the field of enterprise management has a significant impact on the process of its solution, hence the opinion that a well-identified problem is half of its solution. If a problem is wrongly identified, it may be difficult or impossible to solve. It will not eliminate the difficulties for the organizational unit or prevent similar problems in the future. Identification of a management problem may also be difficult due to various barriers, such as: selection of an inappropriate method of problem identification, lack of substantive and methodological knowledge by the entity identifying the management problem, lack of adequate resources to conduct appropriate identification[131].

The main reasons for irregularities at the stage of searching for and defining management problems include[132]:

- assuming in advance that the problem is clear and obvious, and therefore, instead of conducting a thorough analysis of the problem, intuition is used to formulate it,
- gathering insufficient information on the problem,

[130] Szarucki M., *Evolution... op. cit.*
[131] Ibidem.
[132] Pilcer H., *Identyfikacja problemów w organizacji*, Prace Naukowe Akademii Ekonomicznej we Wrocławiu, Zarządzanie i Marketing nr 754, t. 6/1997.

- the problem is formulated based on opinions rather than facts,
- mismatching of events,
- lack of precision in formulating the problem (too narrow or too general definition of the problem, or defining the problem in terms of its solution),
- inaccurate investigation of the reasons for the problems,
- too little usage of techniques designed to identify the causes of problems,
- elimination of external manifestations of the problem, not the real cause,
- hasty conclusion drawing about the causes before examining all the facts.

In the literature on the subject, there are few studies in which attempts are made to organize the methods of identifying management problems. One approach proposes six classes of methods: methods of detection and problem definition, methods of problem recognition, methods of ordering, methods of critical analysis, methods of exploring the field of solutions and methods of renewing the point of view.

Szarucki M., Bugaj J. propose a division taking into account such criteria as: A) Application objective, B) Complexity degree, C) Nature of processed data, D) Source of processed data, E) Requirements for the entity using the method, F) Costs of application of the method, G) Entity implementing the method, H) Subject of the research, I) Objectivity of the results, J) Research direction, K) Standardization degree, and L) IT support. It should be noted that methods of identifying a management problem may simultaneously meet several specific criteria within the general criteria (e.g., a method meeting the following specific criteria: a1, b1, c3, d3, e2). Unlike classification schemes, where the decoupling rule is to be complied with, this methodological requirement is not mandatory in the typology presented. Methods of identifying management problems can also be divided into functional areas within an organization (e.g., marketing, finance, production or sales)[133]. On the other hand, identification methods used in, e.g., marketing (as part of an opinion leader survey or quality management (as part of process quality improvement, they can also be analyzed in terms of the criteria included in Table 4.2).

[133] Szarucki M., *Evolution... op. cit.*

Table 4.2. Typology of methods for identifying management problems

Marking	General criterion	Specific criteria	Method groups
A	Application objective	(a1) Seeking information about a problem a2) Sorting information about the problem (a3) Problem formulation (a4) Investigation of the causes of the problem	Methods used to search for information about the problem Methods for organizing information about the problem Methods for problem formulation Methods to investigate the causes of the problem
B	Degree of complexity	b1) Simple b2) Complex	Simple methods Complex methods
C	Nature of data to be processed	(c1) Quantitative (c2) Qualitative (c3) Quantitative-qualitative	Methods processing quantitative data Methods processing qualitative data Methods processing quantitative-qualitative data
D	Source of data processed	(d1) Original (d2) Secondary (d3) Mixed	Methods processing data from primary sources Methods processing data from secondary sources Methods processing data from mixed sources
E	Requirements for the entity using the method	(e1) Low (e2) Average (e3) High	Methods that place low requirements on the entity Methods that place average requirements on an entity Methods that place high requirements on an entity
F	Costs of applying the method	(f1) Low (f2) Average f3) High	Methods with low application costs Methods with average application costs Methods with high application costs
G	Entity implementing the method	g1) Individual g2) Team	Methods implemented by the individual Methods implemented by the team
H	Investigation subject	(h1) System component (h2) System component sets (h3) Whole system	Methods for testing a component of the system Methods for testing sets of system components System-wide test methods
I	Degree of objectivity of the results	(i1) Low (i2) Average (i3) High	Methods with a low degree of objectivity of results Methods with an average degree of objectivity of results

			Methods with a high degree of objectivity of results
J	Direction of the investigation procedure	j1) Inductive j2) Deductive j3) Inductive and deductive	Methods based on inductive investigation procedure Methods based on a deductive investigation procedure Methods based on mixed investigation procedure
K	Degree of standardization	k1) Low k2) Medium k3) High	Methods with a low degree of standardization Methods with a medium degree of standardization Methods with a high degree of standardization
L	IT support	l1) Not present l2) Present	Methods using IT support Methods not using IT support

Source: Szarucki M., Bugaj J., Metody identyfikacji problemów zarządzania w organizacji - próba typologii, Journal of Management and Finance, vol. 14, no. 2/2/2016, s. 435-447; Cowan D.A., The effect of decision-making styles and contextual experience on executives' descriptions of organizational problem formulation, Journal of Management Studies, Vol. 28, No. 5/1991; Hector D., Christensen C., Petrie J., A problem-structuring method for complex societal decisions: Its philosophical and psychological dimensions, European Journal of Operational Research, Vol. 193, No. 3/2009.

It is worth mentioning that the use of methods for identifying management problems may be subject to various limitations. They can be divided into two groups, objective and subjective, depending on their nature. The first group includes factors related to the external environment (environment outside the organization), including such areas as: economic, legal, political, socio-cultural, technological, and ecological. On the other hand, subjective limitations concern the internal environment, i.e., the organization's internal situation, and include resources. Resource constraints may be temporary or permanent, depending on the specificity of the organization's functioning.

4.3. Problem identification and solving techniques

FMEA

The purpose of Failure Mode and Effect Analysis (FMEA) method is to systematically identify potential defects and their causes, which may occur during the design or manufacture of a product and which may limit, to the greatest extent, the proper use of the product or reduce the efficiency and effectiveness of the product production process[134]. FMEA (Failure Mode and Effect Analysis) method - also known under other names: FMECA (Failure Mode and Criticality Analysis) and AMDEC (Analys des Modes de Defaillace et Leurs Effets) - started being used in the 1960s in the United States of America for astronautics products. This method was used to verify the design of various elements of spacecraft in order to ensure the safety of the participants of the expedition. The success of this method in NASA caused it to be applied in the aerospace and nuclear industries. In the 1970s and 1980s, this method became known in Europe and new applications were found for it in the chemical, electronics and automotive industry, where the most dynamic application of this method was observed. In the 1990s, it was adapted to the ISO 9000 standard, and in particular to QS 9000 for the automotive industry[135].

The objective is achieved by establishing cause and effect relationships between potential product defects, taking into account risk factors. This method is based on[136]:

- the assessment of the risk of error (identification, analysis, prioritization);
- the assessment of the consequences (effects) of the error;
- developing risk response measures (planning, execution, assessment, documentation).

There are two types of the method for analyzing causes and effects of defects: product/construction analysis and process analysis. The FMEA of a product (construction) is carried out during preliminary design works. The aim is to identify the strengths and weaknesses of the product in order to introduce conceptual changes before the start of construction work and subsequent production. Weak points of the product or construction may concern, e.g., functions performed by the product, reliability of the product during operation, ease of operation and repair, construction technology.

Conducting the FMEA of a product (construction) is recommended in the case of placing new products on the market or significantly improved products, using new materials or

[134] Sak K., Ingaldi M., *The use of the FMEA method to assess the quality of diary products*, Archives of Engineering Knowledge, vol. 2(2)/2017, pp. 6-9.
[135] McManus, H., *Product Development Value Stream Mapping (PDVSM) Manual,* Publishing House: MIT Lean Aerospace Initiative, Cambridge 2005.
[136] Szatkowski K., *Nowoczesne zarządzanie produkcją. Ujęcie procesowe*, Wydawnictwo: PWN, Warszawa 2014.

technologies, noticing new possibilities of using the product and a high risk for people and the environment, if any defects are unacceptable[137].

Process FMEA concerns the broadly understood process of manufacturing a product, its parts and sets, as well as processes related to its usage and servicing. The aim of the process FMEA is to identify factors that may make it difficult to meet the requirements of the product specification or which interfere with the process. These factors are related to the methods and parameters of processing, machines and equipment used, as well as measuring and control measures. This method can be used in the initial design of production processes, before the start of serial production and during serial production in order to improve unstable and inefficient processes.

The method is based on analytical determination of cause-effect relationships of potential product defects as well as on taking into account the criticality factor (risk) in the analysis. Its aim is to consistently and systematically identify potential product/process defects and then eliminate them or minimize the risk associated with them. Thanks to the FMEA method we can continuously improve our product/process by subjecting it to further analysis and on the basis of the obtained results introduce new corrections and solutions, effectively eliminating sources of defects and providing us with new ideas to improve product properties. It can be used for very complex processes in both mass and unit production[138].

The analysis can be carried out for the whole product, a single component or structural element of the product, as well as for the whole technological process or any of its operations. There are two types of FMEA analysis: product and process analysis.

FMEA product analysis is focused mainly on optimizing the reliability of the product. As a result, we obtain information about strong and weak points of the product. In addition to preventive measures, it allows us to determine the actions that should be taken when a product leaves our company, e.g. during transport or service.

[137] Sak K., Ingaldi M., *The... op. cit.,* pp. 6-9.
[138] Morgan, J. M., Liker J.K., *The Toyota Product Development System; Integrating People, Process, and Technology*, Publishing House: Productivity Press, New York 2006.

FMEA process analysis is used in the initial phase of designing technological processes, before starting serial production (production planning) and in serial production in order to improve processes that are unstable or do not provide achievement of required performance[139].

The first step of the analysis is to identify all the elements of the tested product or process and to arrange them in the technological order. Then, for individual elements, the types of defects which may limit the product's ability to perform a specific function are determined. The effect and cause are determined for each defect. The Ishikawa diagram (see section 10. 3. 2) and brainstorming can be used for this purpose. In order to describe each identified defect, three priority numbers are used, on a scale of 1-10[140]:

- priority number of occurrences P- is the probability of occurrence of the defect,
- priority number of detection D - indicates the difficulty of detecting the defect before the product is “released" to the market,
- priority number of the effects of the defect S - determines the severity of the defect for the customer.

Due to the wide range of the adopted point scale, it is recommended to prepare tables that facilitate the assignment of individual priority numbers. The risk assessment indicators are then calculated by multiplying these three figures by the values of the priority numbers adopted and ranked in order of the results obtained. The higher the value of the S indicator, the more significant the defect is. The analysis of defects, their consequences and causes carried out in this way allows for planning and taking preventive or corrective actions. Using FMEA, apart from preventing errors and mitigating the effects of errors, brings many other benefits included in the group of teamwork methods, such as: creating teamwork and integrating teams during joint problem solving, increasing knowledge and experience of employees, improving product reliability or process efficiency, increasing customer satisfaction, reducing costs, defining risk and ensuring appropriate actions to minimize it.. Their idea is based on the assumption that all employees are responsible for shaping the quality of processes and achieved results[141].

[139] Shehab E., Haque B., Al-Ashaab A., *Value Stream Mapping and Analysis of Product Development (Engineering) Processes*, Proceedings of the 8th International Conference on Manufacturing Research ICMR 2010.
[140] Szatkowski K., *Nowoczesne... op. cit.*
[141] Sak K., Ingaldi M., *The... op. cit.,* pp. 6-9.

Ishikawa Fishbone Diagram

The Ishikawa diagram, the cause and effect diagram, is also known as the fish diagram, or the fishbone diagram, as well as the error tree diagram, because when the diagram is turned 90° clockwise, the diagram resembles a tree. It is used to illustrate cause and effect relationships, thus helping to separate causes from the consequences of a situation and to see the complexity of the problem[142].

Ishikawa has developed a cause and effect diagram in which the analysis begins with a statement of the effect (e.g. absence, failure or other undesirable state) and continues towards the identification of all possible reasons that caused it. Among the causes he listed five main components - the so-called 5Ms[143]:

- Manpower,
- Methods,
- Machinery,
- Materials,
- Management.

Each of these components is broken down into particular causes, which should be considered individually as problems to be solved. The cause and effect diagram is a graphic analysis of the influence of various factors and their interrelationships causing a specific quality problem and an analysis of the results (effects) caused by the functioning of these links. This method was created to identify the relationship between customer requirements and the quality of the final product and to make it easier to determine its characteristics. *The diagram logically and chronologically organizes causes or actions according to the defined problem*.

The Ishikawa diagram is presented as a multi-step top-down process in which the causes directly identified on the main axis are treated as the effects of other causes. The consequence of the graph is a hierarchical division of causes. The procedure for creating a cause and effect diagram consists of consecutive steps.

[142] Hagemeyer C., Gershenson J., Johnson D., *Classification and application of problem solving quality tools: A manufacturing case study*, The TQM Magazine, vol. 18/2006, pp. 455-483.
[143] Liker J., *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*, Puhlishing House: Mcgrow-Hill, New York 2004.

First of all, the problem faced by the company should be clearly and accurately defined, information should be gathered and all possible causes of the phenomenon under consideration should be discussed, and the main categories of possible causes should be identified. An effective technique for gathering information in a team is a brainstorming session. A review of the brainstorming results allows for the causes to be categorized. The set of categories of causes should be adapted to the problem under analysis. The most common categories of causes (according to the 5M+E rule) are[144]:

- Man,
- Material,
- Machine,
- Method,
- Management,
- Environment.

Depending on the type and field of the analyzed problem, it is also possible to use other categories of causes, e.g., equipment, information, procedures, processes, work organization, competition, suppliers.

The starting point is a horizontal axis facing right, which is the description of a clearly formulated problem (effect) and which connects the main categories of causes in the form of oblique arrows leading to the phenomenon under study. The next step is to identify the causes, which are broken down into the root (main) causes and sub-causes. Horizontal arrows, which symbolize the main causes of the problem, are assigned to each cause category. The graph is expanded by adding further causes and sub-causes (Figure 4.1).

