ADVANCED USING OF SPREADSHEET TO ANALYZE LOGISTICS DATA - THEORETICAL INTRODUCTION

BUSINESS ANALYTICS SKILLS FOR THE FUTURE-PROOFS SUPPLY CHAINS

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Preface

The functioning of modern supply chains is not possible without IT support. The development of digital technologies allows companies to monitor and improve the implemented processes continuously. Modern IT systems allow for the collection and storage of data, which in consequence provides almost unlimited possibilities for their analysis. Recognizing the development of highly specialized analytical tools, in our opinion we cannot forget about spreadsheets as the most accessible analytical tools.

The content presented in this book was developed based on the results of research conducted as part of the Business Analytics Skills for Future-proof Supply Chains (BAS4SC) project. They constitute a theoretical introduction to the analysis and optimization methods of processes implemented within supply chains. The book, together with the teaching materials also developed in the BAS4SC project, constitute a whole that allows you to gain both knowledge and skills in using analytical methods and a tool in the form of a spreadsheet for this purpose.

We hope that this book, which is a theoretical introduction to the analysis and optimization of supply chains using a spreadsheet, will be an important source of both knowledge and inspiration for developing analyses and improving logistics processes.

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INTRODUCTION

The book *Advanced Using of Spreadsheet for Logistics Data Analysis – Theoretical Introduction* is the first in a series of three books developed as part of the Business Analytics Skills for Future-proof Supply Chains (BAS4SC) project co-financed by the ERASMUS+ Program. This book can be used as an academic handbook to develop analytical knowledge and skills in the area of logistics. Its content was created based on research conducted as part of the BAS4SC project. The identification and selection of content that should be included in such a textbook was carried out in three stages. In the first stage of the study, education programs in the field of business analytics implemented at universities in Europe and North America were analyzed. The education programs of 66 universities were analyzed. Key competencies that business analysts should have, especially those performing their tasks in the area of logistics, were selected from them. In the second stage, surveys were conducted among business representatives (with particular emphasis on logistics, production, and trade enterprises), academic teachers, and students, the aim of which was, firstly, to determine the degree of significance of the competencies distinguished in the first stage of the study for contemporary business and, secondly, to determine whether these competences are already included in the educational effects of programs implemented at universities. The results of the first two stages of the study allowed for the indication of analytical competencies that are key from the point of view of business practice. In this way, over 100 key competencies were distinguished. In the third stage of the study, these competencies were systematized and classified, and according to experts, 33 of the most important were distinguished. Thanks to this, it was possible to create three educational programs. The first of them is: Advanced Application of Spreadsheet for Logistics Data Analysis.

This book is a theoretical introduction to issues related to data analysis methods and techniques that can be implemented using a spreadsheet. The content of the handbook is supplemented by teaching materials also developed as part of the Business Analytics Skills for Future-proof Supply Chains project, which presents practical aspects of performing individual analyses in one of the most popular spreadsheets. The division of the content into theoretical and practical also results from the fact that the functionalities of spreadsheets change very dynamically over time. By implementing teaching programs, we want to provide the latest solutions in the form of files made available to participants of educational programs. The latest versions of teaching materials and exercise files are available at: WWW.

The book is divided into 10 chapters, each of which presents a selected aspect of the functioning of the supply chain and possible analytical methods that can be used within it. The first chapter is devoted to introductory issues. It describes the contemporary way of perceiving the importance of collecting and analyzing data for the functioning of logistics processes. It also presents spreadsheets as a tool with many functions that can be used in business and especially in logistics.

The second chapter presents data visualization methods using charts and managerial dashboards. The authors present not only types of charts but also recommendations for the use of individual charts to present data of a specific nature. This issue is particularly important when analyzing large data sets when it is necessary to present them in a way that is simplified on the one hand and reflects the information contained in them on the other.

The third chapter is devoted to issues related to optimization as a theoretical concept and the application of these methods in the field of warehouse and inventory management. Both optimization methods and theoretical foundations of issues related to warehouse space planning and the relationship between inventory size and demand for warehouse space are presented.

Chapter four describes the concept of supply chain controlling. The scope of controlling in the area of logistics is presented. The concept of efficiency is also indicated as one of the key ones in the optimization of supply chain processes. The description is enriched with performance measures and indicators used in the area of logistics.

The fifth chapter is devoted to issues related to analytics in the area of procurement and purchasing. After a theoretical introduction on the functioning of purchasing and supply in supply chains, methods of evaluating and selecting a supplier are presented. The focus is on the most popular methods: weighted (supplemented with graphic illustrations) and AHP.

Chapter six is devoted to issues related to outsourcing. The idea of outsourcing, its advantages and disadvantages are presented. Outsourcing is presented as one of the methods allowing for the optimization of the costs of logistics processes in the enterprise. From an analytical point of view, the Make or Buy method is described, which allows for an objective indication of whether outsourcing will reduce the costs of implementing a selected logistics process.

Chapter seven focuses on the optimization of the logistics network, in particular on the location of the nodes of this network. The impact of the location of warehouses in the distribution network or production plants on the functioning of the network and the costs associated with it is described. The center of gravity method is presented as the basic method for optimizing the location of network nodes.

The subject of chapter eight is forecasting, and in particular forecasting methods based on time series. Methods of calculating forecasts using the average methods (simple, arithmetic, moving and weighted), exponential smoothing and regression are indicated. The chapter is supplemented by an indication of the use of artificial intelligence in forecasting.

Chapter nine is devoted entirely to the issue of inventories in the enterprise. Both theoretical issues and calculation methods used in estimating costs related to inventories, and values of parameters of inventory replenishment systems depending on the planned level of customer service are presented.

The last chapter of the manual is devoted to transport optimization. This is a particularly important issue with many dimensions of possible improvement. The range of optimization methods is very wide. In this respect, the authors decided to present mathematical models for optimizing the transport execution time and the number of kilometers traveled, along with methods of searching for the best solution within these models using Solver.

1. INTRODUCTION TO SPREADSHEET ANALYSIS

This chapter is devoted to the most important issues related to data analysis using an Excel spreadsheet, which can also be used to analyze logistic data. It contains:

- basic definitions,
- data analysis,
- the importance of data for logistics,
- spreadsheet and its application.

1.1. Introduction

The analysis and management of information in an enterprise covers all organizational units at subsequent levels of the economic system, i.e. operational, tactical, strategic, as well as knowledge management. Data analysis and management include the following activities (Szymonik, 2010):

- constituting the information function of the enterprise, i.e. acquiring, storing, processing, sharing and using information,
- within the planes (technological, organizational, human resources) influencing the implementation of this function.

The guarantee of the success of any undertaking is achieving an information advantage, defined as the ability to acquire, process and disseminate information, which will enable, for example, dominating competitors or improving the logistics process. Information advantage can be gained, among others, by: by meeting the expectations of specific users, e.g. supply chain participants, by providing qualitative information characteristics from which to exchange (Szymonik, 2015):

- relativity – information meets the needs and is important for the recipient,

- accuracy – information is adequate to the level of knowledge represented by the recipient, precisely and exactly reflects and defines the topic,
- up-to-date – the update cycle is consistent with the content and the pace of change,
- completeness – information contains an optimal and sufficient amount of data to transform the information into specific knowledge, and its level of detail depends on the needs of the recipient,
- consistency – individual data harmonizes with each other, the form corresponds to the content, data updating is consistent with the goals,
- appropriateness – appropriate presentation of information and description for presentation, enabling correct interpretation,
- availability – information is available from anywhere and at any time,
- credibility – the information confirms the truthfulness of the data and contains elements ensuring the reliability of the message,
- congruence – information is consistent with other information, interpreted in the appropriate context, functioning in a familiar communication system.

1.2. Data analysis

Data is a representation of raw, unstructured facts, concepts, instructions or results gathered from observations or records about phenomena, objects or people that can be shaped and formed to create information in a form that can be communicated, interpreted, deduced, inferred or processed by humans or automatic devices.

Data analysis is the process of examining, interpreting and presenting information collected from various sources. Using a variety of techniques and tools, data scientists turn raw data into actionable information that helps enterprises make decisions, identify trends, and solve problems. In today's world, where companies generate huge amounts of data, learning data analysis is becoming more and more important, and its skill is becoming more and more desirable on the labor market (www_1.1). Data analytics is a key process in science and business to transform raw data into useful and valuable information through various methods and analytical techniques.

The use of modern analytical techniques in logistics allows data to be transformed into valuable resources, supporting innovation and the development of business intelligence, which is a key element of the modern business approach (Zhang & Shao, 2020; www_1.2).

In the context of logistics and supply chain, the key challenges in managing this data fall into three main areas. Firstly, there is the problem of data pre-processing and compression. Secondly, logistics data management faces difficulties due to the fragmentation of companies in the supply network, such as missing data or disruptions in network equipment, which increases the risk for both suppliers and customers. Thirdly, there is an insufficient level of sophistication in data analysis and decision support. Deficiencies in modelling technology, data mining methods and decision support systems limit the ability to provide valuable information for logistics operations.

1.3. MS Excel Spreadsheet and its application

Excel is one of the most widely used programmes on company computers, as it is where most corporate reports are prepared. In addition, many company systems export data in formats that are compatible with Excel, making it easier to organise and view information in a clear and structured manner. With the VBA programming language, which is an integral part of Excel, the programme gains even wider application possibilities, such as automating routine tasks, creating more advanced tools or developing functions. VBA is a key tool for spreadsheet automation, enabling the creation of macros for repetitive tasks and integration with other elements of Microsoft Office, as well as with programmes such as AutoCAD (Shinsato Jr et al., 2023). Excel Spreadsheet is a spreadsheet program in the Microsoft Office group of applications. MS Excel provides features such as calculations, charting tools, pivot tables and a macro programming language called Visual Basic for Applications. It also offers a set of statistical analysis functions and other tools that can be used to run descriptive statistics and perform several different statistical tests.

A spreadsheet is a computer program used to perform various types of calculations, often very complex ones. In spreadsheets, we can present data, mainly numerical, in the form of a set of tables that allow automatic processing of this data, its analysis and presentation in various ways, e.g. in the form of various types of charts, ranging from simple line charts, through pie charts and bar charts, to eye-catching bubble charts. The most important capabilities that spreadsheets provide to the user are (www_1.2): (1) data analysis, (2) performing calculations, (3) preparing offers, (4) presentation of results, (5) creating charts, (6) creating reports and summaries.

In each cell of a spreadsheet, you can enter numerical data, text data or a formula in the sheet called a **formula**, which allows you to calculate a given value based on the contents of the cells. It can include in its content the **addresses** of these cells, mathematical symbols and more advanced operations such as **functions** – not only mathematical, but also statistical, financial, date and time or database functions, which are the most important and frequently used tools that a spreadsheet provides. A **function** in a spreadsheet, on the other hand, is an algorithm specially designed by the programme's creators, ready-to-use formulas that allow specialised calculations or searches for specific values. Examples include the Average function, which calculates the arithmetic mean of given numbers, or the Maximum function, which searches for the largest of given numbers, and many others. With the help of these functions, data entered into the programme is processed automatically and can be used to create simulations. Formulas in the worksheet are built using standard rules for creating mathematical expressions. The entry of a formula should always be preceded by an equals sign, e.g. =A8+C11 or =(F14-E10)*12 etc. Formulas are used to calculate and analyse data in a spreadsheet. If a number in the formula is changed, the programme will make the changes automatically and still display the correct result. This way, you do not have to change everything manually. Good spreadsheets, such as Excel, for example, have ready-made functions built in (www_1.2).

The superiority of spreadsheets over other types of software also lies largely in the ability to perform a very large number of calculations with a lot of data, without having to manually confirm each individual action. Performing calculations in such an automated manner significantly reduces working time and requires incomparably less effort from the employee.

In addition, as already mentioned, spreadsheets make it possible to illustrate the data collected and the results of the calculations in a way that is clear and attractive to the recipient, such as various types of charts and diagrams. Sophisticated spreadsheet programmes are able to generate many different types of graphs, which can be used for statistical purposes, optimisation of a particular process or visualisation of changes to be implemented in an organisation. For this reason, they are very often used in various types of presentations of planned projects, where they are used to show the results obtained or predicted for the future. Both charts and pivot tables make it easier to see interdependencies and trends, and thus to better determine the effectiveness of particular activities or tools (www_1.2).

Spreadsheets are often used as a multifunctional tool for data entry, storage, analysis and visualisation. Most spreadsheet software allows users to perform all these tasks, but spreadsheets are best suited for data entry and storage, while analysis and visualisation should be done separately. Analysing and visualising data in a separate program or at least in a separate copy of the data file reduces the risk of contamination or destruction of the raw data in the spreadsheet (Broman & Woo, 2018).

1.4. The most important tools provided by spreadsheets

The spreadsheet offers a wide range of tools that can be used to analyse both logistics data and other types of data. Among the tools provided by the MS Excel spreadsheet, the following should be mentioned:

- Data filtering,
- Data sorting,
- Statistical analysis functions,
- Linear regression analysis tool,
- Correlation diagram,
- Pivot tables,
- Solver,
- Macros,
- Power Query,

- 3D maps.

Information gathering often involves large data sets, characterised by redundancy. Before any further analysis of them can be carried out, only those data that meet specific criteria, tailored to the information needs of decision-makers, need to be extracted from the database. In Excel, two filtering methods are available, located on the Data ribbon (Fig. 1.1): autofilter (Filter command) and Advanced filter (Advanced command).

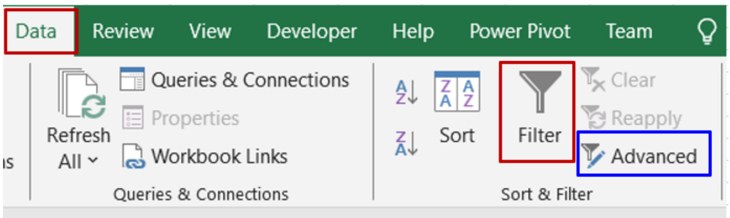


Figure 1.1. View of the Data ribbon with filter commands

Source: own study

Filtering data by format (autofilter, Filter by Colour option) allows you to select values with a specific font colour, cell fill colour or that contain a specific cell icon, inserted via Conditional Formatting (Fig. 1.2).

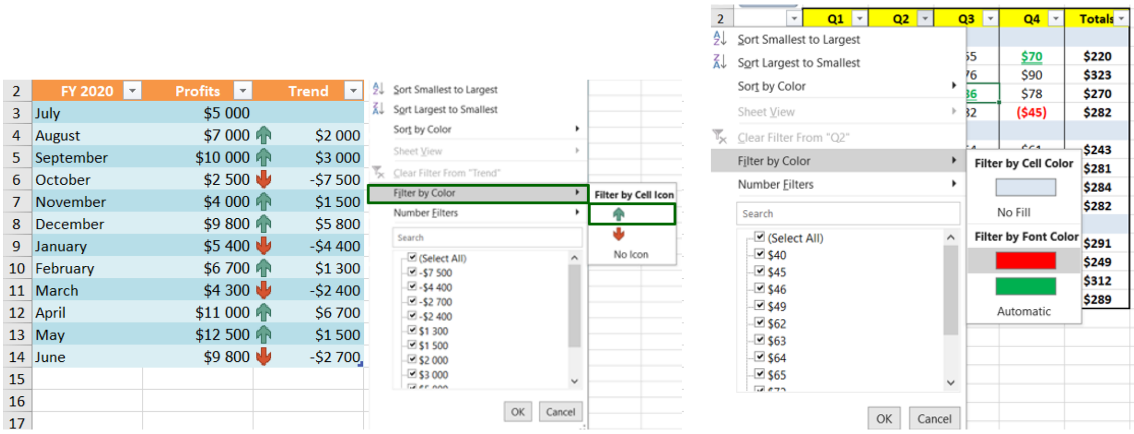


Figure 1.2. Example of the application of the autofilter by format (by cell icons and font colour)

Source: own study

If more criteria need to be defined, the advanced filter should be used. When applying the advanced filter, a so-called filter criterion must be defined.

When working with databases, there is often a need to organise data in a specific order according to user-defined criteria. This process can be achieved by **sorting**. The simplest form of sorting is simple sorting, that is, by a single criterion. There is also the possibility of multi-level sorting, during which the database is sorted according to two or more criteria (Fig. 1.3).

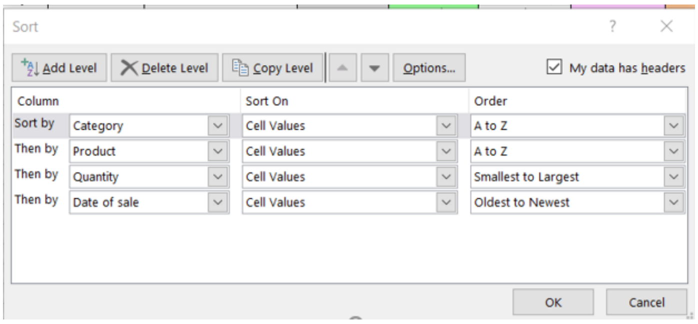


Figure 1.3. View of the Sorting window with set criteria for multi-level sorting

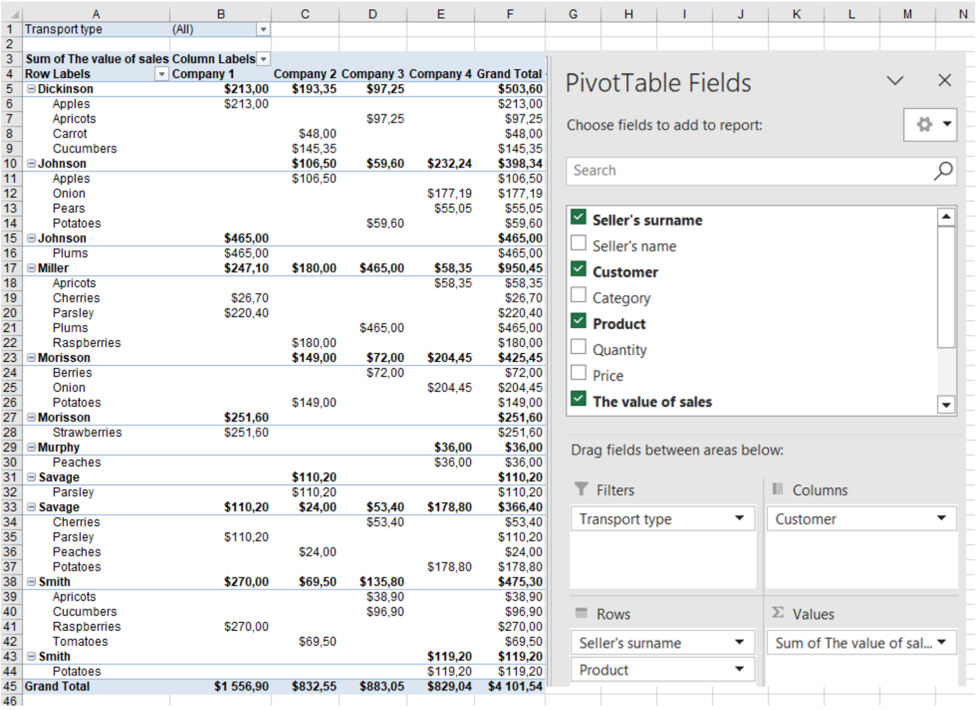
Source: own study

Evaluating datasets for meaning can be difficult, especially as the volume of data increases. Sifting through rows of raw data in spreadsheets can be virtually impossible with any hope of seeing deeper meaning. Numerical summaries can be helpful, but they can still be inadequate. Transforming these numerical summaries into pivot tables and pivot charts can often make them more comprehensible with excellent layout and visual representation.