[144] Ismyrlis V., *The contribution of quality tools and integration of quality management systems to the organization*, The TQM Journal, vol. 29/2017, pp. 677-689.

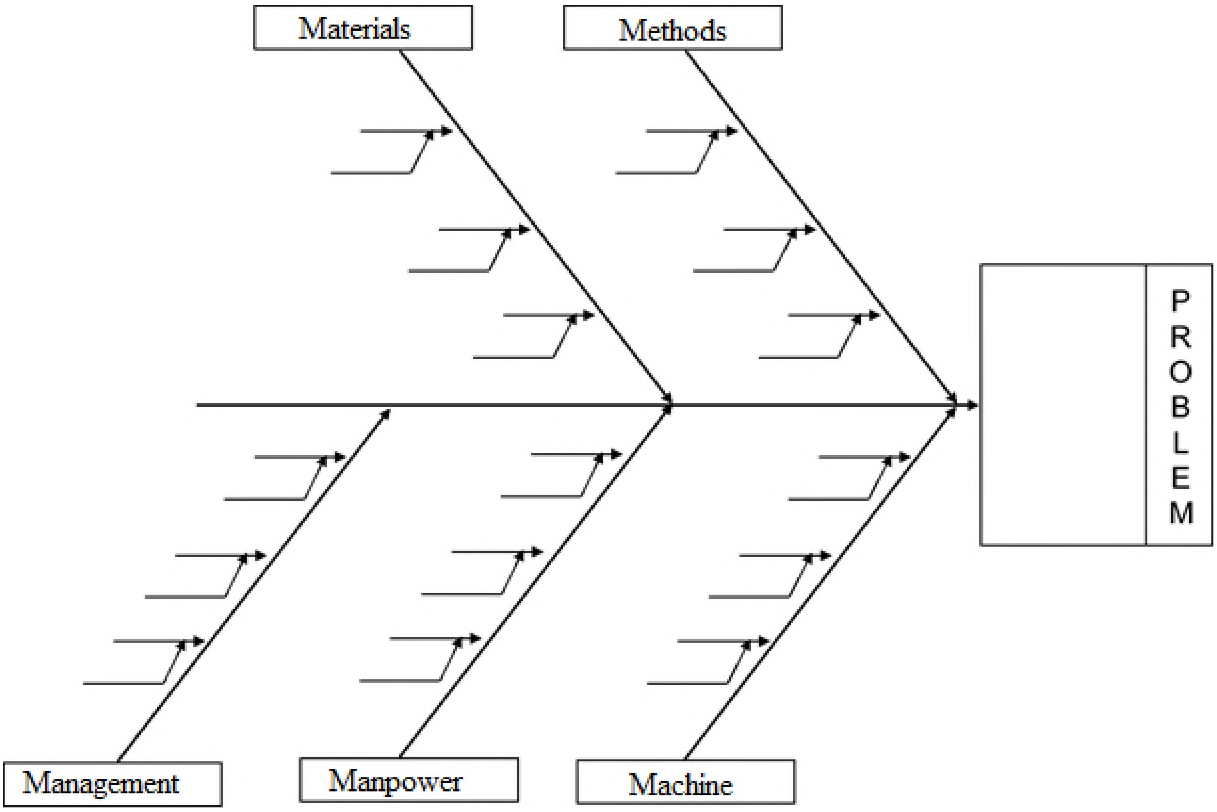

Figure 4.1. Ishikawa Diagram

Source: https://leanactionplan.pl/wizualizacja-danych-jakosciowych/ (access 13.06.2019).

Each arrow means *"...contributes to..."*, i.e. moving from the sub-causes in the direction of the main horizontal axis, we interpret the graph by answering the question *"what effect does it have?"*. However, reading the diagram from the horizontal arrow to the sub-causes, we answer the question *"why?"*. The development of the graph ends when the phenomenon is fully identified.

It should be checked if all potential causes are included in the graph. Graphic analysis of the problem allows to identify and consider other causes that were previously omitted or not taken into account.

A small number (2 to 4) of causes likely to have the greatest impact on the effect should be selected and identified, and an analysis of whether the identified significant cause actually identifies the problem being investigated should be made, and a way of eliminating the most likely process of creating the investigated non-conformity should be devised. The results of the analysis should be formulated in the form of conclusions. Ultimately, the consequence of the graphic form of presenting the causes and effects of potential failures is a transparent consideration of the problem under investigation. The diagram allows you to identify the causes of the problem and determine their mutual dependencies.

With the help of Ishikawa's chart, we can indicate all the relevant relationships between different causes and discover the source of failure or abnormal course of the process. The purpose of this method is also to analyze the results of a given course of action, i.e., to detect potential failures of the project and to prioritize the causes of problems. The use of the diagram enables the identification and classification of all causes of a certain problem and the identification of the process imperfection cause. Analysis of causes and effects is particularly useful in teamwork because of the complexity of the problems and the diverse knowledge and experience of team members regarding the causes of problems. The preparation, creation, and analysis of the diagram should take place in a group[145].

Advantages of using the Ishikawa diagram in supply chain project management include[146]:

- simplicity of analysis,
- the ability to identify, classify and prioritise the causes of problems in a single analysis,
- transparency of results (structured, legible diagram).

During the creation of the Ishikawa diagram, some barriers may appear. Among the main difficulties are[147]:

- insufficient analysis of the problem (too cursory),
- the problem of information assignment - classification of causes into given categories,
- classification of primary and secondary causes,
- formulation of conclusions.

These barriers can be overcome through group work on the diagram (brainstorming), which will contribute to the identification of more causes (the literature sources recommend the creation of the Ishikawa diagram by a group of specialists in various fields, with theoretical

[145] Jayaprasad G., Dhanlakshmi P., Hemachandran S., *Analysis of electrical discontinuity problem in MLB using Ishikawa model*, Circuit World, vol. 42/2016, pp. 201-206.
[146] Ismyrlis V., *The... op. cit.* ,pp. 677-689
[147] Kowalik K., *Ishikawa Diagram in theory and practice of quality management*, Archives of Engineering Knowledge, vol. 3, issue 1/2018, pp. 15-17.

knowledge of how to carry out this analysis). In addition, the number of classification errors can be significantly lower than in the case of individual work. The advantage of working in a group is also getting a range of diversified conclusions[148].

5 WHY?

The creator of the 5 WHY method is Sakichi Toyoda. During the development of the industrial methodology, this method was quickly refined and implemented within the Toyota automotive corporation. It is one of the basic components determining the ability to cope with difficult situations. Taiichi Ohno, founder of the Toyota Production System, describes 5W as a method of Toyota's scientific approach to asking the question “Why?" several times, making the nature of the problem, as well as its solution, more obvious[149].

The 5 WHY diagram (Figure 4.3), also called the why-why diagram is included as one of the methods for checking and controlling the production process.

[148] Jayaprasad G., Dhanlakshmi P., Hemachandran *S., Analysis... op. cit.,* pp. 201-206
[149] Krzemień E., Wolniak R., *Tworzenie komputerowego oprogramowania wspomagającego zarządzanie – analiza stosowanych koncepcji*, Przegląd Organizacji, nr 4/2004, s. 38-41.

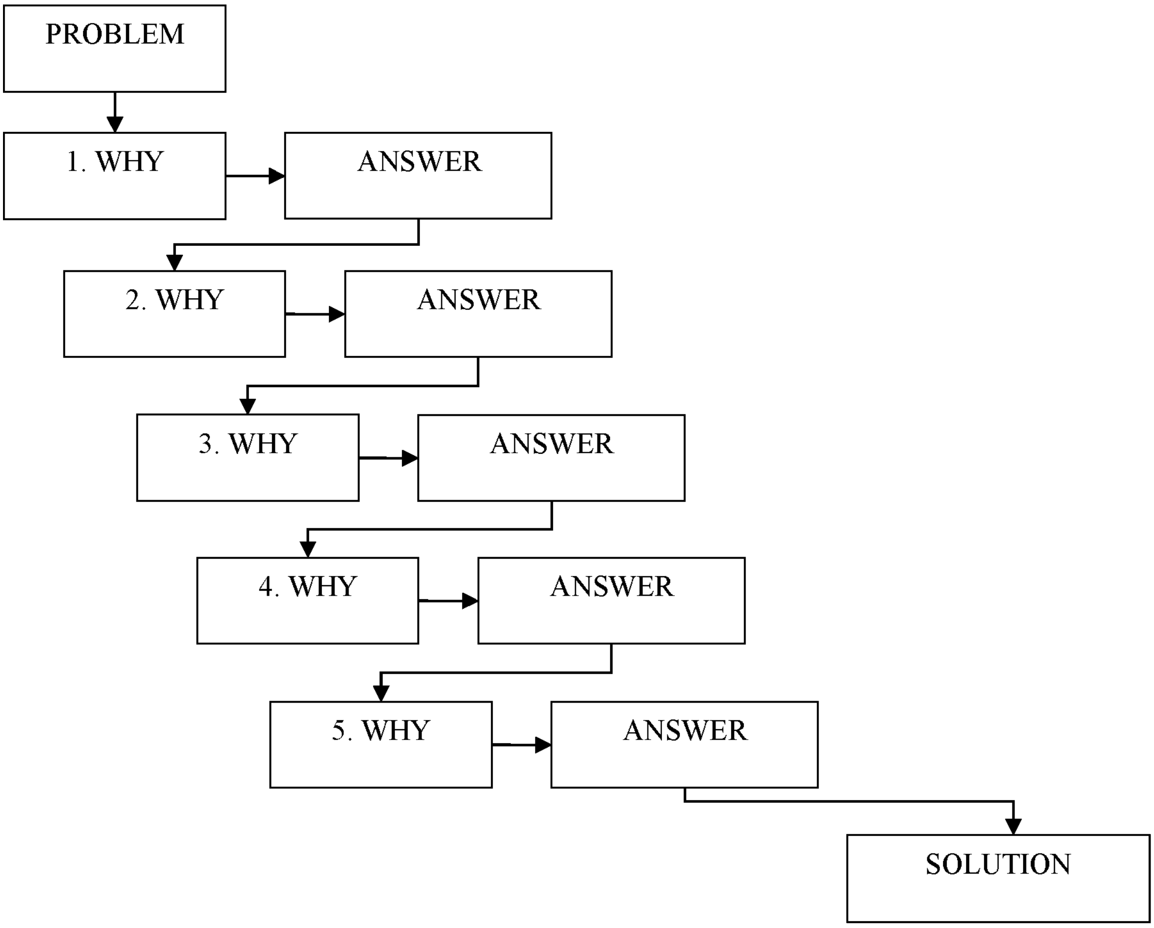

Figure 4.2. Diagram of the 5 WHY method

Source: own study.

The 5 WHY method allows you to find the causes of a problem. This is a method that touches upon two aspects. The first one concerns the causes of the problem - why did the problem arise? Then the second aspect concerns the detection of the problem - why the current system/methods of control/process supervision did not detect the problem when it appeared.

The course of the 5 WHY method can be divided into three stages. The first step is to collect information about the problem. The following aspects are analyzed at this stage[150]:

- What actually happened?

[150]Wolniak R., Skotnicka-Zasadzień B., *Wykorzystanie komputerowego wspomagania w zakresie metody 5Why w przemyśle*, [w:] Knosala R. (red.), *Komputerowo zintegrowane zarządzanie*, t. 2, Wydawnictwo: Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją, 2011, pp. 570-572.

- When?
- What is the scale of the problem, how many problems do we have, the percentage of defects, etc.?
- What threat does this problem pose to the customer, user or organization?

Thanks to data collection, it is possible to go to the second stage, i.e., to establish a project team that will analyze the causes of the problem. Once a working group has been set up, the problem should be precisely and accurately described. The last step is to carry out the analysis and verify it. Analysis in the 5 WHY method consists in establishing the problem and then, through a logical sequence of questions starting with the word *why*, finding the real cause of the problem. According to the guidelines, the number of questions should not be fewer than five[151].

[151] Peerally M.F., Carr S., Waring J., Dixon-Woods M., *The problem with root cause analysis*, BMJ quality & safety, vol. 26(5)/2017, pp. 417–422

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[15] Peerally M.F., Carr S., Waring J., Dixon-Woods M., *The problem with root cause analysis*, BMJ quality & safety, vol. 26(5)/2017.

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[17] Sak K., Ingaldi M., *The use of the FMEA method to assess the quality of diary products*, Archives of Engineering Knowledge, vol. 2(2)/2017.

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[22] Wolniak R., Skotnicka-Zasadzień B., *Wykorzystanie komputerowego wspomagania w zakresie metody 5Why w przemyśle*, [w:] Knosala R. (red.), *Komputerowo zintegrowane zarządzanie*, t. 2, Wydawnictwo: Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją, 2011.

5. SUPPLY CHAIN BIG DATA ANALYSIS

5.1. Big Data definition

To correctly define Big Data, which is a key element of the Fourth Industrial Revolution[152] requires characterization of such concepts as Industry 4.0 or the Internet of Things.

The aim of Industry 4.0 is to change the approach to the organization of production processes, which brings decentralization of the course and control of production processes, guaranteeing the possibility of self-regulation of production processes[153]. Industry 4.0 is an idea concerning the implementation of automation of manufacturing processes, analysis and data exchange, as well as the use of the most modern digital technologies to create the so-called Cyber-Physical Systems[154].

The concept of Industry 4.0 is often associated with four key elements, namely: Intelligent Factory and Cyber-Physical Systems, the Internet of Things or the Internet of Services [155]. **Intelligent Factories** enable comprehensive implementation of processes, ensure full availability of services strictly customized to the clients' requirements and guarantee sustainable development of the company. Intelligent Factories use **Cyber-Physical Systems (CPS)** integrating physical operations performed during production processes and data processing and CPS communication infrastructure connect two worlds - real and virtual, which enable full synchronization of information regarding both physical manufacturing processes and virtual data processing. As part of the Industry 4.0 concept, Intelligent Factories use Cyber-Physical Systems to control and monitor the physical proceedings of operations and to undertake individual decisions, enable information exchange between individual users using the Internet

[152] Maar B., Big Data Using Smart Big Data, Analytics And Metrics To Make Better Decisions And Improve Performance, Wiley, Chichester 2015, p. 9.
[153] Gubán M., Kovács G., Industry 4.0 Conception in Acta Technica Corviniensis – Bulletin of Engineering Tome X, Timisoara 2017, p. 112.
[154] Salkin C., Oner M., Ustundag A., Cevikcan E., A Conceptual Framework for Industry 4.0 in Ustundag A., Cevikcan E. (eds.), Industry 4.0: Managing The Digital Transformation, Springer, Berlin 2018, p. 34. Stăncioiu A., The Fourth Industrial Revolution "Industry 4.0" in Fiabilitate si Durabilitate - Fiability & Durability No 1/ 2017, Târgu Jiu, 2017, p. 75.
[155] Bartodziej C. J., The Concept Industry 4.0. An Empirical Analysis of Technologies and Applications in Production Logistics, Springer, Berlin 2017, p. 35.

of Things, and offer services adjusted to the expectations of final recipients[156]. The **Internet of Things** is a technology that assumes the exchange and processing of data using communication networks (usually the Internet) between objects, devices and machines (integrated in the CPS) that gather data on the processes[157]. The Internet of Things enables the exchange of data and information that are integrated with each other within CPS systems used to implement automated processes in Intelligent Factories. **Internet of Services** is based on technology in which services are offered to recipients using the Internet. This technology assumes the possibility of selecting individual services offered by different suppliers, thus enabling the selection of only those services that add value from the final recipient's point of view. The Internet of Services focuses on providing the right software, tools and virtual space for the user to fulfill customer's requirements[158].

In relation to supply chain management, which assumes the use of Big Data analyzes, it is also necessary to define the concept of Logistics 4.0. In general, Logistics 4.0 can be defined as a mutual interaction of the supply chain links, focusing on the constant exchange of a very large amount of data. In a more detailed approach, this concept is described as a series of autonomous systems that interact and communicate with each other as part of the processes being performed. Logistics 4.0 process approach covers all processes that are executed by individual links in the supply chain. In the technological context, the concept of Fourth Logistics Generation includes all tools and techniques used for implementation processes that are supported by modern, mostly autonomous systems facilitating the implementation of individual activities[159]. The major purpose of Logistics 4.0 is to support decision-making processes as well as all activities pursued within supply chains so that all activities that can be automated are performed using appropriate machines and devices, and system users who

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[156] Gunal M. M., Simulation for the Better: The Future in Industry 4.0 in Gunal M. M. (ed). SIMULATION FOR INDUSTRY 4.0: Past, Present, and Future, Springer, Berlin 2019, pp. 276-277.
Hofmann E., Rüsch M., Industry 4.0 and the current status as well as future prospects on Logistics in Computers in Industry no. 89, Gallen 2016, p. 25.
Stăncioiu A., The Fourth Industrial Revolution "Industry 4.0" in Fiabilitate si Durabilitate - Fiability & Durability No 1/ 2017, Târgu Jiu, 2017, p. 75.
[157] Bouhaï N., The IoT: Intrusive or Indispensable Objects? in Bouhaï N., Saleh I. (eds.) Internet of Things: Evolutions and Innovations, Wiley, Chichester 2017, p. 5.
[158] Papazoglou M., Pohl K., Metzger A., van den Heuvel W-J., The S-Cube Research Vision in Papazoglou M., Pohl K., Parkin M., Metzger A. (eds.) Service Research Challenges and Solutions for the Future Internet: S-Cube - Towards Engineering, Managing and Adapting Service-Based Systems, Springer, Berlin 2010, pp. 1-2.
[159] Szymańska O., Adamczak M., Cyplik P., Logistics 4.0 – A New Paradigm Or Set Of Known Solutions? in Research in Logistics & Production Vol. 7, No. 4, 2017, p. 303.

continuously communicate with each other and with all intelligent devices integrated within the CPS system, execute decision and optimization processes in an efficient and effective manner[160].

Every user, machine or device connected to the Internet generates huge amounts of data that should be collected and stored for further analysis, however, due to their size and speed of recording, the use of current tools and analysis techniques becomes ineffective and sometimes impossible[161]. The term Big Data means very large data sets that require proper sorting and standardization in order to enable effective analysis to ensure decision support. The analysis cannot be performed in a traditional way due to the fact that the size of data sets, as well as the lack of structuring, makes it impossible to use the analytical techniques used hitherto. The Big Data development arises directly from the development of the Internet and e-commerce due to the increasing speed of data generation every day. This data is also generated as a result of the development of the Industry 4.0 concept as well as Cloud Computing and the Internet of Things. The development of e-commerce and ICT devices, enabling the generation of more and more data, was associated with the necessity of not only changing the manner of collecting, but also storing hefty data sets with respect to physical data storage computer hardware and the system[162].

When talking about Big Data, it should be pointed out that they are usually defined as huge data sets that cannot be stored and analyzed in the time required by the customer using traditional equipment and systems used heretofore. However, it should be noted here that the size of files, and thus the amount of data collected for analysis, cannot be the only determinant indicating affiliation to Big Data. It is, therefore, important here to distinguish Big Data from ordinary large data sets that can be analyzed using known analytical tools. Big Data was defined in 2001 by using the 3V model referring to three dimensions such as Volume, Velocity and

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[160] Barreto L., Amaral A., Pereira T., Industry 4.0 implications in logistics: an overview in Manufacturing Engineering Society International Conference 2017, p. 1246.
Wrobel-Lachowska M. Wisniewski Z., Polak-Sopinska A., Lachowski R., ICT in Logistics as a Challenge for Mature Workers, Knowledge Management Role in Information Society in Goosens R. H. M. (ed.). Advances in Social & Occupational Ergonomics, Springer, Cham 2017, p. 175.
[161] Maar B., Big Data Using Smart Big Data, Analytics And Metrics To Make Better Decisions And Improve Performance, Wiley, Chichester 2015, p. 9.
[162] Chen M., Mao S., Zhang Y., Leung V. C. M., Big Data: Related Technologies, Challenges and Future Prospects, Springer, Berlin 2014, pp. 1-2.
Kalyvas J. R., A Big Data Primer for Executives in Kalyvas J. R., Overly M. R. (eds.) Big Data: A Business and Legal Guide, CRC Press, Boca Raton 2015, p. 1.

Variety. In subsequent years, this model was developed and Value was added[163]. Currently, the model based on 5 dimensions, namely Value, Variety, Velocity, Veracity and Volume which are used to characterize Big Data[164].

Value refers to the possibility of using the collected data and their structuring capabilities for later use in decision-making processes. **Variety** refers to the degree of data structuring as well as various data formats collected by the company, which most often have to be harmonized for later analysis. **Velocity** is associated with the speed of data generation, recording and transformation, which is particularly important in relation to the consumer's requirements for an ever shorter analysis time. **Veracity** deals with the quality of data collected, the amount of unnecessary data whose possession will not positively affect the result of the analysis, and may only delay the entire process, as well as the extent to which the collected data correspond to the analytical requirements. **Volume** refers to the number of data that is generated and subjected to subsequent decision analysis. In addition, it can be predicted that in the next years the model describing the functionality of Big Data will be expanded by further elements (next **Vs**)[165].

[163] Chen M., Mao S., Zhang Y., Leung V. C. M., Big Data: Related Technologies, Challenges and Future Prospects, Springer, Berlin 2014, pp. 3-4.
[164] Cuzzocrea A., Leung C K-S., Jiang F., MacKinnon R. K., Complex Mining from Uncertain Big Data in Distributed Environments: Problems, Definitions, and Two Effective Efficient Algorithms in Li K-C, Jiang H., Zomaya A. Y. Big Data Management and Processing, CRC Press, , Boca Raton 2017, pp. .297-298.
Rao P. V., Reddy A. R., Sucharita VBig Data Analytics in Aquaculture Using Hive and Hadoop Platform in Prasad A. V. K., Exploring the Convergence of Big Data and the Internet of Things, IGI Global, Hershey 2018, p. 30.
[165] Mrozek D., Scalable Big Data Analytics for Protein Bioinformatics: Efficient Computational Solutions for Protein Structures Springer, Berlin 2018, pp. 34-35.

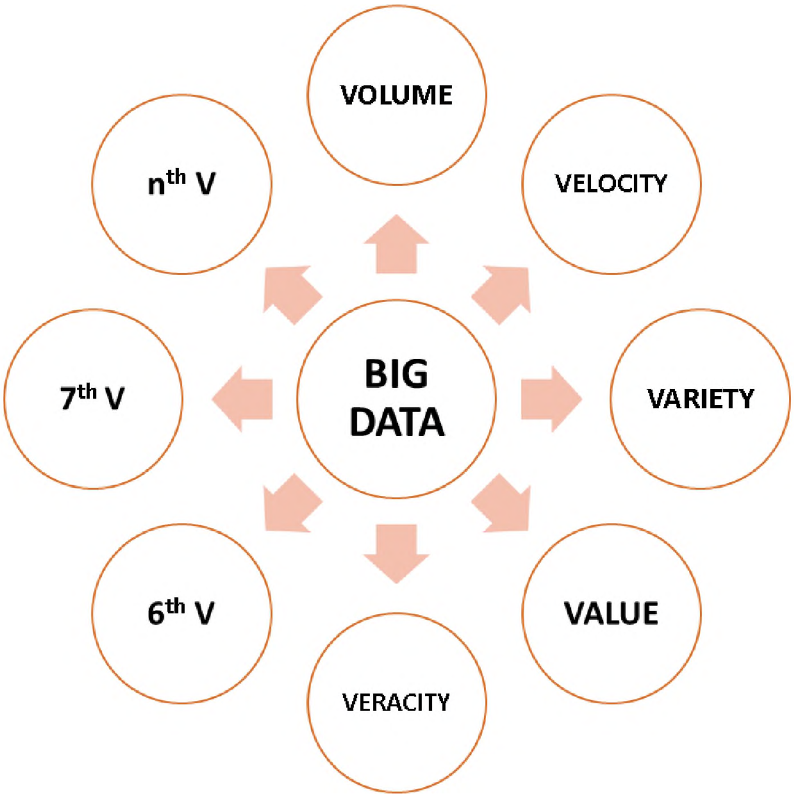

Figure 5.1. The dimensions of Big Data

Source: own study based on Mrozek D., Scalable Big Data Analytics for Protein Bioinformatics: Efficient Computational Solutions for Protein Structures Springer, Berlin 2018, pp. 34-35.

Due to the origin and features that characterize individual data used in the decision-making processes of many organizations, data from e-mail, electronic, social media, search engines, as well as business data or data from various types of indicators should be distinguished. In addition, it should be noted that due to the large number and complexity of data generated each day, it is necessary to structure the data and filter them out, i.e. eliminate data that, from the decision-making process point of view, is of no importance to the policy-maker, and its presence in data sets, as well as its subsequent use may result in analytical errors that can translate into a decrease in the efficiency of the decision-making. Therefore, the use of such a tool as Big Data is increasingly becoming a necessity which is a result of technological progress, enabling companies to fulfill the expectations of final recipients, which is possible only by accurate identification of their requirements[166].

The very development of the use of Big Data tools stems from the fact that every day the amount of data that is produced not only by commercial, production or transport enterprises, but also by individual users rises very fast. It is predicted that by 2020 the number of data generated by users will increase to 40 zettabytes, while the annual increase in the amount of data is at the level of 40%. It should be obvious, therefore, that the amount of data generated by each user or system will rise at a faster and faster pace, which will also directly translate into the emergence of stumbling blocks related to data analysis. Current processes, very often highly automated in the supply chains, require essentially adaptation of products and services to the expectations of end users, and require error-free decisions to be undertaken in a shorter period of time. Therefore, the use of tools limited to only speed and quantity of the analyzed information becomes ineffective. The solution is Big Data, which allows not only to collect and store data in an automated manner, but also enables to make decisions based on analyzes that are performed within the framework of the Industry 4.0 tool[167].

While defining Big Data, one should also mention the concept of **Data Mining**, which is a concept that very often accompanies large data sets. Data Mining is based on the use of techniques, most often advanced computer tools, for obtaining data that are not immediately visible to the user, and their identification requires a complicated analytical process. Data Mining is most often used in search of certain patterns and algorithms that can be implemented, for example, as part of identifying irreplaceable customers. Very often, Data Mining is used as a component of Customer Relationship Management systems (CRM).[168] As far as the importance of Big Data for modern, automated systems to which digital supply chains belong is concerned, Data Mining plays a crucial function as it helps to identify and analyze unstructured sets of data requiring additional, often impossible to perform from the user's point of view analytical activities.

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[166] Rao P. V., Reddy A. R., Sucharita VBig Data Analytics in Aquaculture Using Hive and Hadoop Platform in Prasad A. V. K., Exploring the Convergence of Big Data and the Internet of Things, IGI Global, Hershey 2018, p. 30.
[167] Barské – Erdogan A., Big Data Handbook, Lulu, Morrisvillepp 2013, pp. 4-5.
[168] Witten I. H., Frank E., Hall M. A., Data Mining: Practical Machine Learning Tools and Techniques, Elsevier, Oxford 2011, p. 8.
Tufféry S., Data Mining and Statistics for Decision Making, Wiley, New Jersey 2011, pp. 1-2.

Data types that can be analyzed using Big Data tools can be characterized in the following ways:

- structured – data usually stored in SQL databases and allow the user to exploit the information placed in tables, characterized by the occurrence of both named rows and columns, and abounds in opportunities of the implementation and comparing operations of data between sets. Data structuring requires primarily to indicate the purpose, type of data and their basic characteristics on the basis of which fully organized sets of information are created.
- semi-structured – non-relational databases do not always allow the exchange of information between sets, and may also be characterized by a differentiated format, however, some of their features enable the user to make basic analyzes supporting decision-making processes.
- unstructured – usually these are data with very different formats (numbers, text, images, etc.) that are not assigned to any model or scheme. Typically, this dataset contains all the information that is generated by both devices and systems and by their users, such as data from satellites, data from the history of Internet browsing, data downloaded directly from users or information from the social media[169].