Excel gives users the ability to create pivot tables and associated pivot charts. These beneficial tools contribute to the automation of the data analysis process and allow almost instantaneous changes to the patterns in which the data is organised, as well as to the parts of the data that are viewed. Reports that meet any need can be generated instantly to answer questions that arise about the data. Pivot tables allow individual data points to be highlighted for immediate comparison with other points, allowing for easy comparison of many different variables.

Pivot tables are an analytical tool in which, as the name suggests, you can freely rearrange the information contained in them. By using a pivot table, you can freely redesign rows and columns so that the resulting table form is clearer or more clearly indicates specific data that the user wants to emphasize. Knowledge of this spreadsheet function is essential when creating summaries and reports (www_1.2). With a pivot table, it is possible to invert data that is in rows. Data can be moved into columns running right across the spreadsheet, which can help the data take a more useful form when converted to a visual chart. The automation of data manipulation contributes to speeding up the process and eliminates potential human error resulting from manual data manipulation. Pivot tables and pivot charts are dynamic in nature and allow their content to be changed instantly to answer specific data-related questions, whereas significant effort would need to be put into rearranging the data to answer the same questions with traditional tables (Miller, 2014).

An example of a pivot table report showing the total value (Values area) of products sold by each vendor (Rows area) to individual contractors (Columns area) by a given mode of transport (Filters area) is presented in Figure 1.4.

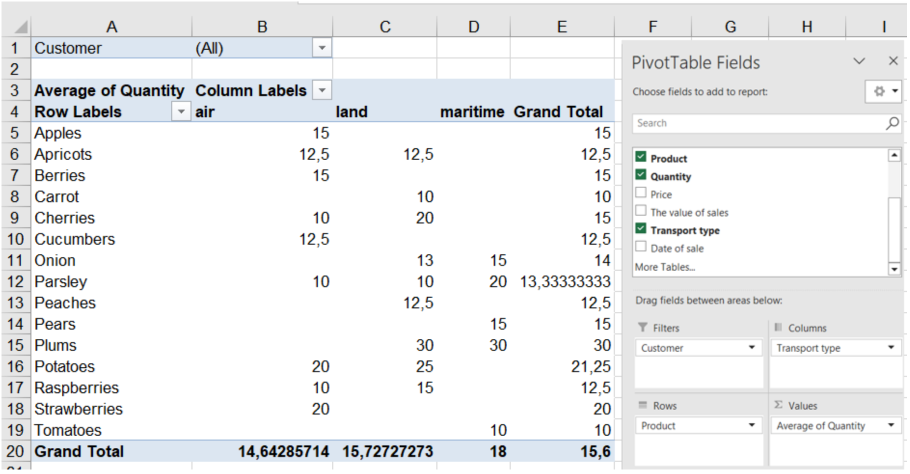


Transport type	(All)				
Sum of The value of sales	Column Labels				
Row Labels	Company 1	Company 2	Company 3	Company 4	Grand Total
Dickinson	**$213,00**	**$193,35**	**$97,25**		**$503,60**
Apples	$213,00				$213,00
Apricots			$97,25		$97,25
Carrot		$48,00			$48,00
Cucumbers		$145,35			$145,35
Johnson		**$106,50**	**$59,60**	**$232,24**	**$398,34**
Apples		$106,50			$106,50
Onion				$177,19	$177,19
Pears				$55,05	$55,05
Potatoes			$59,60		$59,60
Johnson	**$465,00**				**$465,00**
Plums	$465,00				$465,00
Miller	**$247,10**	**$180,00**	**$465,00**	**$58,35**	**$950,45**
Apricots				$58,35	$58,35
Cherries	$26,70				$26,70
Parsley	$220,40				$220,40
Plums			$465,00		$465,00
Raspberries		$180,00			$180,00
Morisson		**$149,00**	**$72,00**	**$204,45**	**$425,45**
Berries			$72,00		$72,00
Onion				$204,45	$204,45
Potatoes		$149,00			$149,00
Morisson	**$251,60**				**$251,60**
Strawberries	$251,60				$251,60
Murphy				**$36,00**	**$36,00**
Peaches				$36,00	$36,00
Savage		**$110,20**			**$110,20**
Parsley		$110,20			$110,20
Savage	**$110,20**	**$24,00**	**$53,40**	**$178,80**	**$366,40**
Cherries			$53,40		$53,40
Parsley	$110,20				$110,20
Peaches		$24,00			$24,00
Potatoes				$178,80	$178,80
Smith	**$270,00**	**$69,50**	**$135,80**		**$475,30**
Apricots			$38,90		$38,90
Cucumbers			$96,90		$96,90
Raspberries	$270,00				$270,00
Tomatoes		$69,50			$69,50
Smith				**$119,20**	**$119,20**
Potatoes				$119,20	$119,20
Grand Total	**$1 556,90**	**$832,55**	**$883,05**	**$829,04**	**$4 101,54**

Figure 1.4. Example of a pivot table report in Excel

Source: own study

Because the fields in the pivot table can be positioned in any configuration, the result is a different report layout effect each time. Figure 1.5 shows a pivot table created from the same source list as the pivot table in Figure 1.4, but this time it presents a report to analyse the average quantity (Values area) of products sold (Rows area) and delivered to a given customer (Filters area) using a given Transport type (Columns area).



Customer	(All)			
Average of Quantity	Column Labels			
Row Labels	air	land	maritime	Grand Total
Apples	15			15
Apricots	12,5	12,5		12,5
Berries	15			15
Carrot		10		10
Cherries	10	20		15
Cucumbers	12,5			12,5
Onion		13	15	14
Parsley	10	10	20	13,33333333
Peaches		12,5		12,5
Pears			15	15
Plums		30	30	30
Potatoes	20	25		21,25
Raspberries	10	15		12,5
Strawberries	20			20
Tomatoes			10	10
Grand Total	14,64285714	15,72727273	18	15,6

Figure 1.5. Pivot table showing the Average number of sold products delivered to a given Customer using individual types of transport

Source: own study

Currently, there is an increased interest among entrepreneurs in 'what if?' spreadsheets with optimisation capabilities, such as **EXCEL Solver** (Microsoft Co.). Excel Solver is primarily used to solve and optimise process design and integration. Practicing engineers also use spreadsheets for many tasks, as process optimisation is becoming an increasingly common task in process synthesis, design and integration.

Due to its usefulness, the solver is very often used in the decision-making process for optimising issues such as: efficient use of existing materials, reducing delivery and transport costs, determining production volumes or determining the best multi-shift work schedule.

Solver is a free add-in for the Microsoft Excel spreadsheet. Excel Solver has two non-linear unconstrained optimisers, the quasi-Newton method and the reduced gradient method. These are used within the Generalized Reduced Gradient algorithm for solving constrained optimisation problems. The linear simplex method with constraints on variables and the branch-and-bound method can be used to solve linear and integer problems. The approach used to obtain better initial estimates of the underlying variables in any one-dimensional search can be specified in the Solver options. Linear extrapolation from the tangent vector or quadratic extrapolation can be used, which can improve results for highly non-linear problems. It is also possible to specify a differential method to estimate the derivatives of the objective and constraint functions: Forward, when the values of the constraints change relatively slowly, or Central, used for problems when the constraints change rapidly, especially near the limits of the active constraints (Ferreira et al., 2004).

In order to perform the calculation, you must first start by coding the contents of the Excel worksheet and place the formula that calculates the function in the selected cell. The parameter values of the function, as well as the arguments to be sought, must be coded in the cells of the selected worksheet range. In addition, the formulas needed to include variable constraints in the calculation should be saved. Next, the Solver dialog box should be displayed, designed to determine the relationships necessary to reach a solution. In the window, by referring to the cell addresses, one should indicate (Bomba & April, 2012):

- Objective cell, e.g. $A$2,
- the sought values of the objective function (Max, Min or Value),
- the range of variables sought, e.g. $H$8:$H$13,
- Constraint relations,
- Solution method (non-linear GRG, LP simplex or Evolutionary).

The solver will perform the optimisation calculation when the Solve button is pressed, resulting in a displayed report with the results.

Task description: The company produces two products: A and B. Each of them generates profit, but requires different amounts of work time and materials (input data can be found in Table 1.1).

Table 1.1. Input data for an optimisation task solved by the Solver

Maximum	Product	Profit per unit	Work time (hours)	Material (kg)
	A	50	2	1
	B	40	1	2
Work time			100	
Quantity of materials				80

Source: own study

Determine how many units of each product to produce in order to maximise profit, with constraints on work time and material availability?

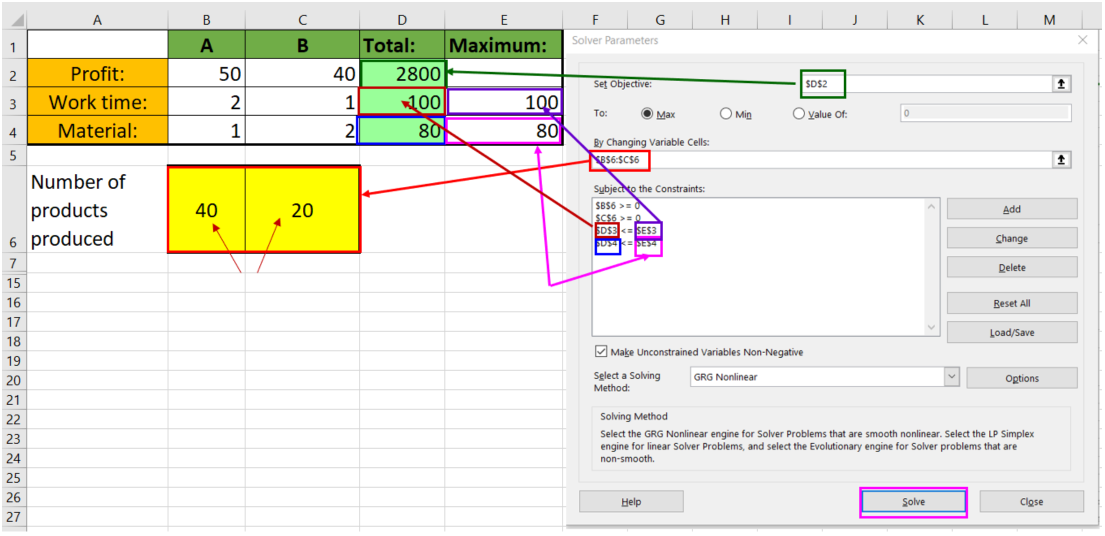


Figure 1.6. Applying Solver to an Example Optimization Task

Source: own study

Macros in Excel are command sequences written in the Visual Basic for Applications (VBA) programming language, allowing the automation of frequently performed actions in a spreadsheet. Thanks to macros, a series of tedious and repetitive operations can be reduced to a single click of a button or key combination. If a number of the same operations are frequently performed on some data in a company, it is likely that they can be automated using a macro. Obviously, it is worth creating a universal macro, capable of performing a sequence of specific actions not only on one piece of data, but also if the layout of the data changes slightly or if the number of data increases or decreases. For this reason, when designing a macro, it is important to use a command that can be applied to multiple sheets, not just one, in a particular situation.

Examples of work automation using macros: (1) automatic data sorting, (2) automatic data input, (3) automatic filling of forms, (4) automatic report generation, (5) automatic creation and processing of forms and surveys, (6) automatic integration with other systems.

Microsoft Power Query (PQ) is a Microsoft Excel spreadsheet add-in for versions prior to Excel 2016, designed by Microsoft to support Self-Service Business Intelligence solutions. It is also worth emphasizing its usefulness when working with data, collecting it or analyzing it. PQ allows you to download data from many different areas; starting from relational databases, through data from SharePoint and the operating system, and ending with data downloaded from any website. An additional advantage is that it allows for preliminary data processing, as well as preparing it for further analysis or visualization. The implementation of the above functions is possible thanks to the special language "M", used in Power Query to create formulas and giving great possibilities of using advanced functions to work on data using selected operators.

Power Map is an add-in for Microsoft Excel Professional and Office 365 Professional that lets you create clear geospatial visualizations of your data directly from Excel. In many data visualization cases, Power Map completely eliminates the need for programming, allowing you to work directly with data in a spreadsheet and present relationships directly on a map. As a helpful debugging tool, it lets you retrieve information from a database, import it into Excel, visualize it, and draw conclusions without having to write code to plot the data on a map (Au & Rischpater, 2015).

Power Map can help create 3D visualisations by plotting up to a million data points as column, heat and bubble maps on a Bing map. If the data is time-stamped, it can also create interactive views that show the change in data over time and space (Clark, 2014).

1.5. Spreadsheet applications in various sectors

The Excel spreadsheet is most often used as a tool in manufacturing companies that do not have integrated information systems.

The first association with the use of spreadsheets is, of course, various types of office work. It is used to create employee lists, sales reports and calculate employee salaries. Programs of this type are also widely used in accounting, thanks to advanced financial calculation functions. The charts and pivot tables available in the spreadsheets also help you visualize interest accumulating when selling financial products, both in banking, insurance companies and the investment sector. In addition, spreadsheets are also used to collect and process information needed to optimize processes and machines used in industry. The inherent use of sheets also includes creating various types of patterns and templates for commercial offers (www_1.2).

Excel is also used in the field of logistics. In their work, logisticians very often use spreadsheets to support decisions in the area of logistics. These include:

1) Stock control analysis:
   - analysis of the structure, dynamics and volume of purchases,
   - analysis of completeness and suitability of stocks,
   - stocks productivity indicators,
   - analysis of stock-related costs.
2) Dynamic analysis of the development of logistic measures over time using a pivot table:
   - analyzing and comparing purchase costs,
   - comparison of indicators over time,
   - multi-currency analysis and calculations,
   - analysis of extensive databases using a pivot table,
   - analysis in the field of transport.
3) Graphical presentation of data in reports in the form of various types of charts.
4) Budget and operational logistics reports.

The Excel spreadsheet is used as a reliable tool for preparing complex reports when there are problems with reading them after they have been generated by logistics systems such as ERP or WMS, which have their own reporting systems. Pivot tables are very useful, as they cannot be created in other IT systems supporting logistics processes and those created in Excel are clear, understandable and transparent (www_1.3).

Logistics is an area of management where we often deal with quantifiable values that can be described with a mathematical model, which makes Excel ideal for analyzing specific decision-making issues in the field of logistics. Here are examples of some of them:

- coordination of the flow of resources in the supply chain,
- implementation of transport tasks,

- minimization of empty runs in transport,
- intermediary issue,
- the travelling salesman issue,
- economic order quantity model,
- optimization of the production range to maximize profit,
- capacity and material demand planning in a production company,
- optimization of production and distribution of products,
- optimization of order fulfillment of orders,
- XYZ analysis in stocks management,
- solving the problem of calculating logistics service prices,
- multi-criteria analysis and evaluation.

Chapter Questions

1. What are the main challenges related to information and data management in the context of a dynamically changing organizational environment and logistics system?
2. What actions can organizations take to ensure high quality information and meet user expectations in the context of supply chain management?
3. What are the benefits of using spreadsheets in data analysis and presentation of results in various projects?

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2. DATA VISUALIZATION METHODS

The chapter discusses data visualization and its use for more effective and accurate data analysis. The most important issues of this chapter include:

- the needs for using data visualization and its benefits,
- types of data visualization – when and what visualizations to use,
- comparison of charts with respect to their properties,
- describing dashboards,
- describing the concept of building dashboards.

2.1. Introduction

Nowadays, it is impossible to imagine the functioning of the world without data analysis. With the abundance of information available, data visualization is one of the most important tools that help understand it, make conclusions and, as a result, make business decisions (Buono, 2016). Visualization methods help analyze data and transform it into information and knowledge about business. Thanks to data visualization, it is easier to make business decisions based on about facts, not just a feeling (Graudina & Grundspenkis, 2005). The data visualization methods themselves develop with the development of technology, mainly BI tools. It was the development of BI that popularized Dashboards, which allow users to analyze and monitor data in real time (Tezel et al., 2009).

This chapter covers the selection of different types of charts and discusses the process of creating dashboards. There are many types of charts, including column charts, bar charts, line charts, pie charts, area charts, stock charts, surface charts, radar charts, donut charts, point charts, funnel charts, scatter charts, but also histograms, heat maps and tree maps. The choice of chart should be adapted to the type of data being analyzed and should be conditioned by the need for the analysis being performed.

All kinds of data visualizations allow for better understanding. Visualizations allow you to pay attention to the most important things, deviations and trends. Additionally, presenting data on charts, maps and dashboards converts data into information, which may result in getting closer to the knowledge needed to make business decisions (Hansoti, 2010).

2.2. Data Visualization methods

Column charts

Column charts (vertical layout) and bar charts (horizontal layout) are some of the most famous and used charts. They use bars to show the value of category data, where the length of the bars represents the value of the data. The higher the value, the higher the bar. Thanks to column charts, you can compare the size of categories and, above all, compare the differences between them. The categories may be time, measurement (e.g. sales, costs, margin), place, location. Charts can be stacked, where several categories will be in one bar per time, or grouped, where all categories will be next to each other. Individual categories can be grouped together (www_2.1).

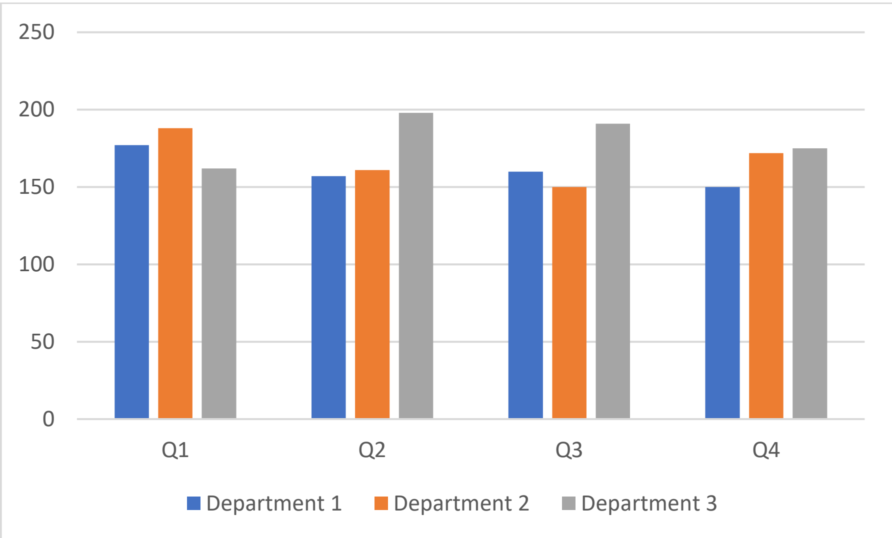

Figure 2.1. Clustered column chart

Source: own study

In the indicated Figures 2.1 and 2.2 you can notice the differences between the stacked and grouped chart. Charts can be grouped together in various ways, so we can look at the same data from different perspectives. Bar charts are often used to present sales results, margins per district, or to present support for political parties during elections.

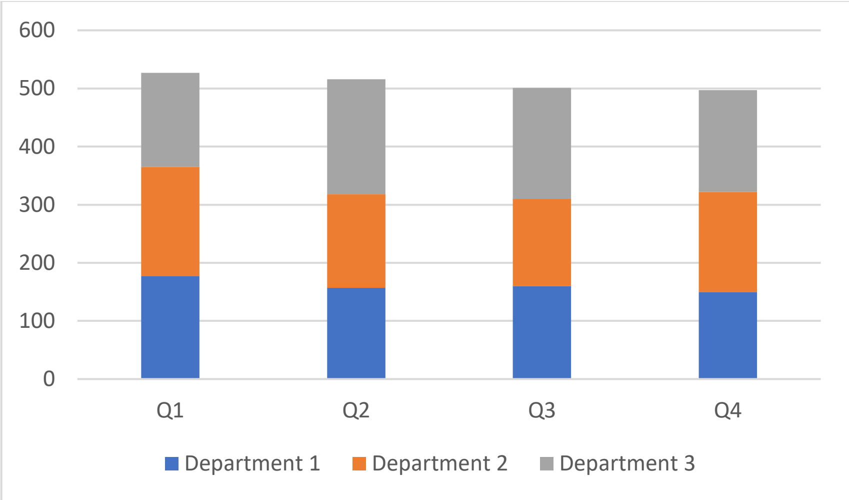

Figure 2.2. Stacked column chart

Source: own study

Pie charts

Pie charts are another popular chart that shows the contribution of different categories to the overall metric. The chart should not be used for time-sensitive data, but is valid for aggregate analysis (year, quarter, month). The chart highlights the dominant category in terms of e.g. sales value (www_2.1).

Figure 2.3 above shows the distribution of sales in a pie chart. The larger the share of the value of the examined category in the whole is, the larger the sector of the circle. The chart can be successfully used when presenting the budget structure or showing the sales structure per division or branch (www_2.2).

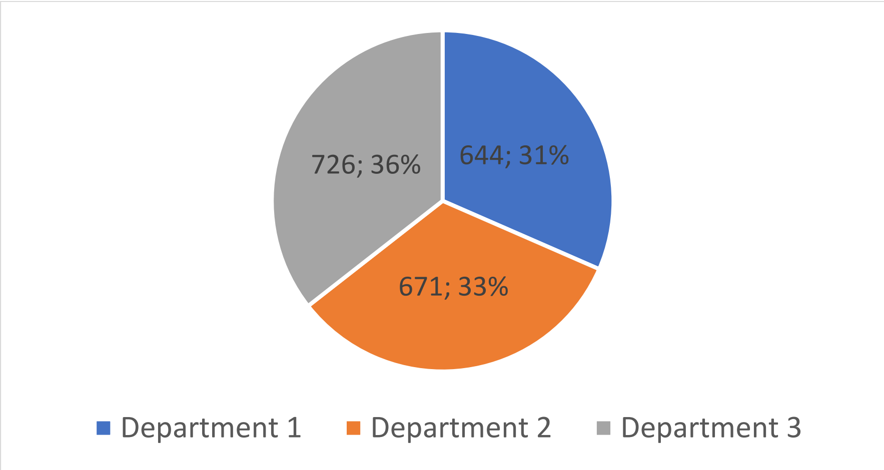

Figure 2.3. Pie chart

Source: own study

Line charts

Line charts are charts that can be used to present data over time. Thanks to this approach, we can easily analyze the trend, trend dynamics, or even forecast values in the future (www_2.3).

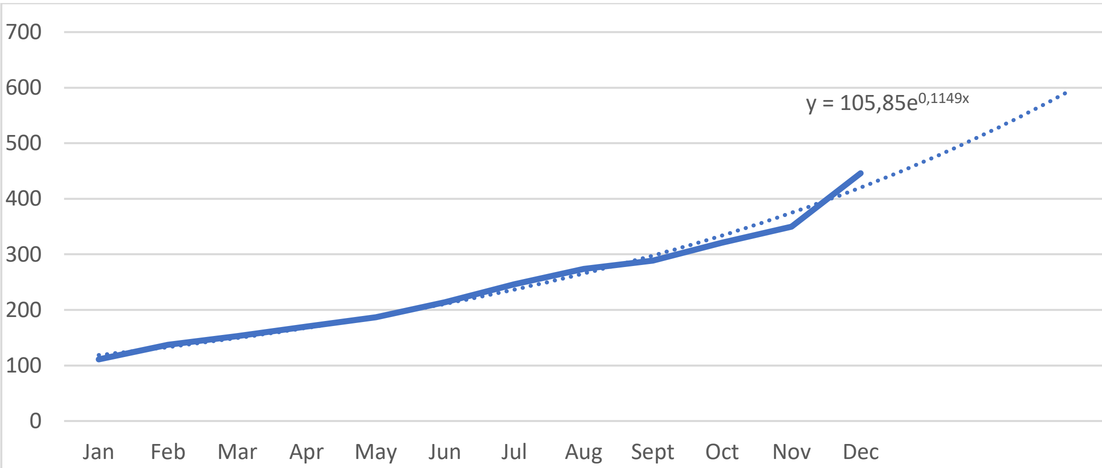

Figure 2.4. Line chart

Source: own study

Figure 2.4 above shows sales per month, demonstrating the exponential trend in those sales. A line chart is a combination of points showing the size of a given category over time. Charts can be used to present currency rates or show the sales trend of a given product (www_2.1).

Stock charts

Stock charts are used to represent stock prices on the stock exchange. The chart is able to show the opening price, closing price and minimum and maximum values at a specific time (www_2.4).

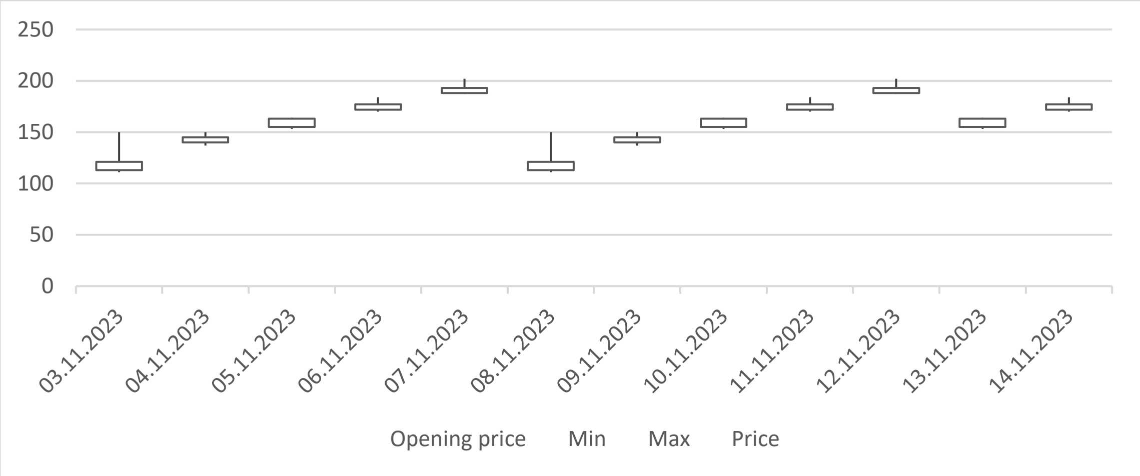

Figure 2.5. Stock chart

Source: own study

Figure 2.5 below shows the opening and closing price of the stock from November 3 to November 14, 2023, along with the maximum and minimum values in this range. The chart is used to present stock prices and currencies (www_2.2).

Surface charts

Surface charts give you the ability to present three-dimensional data on a two-dimensional graph. They allow you to show two independent variables with one dependent variable. The dependent variable is shown using different colors or heights. The chart can be used, for example, to model the topography of a terrain (www_2.5).

Radar charts

Radar charts are used to show multiple variables for selected categories. The chart is not used in a time perspective, but is used to assess a given category, e.g. to assess the skills of a sports player and his skills, but also to assess whether the service provider meets the criteria (www_2.4).

Figure 2.6. Radar chart

Source: own study

Figure 2.6 above shows a radar chart that evaluates the individual features of each supplier. The chart allows you to compare them with each other in order to choose the supplier best suited to the needs of the analyzing entity.

Histograms

Histograms can be used to present the distribution of numerical data, which improves understanding of the distribution around the mean value and allows the identification of group sizes. Histograms are used for statistical research, including examining distributions in a given population (www_2.2).

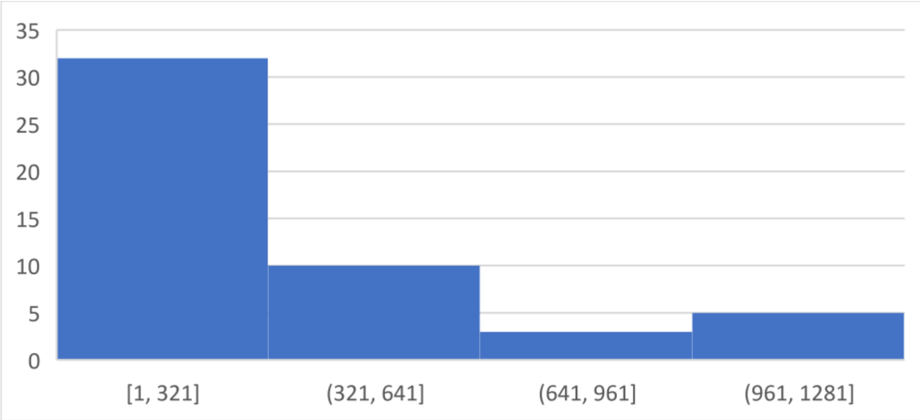

Figure 2.7. Histogram

Source: own study

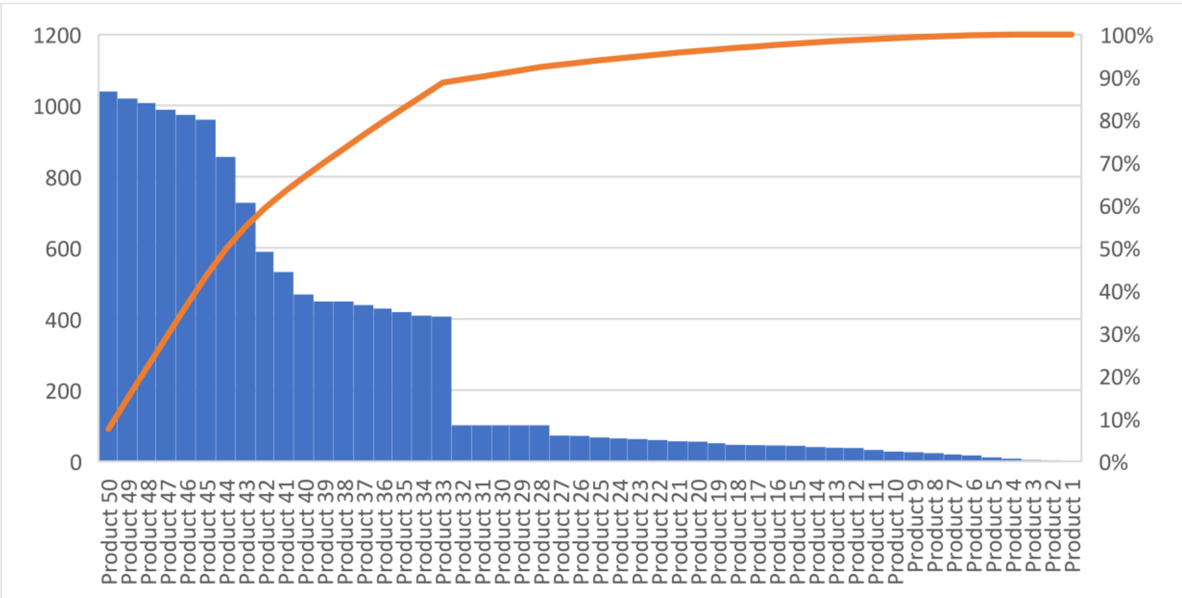

Figure 2.8. Pareto chart

Source: own study

Figures 2.7 and 2.8 above show the sales distribution using a histogram, Pareto and Lorenz curve. There are 4 distribution groups visible, where the largest pool consists of the smallest customers. Using Pareto chart you can pay attention to how many first customers are responsible for what percentage of sales.

Heat maps

Maps are used to visualize data taking into account geolocation or territorial units. The marked areas become increasingly darker in color with higher values. Maps can also contain various types of charts. You can also plot a time axis on maps, so you can observe changes in values for a selected location (www_2.4).

Figure 2.9 above shows a heat map highlighting sales per region. It can be seen that the highest sales are in the Lubuskie Voivodeship in Poland.

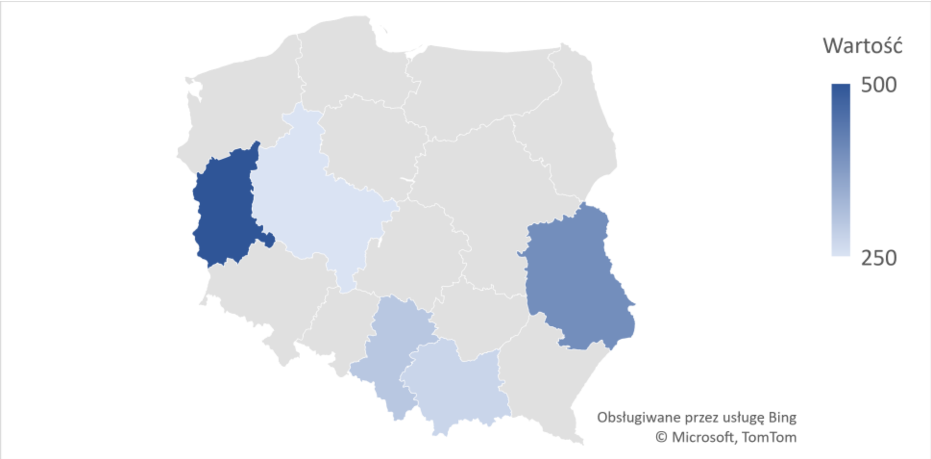

Figure 2.9. Heat map

Source: own study

Combo chart

Combo charts are a combination of several of the charts listed above. They can be used to visualize various data. In such charts, you can use an auxiliary data axis for more convenient data visualization. Such a chart can be used to analyze, for example, sales and profitability (www_2.2).

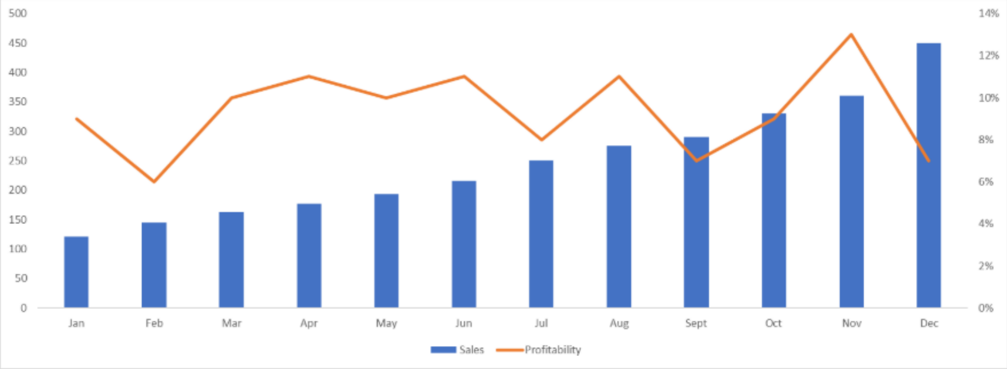

Figure 2.10. Combo chart

Source: own study

Figure 2.10 above shows sales with profitability using a secondary axis. The chart can be used for many analyzes where there is a need to use different charts.

Dashboards

Dashboards are a collection of many charts, maps and tables that enable you to monitor and analyze data, KPIs and operational and financial results. Dashboards can present results in real time and can be fully flexible and cascading. The interactivity of dashboards allows you to deepen your analyzes and move from general to specific. The purpose of Dashboards is to support business management, i.e. the data must provide information needed to make business decisions (www_2.2).

Dashboards can be compared, as the name suggests, to a car's dashboard, which contains the most important information, indicators, meters and trends regarding the data being examined (www_2.6). Interactivity, i.e. data filtering, the ability to go from general to specific, is the distinguishing feature of dashboards. Any type of interactive buttons/filters should be user-friendly and easy to work with on a daily basis (www_2.6).

Dashboards enable quick and effective decision-making for executives, analysts and managers by providing information on process performance, so that all dashboard recipients can better understand the business. An additional benefit is tracking the achievement of goals and focusing on the most important information. Another advantage is that you can easily isolate the least effective process stages or the largest deviations from goals, which allows you to introduce corrective actions much faster. Dashboards have an advantage over traditional reports in that they present data in practice in real time (www_2.7).

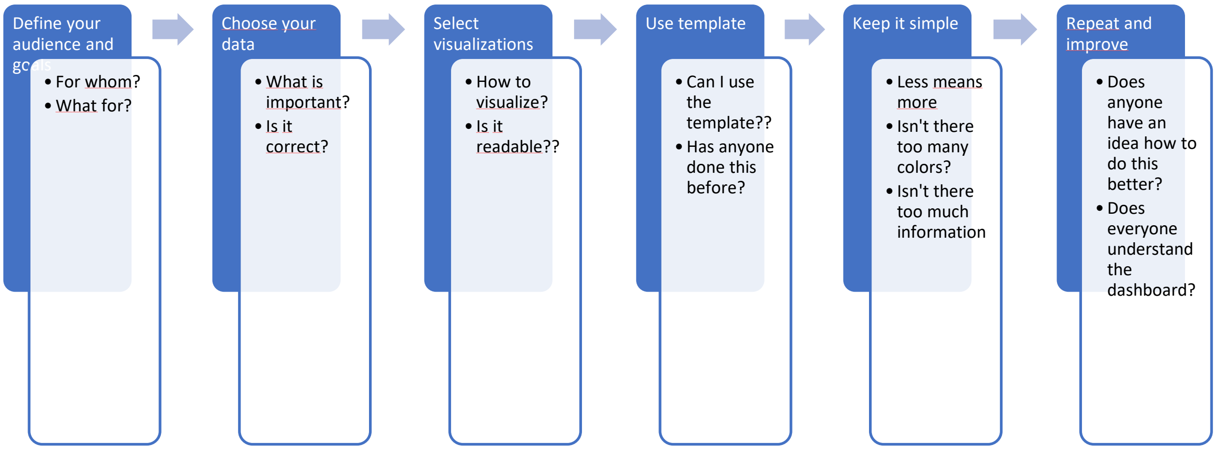

Figure 2.11. How to create a Dashboard

Source: own study based on: (www_2.8)

Figure 2.11 shows step by step how to approach creating a dashboard. The most important thing is to know the reason for creating the report, who it is supposed to help do their job better and what we want to achieve. The next step is to know what data to use and make sure it is correct. The next step is to appropriately adjust the visualization to the data or use available templates. The last steps are the most important, because when creating a dashboard, we must remember that less is more and that the dahsboard should be useful to the recipient. This means that it has to be legible, transparent, pleasing to the eye, and that the creator of the dashboard should modify it if the recipient requires it (www_2.8).