The tools that are most often used under Big Data include:

- Hadoop – an open platform for storing hefty data stores,
- Map Reduce – a model used to process huge data sets,
- Mahout – a tool used in machine learning processes to improve the processes performed by intelligent devices,
- Hadoop and Distributed file system – a system thanks to which the user has full access to collected and analyzed data,
- Hive – it is used to process fully structured data in Hadoop system,
- Hbase – Hadoop database,

[169] Jain V. K., Big Data and Hadoop, Khanna Publishing, New Delhi 2017, pp. 12-14.

- Apache Pig – a platform enabling the design and implementation of software based on Hadoop system[170].

Big Data is used in many areas of business activity, for example, it includes:

- medicine and IT,
- intelligent transport and storage,
- Finance and Accounting,
- e-commerce,
- communication in the supply chain[171].

The biggest advantages of using Big Data include savings related to the possibility of reducing the expenditures of enterprises resulting from adjusting the product or service to the customer without the necessity of performing a cost-intensive and time-consuming phase of designing and prototyping. Customers receiving fully customized products in the shortest possible time can be characterized by a high level of satisfaction related to the service at the highest quality level. The increase in the level of service translates directly into the growth in profits and also supports the improvement of the position on the market. The Big Data techniques not only contribute to the development of the company in terms of adapting products to the expectations of customers, but also enable a full market analysis and trends exploration that guarantee the indication of those areas of activity that should become a new market. This tool enables to resign from both unprofitable business areas as well as clients. In addition, the most important advantage of using the Big Data tool is increasing the efficiency of the organization in terms of detecting errors and irregularities affecting the decline in the efficiency of the processes executed by the enterprise.

It should also be pointed out here that Big Data tools definitely support decision-making processes, however their use is expensive and very often requires not only the implementation of a new system, but also investment in new computer equipment, which in many cases may

[170] Rao P. V., Reddy A. R., Sucharita VBig Data Analytics in Aquaculture Using Hive and Hadoop Platform in Prasad A. V. K., Exploring the Convergence of Big Data and the Internet of Things, IGI Global, Hershey 2018, p. 31.
[171] Mrozek D., Scalable Big Data Analytics for Protein Bioinformatics: Efficient Computational Solutions for Protein Structures Springer, Berlin 2018, p. 35.

result in the organization's resignation. In addition, many entrepreneurs do not decide to use the tool due to lack of information or insufficient information about not only the implementation itself, but also the management or the benefits of using autonomous data analysis and decision-making processes.

Due to the supply chains being targetetd at adapting products and services strictly to the customers' requirements, data analysis and making the right decisions based on it, is crucial in the context of gaining customer satisfaction, and competitive advantage. Sometimes small enterprises that decide to use Big Data tools have an opportunity to overtake competitors' customers because of the complexity of services and the ability to predict all the expectations of final consumers. In connection with the above, it should be stated that Big Data is one of the most important aspects of the IV Industrial Revolution and will certainly play a crucial role in the markets of many organizations with regard not only to their expansion, but also their existence[172].

The biggest disadvantages of Big Data tools include, above all, high implementation costs requiring appropriate investment expenditures, the necessity to adequately secure data against unauthorized users' access, the need to ensure qualitative data ensuring higher effectiveness of analyzes[173].

5.2. Big Data Analysis

The definition of the Big Data concept presented in the previous chapter indicates that Big Data is a tool used as part of complex analyzes in large sets of information that cannot be evaluated employing the analytical tools used heretofore. Big Data Analysis is defined as a set of activities performed in the scrutiny of various types of data ranging from Data Mining to complex machine learning processes[174]. Otherwise, Big Data Analysics can be described as

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[172] Maheshwari A., Big Data, McGraw Hill Education, New Delhi 2017, pp. 8-10.
Morabito V., Big Data and Analytics: Strategic and Organizational Impacts, Springer, Berlin 2015, pp. 108-109.
[173] Kaur K., Bharti V., A Survey on Bi Data – Its Challenges and Solution from Vendors in Mittal M,, Balas V. E., Goyal L. M., Kumar R. (eds.), Big Data Processing Using Spark in Cloud, Springer, Berlin 2018, p. 4.
Bottles K., Begoli E., Worley B., Understanding the Pros and Cons of Big Data Analytics in Physician executive 40(4):6-10, 12 · July 2014, pp. 6-12.
[174] Dasgupta N., Practical Big Data Analytics: Hands-on techniques to implement enterprise analytics and machine learning using Hadoop, Spark, NoSQL and R, Packt Publishing Ltd, Birmingham 2018, p. 13.

"the application of techniques within the digital energy ecosystem that are designed to reveal insights that help explain, predict, and expose hidden opportunities to improve operational and business efficiency and to deliver real-world situational awareness."[175]

In order to properly understand the concept that Big Data Analysis, the concept of analysis should be correctly defined.Analysis can be described as "a process that involves the use of statistical techniques (measures of central tendency, graphs and so on), information system software (data mining, sorting routines) and operations research methodologies (linear programming) to explore, visualize, discover and communicate patterns or trends in data."[176] The analysis of data is, therefore, the utilization of available methods and techniques to identify and effectively apply available information through an effective decision-making process and the development of models and algorithms for organization data management. Due to the features which characterize scrutiny, the analysis can be divided into Descriptive Analytics, Predictive Analytics and Prescriptive Analytics. **Descriptive Analytics** can be applied only for the analysis of historical data and current information on the grounds of the use of simple computational tools, such as statistical techniques, thanks to which it is possible to indicate the regularities and trends in the analyzed data. In addition, employing this analysis does not allow predicting future events or data values in subsequent analytical periods, equaling the emergence of the need of applying **Predictive Analytics** for this purpose. Its main purpose is to determine the value of data that will be generated in the future periods, as well as the probability of occurrence of individual events. This analysis uses advanced forecasting techniques which, based on historical data and trends or algortymes, determine how data will be shaped in the future. By this analysis, organizations are able to develop a proper strategy that can improve the level of customer service, and increase its profits as well. **Prescriptive Analytics** is based on both descriptive and predictive analysis, but its main objective is to develop a range of acceptable solutions and find the optimal solution for the assumed conditions limiting the solutions. This analysis focuses primarily on achieving the optimization purposes while fulfilling the limitations directly affecting the decision-making process. Prescriptive analytics

[175] Stimmel C. L., Big Data Analytics Strategies for the Smart Grid, CRC Press, Boca Raton 2015, p. 8.
[176] Sedkaoui S., Data Analytics and Big Data, Wiley, Hoboken 2018, p 44.

usually applies methods from the field of operations research and optimization theory[177], which are in greater detail identified in section **3. Operations research and optimization theory.**

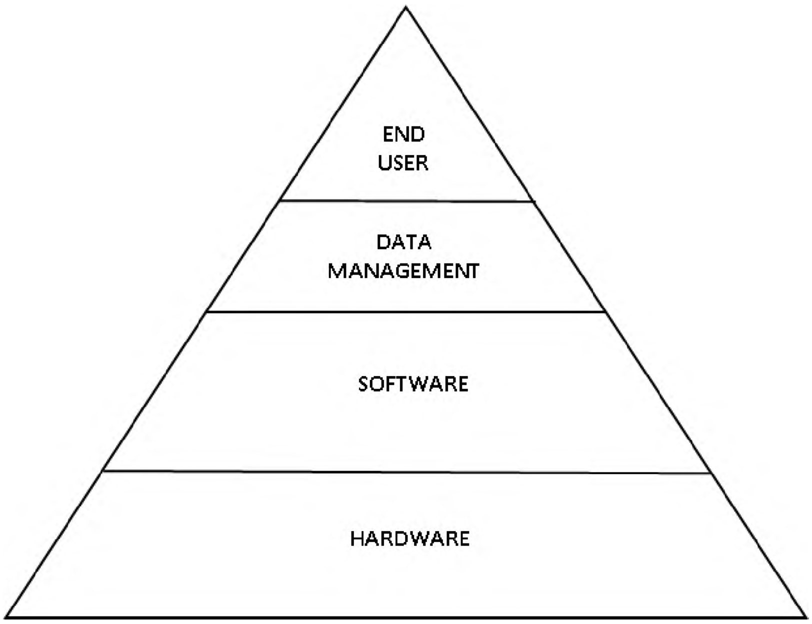

Figure 5.2. Big Data Analysis Layers

Source: Dasgupta N.Practical Big Data Analytics: Hands-on techniques to implement enterprise analytics and machine learning using Hadoop, Spark, NoSQL and R, Packt Publishing Ltd, Birmingham, 2018, p. 13.

Big Data as an analytical tool consists of four layers, components that are crucial for the effective use of large data sets. The lowest layer includes **computer hardware**, which is relevant from the point of view of providing infrastructure, which to a large extent includes servers used not only for data collection, but also for their storage. The appropriate disk space, both physical and virtual, is particularly crucial because it enables later analytical processes ensuring access to all data required in the process. The next layer is a **software**, which is an instrument for conducting database analysis. One of the most frequently used tools in Big Data Analytics is Hadoop, however, the analysis also uses Data Mining or statistical analysis tools as well. The third layer includes **data management**, which major purpose is to provide

[177] Kumar U. D. , Pradhan M., Ramanathan R., Basics of Analytics and Big Data in Ramanathan R., Mathirajan M., Ravindran A. R. (eds.), Big Data Analytics Using Multiple Criteria Decision-Making Models, CRC Press, Boca Raton 2017, pp. 71-74.
Sedkaoui S., Data Analytics and Big Data, Wiley, Hoboken 2018, p. 45.

adequate information required for the analytical process, sometimes allowing indication of information that has been unused in a company due to the limited capabilities of the analytical tools used heretofore. It also ensures full transparency in the analysis of information and the security of its utilization by **end users** located on the last layer. As for the effectiveness of using Big Data, it allows the productive use of the availability of data, and ensures that decisions can be taken flawlessly and in a much shorter time by decision makers supported by Big Data instruments in a much more advanced way than traditional analytical methods[178].

Differences between traditional analytical methods and the Big Data analysis concern several important aspects. First of all, traditional analytical methods allow to analyze only ordered, limited historical data sets whereas large sets of data refer in many cases to infinite sets of information, the analysis of which enables to recognize many aspects that would be impossible to identify using traditional instruments. In addition, traditional analytical tools usually refer only to basic, most often statistical techniques, the use of which does not guarantee the effectiveness of the decision process. Big Data Analytics applies advanced mathematical and analytical models, which include linear or multi-criteria programming methods carried out as part of operations research. Decision-making processes, performed by using traditional methods, are usually characterized by much lower effectiveness and frequency of value-adding information than Big Data. This is because they have a clearly defined objective, and the perception of any additional conditions, which can sometimes affect the process indirectly but significant for the decision-making, is impossible for the end user. In case of Big Data, the purpose of the analysis is also clearly defined, however, intelligent analytical tools allow the recognition of many additional, at first glance invisible factors, significantly affecting the outcome of the decision-making process. In addition, traditional analytical methods are characterized by a designated level of analysis uncertainty resulting from the human factor responsible for the errors in the decision-making process resulting from the subjectivity of the analysis itself. Big Data analyzes executed by advanced computer instruments are devoid of any uncertainty about the correctness of individual decisions. In addition, the analysis of large data sets for traditional methods involves a longer analysis time, which adversely affects not

[178] Dasgupta N., Practical Big Data Analytics: Hands-on techniques to implement enterprise analytics and machine learning using Hadoop, Spark, NoSQL and R, Packt Publishing Ltd, Birmingham 2018, pp. 13-14.

only the level of customer service, but also the correctness of the decision resulting from the necessity to apply a number of additional, error-prone actions[179].

Machine Learning is one of the Big Data tools based on artificial intelligence solutions, applying them to the learning processes of appropriate devices or software using data available in large sets to create algorithms and schemes solutions that do not require later control processes or user control. On the basis of access to relevant device data and tools, they utilize the required information to create algorithms and schemas, as well as to improve them to perform effective, error-free and time-effective analyzes. Machine learning can be divided into three types shown below:

- supervised learning – as part of this type of machine learning, the user provides a device with a set of relevant data to be applied in teaching processes with appropriate decisions that should be taken as part of the decision-making process to accelerate the learning process and increase its confidence,
- unsupervised learning – as part of this method, the user provides the device only a set of data devoid of the expected responses in order to perform the learning process by the machine itself,
- semi supervised learning – the user provides a set of data, in which a part has a set of expected solutions, while the other information does not have a specific decision purpose.

As part of the use of machine learning, it is necessary to perform specific steps to increase the effectiveness of the instrument. The following areas should be distinguished here[180]:

1) Problem identification – it is necessary to flawlessly define the purpose of the decision-making process due to the need to select the appropriate analytical tools, as well as to indicate any limitations affecting the decision.
2) Data collection – which is implemented with the utilization of advanced Big Data tools, which include both Hadoop based on SQL and NoSQL databases as well.

[179] Sedkaoui S., Data Analytics and Big Data, Wiley, Hoboken 2018, p. 50.
[180] Mehta R., Big Data Analytics with Java, Packt Publishing Ltd, Birmingham 2017, pp. 99-107. Agneeswaran V. S., Big Data Analytics Beyond Hadoop: Real-Time Applications with Storm, Spark, and More Hadoop Alternatives, FT Press, New Jersey 2014, pp. 55.

3) Data filtering – the stage is required as part of machine learning due to the necessity of learning the model from which data should be used in later analyzes and which information should be rejected by the tool in the case of later processes of making a decision.
4) Researching and testing of the data set – this step consists of dividing the previously filtered data into information developed for learning of new decision algorithms, as well as data used for subsequent testing of correctness of solutions undertaken by the created decision-making schemes.
5) Choosing the right model – this stage is associated with an indication of the relevant model data or a set of algorithms selected for the purpose of the decision, as well as other aspects related to, for example, the data format or how to collect them.
6) Evaluation and improvement of the created tool – this step requires verification of the correctness of the model used in terms of appropriateness of its decisions, as well as fulfilling the objectives set out in the first stage.
7) Model implementation – an appropriately optimized model requires periodic control consisting mainly of collecting decisions made as a result of using the tool, as well as comparing them with each other in order to verify the suitability and optimality of the algorithm executed in the decision making process.