Figure 2.12 shows an example of a sales dashboard, showing sales to the largest customers and comparing them to last year. The achievement of sales targets and the division of sales into regions were also taken into account. Sales dashboards allow you to track sales and intervene quickly in the event of unexpected drops or failure to meet the budget.

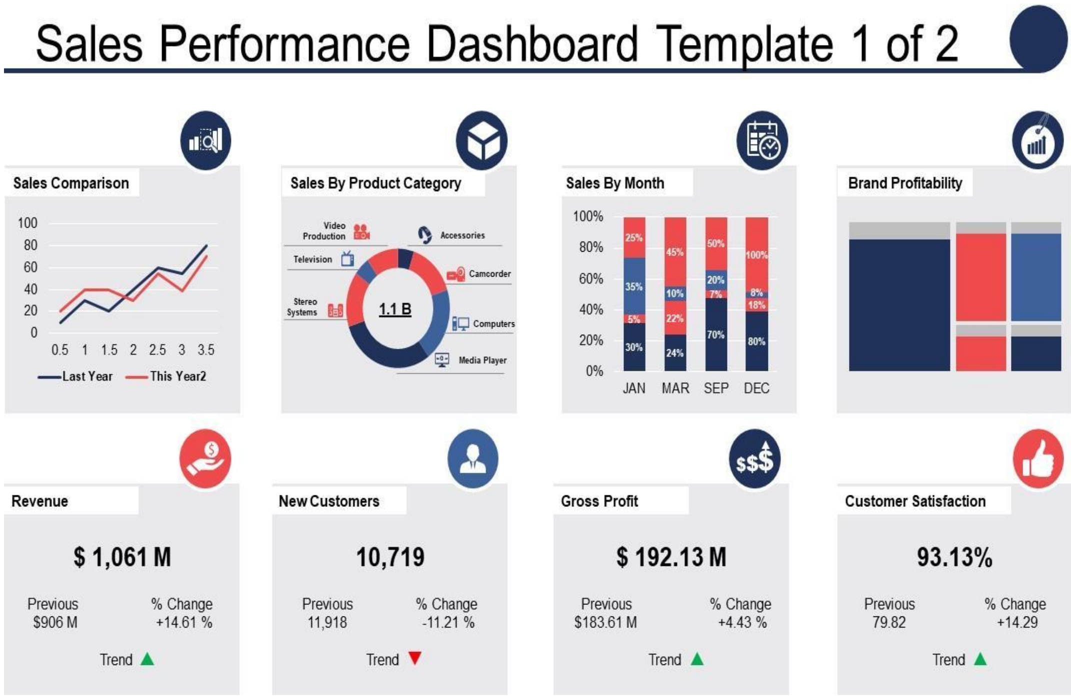

Figure 2.12. Sales dashboard example

Source: (www_2.9)

Figure 2.13. Use of dashboards

Source: own study based on: (www_2.8)

Figure 2.13 shows possible uses of dashboards. There is practically no field in which dashboards cannot be used to improve processes and make the right business decisions. Data visualization using dashboards builds employee awareness of operations in every possible process.

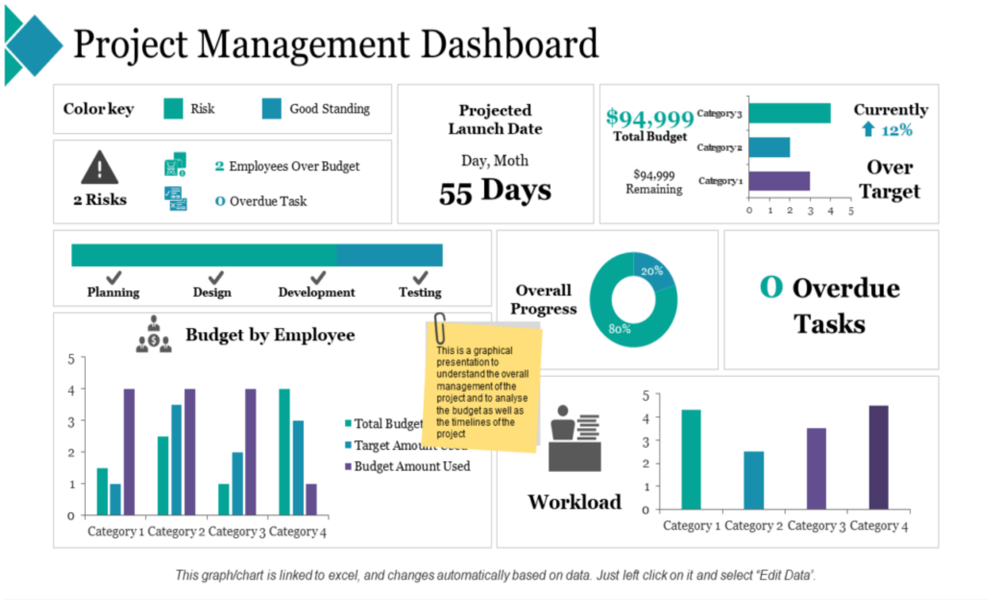

Figure 2.14. Example of an operational dashboard

Source: (www_2.10)

Figure 2.14 shows an example of a dashboard supporting project management. The visualization supports the preview of work progress and indicates at-risk stages. The visualization uses several types of charts that are graphically consistent with each other.

Dashboards are easiest to create using programs such as Power BI, Qlik, Tableau, Google Data Studio and other Business Intelligence tools. Additionally, an alternative option is to use the most popular "spreadsheet", i.e. MS Excel.

2.3. Comparison chart types

Data visualization is the ability to get to know data and extract knowledge from it that supports running a business. The appropriate selection of charts, maps or comprehensively created dashboards can build a competitive advantage. The tools should make it possible to go into the details of the analysis, so that the recipient of the visualization is able to draw interesting conclusions.

Table 2.1 compares the properties of chart types that can be used for data analysis. Based on the table, you can select the appropriate type of chart for your needs.

Table 2.1. A table comparing chart types according to their properties

Chart Type	Suitable for trend analysis	Correctly shows the measure of time	Perfect for comparing category sizes	Effective in showing percentage data	Good for presenting relationships between variables	Accessible to the general community
Column	No	Yes	Yes	Yes	No	Yes
Line	Yes	Yes	No	No	Yes	Yes
Pie	No	No	Yes	Yes	No	Yes
Area	No	No	Yes	Yes	No	Yes
Stock	Yes	Yes	No	No	Yes	Yes
Surface	No	No	No	No	Yes	Yes
Radar	No	No	Yes	No	Yes	No
Scatter plot	No	No	No	No	Yes	Yes
Histogram	No	No	Yes	No	No	Yes
Heat map	No	No	Yes	Yes	No	Yes
Combo	Yes	Yes	Yes	Yes	Yes	Yes

Source: own study

Chapter Questions

1. What are some of the challenges that can arise when creating dashboards?
2. Does the choice of chart type affect data interpretation and decision-making? Explain your answer.

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3. OPTIMIZATION IN SUPPLY CHAIN MANAGEMENT

In the chapter, the most important issues related to inventory management have been presented. Particular emphasis has been placed on the analysis of logistic data, for which a spreadsheet can be utilized. Here you will find:

- concept of optimization in logistics,
- the role of the warehouse in the supply chain,
- determining warehouse space,
- selected methods of inventory management in the supply chain,
- the Solver tool.

3.1. Introduction

Optimization in logistics is the process of finding the most effective way of organizing the flow of goods, information, and resources throughout the entire supply chain, from the initial point to the final one, with the minimization of operational costs while simultaneously ensuring high quality and meeting customer requirements (Reszka, 2012). The goal of optimization in logistics is to improve various aspects of activity, such as (Antoniuk et al., 2021; Gupta et al., 2022):

- reduction of goods flow time,
- optimization of transportation, warehousing, and handling costs,
- improvement of logistics service quality,
- increased flexibility and responsiveness to changes in demand,
- reduction of inventory levels while ensuring continuity of supply,
- improved management of warehouse space and transportation resources,
- integration and automation of logistics processes.

Logistical optimization models are applied in reference to (Smyk, 2023): (1) distribution network design (determining the locations of distribution centers) – described in the chapter on Logistic Network Optimization, (2) designing transportation systems (optimization of transport tasks, minimization of empty runs, determining delivery routes) – described in the chapter on Transport Optimization, (3) inventory management (allocation of stocks, estimating their size, determining order placement timings) – described in the chapter on Analytics in Supply and Procurement and below in the subsection Selected Methods of Inventory Management in the Supply Chain, (4) designing and managing warehouse activities (maximizing warehouse space efficiency) – described in the subsection Determining Warehouse Space.

In the context of optimization models, there are many optimization methods where the main classification of these methods is based on the type of optimization task to be solved. The following **optimization methods** can be distinguished according to (Jayarathna et al., 2021; Kusiak et al., 2021):

- type of problem being solved: linear programming methods, nonlinear optimization methods,
- constraints: unconstrained optimization methods, constrained optimization methods,
- dimension of the problem (number of optimization variables): univariate methods, multivariate methods (multiple optimization variables),
- optimization criteria: single-criterion methods; multicriteria methods (multiple optimization criteria).

In logistics, the number of criteria is often considered, and optimization tasks are formulated as either single-criterion or multicriterion. In practice, single-criterion optimization tasks are usually solved, mainly due to the simplicity of the models and their ease of application. Multicriterion optimization tasks require complex models, which often leads to situations where an optimal solution according to one criterion may negatively affect the outcome aligned with another criterion's goal. As a result, multicriteria solutions necessitate forging a compromise between different objective functions, complicating the determination of the unequivocally best, optimal solution (Smyk, 2023). Therefore, in seeking partial criteria and objectives for the optimization of logistical tasks, it is important to ensure that they are (Silva et al., 2005):

- complete (affecting a specific decision problem),
- non-redundant,
- minimized (aiming to reduce the decision problem size),
- operational (measurable),
- differentiating solutions (allowing the identification of the best – optimal solution).

In business activities, it is crucial that the optimization criterion is clearly defined, and the optimization model should correspond to the fundamental nature of the analyzed problem (Smyk, 2023). This criterion is referred to as the objective function and is selected in the context of the decision being made or at the initial stage of logistical planning. This function serves as a measure for evaluating the quality of the solution, where the optimal solution is achieved when the function takes an extremum (minimum or maximum) (Gupta et al., 2022).

3.2. The role of the warehouse in the supply chain

In a modern logistics system, every material manipulation is subject to thorough verification already at the design stage. Even minor shifts of goods over short distances, which usually occur within a building or between the facility and a transport intermediary, are starting to play a very important role. The **warehouse** is intended for storing material goods in a designated space of the warehouse building, according to established technology, equipped with appropriate devices and technical means, managed and serviced by a team of people equipped with the necessary skills (Miszewski, 2019). The best possible placement of goods in a given space allows for fuller utilization of the facility's limited capacity and reduces the number of manipulations with a given inventory (Ghiani, 2004; Muller, 2002).

In the context of the supply chain, the warehouse have an extremely important role, serving as a key center for coordination and storage of goods, which is essential to ensure the smooth flow of products from producers to consumers. Its operation is fundamental for effective inventory management, allowing for the minimization of the risk of shortages and excesses, thereby maintaining a balance between demand and supply. Moreover, the warehouse plays an important role in the quality control process, offering the possibility to check and prepare products for further distribution, ensuring their compliance with standards and customer expectations. The introduction of modern **Warehouse Management Systems** (WMS) contributes to significant optimization of logistic processes, which in turn increases operational efficiency and allows for the reduction of operational costs. Finally, warehouses are extremely important in adapting the supply chain to dynamically changing market conditions, enabling organizations to quickly respond to the evolution of demand and changing consumer preferences, which is key in maintaining market competitiveness (Gu et al., 2007; Ramaa et al., 2012).

3.3. Determining warehouse space

Basic requirements in warehouse operations include receiving **stock keeping units** (SKUs) from suppliers, storing SKUs, taking orders from customers, picking SKUs and assembling them for shipment, and sending completed orders to customers. Designing and operating a warehouse that meets these requirements involves many issues. Resources such as space, labor, and equipment must be allocated among various warehouse functions, and each function must be carefully implemented, operated, and coordinated to meet system requirements in terms of capacity, throughput, and service at the minimum resource cost. Warehousing deals with the organization of goods in the warehouse to achieve high space utilization and enable efficient material transport (Gu et al., 2007).

The storage function is shaped by three basic decisions: how much inventory of a given SKU should be stored in the warehouse; how often and at what time the inventory for an SKUshould be replenished; and where within the warehouse the SKU should be stored, distributed, and moved between different storage areas. The first two questions lead to issues related to batch size and problems that fall into the traditional area of inventory control (Hariga & Jackson, 1996). The two main criteria for making decisions about allocation to storage zones are storage efficiency, which corresponds to storage capacity, and access efficiency, which corresponds to the resources consumed by sales and order fulfillment (Gu et al., 2007).

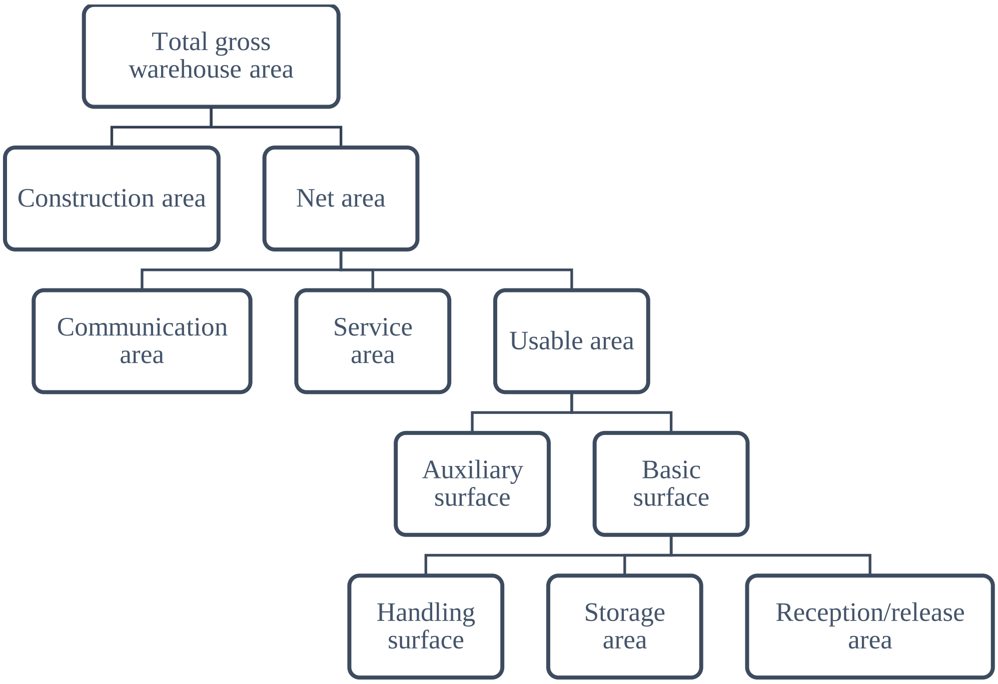


Figure 3.1. Division of warehouse space

Source: (Dudziński & Kizyn, 2002)

Calculating warehouse space requires consideration of its various types (Fig. 3.1). In an enterprise, the usable area is divided into zones corresponding to the phases of the warehousing process: receiving, storage (short and long-term), order picking, dispatch, as well as handling and auxiliary space. The size and shape of the warehouse depend on the following variables:

- the types, number, and dimensions of positions where warehouse activities are performed in the receiving and dispatching zones,
- the dimensions and quantities of storage fields in the storage area,
- the dimensions and quantities of laydown areas,
- parameters of shelving rows and the number of columns in rows,
- the width of the working aisle for the selected forklift,
- the width of communication paths for equipment and personnel.

The total warehouse area *S* can be expressed by the formula:

$$S = f_s + f_p = f_s + f_w + f_d + f_a$$

where:

f_s – storage area,

f_p – auxiliary area,

f_w – area designated for receiving, sorting, and dispatching materials,

f_d – area occupied by passages and driveways,

f_a – administrative and social area.

Formula used in Excel:

S = [the storage area] + [the auxiliary area] = [the storage area] + [the area designated for receiving, sorting, and dispatching materials] + [the area occupied by passages and driveways] + [the administrative and social area]

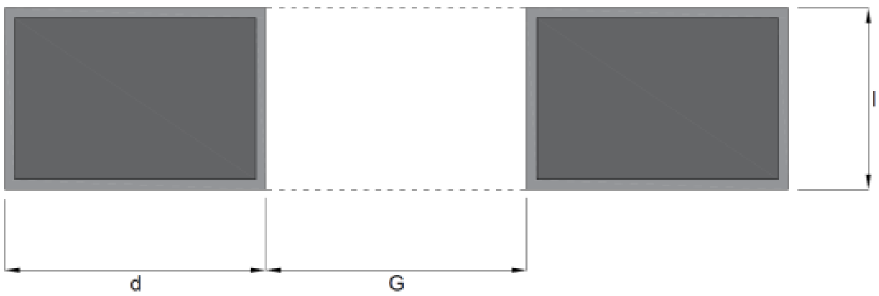


Figure 3.2. A warehouse module for row storage without equipment with perpendicular arrangement of palletized LU

Source: own study

The part of the warehouse area that includes the horizontal projection of the smallest repeatable part of two rows or blocks of load units (LU) along with handling clearances for storage and the handling path between them is the warehouse module. Adopting this size allows for estimating the size of the warehouse area. Warehouse modules for row storage without equipment can be arranged in two ways (Fig. 3.2 and Fig. 3.3).

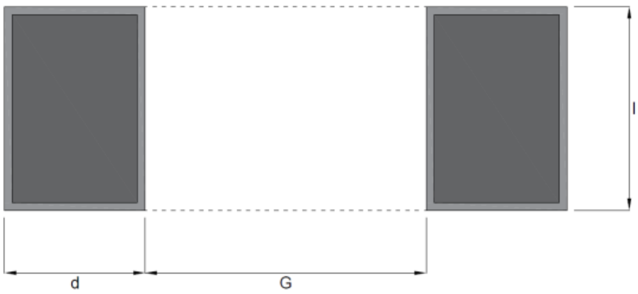


Figure 3.3. A warehouse module for row storage without equipment with parallel arrangement of palletized LU

Source: own study

The area of a warehouse module for row storage without equipment is calculated using the formula:

$$M = (2 \times d + G) \times l$$

where:

d – width of the laydown area [m],

G – width of the handling path [m],

l – length of the storage field [m].

The capacity of the module is equal to 2 palletized load units for single-level storage and $2 \times n$ palletized load units for stacked storage when stacking in n levels.

Formula used in Excel:

M = (2 * [width of the laydown area] + [width of the handling path]) * [length of the storage field]

Warehouse modules for block storage without equipment can be arranged as shown in Fig. 3.4.

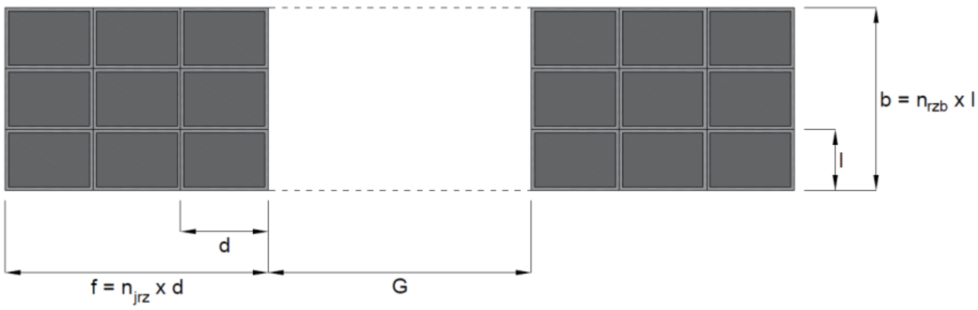


Figure 3.4. Warehouse module for block storage without equipment

Source: own study

The area of a warehouse module for block storage without equipment is calculated using the formula:

$$Mb = (2 \times f + G) \times b = (2 \times n_{LUz} \times d + G) \times n_{LUb} \times l$$

where:

f – block width [m],

G – width of the handling path [m],

b – block length [m],

n_{LUz} – number of loading units in a block row,

d – width of the storage area [m],

n_{LUb} – number of rows in the block,

l – length of the storage field [m].

The capacity of the module is equal to $2 \times n_{LUz} \times n_{LUb}$ palletized load units for single-level storage and $2 \times n_{LUz} \times n_{LUb} \times n$ palletized load units for stacked storage when stacking in n levels.

Formula used in Excel:

Mb = (2 * [block width] + [width of the handling path]) * [block length]

Additionally, the volume can be calculated for storage modules – taking into account the height of the loading unit or when loading units are stacked. The **volume of a storage module** (module capacity) depends on its surface area (*Mb*) and the height at which the loading unit was formed (*h*). The volume of the module is calculated from the formula:

$$V_M = [(2 \times f + G) \times b] \times h$$

$$h = n_{rh} \times h_0 + h_p$$

where:

f – block width [m],

G – width of the handling path [m],

b – block length [m],

h – high palletized load units [m],

n_{rh} – number of layers per palletized load units,

h_0 – height of the collective packaging [m],

h_p – media height [m].

The first part of the formula is the formula for the module surface area, and the second part is the height of the formed loading unit.

</>

Formula used in Excel:

V_M = {(2 * [block width] + [width of the handling path]) * [block length]} * [high palletized load units]

The **volume of the warehouse module** (module capacity) depends on its surface area (Mb) and the height to which the load unit (H) has been formed. The volume of the module is calculated using the formula:

$$V_M = [(2 \times f + G) \times b] \times H$$

$$H = n \times h = n \times (n_{rh} \times h_0 + h_p)$$

where:

f – block width [m],

G – width of the handling path [m],

b – block length [m],

H – block height [m],

n – number of units piled up,

h – high of palletized load units [m],

n_{rh} – number of layers per palletized load units,

h_0 – height of the collective packaging [m],

h_p – media height [m].

Formula used in Excel:

V_M = {(2 * [block width] + [width of the handling path]) * [block length]} * [block height]

The utilization of warehouse space is assessed by the ratio of the used area to the total available area. In warehouses where pallet racks are not used, achieving the highest value of this indicator is ensured by storing materials in a block layout, with space utilization values ranging from 0.6 to 0.8. For comparison, this indicator for a row storage layout ranges from 0.25 to 0.6. Striving to optimize space utilization with this type of storage leads to limitations in the conditions for stacking materials and lack of access to the assortment located in the middle of the blocks, and is only applicable for homogeneous assortments, without requiring additional financial outlays for warehouse equipment. In cases where the only criterion for evaluation is to increase the quantity of stored assortment, a good solution turns out to be the use of flow-through pallet racks. They provide a high utilization rate due to the limitation of the number of transport paths, but at the same time, they require the use of the FIFO (First In, First Out) principle. Maximum utilization of available warehouse space is possible thanks to the use of the free space storage method, which assumes that the assortment can be placed in any free rack slot (Kisielewski & Talarek, 2020).

3.4. Selected methods of inventory management in the supply chain

Inventory management in the supply chain is a key element that ensures operational fluidity, cost minimization, and customer satisfaction. There are many methods of inventory management, each of which may be appropriate depending on the specifics of the industry, product characteristics, demand dynamics, and other operational factors (Cyplik & Hadaś, 2012).

The classic concept of inventory management allows for managing inventories in a distribution network, where they are usually located in various places. Solving the problems of inventories located in multiple locations focuses primarily on analyzing the size of safety stocks (Mascle & Gosse, 2014). Safety stock depends on the variability of demand in the inventory replenishment cycle, expressed as the standard deviation of demand in that period and a safety factor dependent on the adopted service level. If the same service level is assumed for different inventory storage locations, then the level of safety stock depends on the demand variability served from a given location. In the formulas, it is assumed that the same service level has been adopted at all market service points ($\omega_{MR1} = \omega_{MR2} = \omega_{MR3} = ... = \omega_{MC}$) and the same inventory replenishment system are adopted in all market service points (Cyplik & Hadaś, 2012).

The safety stock depends on the variability of demand in the inventory replenishment cycle, expressed by the standard deviation of demand in this period, and a safety factor dependent on the adopted service level. If the same service level is assumed for different inventory storage locations, the level of safety stock depends on the demand variability served from a given location. The problem is not calculating the total demand in the case of multiple demand location points (the total demand is the sum of the average demands in each location). To calculate the standard deviation of the sum of demands, one should use the square root law, which assumes that the standard deviation of the sum of demands is equal to the square root of the sum of their standard deviations. Below are formulas that allow for these calculations. The obtained results will be correct under the assumption that the same service level *($\omega_{L1} = \omega_{L2} = \omega_{L3} = \dots = \omega$)* and the same inventory replenishment system are adopted in all market service points (Cyplik & Hadaś, 2012).

Formula to calculate safety stock:

$$S_S = \omega \times \sigma_{DT}$$

Formula to calculate the standard deviation of the sum of demands:

$$\sigma_{(D1+D2+D3+\dots Dn)} = \sqrt{\sigma_{D1}^2 + \sigma_{D2}^2 + \sigma_{D3}^2 + \dots + \sigma_{Dn}^2}$$

where:

n – number of localization,

D_n – individual demand value in the n localization.

The total safety stock for demand handled e.g. from a central warehouse can be calculated as:

$$S_{ST} = S_{S(D1+D2+D3+\dots+Dn)} = \omega \times \sigma_{(D1+D2+D3+\dots Dn)} =$$

$$= \omega \times \sqrt{\sigma_{P1}^2 + \sigma_{P2}^2 + \sigma_{P3}^2 + \dots + \sigma_{Pn}^2} =$$

$$= \sqrt{\omega^2 \times \sigma_{P1}^2 + \omega^2 \times \sigma_{P2}^2 + \omega^2 \times \sigma_{P3}^2 + \dots + \omega^2 \times \sigma_{Pn}^2} =$$

$$= \sqrt{S_{SL1}^2 + S_{SL2}^2 + S_{SL3}^2 + \dots + S_{SLn}^2}$$

where:

S_{ST} – total safety stock,

S_{SLn} – safety stock in n location.

In the special case, if the safety stock at all points in the location is the same (generally as a result of the same demand served by each of these points) and is equal to S_{STn}, then the centralized stock S_{STD} is equal to:

$$S_{STD} = S_{STn} \times \sqrt{n}$$

where n is the number of stock location points.

Formula used in Excel:

SST = [safety factor] * [standard deviation of the sum of demands at points D1-Dn in the replenishment cycle] = [safety factor] * SQRT[(STDEV.P([cell range for D1])^2) + (STDEV.P([cell range for D2])^2) + … + (STDEV.P([cell range for Dn])^2)]

One of the issues requiring analysis in the context of supply chain optimization is the location of warehouses, taking into account the relationship between significant parameters. The way of stock location can be considered in two ways – as dispersed stock or centralized stock.

In the case of dispersed stock (Fig. 3.5), customers are served directly from stock located in regional warehouses (RW), where the safety stock is maintained. For calculation purposes, the following assumptions are made (Krzyżaniak, 2006):

- demand is evenly distributed across n regional warehouses,
- weekly demand in each of these warehouses can be described by a distribution with an average demand of D_{RW} and a standard deviation of σ_{DRW},,
- the purchase price from the supplier is equal to P,
- the coefficient of weekly inventory carrying cost is u_t and is the same in all warehouses,
- the replenishment cycle time in regional warehouses is equal for each warehouse and amounts to T_1 (without significant deviations).

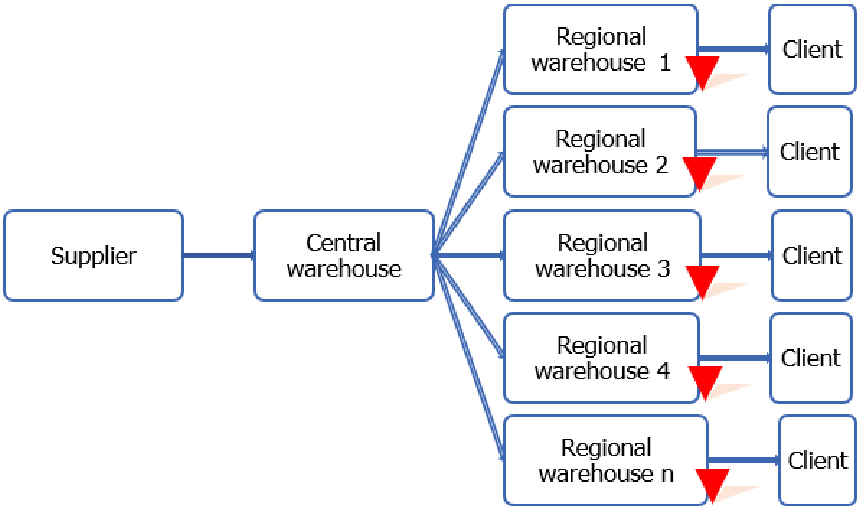


Figure 3.5. Distributed inventory case illustration

Source: (Krzyżaniak, 2006)

Given the assumptions, the total weekly cost of maintaining safety stock in the network is equal to:

$$C_1 = \sum_{1}^{n} HCSS_{RW}$$

With an even distribution of demand among all warehouses, we obtain:

$$C_1 = n \times SS_{RW} \times P \times u_t = n \times \omega \times \sigma_{DRW} \times \sqrt{T_1} \times P \times u_t$$

where:

ω – safety factor, dependent on the chosen service level and the type of distribution describing the given frequency distribution of demand,

SS_{RW} – safety stock in each of the regional warehouses.

Since $\sigma_{DRW} = V \times D_{RW}$, where V is the coefficient of variation $V = \frac{\sigma_D}{D}$, the formula takes the form:

$$C_1 = n \times \omega \times V \times D_{RW} \times \sqrt{T_1} \times P \times u_t$$

In the general model for centralized stock (Fig. 3.6), customers are served from the central warehouse (CW) with direct deliveries, such as courier shipments. For calculation purposes, the following assumptions are made (Krzyżaniak, 2006):

- the weekly demand in the central warehouse is the sum of the demands observed in the markets associated with the individual regional warehouses and can be described by a distribution with an average $D_{CW}=n \cdot D_{RW}$ and a standard deviation $\sigma_{DCW} = \sigma_{DRW} \times \sqrt{n}$ (according to the square root law),
- the weekly inventory carrying cost coefficient u_t is the same as for the regional warehouses,
- the replenishment cycle time in the central warehouse is T_2,
- in case of demand from customers, the product is shipped directly to the customer in the form of a courier shipment with a unit cost c_{CS}, which allows maintaining a similar customer order fulfillment time as in the case of service from regional warehouses.

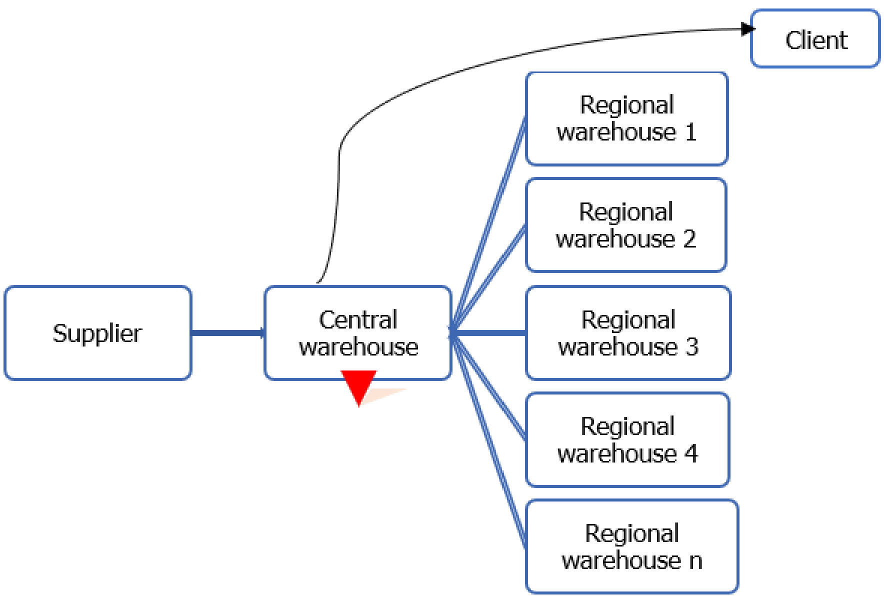


Figure 3.6. Centralized inventory case illustration

Source: (Krzyżaniak, 2006)

The weekly cost of maintaining safety stock in the central warehouse is equal to:

$$C_{2(SS)} = SS_{CW} \times P \times u_t = \omega \times \sigma_{DCW} \times \sqrt{T_2} \times P \times u_t.$$

Because, as intended $T_2 = \alpha \times T_1$:

$$C_{2(SS)} = \omega \times \sigma_{DCW} \times \sqrt{\alpha \times T_1} \times P \times u_t = \omega \times \sigma_{DRW} \times \sqrt{n \times \alpha \times T_1} \times P \times u_t$$

Because it happens $\sigma_{DRW} = V \times D_{RW}$, where V is the so-called coefficient of variation $V = \frac{\sigma_P}{D}$, then the pattern takes the form:

$$C_{2(SS)} = \omega \times V \times D_{RW} \times \sqrt{n \times \alpha \times T_1} \times P \times u_t$$

It is worth noting that the assumption $T_2 = \alpha \times T_1$ takes into account different solutions for organizing deliveries for both cases. For example, in the case of distributed stocks, deliveries to regional warehouses may be carried out according to the periodic review system, and in a centralized system based on the so-called reorder point (information level). It can be assumed that this will usually occur $T_2<T_1$.

Total weekly direct courier costs to the customer are equal:

$$C_{2(supplies)} = n \times D_{RW} \times c_{cs}$$

Asking the question: when is it profitable to disperse inventory, that is, when will it be cheaper to maintain safety stock in n regional warehouses and serve local customers from them than to concentrate inventory in a central warehouse and fulfill customer orders with direct deliveries, the answer comes down to solving the inequality:

$$C_1 < C_{2(SS)}+C_{2(supplies)}$$

that is:

$$n \times \omega \times V \times D_{RW} \times \sqrt{T_1} \times P \times u_t < \omega \times V \times D_{RW} \times \sqrt{n \times \alpha \times T_1} \times P \times u_t + n \times D_{RW} \times C_{cs}$$

After transformations we get::

$$V < \frac{n \times c_{cs}}{\omega \times \sqrt{T_1} \times P \times u_t \times (n - \sqrt{n \times \alpha}}$$

From this form we obtain dependencies, the fulfillment of which guarantees the fulfillment of the inequality $C_1 < C_{2(SS)}+C_{2(supplies)}$ and the condition imposed:

$$V < \frac{\left[\frac{c_{cs}}{P \times u_t}\right]}{\omega \times \sqrt{T_1} \times \left[1 - \sqrt{\frac{\alpha}{n}}\right]}$$

or

$$\omega < \frac{\left[\frac{c_{cs}}{P \times u_t}\right]}{V \times \sqrt{T_1} \times \left[1 - \sqrt{\frac{\alpha}{n}}\right]}$$

However, the following relationship is the most informative because it combines all cost elements in the expression on the left side of the inequality, and on the right side, parameters related to implementation and the required level of service:

$$\left[\frac{c_{cs}}{P \times u_t}\right] > V \times \omega \times \sqrt{T_1} \times \left[1 - \sqrt{\frac{\alpha}{n}}\right]$$

The strengths of the classic inventory management concept are as follows:

- simplicity and clarity – they are easy to understand and implement,
- help in minimizing the total costs of inventory management by balancing the costs of ordering and holding inventory, aiming for economic order quantity,
- clear and defined decision-making processes that help manage orders and inventory based on calculations and predefined rules.

The weaknesses of the classic inventory management concept include:

- the need for an assumption of constant and predictable demand, which does not always correspond to the dynamic and variable market realities.
- not accounting for demand variability and risk in the supply chain (e.g., delivery delays, market changes),
- lack of flexibility in responding to rapid changes in the market or supply chain, as they are based on fixed parameters and do not anticipate dynamic adaptation to new conditions.

The classic concept of inventory management has its place in the theory and practice of operational management, but in the modern, rapidly changing business world, it is often supplemented with more advanced and flexible methods and analytical tools.

DRP (Distribution Requirements Planning) – coordinates demand with inventory levels in various locations. It is one of the methods optimizing the management of final product deliveries to the distribution network and is used to plan the level and location of inventory storage throughout the supply chain. The purpose of using the distribution demand planning method is to reduce inventories in the distribution network (Nugroho, 2019). At the level of sales points, due to the risk of demand fluctuations, a safety stock is created for each product in each of them, calculated using formulas from the classic theory of inventory management (Magdalena & Suli, 2019).

Demand planning begins at the lowest level (e.g., at a retail sales point) and ends at the highest level (e.g., in a factory warehouse). The needs at the lower level are input data for the next level. The demand from the highest level can be used as input data for working on the production schedule (Fertsch, 2006). Demand from distribution centers is used to create an inventory demand schedule and is passed on to production. After comparing with previous forecasts, a production plan, material requirements, and distribution with a delivery schedule to individual distribution centers are developed (Ngatilah et al., 2020). Thanks to DRP, the service level for supply chain links that have direct contact with the customer is determined (batch size, inventory availability, delivery deadlines) (Fechner, 2007).

The DRP system allows for estimating delivery schedules for each stock keeping unit (SKU) to sales points. It requires having the following information (Mukhsin & Sobirin, 2022):

- the structure of the distribution channel through which the SKU flows,
- forecast of demand for individual SKUs at the point of sale level,
- the current stock level (on-hand stock) of a given SKU,
- target level of safety stock,
- recommended replenishment amount,
- replenishment delivery time.

DRP Algorithm (Ngatilah et al., 2020):

1. Netting – projected on-hand is an on-hand inventory. It can be calculated using formulation below:

$$\textbf{Projected on Hand}_{(t)} = (\textbf{On Hand}_{(t-1)} + \textbf{Scheduled Receipt}_{(t)} + \textbf{Planned Order Receipt}_{(t)} - \textbf{Gross Requirement}_{(t)})$$

Net Requirement can be calculated using formulation below:

$$\textbf{Net Requirement}_{(t)} = (\textbf{Gross Requirement}_{(t)} + \textbf{Safety Stock}) - (\textbf{Scheduled Receipt}_{(t)} + \textbf{Projected on Hand}_{(t-1)})$$

2. Lotting is the process to find the order or production lot size in every network distribution. There are several lottting method. Lotting in DRP represented by plan order receipt (Porec). Planned order receipt (Porec) is a Net Requirement that has been adjusted according to the Lot size order or production.