Analyzes performed on the basis of the Big Data tool are very often identified with Business Intelligence instruments. However, a difference between these concepts should be noticed here. The first important issue concerns the infrastructure used for data analysis in both cases. With regard to BI, data is usually stored on stationary devices that are used for analysis. In case of Big Data Analyzes, due to its size, data is stored in cloud spaces or divided into specific sets of information integrated with each other in order to enrich the analytical process with any interactions influencing the decision process, allowing to solve the problem in a much more comprehensive and suitable way. The structure of the analytics system based on Big Data is shown in the Figure 5.3.

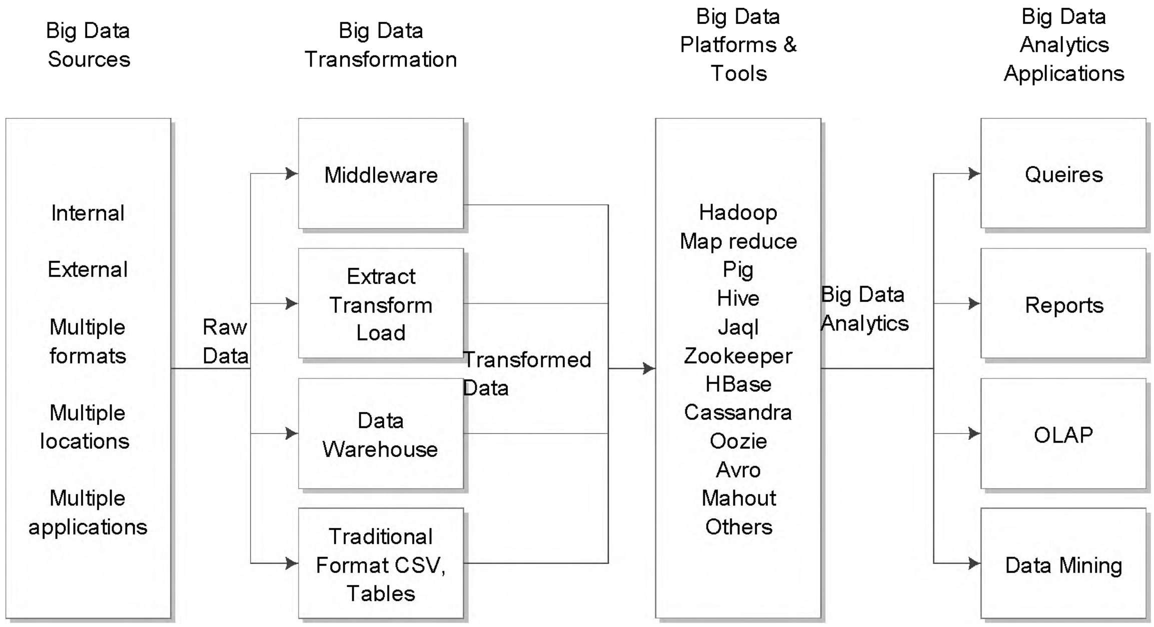

Figure 5.3. Big Data Analytics architecture

Source: Raghupathi W., Raghupathi V. Big Data Analytics—Architectures, Implementation Methodology, and Tools in Kudyba S. (ed.), Big Data, Mining, and Analytics Components of Strategic Decision Making, CRC Press, Boca Raton, 2014, p. 53.

To use a variety of data and indicate information significantly affecting the decision-making process, it is necessary to recognize the relevant data and reject data that may interfere with the process of problem optimization. The data generated from various sources, both from the organization's system and from other enterprises constitutes the next links of the supply chain. Very often, the data is unstructured or partially structured and has different formats that makes comparing and analyzing it harder. In order to implement the decision-making process, the data must be standardized so that they can be compared, and then it is necessary to indicate the data required for the analysis and to reject information that may cause inaccuracies in the decision-making process. In order to properly prepare the data for analysis, the analytical algorithm appropriate for the type of data collected and their characteristics needs to be selected. Optimal for decision-making purposes as well as constraints related to the diversity of data, the model enables analysis of large data sets that allows making an autonomous decision that guarantees the achievement of the goal assumed by the system user[181].

In other words, each analysis is characterized by a specific sequence of activities that should be implemented as part of the decision-making process. The individual steps implemented as part of the data analysis can be called the life cycle of the analytical process, which each time starts with the collection of relevant data from various sources[182].

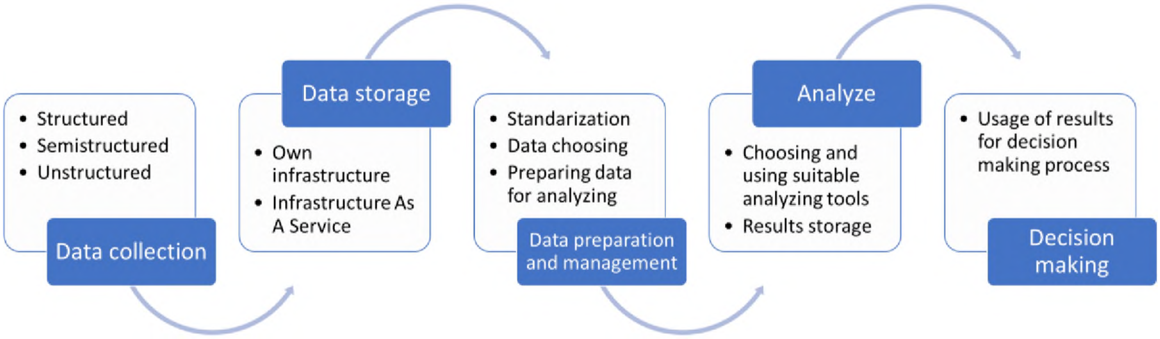

Figure 5.4 Big Data Analysis Life Cycle

Source: Own study based on: Kumar U. D. , Pradhan M., Ramanathan R. Basics of Analytics and Big Data in Ramanathan R., Mathirajan M., Ravindran A. R. (eds.), Big Data Analytics Using Multiple Criteria Decision-Making Models, CRC Press, Boca Raton, 2017, pp. 77. Stimmel C. L. Big Data Analytics Strategies for the Smart Grid, CRC Press, Boca Raton, 2015, pp. 9-10.

Data collection involves downloading various types of information from both the organization's system and its environment due to the complexity of the analysis performed with the employment of Big Data tools and the ability to conduct the decision-making process based on all factors affecting the process. Storage of data from different areas, regardless of the

[181] Raghupathi W., Raghupathi V. Big Data Analytics—Architectures, Implementation Methodology, and Tools in Kudyba S. (ed.), Big Data, Mining, and Analytics Components of Strategic Decision Making, CRC Press, Boca Raton, 2014, pp. 52-54.
[182] Kumar U. D. , Pradhan M., Ramanathan R. Basics of Analytics and Big Data in Ramanathan R., Mathirajan M., Ravindran A. R. (eds.), Big Data Analytics Using Multiple Criteria Decision-Making Models, CRC Press, Boca Raton, 2017, pp. 76-79.
EMC Education Services., Data Science & Big Data Analytics: Discovering, Analyzing, Visualizing and Presenting Data, Wiley, Indianapolis 2015, p. 26.

organization's infrastructure, allows analysis of various time intervals, including huge sets of data as opposed to analyzes carried out on the basis of only selected sets of information. Therefore, this process enables full complexity and affects an increasing level of probability of the effectiveness of the decisions made. At the next stage, the data collected requires a certain standardization that allows users to indicate the information that should be analyzed and exclude that information that may adversely affect the process. Adaptation of data to the requirements of the analysis enables the selection of an appropriate analytical model and results in the use of the outcomes achieved in the decision-making process, as well as supporting later decisions implemented in the course of subsequent data analyzes.

Among the requirements for Big Data analytical tools, there is certainly an increase in requirements for the used hardware and software, which in the era of increasing amounts of data collected and processed may be insufficient. In addition, such infrastructure, which enables a full analysis of data may be associated with an increase in costs, and hence translates into the inability to use many analyzes, in particular by small and medium-sized enterprises (SMEs), which financial capabilities are significantly lower, in comparison to large plants. As regards the amount of data, which collection and storage is difficult due to the considerable limitations of equipment or software acquired, analyzes are accomplished within the cloud systems described in the first Volume of the book entitled *Supply Chain Project Management Volume I Supply Chain Project Management Core and Environment* in section **5.2 Business Process Management.**

An important aspect of the use of cloud systems is that it allows the collection, storage and segregation of countless amounts of data, as well as the use of multiple platforms located on the servers of service providers without the necessity of buying one's own infrastructure. Using both platforms: infrastructure and software as services, is a particularly beneficial solution for enterprises with limited financial resources as it makes it possible to use Big Data instruments to analyze large data sets without the required implementation of computer hardware and software. Furthermore, in many cases, it is also possible to commission analyzes to organizations dealing strictly with data analysis using Big Data, thanks to which enterprises are not obliged to employ qualified staff responsible for the effectiveness of decision processes, and only use ready-prepared data provided by an external organization.

One of the next big data challenges is to provide full access to the required data. In case of data analyzed by the enterprise on stationary servers, it is necessary to ensure full real-time access to information, the analysis of which is crucial with respect to the efficiency of the decision-making process. Data should be stored in a transparent manner so that the use of Big Data tools is effective[183].

5.3. Big Data analysis implementation in supply chain

In the era of digitization of supply chains, which involves numerous enterprises on international markets and their implementation of solutions from the field of Industry 4.0 and Logistics 4.0, the use of one of the most important tools of the IV Industrial Revolution, that is Big Data, is almost obligatory for all organizations striving to develop their activities to execute innovative data analysis. The essence of cooperation within individual chain links is to make joint decisions regarding process management in order to increase their efficiency, primarily to provide the right products or services to customers at the time when they require it. One of the major purposes of using Big Data instruments is the ability to effectively improve processes while shortening the decision cycle. This means that the analyzes performed as part of the use of Big Data allow end users to improve their supply chains as a result of more effective planning of the processes implemented in them. In addition, the use of Big Data tools makes it possible to identify many additional factors that affect or will affect significantly the cooperation within individual links of the chain[184].

With regard to Big Data Analysis in the context of supply chain management, the definition of Big Data and Predictive Analytics (BDPA) should be mentioned. According to it, BDPA can be understood as a "holistic approach to manage, process and analyze data regarding high volume, variety, velocity, veracity, and value to create actionable insights for sustained

[183] Kulkarni P., Joshi S., Brown M. S.,BIG DATA ANALYTICS, PHI Learning Pvt. Ltd., New Delhi 2016, p. 5. Wu C., Buyya R., Ramamohanarao K., Big Data Analytics = Machine Learning + Cloud Computing in Buyya R., Calheiros R. N., Dastjerdi A. V. (eds.). Big Data: Principles and Paradigms, Morgan Kaufmann, Cambridge 2016, p. 18.

[184] Pal K., Building High Quality Big Data-Based Applications in Supply Chain in Kumar A., Saurav S. (eds.), Supply Chain Management Strategies and Risk Assessment in Retail Environments, IGI Global, Hershey 2017, pp. 8-9.

value, delivery, measuring performance and establishing competitive advantages."[185] BDPA uses available techniques and methods that use large data sets in the processes of predicting future events based on developed algorithms and analytical schemes to optimize all activities executed as part of supply chain management[186].

The use of Big Data Predictive Analytics in supply chain management processes allows to expand the efficiency of the individual links and the entire value chain as a result of increasing the transparency of all processes executed within individual organizations. Due to the fact that people were using non-comprehensive analytical techniques heretofore, it had not been possible before. Ensuring an appropriate level of immunity to protect the activities performed within the chain against disturbances, as well as its detection would be impossible without the employment of advanced analytical techniques providing productivity growth of each chain link[187]

"SCM Big Data Analytics is the process of applying advanced analytics techniques in combination with SCM theory to datasets whose volume, velocity or variety require information technology tools from the Big Data technology stack; leveraging supply chain professionals with the ability to continually sense and respond to SCM relevant problems by providing accurate and timely business insights."[188].

Implementation of Big Data solutions may concern improvement of existing processes in terms of maximizing profits, reducing costs or the cycle of the entire process or refer to products to be introduced to the market[189].

The implementation of the decision-making process using Big Data Analysis is particularly crucial as far as the supply chain management is concerned due to much more congeneric and

[185] Eybers S., Hattingh M. J., Critical Success Factor Categories for Big Data: A Preliminary Analysis of the Current Academic Landscape in Cunningham P., Cunningham M. (eds), IST-Africa 2017 Conference Proceedings IIMC International Information Management Corporation, Windhoek 2017, p. 2.
[186] Bag S., Big Data and Predictive Analysis Is Key to Superior Supply Chain Performance: A South African Experience in Management Association, Information Resources , Web Services: Concepts, Methodologies, Tools, and Applications: Concepts, Methodologies, Tools, and Applications, IGI Global, Hershey 2018, p. 1511.
[187] Gunasekaran A., Papadopoulos T., Dubey R., Wamba S. F., Childe S. J. Hazen B., Akter S.,Big data and predictive analytics for supply chain and organizational performance in Journal of Business Research no. 70 (2017), Elsevier, 2017 p. 308.
[188] Rozados I. V., Tjahjono B., BIG DATAANALYTICS IN SUPPLY CHAIN MANAGEMENT: TRENDS AND RELATED RESEARCH in 6th International Conference on Operations and Supply Chain Management, Bali 2014, p. 6.
[189] Brinch M., Stentoft J., Jensen J. K., Big Data and its Applications in Supply Chain Management: Findings from a Delphi Study in Proceedings of the 50th Hawaii International Conference on System Sciences, 2017, p. 1352.

complex services offered by its participants. When developing distribution networks integrating both service providers and service users, they can be characterized by the increasing amount of data generated by system participants. Therefore, supply chain management should focus on the possibility of making optimal decisions in the shortest possible time. Hence, the use of Big Data instruments is relevant for many SCM processes, where apart from the shortest cycle of activities it is necessary to make the right decisions without interference[190].