3. Offsetting is an order quantity that is planned to be ordered in the planned time period. Offsetting in DRP represented by plan order release (Porel). Porel is a Porec that has been adjusted according to the Lead time order or production.

4. Explosion – total inventory and distribution cost can be obtained using formulation below:

$$\textbf{Total Inventory and Distribution Cost} = \textbf{Ordering Cost} + \textbf{Holding Cost} + \textbf{Delivery Cost}$$

The DRP model is particularly useful in large, complex organizations where managing the flow of products through the distribution network is crucial for operational efficiency and customer satisfaction. The strengths of the DRP model include:

- improved coordination in the supply chain through better information and goods flow from the producer to the consumer, leading to more efficient distribution,

- increased forecasting accuracy, as it considers actual order data and inventory levels throughout the chain, which helps optimize inventory levels and reduce costs,
- improved product availability by ensuring that stocks are placed where they are most needed, thereby minimizing the risk of shortages and production downtime.

The weaknesses of the DRP model are associated with the following elements:

- complexity of implementation, especially in large organizations with extensive supply chains, which requires precise planning and coordination,
- high initial costs related to purchasing software, hardware, and employee training,
- dependency on the accuracy and timeliness of input data, inaccuracies in the data can lead to forecasting and planning errors, which ultimately may cause excessive or insufficient inventories.

Despite its advantages, the DRP model requires precise execution and ongoing management to effectively support operational decisions within the supply chain.

EOQ (Economic Order Quantity) is a mathematical model used to determine the optimal order quantity that minimizes the total costs associated with ordering and holding inventory. This method is ideal for products with stable and predictable demand. The method makes the following assumptions (Battani et al., 2015):

- monthly or annual demand for the ordered product is known and predictable,
- the product is delivered very quickly after ordering,
- the cost of a unit order is fixed.

The Wilson formula is used to calculate the Economic Order Quantity (Krzyżaniak, 2005; Muckstadt, 2010).

Formula to calculate EOQ:

$$EOQ = \sqrt{\frac{2 \times D \times C_S}{C_K}}$$

where:

D – expected demand over a longer period of time,

C_S – cost of stockpiling – purchasing one batch, independent from its size,

C_K – the cost of keeping one unit of a given product in stock over a given period of time, most often defined as a certain fraction of the purchase price, and therefore:

$$C_K = \mu_o \times P$$

P – purchase price,

μ_o – percentage of the maintenance cost in the purchase price.

Formula used in Excel:

EOQ = SQRT((2 * [expected demand] * [cost of stockpiling]) / [the cost of keeping one unit])

The EOQ model is particularly useful in inventory management for standard products with stable demand. It is an analytical tool that assists in making decisions about order quantities but requires accurate data on costs and demand. The strengths of the EOQ model are:

- minimization of total costs – EOQ identifies the order quantity that optimizes the balance between ordering costs and storage costs, aiming to minimize the total inventory-related costs,
- increased operational efficiency – by establishing an optimal order schedule, the EOQ model enables better planning and resource management, which translates to smoother operations and a lower likelihood of production interruptions caused by shortages or excess stock,
- simplification of the decision-making process in inventory management – EOQ provides clear guidelines on when and how much to order, which helps in standardizing purchasing processes and may reduce the need for continuous monitoring and decision-making regarding stock levels.

However, the EOQ model requires the adoption of certain assumptions, which are associated with the following weaknesses:

- the need for a constant demand assumption – EOQ assumes that the demand for the product is constant and predictable at all times; in reality, demand is often variable and influenced by seasonality, market trends, competitive actions, and other external factors, which can make the accurate application of the EOQ model challenging in dynamic market conditions,
- the need for an assumption of fixed ordering and holding costs – in practice, these costs can vary based on many factors, such as changes in material prices, transportation costs, warehouse rental rates, labor rate changes, or inflation,
- lack of flexibility in responding to changes – the EOQ model generates a fixed number of orders for a specific period and does not anticipate automatic adjustments to rapidly changing market or operational conditions; this means that it is necessary to manually review and adjust EOQ orders to avoid excessive stock accumulation or the risk of stockouts, which can be time-consuming and complicated.

Given these limitations, many companies use the EOQ model as a starting point or preliminary guideline, while adapting their inventory management strategies to accommodate market dynamics and operational specifics.

3.5. Using the Solver tool in solving optimization problems

Solver is an add-in for Microsoft Excel used for advanced analysis and solving optimization problems. It allows users to define multiple decision variables, constraints, and objectives, and then employs various mathematical methods to find optimal solutions (see chapter Introduction to spreadsheet analysis). It is particularly useful in situations requiring complex computations, such as logistics path planning, resource allocation, or budget optimization (Bomba & Kwiecień, 2012; Mason, 2013).

Solver is used to solve single-criterion optimization tasks where the number of decision variables does not exceed 200. Its application requires creating a mathematical model within the spreadsheet workspace. The optimization model consists of three elements (Baj-Rogowska, 2013; Mason, 2012):

- objective cells (objective function) – these are cells in the spreadsheet model that, when Solver is applied, are to minimize, maximize, or set to a specified real number value,
- variable cells (decision variables) – they are cells containing the sought-after values, which are iteratively changed and substituted by the Solver add-in into the objective function until an optimal solution is found,
- constraint cells (can be applied concerning the value of the objective cell and variable cells) – introduced constraint conditions in the form of formulas within spreadsheet cells, where the value must be within specified limits or reach target values.

Solver in Excel utilizes various optimization methods to find the best solutions for defined problems. Each method has its specific applications and is chosen based on the nature of the optimization problem. Solver allows the user to select the appropriate method depending on the characteristics of the problem to be solved. The main methods include (Baj-Rogowska, 2013; Delgado-Aguilar et al., 2018):

- Simplex Method (Simplex LP) – this is the most commonly used method for solving linear programming (LP) problems; it is effective in situations where the objective function and all constraints are linear,
- GRG Method (Generalized Reduced Gradient) – it is an advanced method used to solve nonlinear problems; it is particularly useful when the objective function or constraints are nonlinear but still continuous and differentiable,
- Evolutionary Method – it is used to solve global optimization problems, especially when the objective function is complex, nonlinear, and discontinuous; the evolutionary method employs techniques similar to genetic algorithms, exploring various possible solutions to find the best one,
- Integer Constraints – Solver can be used to solve problems where some or all decision variables must take integer values; this is useful in situations where

solutions require discrete values, such as the number of units to produce or the number of employees to hire.

Solver in supply chain optimization is valuable when there is a need to optimize complex problems, such as minimizing transportation costs, optimizing delivery route planning, or managing inventory. It is particularly useful in situations that require the analysis of multiple variables and constraints, where traditional methods may be insufficient or too time-consuming.

3.6. Optimizing the use of warehouse space – an example of using the Solver tool

The content of the task

The Alfa company has a warehouse with a total area of 10,000 m², which must accommodate three types of products: A, B and C. Each of these products has different requirements for warehouse space, has its own specific safety stock and generates different profits per product unit:

- product A: requires 14 m² per unit, safety stock is 40 pcs., generates a profit of 30 euro,
- product B: requires 12 m² per unit, safety stock is 60 pcs., generates a profit of 32 euro,
- product C: requires 18 m² per unit, safety stock is 90 pcs., generates a profit of 23 euro.

Products A, B and C go to markets X, Y and Z. The total demand for all products in the markets is:

- market X: 220 pcs.,
- market Y: 230 pcs.,
- market X: 332 pcs.

How many units of each product should be held in the warehouse to maximize the total profit from the warehouse space used without exceeding the total warehouse space available, assuming that Alfa meets all demand?

Solution:

Objective function: maximizing the total profit from products.

Constraint: size of warehouse space, storage space for a unit of product, volume of market demand.

[1] preparing a data sheet,

[2] defining decision variables,

[3] calculation of auxiliary variables,

[4] determining the objective function,

[5] configuring Solver,

[6] indication of the optimization method,

[7] run Solver,

[8] evaluation of the obtained solution.

Example in Excel:

[1] Prepare and complete the table with input data from the task: safety stock for each product, unit warehouse space, unit profit, demand in each market, total warehouse space

		Market			Safety stock	Unit warehouse space	Profit individual
		X	Y	Z			
Product	A				40	14	30
	B				60	12	32
	C				90	18	23
		220	230	332			

Total warehouse area
10000

[2] Define decision variables – the number of products of each type in stock

		Market			Safety stock	Unit warehouse space	Profit individual
		X	Y	Z			
Product	A				40	14	30
	B				60	12	32
	C				90	18	23
		220	230	332			

Total warehouse area
10000

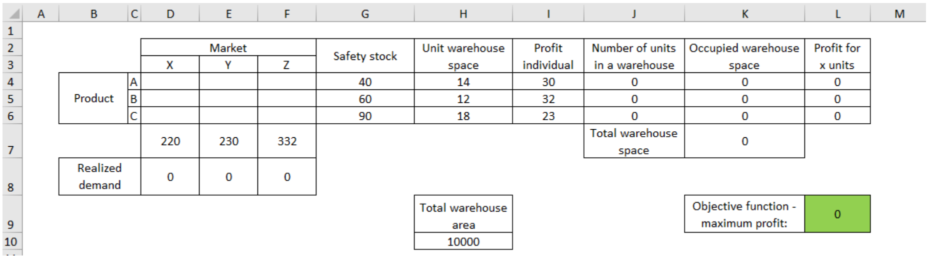
[3] Calculate auxiliary variables

- **Number of units in stock: = SUM([cell range for each market and single product])**
- **Occupied warehouse space: = [Unit area Warehouse] * [Number of units in stock]**
- **Profit for x units: = [Number of units in stock] * [Profit unitary]**
- **Realized demand: = SUM([range of cells for each market])**
- **Sum of warehouse space: = SUM([Occupied warehouse space])**

		Market			Safety stock	Unit warehouse space	Profit individual	Number of units in a warehouse	Occupied warehouse space	Profit for x units
		X	Y	Z						
Product	A				40	14	30	0	0	0
	B				60	12	32	0	0	0
	C				90	18	23	0	0	0
		220	230	332				Total warehouse space	0	
Realized demand		0	0	0		Total warehouse area				
						10000				

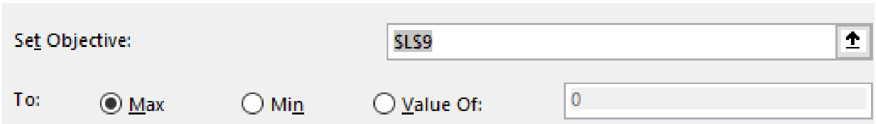
[4] Determine the objective function - maximizing profit from product sales

Objective function: **=SUM([Profit for x units])**

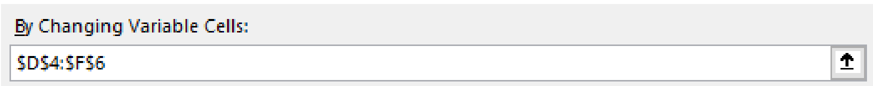


[5] Configure Solver

Set the goal – cell with the goal function and maximization of the goal function

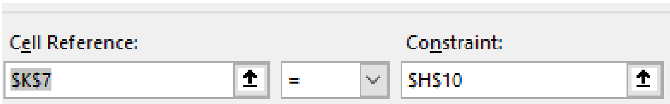


Indicate the cells whose values are to be set – the number of products of each type in stock

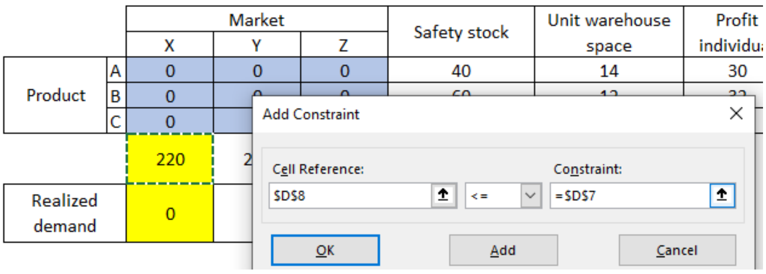


Add restrictions:

- occupied warehouse space = maximum warehouse space

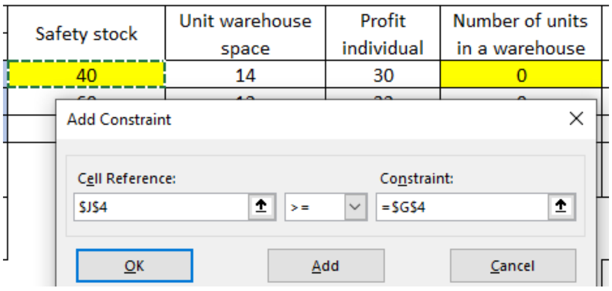


- realized demand in market X <= demand in market X



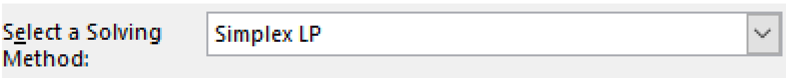
- realized demand in market Y <= demand in market Y

- realized demand in market Z <= demand in market Z
- number of units of product A in stock >= safety stock for product A



- number of units of product B in stock >= safety stock for product B
- number of units of product C in stock >= safety stock for product C

[6] Indicate the optimization method – e.g. LP Simplex



[7] Run Solver – press the Solve button

[8] Evaluate the solution you received

		Market			Safety stock	Unit warehouse space	Profit individual	Number of units in a warehouse	Occupied warehouse space	Profit for x units
		X	Y	Z						
Product	A	0	0	40	40	14	30	40	560	1200
	B	220	140	292	60	12	32	652	7820	20853
	C	0	90	0	90	18	23	90	1620	2070
		220	230	332				Total warehouse space	10000	
Realized demand		220	230	332						
						Total warehouse area			Objective function - maximum profit:	24123
						10000				

Chapter Questions

1. How can the Solver add-in in Microsoft Excel support decision-making processes in an enterprise?
2. How does the selection of the appropriate optimization method affect the results of the analysis?

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4. CONTROLLING IN SUPPLY CHAIN MANAGEMENT

In this chapter, key issues related to controlling in supply chain management are presented. Particular emphasis is placed on the analysis of logistic data, which can be conducted using a spreadsheet. Here, you will find:

- concept of controlling,
- objectives and scope of controlling in the supply chain,
- basic Key Performance Indicators (KPIs) in the supply chain.

4.1. Introduction

Controlling can be defined by identifying its main task, which is to ensure result-oriented planning, control, and monitoring of a company's activities based on accounting and financial data (Hahn, 1987). Controlling can be described as "a system of mutually agreed measures, principles, goals, methods, and techniques that serves the internal control and management of outcome-related objectives" (Nowak, 2015). **Controlling in the supply chain** is the process of managing and optimizing financial, material, and informational flows throughout the supply chain (Chopra & Meindl, 2007). Supply chain controlling **includes** data analysis, forecasting, performance monitoring, and corrective interventions, which allows for continuous adjustment of activities to changing market and operational conditions (Cigolini et al., 2004). Differences exist between supply chain controlling and enterprise controlling, as presented in Table 4.1.

Table 4.1. Differences between controlling in the supply chain and in the enterprise

Differentiating criterion	Controlling in supply chain	Controlling in enterprise
Range of activity	includes the management and coordination of activities in many independent organizations that cooperate to produce and deliver products to the final recipient	focuses on the internal processes of one organization, focusing on optimization and operational efficiency within the enterprise itself
Strategic goal	strives to optimize the entire process from suppliers to customers, focusing on the integration and synchronization of activities between various entities	focuses on achieving the financial and operational goals of the enterprise itself, such as profitability, operational efficiency and compliance with the budget
Areas of intervention	deals with aspects such as order fulfillment time, logistics costs, quality of cooperation between partners and inventory management at the level of the entire chain	may focus on controlling internal costs, analyzing the profitability of products or departments, and optimizing business processes within the company
Tools and methodologies used	often uses advanced IT systems that integrate data from various enterprises, such as ERP or SCM systems	may use more company-centric tools and systems that may not necessarily be integrated with external business partners

Source: (Mazur et al., 2021; Nesterak et al., 2020; Vollmuth, 2000)

In summary, controlling in the supply chain requires a more holistic approach to management and coordination of activities than controlling focused on a single enterprise, where the priority is the optimization of internal business processes.

In controlling, detailed information about the past is not sufficient; it is also essential to develop and implement new concepts, instruments, and tools that provide precise information about the future development of the enterprise in the supply chain. Therefore, one of the characteristics of a controlling system is the presence of two types of feedback (Nesterak, 2002):

- feedback (feed-back) – regulation that allows for identifying deviations in the plan-execution system and for taking appropriate corrective and preventive actions to avoid deviation from the set goal,
- feed-forward – understood as control related to the use of forecasted quantities and information about past actions to determine what kind of actions should be taken in the future.

In this perspective, controlling directs the future activities of enterprises by creating an "early warning" system. This system identifies signals that can significantly affect the future of the company and the entire supply chain, which in turn influences the achievement of set goals.

Supply chain controlling aims to achieve objectives through integrated analytical, strategic, and operational activities that encompass both internal functions of the enterprise and its interactions with external partners in the supply chain. **Key objectives of supply chain controlling** include (Chopra & Meindl, 2007):

- Increasing operational efficiency through process analysis, workflow optimization, and waste minimization, which improves the overall performance of the supply chain,
- Cost reduction, as controlling and continuous monitoring of costs within the supply chain help identify areas where savings can be achieved without compromising quality,
- Ensuring compliance and quality by monitoring and ensuring adherence to regulations and quality standards throughout the supply chain,
- Improving collaboration between partners through better planning, communication, and coordination of activities,
- Increasing the flexibility and resilience of the supply chain by developing the ability to quickly adapt to market changes or operational environments and minimizing the risk of downtime or disruptions,
- Optimizing inventory management, which balances the needs for cost reduction with requirements for product availability,

- Improving the decision-making process by providing key data and analyses that support strategic and tactical management decisions,
- Ensuring continuous improvement by promoting a culture of continuous improvement within the supply chain through regular reviews, assessments, and process updates.

In summary, controlling supports the implementation of supply chain strategies by providing precise data and analyses that assist in strategic planning and process optimization. Through real-time monitoring of indicators, it enables quick responses to changing market conditions and customer needs. Additionally, controlling supports risk management in the supply chain by identifying potential threats and proposing solutions that minimize their impact on achieving set goals.

4.2. Key performance indicators in the supply chain

In the literature, the issue of supply chain controlling is most often analyzed from the perspective of the tools used. Bibliographic sources indicate that the most effective controlling tools include activity-based costing, target costing, indicator systems, balanced scorecards, and benchmarking (Dobroszek, 2011; Guersola et al., 2018). This study, which focuses on the use of spreadsheets in the analysis of logistic data, emphasizes indicator analysis due to its applicability in this particular tool.

Key Performance Indicators (KPIs) used in supply chains are an essential tool for measuring and monitoring the efficiency and effectiveness of activities within the supply chain. KPIs can be categorized based on the pillar they cover (Dobroszek, 2011):

- supply chain pillar – at this level, indicators are used that apply to the entire supply chain, such as total order fulfillment time across the supply chain, total supply chain costs, and the cash-to-cash cycle,
- partner relationship pillar – on this level, indicators are calculated that reflect the cooperation between business partners and the resulting effects, such as the relationship between the supplier and the retailer; characteristic indicators

in this area include the ability to fulfill deliveries and the payment reliability of merchants,

- individual economic entity in the supply chain pillar – although entities in the supply chain function in connection with each other and pursue a common goal, each should assess its economic activity separately.

The most commonly used key performance indicators in supply chains include (Dias & Silva 2021; Lehyani eta la., 2018; Rasool et al., 2023; Yurtay et al., 2023):

- OTIF (On-Time In-Full) – measures the percentage of orders delivered to the customer on time and in full, according to their specifications.

Formula:

$$\boldsymbol{OTIF = \left(\frac{number\ of\ orders\ delivered\ on\ time\ and\ in\ full\ quantity}{total\ number\ of\ orders}\right) \times 100\%}$$

The high level of OTIF implementation indicates the effectiveness of inventory management, production planning, transportation time management and accuracy in the order acceptance process.

Formula in Excel:

OTIF = ([number of orders delivered on time and in full quantity] / [total number of orders]) * 100%

- order processing time LT (Lead Time, Order Fulfillment Time) – measures the time from accepting an order to its delivery to the customer.

Formula:

$$\boldsymbol{LT = delivery\ date - date\ of\ acceptance\ of\ the\ order}$$

Lead time includes:

- order preparation time – the time needed to process the order in the system,
- production time – the time required to manufacture or prepare the ordered products,
- delivery time – the time that elapses from the moment the product is sent to the customer until it is received.

Formula in Excelu:

LT = [delivery date] – [date of acceptance of the order]

- customer service level – measures an organization's ability to meet customer requirements, often defined as the percentage of orders fulfilled without errors (see the chapter on Inventory Management),
- inventory availability rate (IA) – percentage of time that inventory is available to customers without delays.

Formula:

$$IA = \left(\frac{the\ number\ of\ days\ that\ inventory\ was\ available}{total\ number\ of\ days\ in\ the\ period}\right) \times 100\%$$

or

$$IA = \left(\frac{available\ stock\ quantity}{desired\ inventory\ quantity}\right) \times 100\%$$

The indicator measures the percentage of days or instances in which inventory was available for immediate fulfillment relative to the overall demand or number of days in a specified period. This allows for an assessment of how effectively a company manages its inventory in the context of meeting customer expectations.

Formula in Excelu:

IA = ([the numer of days that inventory was available] / [total number of days in the period]) * 100%

or

([available stock quantity] / [desired inventory quantity]) * 100%

- inventory turnover ratio (IT) – measures how often the company uses and replaces inventory in a given period, shows how efficiently the organization manages its resources and responds to market demand.

Formula:

$$IT = \left(\frac{cost\ of\ goods\ sold}{average\ inventory\ level}\right) \times 100\%$$

A too high indicator may indicate a risk of inventory shortages. A too low indicator may signify excessive inventory or poor sales. The ideal level of the inventory turnover ratio depends on the industry and the specifics of the company, as well as its supply chain management strategy.

Formula in Excel:

IT = ([cost of goods sold] / [average inventory level]) * 100%

- Rate of Return (RoR) – percentage of products returned by customers in relation to the total number of products sold.

Formula:

$$RoR = \left(\frac{number\ of\ units\ returned}{total\ number\ of\ units\ sold}\right) \times 100\%$$

A high rate of returns may indicate problems with product quality, discrepancies in descriptions, or improper fulfillment of customer expectations, which negatively affects their satisfaction.

This indicator helps companies identify issues in products or processes that may need improvement. Analyzing the reasons for returns can lead to changes in production processes, enhanced quality of products or services, and better inventory management and forecasting.

Formula in Excel:

RoR = ([number of units returned] / [total number of units sold]) * 100%

- supplier performance index (SPI) – assessing and monitoring supplier performance within the supply chain; determine how well suppliers meet established criteria, such as the quality of delivered products, on-time delivery, or the ability to complete orders without errors (see the chapter on Analytics in the area of supply and purchasing). Formula:

$$\boldsymbol{SPI} = \left(\frac{\boldsymbol{sum\ of\ points\ for\ all\ criteria}}{\boldsymbol{maximum\ possible\ number\ of\ points}}\right) \times \mathbf{100\%}$$

The SPI is usually calculated based on several individual performance indicators, such as delivery quality, timeliness, and flexibility. Points are awarded based on the fulfillment of specific criteria, and the maximum total points correspond to the supplier's ideal performance.

Formula in Excel:

SPI = ([sum of points for all criteria] / [maximum possible number of points]) * 100%

Chapter Questions

1. What are the key objectives of controlling in the supply chain?
2. What actions are taken within controlling to reduce costs in the supply chain?
3. How does controlling ensure compliance and quality in the supply chain?

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5. ANALYTICS IN THE AREA OF SUPPLY AND PURCHASING

The chapter discusses procurement and purchasing strategy. One of the most important challenges in this area is the evaluation and selection of the right suppliers. The most important issues discussed in this chapter include:

- the role and importance of procurement and purchasing,
- division of procurement and purchasing strategies,
- selected methods of evaluating and selecting suppliers.

5.1. Introduction

Supply (supply logistics) is assigned to both basic and auxiliary functions. It contributes to gaining competitive advantage through, among others, selecting suppliers who:

- offer high-quality raw materials at the lowest possible price, contributing to increased customer satisfaction,
- guarantee innovative technologies, which translates into introducing new solutions and products to the market,
- apply sustainable practices that reduce waste and improve the company's image.

Supply allows for obtaining equipment, materials and components necessary for the production of one's own finished product or for selling goods to subsequent links in the supply chain. Supply logistics also connects participants in the supply chain and ensures the desired quality created by suppliers in this chain (Coyle, et al., 2002). Supply also includes activities related to the analysis of the available (current) stock of materials and components that are at the company's disposal. An equally important activity performed in the area of supply logistics is the planning of material requirements based on production plans or orders from customers and on the basis of the structure (specification) of the product manufactured by the company. Supply also includes supervising and responding to changes in delivery conditions (changes in the date, assortment, quantity, etc.). Therefore, it means obtaining something in a planned manner.

Purchasing, on the other hand, is one of the stages of supply logistics. It means purchasing goods and services. However, this is a rather narrow perception of purchasing, which treats purchasing in a way that is separate from other functions performed in the company. The concept of purchasing should be understood as an exchange transaction that begins when material needs are known (Kowalska, 2005). It is preceded by the selection of the source of supply (supplier or subcontractor) and activities consisting in negotiating prices and the deadline for completing the order. Purchasing is a transaction in which a customer purchases a product or service, and the supplier receives payment for it. It therefore includes four stages: (1) specifying the type of purchase; (2) determining the necessary level of expenditure; (3) implementing the actual purchasing process; (4) assessing the effectiveness of the completed purchasing process.

The terms purchasing, supply and supply purchasing are often treated as synonymous terms. However, it should be remembered that these terms differ from each other – their scope is different. Purchases are a narrower concept than supply. Supply purchasing, on the other hand, concerns the acquisition of goods and services needed for the production process.

The role and importance of purchasing and supply in an enterprise largely depend on the availability of industrial and commercial goods. The greater the problem and difficulty in obtaining and purchasing goods (e.g. an unstable market subject to seasonal cycles, shortages and price instability), the more strategic the supply and purchase become. On the other hand, the more standard the type of goods and the generally high level of availability on the market, the less important the supply and purchase. This role is also different if the enterprise has a significant part of its capital tied up in material goods. The associated cost means that more effective management of supply and purchase will affect better management of the enterprise's capital and greater savings. This means that the role of supply and purchase will increase in enterprises where the degree of capital intensity (the share of costs of material goods and related operations in the finished product) of this process is high.

5.2. Sourcing and purchasing strategies – division by supply sources

Due to the possible sources of supply, several different supply and purchasing strategies can be distinguished. They can be differentiated in terms of the number of supply sources. In such a situation, the following strategies can be indicated (Grzybowska, 2011):

- single source of supply (one supplier); (single sourcing) means that based on established criteria, one supplier is selected, who is responsible for the supply of a specific assortment item or assortment group. This solution ensures maintaining close contacts between the recipient and one supplier selected and preferred by the company. It allows for building lasting relationships and relations between business partners, often on the basis of a long-term partnership and agreement. Lasting relationships, stability of cooperation and collaboration, and uniform quality of delivered goods or services are the undoubted advantages of this solution. The disadvantage of the applied strategy is the risk associated with having only one supplier. This is primarily the risk that there will be a loss of continuity of supplies, which may be caused by disruptions in the supply chain and the risk of the buyer becoming dependent on one supplier. This is especially the case when the supplier is a monopolist. In special cases, a supplier monopoly may occur when there are no alternative sources of supply on the market.
- two sources of supply (two suppliers); (dual sourcing) which means purchasing from two equal suppliers who supply the same type of product range or group of products. Cooperation between the buyer and two suppliers is based on the 50-50 principle – the division of orders and purchases is evenly distributed between them. The dual purchase strategy may also take the form of uneven division and differentiation of cooperation between two selected suppliers. This is a see-saw strategy. As the name suggests, this strategy uses the see-saw principle of order

distribution. The division of purchases is uneven (e.g. 70% one supplier, 30% the other supplier). The proportions of orders allocated to suppliers may change depending on the proposed price of the purchase item and its quality. Although these companies have the same rights, there is competition between them for a larger share. This is undoubtedly the driving force of this strategy.

- multiple sources of supply (multiple suppliers), (multiple sourcing) means using the services of multiple suppliers and subcontractors. This strategy ensures high supply security. It is characterized by the triad: multiple suppliers – multiple relationships – multiple strategies. It usually concerns components for the finished product, which are not strategic. The multiple supplier strategy says that it is necessary to use and cooperate with a relatively large number of suppliers, with whom the company creates various types of relationships, levels of cooperation and different transactions. The strategy guarantees the continuity and reliability of supplies. It also allows not to become dependent on a single supplier. The competition existing between suppliers also ensures constant raising of the buyer's requirements and expectations. Problems may occur with maintaining an equal level of quality and technical parameters of both purchased goods and services provided. It is impossible to conduct joint research and development work with such a large number of alternative suppliers.

Another example of a supply and purchasing strategy is the division according to the subject of the purchase. The following strategies can be distinguished (Grzybowska, 2011):

- purchases of individual elements (unit sourcing), which is directed to manufacturing companies that purchase the subject of the purchase in the form of uncomplicated components (simple elements: parts, details, etc.), from which they then produce a finished product. In this solution, the degree of separation of production activities to the outside (outsourcing) is small. It assumes a high degree of vertical integration of production. There is a very high probability that a manufacturing company (buyer) will gather around itself many or very many suppliers of various material goods from which the finished product is manufactured.

- modular purchases (modular sourcing), which means moving away from acquiring individual elements in favour of ready-made assembly modules or complex components that are assembled into a final product.

5.3. Supplier Evaluation and Selection Methods

The evaluation of candidate suppliers is based on criteria established for supplier selection. Experts conduct these evaluations using various decision-making methods. Supplier selection is one of the most critical activities related to purchasing management in the supply chain (Amid et al., 2006). Supplier selection is the basis for long-term supplier partnerships that can significantly contribute to the success or failure of a company (Ali et al., 2023). The decision-making process for supplier evaluation and selection is influenced by the following elements: (1) evaluation method used; (2) minimum order quantity; (3) sourcing strategy; (4) supplier production capacity; (5) product type; (6) type of supplier evaluation; (7) supplier location preferences; (8) supplier selection criteria; (9) production strategy; and (10) supplier production capacity (Nowakowski & Werbińska-Wojciechowska, 2012; de Boer, et al. 2001).

A number of methods and techniques are known for supplier evaluation and selection. Below are some of the classifications (Benyoucef et al., 2003):

- elimination methods, which help companies in the supplier selection process by gradually eliminating those who do not meet certain criteria. One of the elimination methods is the point method, in which each supplier is evaluated based on a set of criteria, such as price, quality, timeliness of delivery, etc. Suppliers who do not reach the minimum number of points are eliminated. A subcategory in this group is the weighted supplier evaluation method.
- optimization methods, which help companies make decisions regarding the selection of the best suppliers based on various criteria. One of the more popular optimization methods is the multi-criteria method (Analytic Hierarchy Process, AHP), which consists of hierarchically ordering criteria and evaluating suppliers based on these criteria. AHP allows for the inclusion of both quantitative and qualitative criteria.

- probabilistic methods, which take into account uncertainty and variability of data in the decision-making process. One of the methods of this group is the TOPSIS method with probabilistic information.

Much attention is currently paid to the problems related to supplier selection and supplier allocation, which are becoming increasingly difficult to solve over time (Khazaei et al., 2023). Supplier selection in today's competitive market is the most important function for the success of the overall cycle efficiency and supply chain organization (Dweiri et al., 2016).

5.4. Supplier evaluation criteria

Determining the right criteria for supplier evaluation enables the best possible choice to be made later. These criteria influence and determine the evaluation of subcontractors' offers. The detailed criteria for supplier evaluation (Fig. 5.1) and their expansion with important parameters (Tables 5.1-5.4) are worth noting.

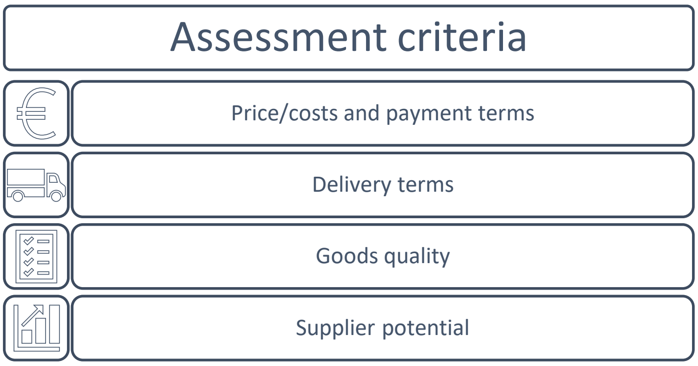


Figure 5.1. Selected supplier evaluation criteria

Source: (Midor & Biały, 2019)

For example, Ha and Krishnan (2008) mentioned that price, quality and delivery are the three most frequently used attributes. Similarly, Koul and Verma (2012) also considered price, quality, cost and service as the main criteria for supplier selection.

One of the key criteria for evaluating suppliers is price (costs) and payment terms (Table 5.1). Price and delivery costs directly affect the total cost of production. The level of profit margin also depends on them. It is also worth remembering that payment terms, such as payment terms and credit availability, affect the financial liquidity of the company. Therefore, flexible payment terms can help manage cash flow and avoid liquidity problems.

Table 5.1. Development of supplier evaluation criteria – Price/costs and payment terms

Evaluation criterion	Characteristic parameters
Price/costs and payment terms	▪ price competitiveness ▪ price stability or variability over a longer period of time ▪ payment terms ▪ possibility of crediting the delivery ▪ scope of discounts granted for larger orders ▪ scope of discounts granted for long-term cooperation ▪ willingness to negotiate prices ▪ delivery costs; transport costs ▪ hidden (additional) costs not directly visible in the price offer ▪ quality-related costs related to complaints, returns, repairs

Source: own study

Table 5.2. Development of supplier evaluation criteria – Supplies

Evaluation criterion	Characteristic parameters
Deliveries	▪ timeliness of deliveries ▪ regularity; frequency of deliveries ▪ completeness of deliveries ▪ accuracy/assortment consistency of deliveries ▪ method of packaging and securing goods ▪ quantitative flexibility; timely flexibility of deliveries ▪ convenience of placing orders ▪ possibility of managing the logistics of deliveries by the supplier (e.g. transport, storage) ▪ reliability of deliveries

Source: own study

Table 5.3. Development of supplier evaluation criteria – Product quality

Evaluation criterion	Characteristic parameters
Product quality	▪ technical quality of the product ▪ quality guarantees ▪ product reliability ▪ product safety ▪ technical service ▪ product compliance with norms and standards ▪ product functionality ▪ product durability ▪ quality control system ▪ ease of repair or maintenance of the product ▪ impact of the product on the natural environment (ecological character)

Source: own study

Table 5.4. Development of supplier evaluation criteria – Supplier potential

Evaluation criterion	Characteristic parameters
Supplier potential	▪ production capacity ▪ technological availability ▪ availability of technical, human and material resources ▪ innovation potential ▪ logistic and operational efficiency ▪ supplier experience ▪ management and organisational capabilities ▪ supplier's market position (market share; reputation) ▪ possibilities of introducing new technologies, products or processes

Source: own study

However, price is not the only criterion for evaluating suppliers. Delivery terms are an equally important criterion (Table 5.2). The supplier's ability to deliver on time, regularly or flexibly is essential to avoid production downtime and ensure continuity of operations.

Another important criterion for evaluating suppliers is the quality of the goods delivered (Table 5.3). High quality goods (raw materials, materials, components) affect the quality of the manufactured product, and as a result leads to customer satisfaction. This in turn increases loyalty and repeatability of purchases and affects the reputation of the company that makes the purchase.

When evaluating and selecting a supplier, attention can also be paid to the supplier's potential for further development (Table 5.4). This criterion refers to parameters that help determine whether the supplier will be able to meet future challenges and market requirements in the short/long term.

5.5. Weighted Point Method

The most commonly used quantitative supplier evaluation method is the evaluation method, which is based on a weighted evaluation (Burdzik, 2017). In this method, the order of selected supplier evaluation criteria is first determined and a weighted factor (weight) is assigned to them. The weighted factor refers to the importance of the selected evaluation criterion.

Companies often use the weighted point system because it is highly reliable and its implementation costs are moderate. In addition, it combines qualitative and quantitative performance factors into a common system. Because decision makers can change the weighted factors assigned to each criterion or change them independently depending on the strategic prioritiesof the company. Thus, the system is flexible (Arsan & Shank, 2011; Maláková, et al., 2020).

The supplier's evaluation is obtained by multiplying each criterion score by a predetermined weighted factor. Then, the obtained values are summed. The preference score (P_S) denotes the supplier's evaluation.

The above shows the formal model:

$$P_S = \sum_{y=1}^{n}(O_i \bullet \varpi_i)$$

Where

P_S – preference score

O – criterion evaluation

ϖ – weighted coefficient.

The weighted coefficient should:

- Be in the range $< 0,1 >$,
- Each subsequent weighted coefficient used is smaller than its predecessor $\varpi_i > \varpi_{i+1} > \varpi_{i+2}$,
- The sum of all weighted coefficients must be equal to 1: $\sum_1^n \varpi_i = 1$,
- The number of weighted coefficients depends on the number of criteria analyzed.