Regardless of the scope of supply chain management, Big Data Analysis can be provided in the following areas:

Table 5.1. Areas of Big Data Analysis utilization

Management area	Description
Marketing	This area is particularly important due to direct contact with the end customer for the purposes of identifying his needs, requirements and indicating the appropriate distribution channel serving the flow of goods from the producer to the final recipient. Data generated from consignees in the form of loyalty programs or direct contact must be adequately analyzed to identify areas on the market in which to invest and to indicate those customers who are unprofitable from the profitability point of view
Procurement	As part of purchasing processes, the identification of any trends or seasonality is particularly crucial due to the possibility of forecasting the volume of demand and the opportunity of total coverage of demand while minimizing costs. On the basis of the supply data, it is also possible to indicate delivery dates that minimize the expenditures of maintaining the inventories and the elimination of excessive stock. The data usually comes from modern systems that include Electronic Data Interchange (EDI)

[190] Awwad M., Kulkarni P., Bapna R., Marathe A., Big Data Analytics in Supply Chain: A Literature Review in Proceedings of the International Conference on Industrial Engineering and Operations Management September 27-29, Washington DC 2018, p. 423.

Warehousing	Storage of goods in this area requires the simultaneous availability of products at the time and place required by customers, while ensuring minimization of expenditures generated by excessive stocks. Effective inventory planning, which is one of the crucial aspects of the activity performed in the supply chain management, can affect the competitive position of the organization. Data on inventories can be downloaded using RFID technology
Transport	In case of transport processes, the relevant effect of the use of Big Data Analyzes is the ability to respond to any process disruptions in real-time so as to prevent the organization from delays or unforeseen situations that could adversely affect the timeliness or reliability of the delivered cargoes

Source: Rozados I. V., Tjahjono B. (2014). BIG DATAANALYTICS IN SUPPLY CHAIN MANAGEMENT: TRENDS AND RELATED RESEARCH in 6th International Conference on Operations and Supply Chain Management, Bali, pp. 6-8.

The use of Big Data tools plays a significant role in the implementation of decision-making processes related to both individual links and the entire supply chains, thus affecting not only the level of customer satisfaction, but also the market position of companies. To increase the effectiveness of the implemented processes and minimize the probability of mistakes, companies choose the most suitable solutions Thanks to an appropriate selection of data and aspects affecting the performance of a given supply chain on the market, one can carry out analyses which consequently allow for a data examination enabling to make optimal decisions. In case of many, complex, integrated processes implemented by individual links in the supply chain, providing only relevant data required for analysis and indicating information that indirectly, albeit significantly, affects the results achieved by the entire chain, is crucial for the validity of the analysis result. Indication of all factors affecting the process seems to be impossible to achieve by using only traditional analytical methods. Therefore, it is necessary, first of all, to use available mathematical models that make it possible to consider all aspects of how they affect both directly and indirectly the decision-making process[191]. Big Data Analytics in relation to Supply Chain Management Systems finds application in the following areas:

[191] Pal K., Building High Quality Big Data-Based Applications in Supply Chain in Kumar A., Saurav S. (eds.), Supply Chain Management Strategies and Risk Assessment in Retail Environments, IGI Global, Hershey 2017, pp. 8-9.

- accelerating the response time to the changing expectations of customers,
- increasing the level of customer service,
- increasing the efficiency of the entire supply chain,
- reducing the cost,
- improving sales processes and customer relations,
- shortening the cycles of order fulfillment.

The implementation of Big Data tools supporting supply chain management necessitates the compensation of factors that may adversely affect its effectiveness[192]:

- time-consuming implementation of analyses resulting from the level of chain complexity and mutual interaction between its participants,
- difficulty in obtaining particular data resulting from a reduced level of trust in relation to chain partners,
- increase in risk resulting from the inability to use the instrument effectively in the decision-making process,
- the inability to assess the profitability of the investment due to the need of adapting the infrastructure to use the,
- the need to acquire the appropriate analytical and decision-making skills,
- lack of relevant data or analytical techniques, as well as inadequate selection of the procedure for the organization's information sets.

In the era of different needs shown by the recipients of products and services of many The ability to fully customize the products or services offered to recipients in the shortest possible time, and to ensure the availability of the goods at the time and place where the customer requires it, while minimizing costs, are crucial factors affecting customer satisfaction and enabling a company to gain a competitive advantage. Supply chains change in the same way as many processes undergoing digitization and automation. The main objective of this is to accelerate the processes provided by all links or to redeem errors resulting from the use of

[192] Awwad M., Kulkarni P., Bapna R., Marathe A., Big Data Analytics in Supply Chain: A Literature Review in Proceedings of the International Conference on Industrial Engineering and Operations Management September 27-29, Washington DC 2018, pp. 419-424.

appropriate algorithms and calculation models. In the near future, autonomous supply chains will not only determine the competitive advantage, but, essentially, will become the determinant of the functioning of many organizations on the market, especially in the industry strictly dependent on innovative technological solutions. Hence, the necessity to introduce many changes, which can result in the achievement of the optimization objective on the supply chain. The Big Data instruments make it possible to pursue the process of automation of activities executed within the chain, and contribute to the autonomy of many processes, which is possible due to appropriate analysis of available data. The opportunity of using huge sets of data stored in cloud systems or applying the services of enterprises offering large data collection analysis creates unlimited possibilities for enterprises in the context of complexity or time allocated for implementation of specific processes. Only correctly analyzed data from various sources allows full verification of the chain's activity and contribute to its development, hence the use of Big Data tools is becoming indispensable.

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6. NEGOTIATIONS AND BUSINESS COMMUNICATION

6.1. Definition and types of negotiation

6.1.1. The scope of negotiation

Negotiations, which unusually often remains a fact that people seem to be oblivious to, constitute an immanent part of human life. Both in professional, and private life, arrangements are made through negotiations. This can be perfectly illustrated by the words of Brian Tracy, who is probably one of the most recognizable authors of books devoted to negotiations, or more broadly, business psychology. Tracy, in his pivotal publication on the topic, describes this process in the following way:

"Your success in business and in life will be determined by your ability to negotiate in your best interests in every situation. Negotiation is a key skill that affects everything you do or say, and almost all of your interactions, both personal and in business. Life may be viewed as one long, extended negotiation session, from the cradle to the grave. Negotiation never stops. It is the way that individuals with differing values and interests find constructive ways to live and work together in harmony"[193].

Katie Shonk, editor of the Program on Negotiation at Harvard Business School, characterizes the process in a very similar way: "Many people dread negotiation, not recognizing that they negotiate on a regular, even daily basis. Most of us face formal negotiations throughout our personal and professional lives: discussing the terms of a job offer with a recruiter, haggling over the price of a new car, hammering out a contract with a supplier. Then there are the more informal, less obvious negotiations we take part in daily: persuading a toddler to eat his peas, working out a conflict with a co-worker, or convincing a client to accept a late delivery"[194].

Both Tracy and Shonk, emphasize the importance of seemingly simple, every day negotiations which are conducted in professional and family life. In the latter case, children can

[193] Tracy B., Negotiation, AMACOM. Amercian Management Association, New York 2013 (eBook), pp. 72-73.
[194] Shonk K., What is negotiation?, https://www.pon.harvard.edu/daily/negotiation-skills-daily/what-is-negotiation/ (20.05.2019).

frequently make for the toughest partners in the informal negotiation and, provided that the parent-child relationship is a healthy one, they constitute non-alternative negotiating partners. To answer the question of why this is the case, one should realize that in almost every other situation, it is possible to change the negotiation partner, even between spouses who in an extreme case can divorce. The needs of one's child cannot be satisfied by taking care of other children; the parent-offspring relationship is practically irreplaceable, which means that - as often admitted by the parents - their position in conversations with children is extremely difficult[195].

To answer the question of what negotiations are, it can be posited that they constitute a process in which two or more parties communicate with a view to satisfying their needs by presenting their viewpoint, most usually being ready to make some concessions in favor of the remaining participants of the process and in order to come to an agreement.

An interesting definition is offered by the employees of Negotiation Experts in the dictionary posted on the organization's website, according to which it is: "an interactive process between two or more parties seeking to find common ground on an issue or issues of mutual interest or dispute, where the involved parties seek to make or find a mutually acceptable agreement that will be honoured by all the parties concerned"[196].

There are many ways to explain what negotiation is, but it is noteworthy that all these definitions emphasize communication and involvement of parties as the basic elements of the process. Communicating, although it seems to be an obvious and common phenomenon, is not a problem-free process. One can simply refer to their own life situations (professional and private), in which a person lacked understanding, it was impossible to come to an agreement, or intentions and declarations of the parties were misread.

Negotiating in business or in politics, not to mention crisis negotiations, for example in hostage situations, is a communication process that should be consciously learnt. This is much more

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[195] The authors of the book entitled "Negotiation" that belongs to a series of "Harvard Business Essentials", consider parent-child negotiations as an immanent element of family life: "Negotiation is an ever-present feature of our lives both at home and work. When a parent and a child talk about how the child will improve his math scores, they are negotiating."
Harvard Business Essentials, Negotiation, Harvard Business School Press, Boston 2003, p. ix.
[196] https://www.negotiations.com/definition/ (20.05.2019).

obvious than the need to also improve communication in private situations[197]. One can take great pleasure in the fact that students who take the course in Negotiations at the Poznan School of Logistics very rarely expect that the effect of taking part in classes will be mastering tricks to help them win negotiations, but rather they seek a better understanding of the process and their potential roles in it.

Becoming acquainted with different types of negotiations, or rather their typology, is an important factor contributing to learning how to negotiate. It is beneficial in understanding the multifaceted nature of the phenomenon under scrutiny. It is worth noting that each and every negotiating event can be assigned to several different typologies. This allows for the assessment of the event after the completion of individual stages of talks or after their closure. It also provides the possibility of more effective preparation of business organizations to negotiations with the same or different partners

It is the first kind of typology to be discussed, and at the same time, it seems, the most rudimentary division of negotiations in the professional sphere. The foundation of this division in based on the broadly understood subject matter of talks, as well as social functions of negotiators and circumstances in which the talks are held.

The following classification based on the scope of negotiation can be adopted:

- political and military negotiations (international treaties & conventions, truces), they seem to be the most commonly present in public awareness due to their frequent quasi-public character, media interest, place in general history as well as other factors owing to which the society has access to them and can assess their proceedings and outcomes,
- business negotiations, extraordinarily widespread, conducted by both business organizations and individual people as part of their financial affairs as well as countries and transnational and international organizations implementing their economic policy,

[197] Learning communication in the personal space is a process that primarily takes place in the family where children/teenagers observe the way in which parents or other adults communicate. Parents can also serve as an exemplar of business negotiation. This assumption also seems to be confirmed in the words of George Siedel who wrote in the acknowledgement section of his book “Negotiating for success”: “Parents. I want to acknowledge my late parents, George and Justine Siedel. While their negotiating skills were forged in difficult times during the Depression, fairness was their highest priority in dealings with others.” p. viii. In this way, Siedel, to a certain extent, indicated his natural teachers of negotiation.
Siedel G., Negotiating for success. Essential strategies and skills, Van Rye Publishing, Michigan 2014, p. viii.

- public consultations (investments, constructions, etc.), a type of talks often accompanied by other kinds of negotiations (political and business), aimed at getting to know the opinions of local communities or larger groups of citizens on the topic of planned activities of politicians or public and private investments. They can also serve as a platform for the investors to explain the character of the planned investment and endeavor at reaching out to people in whose place of residence or economic activity, the investment will be located[198],
- crisis negotiations, associated with emergency situations which pose a threat to human life or property. The most conspicuous example is hostage situation negotiation. Talks of this kind are most often conducted by properly trained officers of public institutions[199]. It is crucial to note that this type of negotiation is governed by different principles than all the previously mentioned types insofar as achieving the assumed goal is the absolute priority which can sometimes justify employment of techniques which are unacceptable or blameworthy in other kinds of negotiations, like for example, the conscious use of lying.

Mediation is a special form of negotiating (criminal & civil law, academic, school, etc.) which can have different scope, and also a distinctive way of holding talks. A mediator participates in

[198] It needs to be remembered that public consultations are standard in democratic countries nowadays. The inclusion of societies, communities, or non-governmental organizations in the decision-making process is proceeding. It is expressed by Sandra Seubert when she writes: "The discussion about the change in the essence of statehood shows that that the forms of political control change themselves, and that participation in the decision-making processes of non-state actors in decentralized negotiation systems and networks is most obvious."
Saubert S., Politisches Handeln in der Bürgergesellschaft, in: Politisch Handeln. Modelle, Möglichkeiten, Kompetenzen, eds. Weißeno G & Buchstein H., Bundeszentrale für politische Bildung, Bonn 2012, p. 115.
[199] Jeff Thomson, a researcher, as well as a police officer, writes about police negotiators in the following way: "Law enforcement crisis and hostage negotiators are world-renowned for their ability to apply expert conflict resolution and communication skills in situations that are tense, (potentially) volatile, and where lives can be at risk."
Thomson J., "Hostage" & "Crisis" Negotiators: Nonverbal Communication Basics, https://www.psychologytoday.com/intl/blog/beyond-words/201308/hostage-crisis-negotiators-nonverbal-communication-basics (20.06.2019).
The same author in yet another paper observes that: "Crisis negotiation has been described as being one of law enforcement's most effective tools."
Thomson J., Crisis or Hostage Negotiation? The Distinction Between Two Important Terms, https://leb.fbi.gov/articles/featured-articles/crisis-or-hostage-negotiation-the-distinction-between-two-important-terms (20.06.2019).

the discourse as a third party as an authority on procedures, while the remaining parties have expertise in the material scope of the talks.

6.1.2. The position of the parties and the character of the potential agreement

It is one of the most significant typologies of negotiation processes, classifying them into two large groups:

- distributive negotiations (also known as position negotiations), it is used in situations when the sum of the goods to which it is applied is limited. Therefore, the interests of the parties are mutually exclusive and the profit of one of them results in a loss to the other one,

- integrative negotiations (also known as problem negotiations), it is employed in situations where achieving profit as part of mutual cooperation is possible, and the sum of goods to which negotiating is applied is unlimited[200].

In distributive negotiating, the parties aim at obtaining possibly the largest share in the benefits of the negotiated agreement. It results in value claiming by all the parties involved as they primarily compete with each other. Under such conditions, the cooperation of negotiators is virtually impossible, because the arguments of each party seem to be unquestionable and most significant. In case of integrative negotiating, one can say quite the opposite - the parties strive to cooperate in order to generate value together, with all of them ultimately benefitting from this scenario.

When introducing this classification, it is crucial to emphasize that one should not simply attribute positive assessment to integrative negotiation, and negative to distributive negotiation. These types, as previously mentioned, are mainly associated with the kind of negotiated agreement, and not with the style preferred by negotiators. In case when the negotiations concern such topics as obtaining access to rare natural resources, granting a limited license, purchasing a piece of art or a historic vehicle or dividing territory or property, the parties strive for success and concentrate on their own needs. This seems to be justified in view of the fact

[200] Harvard Business Essentials, Negotiation, Harvard Business School Press, Boston 2003, p. 3.

that process participants talk about rare goods that are of value to them and the number of which cannot be simply increased.

Siedel indicates that, in some situations, it is possible to transform distributive negotiation into integrative. It is necessary, however, to communicate with the other party and to be oriented towards recognizing his or her real needs and to be able to create ways in which these needs can be satisfied[201]. Obstinate persistence in using distributive negotiation where it is possible to employ integrative negotiation instead does seem, however, to be completely unreasonable. Cooperation that gives a chance for joint profit generation should be easier to achieve than stubborn endeavor at dominating partners in the process. This does not mean, however, that negotiations of this type do not require thorough preparation and proper conduct.

The parties involved. Negotiation processes can also be divided in accordance with the number of parties involved. One can distinguish two basic types of negotiation:

- bilateral - negotiation of two sides (firms, organisations, people, states etc.),
- multilateral - negotiation of more than two sides, sometimes even of more than hundred like in case of the UN.

Bilateral negotiations are more common. Within their framework, two entities try to reach an agreement; the buyer and the seller, the service provider and the service receiver. Such situations take place in case of, for example, buying a car, entering into a contract for the supply of office materials, or commissioning the construction of a house. This does not mean, however, that multilateral negotiations, also in business, are rare. Just imagine negotiations conducted by an investor buying a factory that is to be expanded - the buyer, the current owner of the plant, representatives of local authorities, bank, crew etc. can all join the negotiating table. Each of these parties will want to articulate their position and secure their interests during a multilateral meeting.

6.1.3. Symmetry of sides

Yet another division is based on different power relations of the negotiating parties,

[201] Siedel uses the terms "position-based negotiation" and "interest-based negotiation".
Siedel G., Negotiating for success. Essential strategies and skills, Van Rye Publishing, Michigan 2014, p. 8.

and hence, the following can be distinguished:

- symmetric negotiation - negotiations, where the power (numbers of negotiators, their professional status, experience, level of preparedness, legal support, market position) of all sides are almost equal/comparable,
- asymmetric negotiation - the opposite situation (*NOTICE:* the seemingly weaker party/parties could smartly use the imbalance of powers to outplay the opposite, seemingly stronger party/parties)[202].

In case when the stronger side of negotiations neglects the weaker partner and at the same time neglects the preparation and conducts the talks carelessly, it is likely that they will not achieve the final goal, or at least they will not get as much as they could have if they treated the other party adequately and respectfully[203]. It should also be remembered that an important factor determining symmetry or lack thereof is the choice of the language in which the talks are held. Whether one's native language is used, what the level of language proficiency is, etc. all affect the balance between the parties.

[202] Interesting remarks concerning symmetry and asymmetry of power in negotiation processes can be found in a report by Mara Olekalns and Philip L. Smith entitled "Trust, power (a)symmetry and misrepresentation in negotiation". The authors describe potential behaviors of negotiators in two types of negotiations: "*Power asymmetry.* One interpretation of a relational perspective is that power will be most salient when it is asymmetrically distributed, that is when negotiators have different levels of power. Research shows that under conditions of power asymmetry, high power negotiators are more likely to engage in put downs and threats and to ask fewer diagnostic questions (De Dreu & Van Kleef, 2003; Giebels, De Dreu & Van de Vliert, 1998, 2000; Rubin & Brown, 1975). However, low power negotiators do not necessarily respond submissively (Rubin & Zartman, 1999, 2000), suggesting that power asymmetry triggers a power struggle in which low power negotiators take action to reduce the power gap (Kim et al., 2005)." and "*Power symmetry.* An alternative possibility is that, within power asymmetric dyads, relationships are well-defined and stable (e.g., Tenbrunsel & Messick, 2001). Negotiators recognize the power discrepancy and work within the constraints of this power imbalance. For example, research shows that negotiators exchange *more* accurate information when power is asymmetrically distributed (Tenbrunsel & Messick, 2001)."
Olekans M., Smith P.L., Power (a)symmetry and misrepresentation in negotiation. IACM 2006 Meetings Paper, https://ssrn.com/abstract=913727 (16.08.2019).

[203] Frank F. Pfetsch in his article regarding international talks of political character indicates five elements which can influence asymmetrical negotiations. These factors can also occur during negotiations between economic entities: "On the one hand there is the perceived structural relationship between the negotiators on each side, evaluated as strong or weak, rich or poor etc. There is, secondly, the process of negotiation itself that shows the behavior of the negotiators in their dealings with one another. A third category relates means and ends and asks about the adequacy of instruments used in order to achieve a desired end. A fourth aspect can be identified when a third party intervenes. Fifthly, there is the outcome of the negotiation process. The perspective of symmetry or asymmetry can be found in different forms and at all stages of negotiation development […]."
Petsch F.R., Power in international negotiations: symmetry and asymmetry, https://www.cairn.info/article.php?ID_ARTICLE=NEG_016_0039 (29.08.2019).

6.1.4. Number of negotiators

Negotiation can also be divided on the basis of the number of people representing the parties involved. Two types can be identified:

- individual negotiation - negotiation run by only one negotiator in a session (supported by colleagues in the firm), every party is represented by one negotiator,
- team (group) negotiation - negotiation run by a team of negotiators in a session, who support each other during the process (and are supported by colleagues in the firm), every party is represented by a team of negotiators.

The merit of the first variant is that the negotiator can independently make decisions in the course of talks, is individually responsible for them and does not have to take any extra time to create and organize the team. Individual negotiations work especially well in less complicated negotiation processes. Team negotiation, in turn, is used in difficult, multi-threaded conversations in which knowledge from various areas and the involvement of many people is useful. The unquestionable advantage of this variant is the mutual offloading of negotiators, the division of tasks in the team and joint decision-making. It is also worth remembering that creating a negotiating team is a difficult task and, as can sometimes happen, also time-consuming.

NOTICE: Collective negotiation is a process taking place between an employer and employees about salaries.

6.1.5. The end result for individual parties

It is yet another filter through which distinguishing several types of negotiations is possible. It is extraordinarily popular among both people who are professionally involved in negotiations, as well as those, who do not hold this status. Quite often, even in day-to-day conversations, one can witness WIN-WIN solutions, which can mean a successful closure of smaller or more significant transactions for all the parties.

In this typology, one can distinguish the following categories:

- WIN-WIN, that is such a closure of negotiations as a result of which all the parties involved benefit from the deal,
- WIN-LOSE, such a conclusion of negotiations resulting in one party or a group of participants benefiting. What is even more important, one or more parties lose as a result of the agreement,
- LOSE-LOSE, in this case, the outcome of negotiations is that none of the sides gain anything, all the parties lose something,
- NO OUTCOME (NO DEAL), in this case, negotiations conclude without any agreement. In face of the actual possibilities of all the parties, reaching a satisfactory agreement is unattainable. In view of that, neither do the sides involved gain anything, nor do they lose,
- COMPROMISE is the opposite of NO OUTCOME, because in this case an agreement is made that is, to say the least, unsatisfactory for one or more sides.

P. Stark and J. Flathery conclude that WIN-WIN is "the ideal outcome for almost all negotiations"[204]. Ensuring that no one - if it is possible - exits the process having made no profit, appears to be fair, which also opens the way for further cooperation. Hence the assumption that WIN-WIN is characterized by multiple-entry negotiations, which means that there is a chance to extend the contract or start cooperating in a new area. Negotiations with the WIN-LOSE finale are more likely in the case of one-off negotiations, where they will not be repeated or will happen in the distant future.

Many people who are novice at negotiating forget that the possibility of concluding negotiations in the last three variants exists. If the negotiators strive to make an agreement in a persistent way, considering the signature at the end of the process as a measure of their success, they can conduct the talks in an unprofessional way and hence, lead to the LOSE-LOSE or COMPROMISE outcome. It needs to be pointed out that while the word "compromise" in everyday language has rather positive connotations (people say that in marriage, compromise is necessary to make it last), in negotiations it has a derogatory meaning. There is also a concept

[204] Stark P.B, Flaherty J., The only negotiating guide you'll ever need, Crown Business, New York 2017, p. 12.

of a “rotten compromise”, in which at least one of the parties will end up being dissatisfied with the conditions of the agreement, and therefore, will soon thereafter try to renegotiate it.

More importantly, it is advisable that the negotiators are aware of the fact that the NO DEAL outcome is not synonymous to failure, but rather a sign of a consciously made decision to cease the talks due to depleted possibilities of reaching an agreement.

6.1.6. Duration

Another crucial division regards the way negotiation is organized in time. Two main types can be distinguished:

- one-off negotiation,
- multiphase negotiation.

6.1.7. Communication channel

In the era of ubiquitous digitalization and the unimaginable possibilities for communication available to almost everyone, it is worth paying attention to yet another possible division of the negotiation processes. In this area, one can distinguish:

- direct negotiations, that is, those in which interview partners meet in person,
- remote negotiations, that is, those in which negotiators communicate using electronic tools.

These tools include diversified hardware and software, ranging from regular landline or mobile phone through specialized teleconferencing equipment, e-mail and various applications / communicators commonly available on the market.

Remote negotiations seem to be particularly demanding, due to the fact that using the tools listed above on a daily basis, also in situations involving personal matters, the negotiator may not quite understand that the remote negotiation process differs from “regular” communication and is subject to other rules. This problem is noticed by many authors writing about the issue of communication in business.

6.1.8. Relevance of categories in negotiation

The presented categories of negotiation process division into different types can simultaneously be used when qualifying particular processes. Negotiations can be classified as business, asymmetrical, having a problematic character and at the same time ultimately concluding with a WIN-WIN outcome. This may raise the question of whether, in addition to the theoretical dimension, the use of these typologies may also have practical application. Both the author's negotiating experience and the observation of the negotiation simulations carried out in the course of classes at the Poznan School of Logistics allow to conclude that it is worth carrying out analyses of this type. They can be an important element of the preparation and the ongoing analysis of the negotiating situation, especially in the case of multi-phase talks. And this seemingly obvious distinction between symmetrical and asymmetrical negotiations may be an inspiration to carry out intensive preparations - on the weaker side, it may be in-depth analysis along with the preparation of visualization of the results of negotiation, analysis of weak points of the stronger talk partners, while on the stronger side - analysis of the development potential of the weaker party, the level of its innovativeness, etc. Similarly, in case of other types of negotiations, conscious people who join the talks use previously described assumptions and divisions to properly prepare the negotiators and their organization for action.

6.2. Typology of negotiators

6.2.1. Internal and external negotiators

Just as one can distinguish diversified types of negotiations, it is also possible to categorize negotiators. Clearly they can be classified in accordance with their level of experience, that is, for example, participation in a specific number of individual and team negotiation sessions, membership in negotiation teams as a front man or member of the team, the ratio of victories to failures in sessions, proficiency in foreign languages and factual knowledge. All this information is extremely important and should be taken into consideration by people who commission others to run the talks and create negotiation teams. This kind of familiarity with potential negotiators should be accumulated in an organization and be available to decision-makers.

Based on their knowledge of and familiarity with negotiators, the decision-makers have to determine whether they are going to use their own resources in the negotiation process, or invite people from the outside of the organization to cooperate with them. This suggests yet another possible typology that can be developed to classify negotiators:

- internal, that is, those who are full-time employees/co-workers of the organization which is considering to start the negotiation process,
- external, invited by an organization to cooperate in order to strengthen its power in the negotiation process.

External negotiators are chosen due to their experience, negotiation skills, as well as knowledge of the market to which the talks are related, etc.[205] Companies subcontract external negotiators on a permanent basis, or select them ad hoc, in accordance with the current needs of their organizations. It needs to be remembered, however, that while the possibility of employing external negotiators can be beneficial to the company, they do not become personally engaged in implementing the negotiated agreement. This can result in them negotiating in such a way that does not fully account for the consequences of the obligations made throughout the negotiation process. Such a risk should be taken into account by the commissioning party. This danger can be minimized by creating a mixed team, consisting of both external negotiators and members of the company's staff, who will guarantee that commitments made in the process will be tangible and obtainable.

6.2.2. Behavioral typologies

The categories indicated above are extremely important in the "classification" of negotiators, or potential negotiators, but a large group of theorists and practitioners prefer to use the typology of negotiations based on the behavior of individuals in the course of negotiating,

[205] Harvard points to yet another benefit from the involvement of an independent agent, who is chosen in order: "To put some distance between oneself and the other party. Will you be bargaining with a friend or valued business associate? If you are, are you prepared to drive a hard bargain? Probably not-doing so could damage that important relationships".
Harvard Business Essentials, Negotiation, Harvard Business School Press, Boston 2003, p. 123

which means that these typologies are, to a large extent, related to the personality of the negotiator. Often, these are not well-researched psychological systems, but rather divisions created on the basis of behavioral observations of participants in the processes. Such a classification makes sense due to the fact that an experienced negotiator has had opportunities to meet numerous adversaries in his professional life, but also members of his own negotiation teams, which enabled him or her to observe repetitive behaviors, strivings etc. Researchers who analyze the behavioral patterns of negotiators resort to variegated metaphors describing them, including fauna, colors, or names based on the function. Some of these typologies are more developed and detailed, while others tend to classify negotiators into very basic groups. Both the former and latter approach can be useful.

Brian Buffini suggests classifying negotiators into seven groups:

- the People Pleaser - these people want to be liked and often cater to other peoples' needs, wants or feelings at the expense of their own,
- the Expeditor - they talk, move and think fast,
- the King of the Hill - this type of negotiator needs to win – winning is of paramount importance,
- the Rocking Chair - these people are patience personified, they say little and take their time,
- Earnest and Honest - they tend to be very easygoing and have a laid-back approach, you can trust them; their word means something,
- Emotional Ping-Pong - these people will vacillate depending on emotions: "I want to buy today." "I don't want to buy today." "This is great." "This is awful.", by the way, often the Realtor can be the "Ping-Pong" in the negotiation,
- Linear Logical - these people process their emotions in a linear fashion – Mr. Spock from Star Trek would be a good example[206].

Buffini distinguishes specific groups by focusing on their particularly visible features. One can get the impression that Buffini assigns differentiated models of behaviors, to the categories that have been created by him.

[206]https://abovemag.remax.com/buffini-understand-the-7-types-of-negotiators/ (26.07.2019).

Petry B. Stark and Jane Flaherty recall the typology proposed by Dudley Lunch and Paul L. Kordis. They distinguished three categories that were based on the characteristics of species representing the underwater world:

- Shark (take over or trade off) – must be a winner, believe in scarcity / wishes to get as much as possible, using cursors to cause confusion, need to be right 100 percent of time, able to lie, lack the ability to be creative,
- Carp (give in or get out) – believe in scarcity, bbelieve he/she will always be the loser, avoids making decisions or entering into negotiations, carp feels well in the company of other carps,
- Dolphin (an ideal negotiator) – high intelligence and ability to learn from experience, ability to change his/her behaviour in pursuit of his/her goals, ability to successfully adapt to any situation he/she encounters, no belief in zero-sum strategies[207].

In this classification, a significant factor in creating the categories is the way in which the negotiators themselves perceive their chances of being successful (it is possible for just one person to be the winner vs. everybody can benefit from the process).

The last type of classification recalled here will also be one of the most well-known. It has been put forward by Kennedy, who used colors to mark individual groups of negotiators:

- Red negotiators – aggressive negotiators, aiming at dominating talk partners, striving ruthlessly to achieve the goal,
- Blue negotiators – gentle, assertive negotiators, seeking to conduct talks in a conciliatory manner, taking into account the needs of their partners in the negotiation,
- Purple negotiators – negotiators who can, depending on situation, resort to either blue or red patterns of behavior in order to secure the achievement of their goals[208].

Although it seems that blue negotiators can be thought as Dolphin counterparts, it is worth remembering that excessive courtesy or even submission to the talk partners is not an

[207] Stark P.B., Flaherty J., The only negotiating guide you'll ever need, Crown Business, New York 2017, p. 74 - 80.
[208] Kennedy G., The new negotiating edge: the behavioural approach for results and relationships, Nicholas Brealey Publishing, London 1998.

advantage; similarly, “excessive saturation with red” - among the negotiators it is usual to say that a red one may encounter an adversary who is an even deeper shade of red[209].

6.2.3. Negotiation teams

Types of negotiators play an important role in building negotiation teams. One should keep in mind that each such team needs to have a manager able to control the workload and members of the team. Simultaneously, the members should be selected in such a way that they are able to cooperate with one another productively. Negotiators with dissimilar or even opposing negotiating personalities working on the same team, can generate such deep internal conflicts that conducting negotiations can prove to be ineffective or even impossible.

Also, excessive team unity may be counterproductive. In this case, unity is understood as an attitude during the preparation for talks, and not as a clear lack of consistency of attitudes in their course. This is noticed by the previously quoted Katie Shonk, who writes that the “us versus them” mentality created by the negotiating team may lead to demonizing outsiders and viewing them as the enemy. She also points out that diverse experiences and knowledge constitute potential that can strengthen the negotiating team. However, they become beneficial to the team only when they are conscious and appreciated.[210]

It is also crucial not to invite people who are antagonized or competing with one another to work on one team. If they are unable to control their negative emotions, effective cooperation among the remaining team members will be disrupted.

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[209] Kennedy in his paper on “Negotiating” published in “Trading Journal” writes: “Red behavior is manipulative and aims to get something for nothing (for example, »more for me means less for you«). Red behavior can manifest itself in outright bullying, intimidation, domineering and aggression. It can also be more subtle, even good mannered and, on occasion, covert. In contrast »blue« behavior aims in its assertive forms to trade something for something (form example »more for me means more for you«), but in its submissive forms ends up »giving something for nothing« to red-style domineering negotiators”.
Kennedy G., Negotiating, Training Journal, Aug 2001, ABI/INFPRM Collection, p. S1.
[210] Shonk K., 3Team-building techniques for successful negotiations, https://www.pon.harvard.edu/daily/business-negotiations/team-building-techniques-successful-negotiations/ (26.07.2019).

6.3. Stages of the negotiating process

6.3.1. Preparation

The negotiating process has received a detailed description of its structure. Certainly, the most basic classification is that which identifies: preparation, opening of the negotiation, proper negotiation and finalization. Some authors when discussing the stages of the negotiation also include points regarding the implementation of the contract provisions and their ongoing inspection. Such provisions seem to be particularly crucial because they highlight the fact that negotiations are not an independent process but should rather be intended as a way of achieving a possible agreement.

The authors from the Watershed Associates suggest dividing the process into 5 stages which are called: 1. Prepare, 2. Information Exchange and Validation, 3. Bargain, 4. Conclude, 5. Execute[211].

Without thorough preparation, proper execution of the negotiating process seems to be impossible. Due to this, organizations that plan to carry out the process, should be properly prepared for it. It needs to be highlighted that this kind of work has to be done not only by the negotiators themselves but by a broader group of employees who will be directly or indirectly affected by the negotiated agreement. This is because interviewers should have as wide a range of information as possible to help them choose the purpose and method of negotiation. These include, for example, analysis of current market trends, raw material prices or cooperation history. The organization's management should also be involved in the preparation, because it gives the negotiators a mandate to conduct talks, defines their scope and sets a goal that is satisfying for the company.

The very beginning of the preparation process is making a decision to negotiate. It is neither automatic, nor simple, as it may seem to people from the outside.[212] It involves

[211] The authors attribute the following characteristics to particular stages: Prepare - identify potential value, begin to understand interests, develop fact-base; information exchange and validation – discover and create value, assess interests, build rapport and trust; bargain - create and distribute value, address interest, make and manage concessions, conclude - capture value, confirm interests have been met, thank them; execute - expand value, addressing changing interests, strengthen relationships. https://www.watershedassociates.com/learning-center-item/negotiation-stages-introduction.html (31.07.2019).

[212] George Siedel in the summary of the chapter entitled "Decide Whether to Negotiate" as a key take away tells his readers: "Before beginning a negotiation, ask yourself theses questions: Are you comfortable negotiating in this situation? Do benefits from the negotiation outweigh the cost, such as your time commitment? Do the rewards justify the risks, such as losing a job offer?"

analyzing the initial situation, determining the problem to be solved and indicating the expected outcome of the negotiations. It seems extremely useful to use the SMART method to define the goal set for negotiators, so that they can perceive it as a specific, precise one and, if possible, expressed numerically / quantitatively (e.g. size of ordered lots, percentage increase or decrease in price, duration of the contract, etc.). However, it is worth remembering that one can use intervals. Negotiators should accept these goals, considering them feasible and ethically right. They must also know the duration of the negotiation process assumed by the commissioner.

Using the SMART method enables to avoid idle and insignificant conversations that do not lead to the goal. As a result of using the SMART method, one should be able to define the scope of negotiations, i.e. the area, the activities to be negotiated. At the same time, it should be explicitly stated which areas and activities are excluded from the process. Stemming from this, the negotiator knows the area in which he can safely move, as well as the benefits that the organization will achieve in the event of successful negotiation. Furthermore, it also allows for specifying the interests / needs of the parties involved so that they can be secured / satisfied. Such preparatory activities enable to monitor the entire process and its possible discontinuation (no outcome), in case securing the interest of the enterprise does not seem to be feasible. Just being part of the negotiation process is not the goal of any organization. A particularly important element of preparation is defining the Best Alternative to a Negotiated Agreement (BATNA), i.e. specifying which of the most beneficial actions can be taken in the event of a failure in the negotiation process in which one participates. It is an element of creating an extremely helpful scenario of activities which can be done in various situations. The absence of BATNA could slow down the work of negotiators[213].

Siedel G., Negotiating for Success. Essential strategies and skills, Van Rey Publishing, Michigan 2014, p. 6-7.

[213] Roger Fisher and William Ury are the creators of the concept of BATNA who in an interview with Bert Spector pointed out that developing BATNA can prove to be beneficial even in the most difficult circumstances as it helps to determine the significance and consequences of failure: "That was a word [BATNA - M.W.] we just made up. It was a new concept. Nobody had ever talked about it before. You've got to develop your BATNA first. Otherwise you don't know how to negotiate. Take the Middle East. People on both sides have to un- derstand that unless there's a deal-and that means two states, some agreement on Jerusalem, and shared security-then there will just be more terrorists, more assassinations, more suicide bombings. That's the best alternative, and it's not a very good one".
Spector B., An Interwiev with Roger Fisher and William Ury, The Academy of Management Executive (1993-2005), Vol. 18, No. 3 (Aug., 2004), p. 107.
It is also possible to sometimes see WATNA - Worst Alternative..., as well as introduced by Heidi and Guy Burgess Estimated Alternative... The creators of the last concept point out the sometimes illusory BATNA of negotiators.

During the preparations, a negotiator is appointed along with the negotiating team. This is preceded by a review of the organization's human resources. The factors that play a role in this activity have been discussed earlier. It is worth remembering that at this stage, as well as at a later time, internal negotiations take place, i.e. arrangements within the organization that affect external negotiations, i.e. those that are conducted with representatives of the parties with whom one talks.

Preparation has even more significance if the talks are international or intercultural in nature. Then, in addition to gathering relevant substantive knowledge, a negotiator should make sure that he finds out relevant information about the habits, style of doing business, the state system, etc. of the party with which they plan to start the talks.

6.3.2. Opening the process and negotiations proper

The next stage of the negotiations is to open the process and actually negotiate. The opening is accompanied by a prior contact, establishment of the venue, and sometimes determination of the conditions under which the talks will be conducted, as well as other protocol-related activities. Creating atmosphere by small talk, presentation of the participants, and so on is related to the opening itself. It cannot be considered as an easy step due to the fact that it is the moment during which the scope and order of the meeting is to be determined. This can be difficult, especially if visions of the parties are divergent, but crucial for them (thought-through during the stage of preparations). As part of the opening, the positions of the parties are presented which should not be confused with their interests / needs. The position is a message of the party, which does not have to fully or even at all reflect their interest (e.g., acceptable level of the price of services or goods, delivery conditions, etc.). As part of the opening, anchoring[214] occurs, i.e. an indication of the conditions to which the parties will refer later in the following parts of the process. The answer to this action is counter-anchoring, i.e. indicating the terms of the other party. One should remember the old negotiation rule, according

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Reimer L. E., Schmitz C. L., Janke E. M., Askerov A., Strahl B. T., Matyók T. G., Transformative Change. An Introduction to Peace and Conflict Studies, Lexington Books, Lanham, Boulder, New York, London, 2015, p. 85.

[214] Harvard proposes an extremely simple and sufficient definition of anchoring: "Anchoring is an attempt to establish a reference point around which negotiations will make adjustments".
Harvard Business Essentials, Negotiation, Harvard Business School Press, Boston 2003, p. 49.

to which the first offer is to be rejected. These steps should be thoroughly prepared and carried out so as to build trust among the participants of the conversations and the conviction that the other party acts rationally and that the subject of the conversations can be effectively discussed with them.

The next stage is the actual negotiation, also called the movement phase. In the course of the talks, the parties often, using various negotiation techniques, refer to the proposals presented at an earlier stage, trying to determine the most favorable conditions for themselves, as well as, in case of the WIN-WIN model, good conditions for other participants. This stage should last until the parties have exhausted the supplies of issues necessary for them to discuss. It is not advisable to continue the negotiations at all costs; ongoing monitoring of the expenditures related to conducting the process and analysis of opportunities of its favorable closure is necessary. In this context, the concept of Total Costs of Ownership emerges, i.e. adding up all the costs associated with conducting and prospective closure of negotiations (working time of negotiators and the support team working on their behalf in the organization, external analysis, travel expenditures, etc.). Concessions and profits of the parties take place in the space known as the Zone of Possible Agreement. It is the space of giving and taking in the negotiating process, limited by reservation prices[215] of both/all sides involved in the process. Reservation price which is the lowest acceptable level of price, known to a party of a negotiating process. As part of proper negotiations, two other concepts also come into view. Firstly, 'stretch' which can be thought of as an outcome much above reasonable expectations, a streak of good luck. Secondly, 'most likely' constitutes the reasonable, most expected level of price determined on the basis of analysis. By using these categories, it is possible to evaluate the result achieved during the process, as well as make ongoing decisions during it.

6.3.3. Finalization and implementation of the agreement

The next stage is a summary that completes either the whole process or its part, if the parties have decided to divide the negotiations into sub-processes. During it, the participants clarify and record the arrangements. This is important because it can serve as a tool for

[215] "The *reservation prices* (also referred to as the *walk-away*) is the least favorable point at which one will accept a deal".
Harvard Business Essentials, Negotiation, Harvard Business School Press, Boston 2003, p. 23.

negotiators to eliminate possible misunderstandings that could block the finalization of the process (e.g. signing the contract) or impede its subsequent implementation.

As mentioned earlier, it is important that negotiators do not lose sight of the need to implement the contract. Mature negotiators are characterized by ensuring that as many issues as possible are clarified during the talks, so that when the negotiations are closed, they can proceed with their arrangements quickly and without stress.

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