The above is explained by the formula used in Excel

for a weighted average with five selected supplier evaluation criteria:

$$\textbf{preference score}_{(\text{supplier } 1)} = (\textbf{rating}_{(\text{criterion } 1)} * \omega_{(1)}) + (\textbf{rating}_{(\text{criterion } 2)} * \omega_{(2)}) + (\textbf{rating}_{(\text{criterion } 3)} * \omega_{(3)}) + (\textbf{rating}_{(\text{criterion } 4)} * \omega_{(4)}) + (\textbf{rating}_{(\text{criterion } 5)} * \omega_{(5)})$$

The proposed procedure and description of the calculation process are presented below.

Task content

Evaluate suppliers for the selected assortment item.

[1] Preparing a data sheet; Listing the criteria and assigning weighted coefficients.

[2] Establishing a scale of assessment of individual criteria.

[3] Establishing a set of suppliers subject to assessment; Assigning assessments to individual criteria and suppliers.

[4] Calculating a weighted average for each supplier subject to assessment.

[5] Drawing a graph containing the criteria and their assessment by suppliers.

[6] Performing an analysis and, on its basis, selecting the best supplier; determining which supplier will receive the best assessment

The selected criteria are:

- Quality of the bicycle part (parts do not break, are durable, no complaints),
- Price of the bicycle part (the lower the better),
- Timeliness of deliveries (deliveries are delivered on time),
- Reliability of deliveries (products arrive intact, without damage),
- Compliance of the goods with expectations (the goods arrive exactly as ordered),
- Ordering procedure (simple and intuitive ordering).

The assigned weighted coefficients are as follows:

- Quality of the bicycle part – 30%,
- Price of the bicycle part – 25%,
- Timeliness of deliveries – 15%,
- Reliability of deliveries – 10%,
- Compliance of the goods with expectations – 10%,
- Ordering procedure – 10%.

It was indicated that the assessment of individual criteria will be made on the basis of a 10-point assessment (1-10), where:

- 10 – Very good (perfect fulfillment of the criterion),
- 7–9 – Good (minor problems),
- 4–6 – Average (partial fulfillment, a few problems),
- 2–3 – Poor (numerous problems),
- 1 – Very bad (no fulfillment of the criterion).

It was indicated that five companies supplying bicycle parts were selected for the supplier assessment. These are companies coded: A1, B2, C3, D4, E5.

Excel example:

[1] Prepare a spreadsheet with data; list the criteria and assign weighted coefficients.

		Supplier assessment				
Assessment ctiteria	**Criterion weight**	**A1**	**B2**	**C3**	**D4**	**E5**
Quality	30%					
Price	25%					
Punctuality	15%					
Reliability	10%					
Compatibility	10%					
Ordering procedure	10%					

[2] Define the scale of evaluation of individual criteria according to the established scale and assign them to each supplier who is subject to evaluation.

		Supplier assessment				
Assessment ctiteria	**Criterion weight**	**A1**	**B2**	**C3**	**D4**	**E5**
Quality	30%	9	4	6	10	8
Price	25%	7	9	6	9	7
Punctuality	15%	8	9	7	8	8
Reliability	10%	9	8	4	9	9
Compatibility	10%	10	8	7	10	5
Ordering procedure	10%	8	7	6	10	8

[3] Calculate the weighted averages for each supplier being assessed; The formula for calculating the weighted average for a single supplier is shown below.

=D4*C4+D5*C5+D6*C6+D7*C7+D8*C8+D9*C9

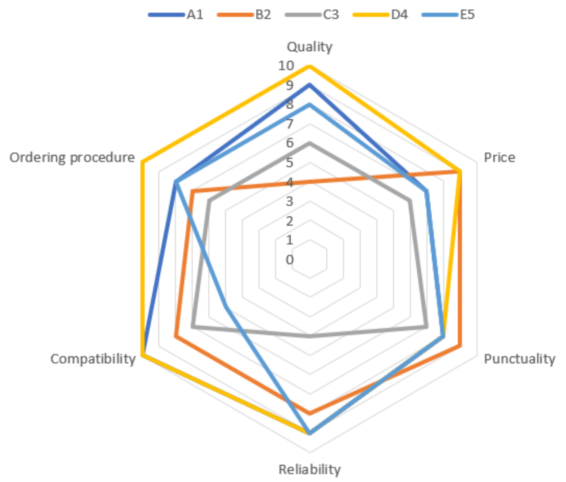
B	C	D	E	F	G	H
		Supplier assessment				
Assessment ctiteria	Criterion weight	A1	B2	C3	D4	E5
Quality	30%	9	4	6	10	8
Price	25%	7	9	6	9	7
Punctuality	15%	8	9	7	8	8
Reliability	10%	9	8	4	9	9
Compatibility	10%	10	8	7	10	5
Ordering procedure	10%	8	7	6	10	8
	Preference score	8,35	7,1	6,05	9,35	7,55

For each supplier, calculate the weighted average, which takes into account the ratings and the weights for a given criterion. To do this, calculate the sum of the products of the rating and the weight for each criterion for each supplier. Copy the formula with absolute addresses for the remaining suppliers;

To copy the formula, it is worth using absolute addresses for the cells that contain the weight of a given criterion.

[4] Draw a chart containing the criteria and their assessment by suppliers;

To visualize the result, it is worth making a radar chart that will show the assessment of each criterion (chart axes) by supplier (colored lines).



The perfect state of the supplier's selected criteria will be the "circle" figure, while the imperfect state will be point 0 "the center".

[5] Perform the analysis and select the best supplier based on it; determine which supplier received the best rating.

		Supplier assessment				
Assessment ctiteria	**Criterion weight**	**A1**	**B2**	**C3**	**D4**	**E5**
Quality	30%	9	4	6	10	8
Price	25%	7	9	6	9	7
Punctuality	15%	8	9	7	8	8
Reliability	10%	9	8	4	9	9
Compatibility	10%	10	8	7	10	5
Ordering procedure	10%	8	7	6	10	8
	Preference score	8,35	7,1	6,05	9,35	7,55

In order to determine the supplier that best meets the criteria adopted during the analysis, the supplier with the highest preference score is selected.

After performing the analysis, it is possible to indicate which supplier best meets the criteria indicated in the company. Cooperation should be established with this supplier. In the event that the purchasing strategy indicates that there should be two suppliers for a given purchase item, the next supplier with the highest preference score should be selected.

The results of the obtained analysis of the supplier evaluation using the weighted average method can be presented in a clear way on a graph. The highest preference score also means the highest sum of weighted scores of the selected criteria.

5.6. Multi-criteria method

The Analytic Hierarchy Process (AHP) is a commonly used procedure for solving problems related to strategic decisions, also for evaluating and selecting suppliers (Ossadnik & Lange, 1999). AHP is a common multi-criteria decision-making method. It was developed to help solve complex decision-making problems. It takes into account both subjective and objective evaluation measures (Dweiri et al., 2016). AHP uses a pairwise comparison of evaluation criteria with respect to an objective. This pairwise comparison allows determining the relative importance of criteria with respect to the main objective. If quantitative data is available, comparisons can be easily made based on a defined scale. This makes the analysis result guarantee an excellent evaluation. The AHP method is an intuitive method for formulating and analyzing decisions. It is based on a subjective methodology. It consists of three main principles: (1) hierarchical structure, (2) priority analysis, and (3) consistency verification (Cheng et al., 2007).

The proposed procedure and description of the calculation process are presented below.

Task content

Evaluate suppliers for the selected assortment item.

[1] Preparation of data sheet; Listing of criteria.
[2] Compare criteria in pairs (scale 1, 2, 3, 4, 5).
[3] Calculate the sum for each criterion.
[4] Calculate the share of each cell in the sum for each criterion.
[5] Calculate global preferences for each criterion.
[6] Show global preferences for each criterion.
[7] Indicate suppliers (A1, B2, C3, D4).
[8] Calculate local preferences for each criterion and supplier.
[9] Calculate the share of each cell in the sum for each criterion and supplier.
[10] Calculate local preferences for each criterion and supplier.
[11] Show local preferences for each supplier for a given criterion.
[12] Establish a ranking of suppliers.
[13] Select a supplier.

The selected criteria are:

- Quality of the bicycle part (parts do not break down, are durable, no complaints),
- Price of the bicycle part (the lower the better),
- Timeliness of deliveries (deliveries are delivered on time),
- Reliability of deliveries (products arrive intact, without damage).

The scale of comparison of criteria was selected:

- 1 – just as good / important,

- 2 – slightly better / more important,
- 3 – definitely better / more important,
- 4 – much better / more important,
- 5 – extremely better / more important.

It was indicated that five companies supplying bicycle parts were selected for the assessment of suppliers. These are companies coded: A1, B2, C3, D4.

Excel example:

[1] Prepare a data sheet; list the criteria.

[2] Compare criteria in pairs (scale 1, 3, 5).

Comparing criteria in pairs allows you to determine which of them is more important. The comparison is made according to the adopted scale.

For example: quality is extremely more important than price, which means choosing a rating of 5. To compare the criteria in the order price and quality, the inverse of the previous rating is taken, i.e. 1/5.

	Quality	Price	Punctuality	Reliability
Quality	1	5	3	2
Price	1/5	1	3	1
Punctuality	1/3	1/3	1	1/5
Reliability	1/2	1	5	1

[3] Calculate the sum for each criterion in the column.

Then sum the scores awarded from the pairwise comparison of criteria in the columns.

=SUM(C12:C15)

B	C	D	E	F
	Quality	Price	Punctuality	Reliability
Quality	1,00	5,00	3,00	2,00
Price	0,20	1,00	3,00	1,00
Punctuality	0,33	0,33	1,00	0,20
Reliability	0,50	1,00	5,00	1,00
Sum	=SUM(C12:C15)	7,33	12,00	4,20

[4] Count the share of each cell in the total for each criterion.

Next, you need to count the share of a given criterion in the total for that criterion. The example shows the appropriate cells in the formula bar, the values look like this for the quality criterion: 1: 2.03 = 0.49; 0.20: 2.03 = 0.10; 0.33: 2.03 = 0.16; 0.50: 2.03 = 0.25. The sum of the shares must be 1.

C21 =C12/$C$16

	Quality	Price	Punctuality	Reliability
Quality	1,00	5,00	3,00	2,00
Price	0,20	1,00	3,00	1,00
Punctuality	0,33	0,33	1,00	0,20
Reliability	0,50	1,00	5,00	1,00
Sum	2,03	7,33	12,00	4,20

	Quality	Price	Punctuality	Reliability
Quality	0,49	0,68	0,25	0,48
Price	0,10	0,14	0,25	0,24
Punctuality	0,16	0,05	0,08	0,05
Reliability	0,25	0,14	0,42	0,24
Sum	1,00	1,00	1,00	1,00

[5] Calculate global preferences for each criterion.

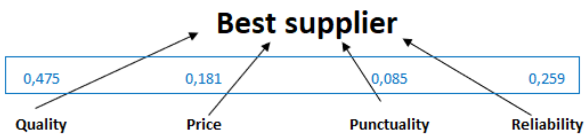
Calculating global preferences for each criterion is a row-wise calculation of the average shares for each criterion. This calculation allows us to determine the global share of this criterion in the entire evaluation to which the suppliers will be subjected.

=average(C21:F21)

	Quality	Price	Punctuality	Reliability	W (average)
Quality	0,49	0,68	0,25	0,48	=average(
Price	0,10	0,14	0,25	0,24	0,181
Punctuality	0,16	0,05	0,08	0,05	0,085
Reliability	0,25	0,14	0,42	0,24	0,259
Sum	1,00	1,00	1,00	1,00	1,00

[6] Show global preferences for each criterion.

The graphical form allows for a better presentation of the preferences of a given criterion in relation to the selection of the supplier.



[7] Indicate suppliers (A1, B2, C3, D4).

[8] Compare suppliers in pairs according to each criterion (scale 1-7).

Comparing suppliers in pairs allows you to determine which of them meets a given criterion better. The comparison is performed according to the adopted scale. The adopted scale for comparing suppliers is 1-7, where 1 means that the suppliers are equally good, 7 - the supplier is extremely better, the remaining values are in between.

The comparison of suppliers is performed for each criterion separately.

For example: for the quality criterion, supplier A1 is as good as supplier B2 (score 1), supplier A1 is slightly better than suppliers C3 and D4 (score 3). To compare suppliers in the reverse order (B2 and A1, C3 and A1, D4 and C3), the inverse of the previous score is taken (i.e., 1/1, 1/3, 1/3, respectively).

Then, the scores awarded from the pairwise comparison of suppliers are summed up in the columns.

Quality	A1	B2	C3	D4
A1	1,00	1,00	3,00	3,00
B2	1,00	1,00	0,20	3,00
C3	0,33	5,00	1,00	0,33
D4	0,33	0,33	3,00	1,00
Sum:	2,66	7,33	7,20	7,33

Punctuality	A1	B2	C3	D4
A1	1,00	3,00	0,33	3,00
B2	0,33	1,00	0,20	3,00
C3	3,00	5,00	1,00	5,00
D4	0,33	0,33	0,20	1,00
Sum:	4,66	9,33	1,73	12,00

Price	A1	B2	C3	D4
A1	1,00	5,00	7,00	4,00
B2	0,20	1,00	3,00	1,00
C3	0,14	0,33	1,00	0,33
D4	0,25	1,00	3,00	1,00
Sum:	1,59	7,33	14,00	6,33

Reliability	A1	B2	C3	D4
A1	1,00	0,20	3,00	5,00
B2	5,00	1,00	5,00	5,00
C3	0,33	0,20	1,00	0,33
D4	0,20	0,20	3,00	1,00
Sum:	6,53	1,60	12,00	11,33

[9] Calculate the share of each cell in the total for each criterion and supplier.

The share of a given supplier in the total for this supplier with respect to each criterion should be calculated.

In the example in the first table for the quality criterion, the formula bar shows the appropriate cells, in the values it looks like this for supplier A1: 1:

2.66 = 0.38; 1: 2.66 = 0.38; 0.33: 2.66 = 0.12; 0.33: 2.66 = 0.12. The sum of the shares must be 1.

=C3/C7

Quality	A1	B2	C3	D4
A1	1,00	1,00	3,00	3,00
B2	1,00	1,00	0,20	3,00
C3	0,33	5,00	1,00	0,33
D4	0,33	0,33	3,00	1,00
Sum:	2,66	7,33	7,20	7,33

Quality	A1	B2	C3	D4
A1	0,38	0,14	0,42	0,41
B2	0,38	0,14	0,03	0,41
C3	0,12	0,68	0,14	0,05
D4	0,12	0,05	0,42	0,14
Sum:	1,00	1,00	1,00	1,00

Price	A1	B2	C3	D4
A1	1,00	5,00	7,00	4,00
B2	0,20	1,00	3,00	1,00
C3	0,14	0,33	1,00	0,33
D4	0,25	1,00	3,00	1,00
Sum:	1,59	7,33	14,00	6,33

Price	A1	B2	C3	D4
A1	0,63	0,68	0,50	0,63
B2	0,13	0,14	0,21	0,16
C3	0,09	0,05	0,07	0,05
D4	0,16	0,14	0,21	0,16
Sum:	1,00	1,00	1,00	1,00

Punctuality	A1	B2	C3	D4
A1	1,00	3,00	0,33	3,00
B2	0,33	1,00	0,20	3,00
C3	3,00	5,00	1,00	5,00
D4	0,33	0,33	0,20	1,00
Sum:	4,66	9,33	1,73	12,00

Punctuality	A1	B2	C3	D4
A1	0,21	0,32	0,19	0,25
B2	0,07	0,11	0,12	0,25
C3	0,64	0,54	0,58	0,42
D4	0,07	0,04	0,12	0,08
Sum:	1,00	1,00	1,00	1,00

Reliability	A1	B2	C3	D4
A1	1,00	0,20	3,00	5,00
B2	5,00	1,00	5,00	5,00
C3	0,33	0,20	1,00	0,33
D4	0,20	0,20	3,00	1,00
Sum:	6,53	1,60	12,00	11,33

Reliability	A1	B2	C3	D4
A1	0,15	0,13	0,25	0,44
B2	0,77	0,63	0,42	0,44
C3	0,05	0,13	0,08	0,03
D4	0,03	0,13	0,25	0,09
Sum:	1,00	1,00	1,00	1,00

[10] Calculate local preferences for each criterion and supplier.

Calculating local preferences for each supplier for each criterion is a matter of calculating the average shares for each supplier in the rows. This calculation allows us to determine the local share of this supplier for a given criterion in the evaluation.

fx =average(I3:L3)

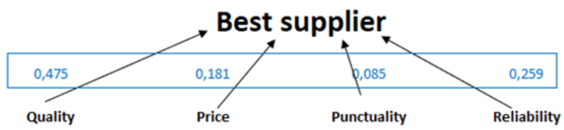
Quality	A1	B2	C3	D4	U(Quality)
A1	0,38	0,14	0,42	0,41	=average(I3:L3)
B2	0,38	0,14	0,03	0,41	0,237
C3	0,12	0,68	0,14	0,05	0,248
D4	0,12	0,05	0,42	0,14	0,181
Sum:	1,00	1,00	1,00	1,00	1,00

Price	A1	B2	C3	D4	U(Price)
A1	0,63	0,68	0,50	0,63	0,611
B2	0,13	0,14	0,21	0,16	0,159
C3	0,09	0,05	0,07	0,05	0,064
D4	0,16	0,14	0,21	0,16	0,166
Sum:	1,00	1,00	1,00	1,00	1,00

Punctuality	A1	B2	C3	D4	U(Punctuality)
A1	0,21	0,32	0,19	0,25	0,244
B2	0,07	0,11	0,12	0,25	0,136
C3	0,64	0,54	0,58	0,42	0,544
D4	0,07	0,04	0,12	0,08	0,076
Sum:	1,00	1,00	1,00	1,00	1,00

Reliability	A1	B2	C3	D4	U(Reliability)
A1	0,15	0,13	0,25	0,44	0,242
B2	0,77	0,63	0,42	0,44	0,562
C3	0,05	0,13	0,08	0,03	0,072
D4	0,03	0,13	0,25	0,09	0,123
Sum:	1,00	1,00	1,00	1,00	1,00

[11] Show local preferences for each supplier with respect to a given criterion. The graphical form allows for a better presentation of the preferences of a given supplier with respect to each criterion.



A1	0,335	A1	0,611	A1	0,244	A1	0,242
B2	0,237	B2	0,159	B2	0,136	B2	0,562
C3	0,248	C3	0,064	C3	0,544	C3	0,072
D4	0,181	D4	0,166	D4	0,076	D4	0,123

[12] Establish a supplier ranking.

Establishing a supplier ranking involves calculating for each supplier the sum of the products of the weight for each criterion and the supplier's rating for that criterion.

=K3*N3+K4*P3+K5*R3+K6*T3

Global Preference	W
Quality	0,475
Price	0,181
Punctuality	0,085
Reliability	0,259

Quality		Price		Punctuality		Reliability	
A1	0,335	A1	0,611	A1	0,244	A1	0,242
B2	0,237	B2	0,159	B2	0,136	B2	0,562
C3	0,248	C3	0,064	C3	0,544	C3	0,072
D4	0,181	D4	0,166	D4	0,076	D4	0,123

supplier 1	A1	0,353
supplier 2	B2	0,299
supplier 3	C3	0,194
supplier 4	D4	0,154

[13] Select a supplier.

The results obtained can be presented graphically. In the analyzed example, the highest evaluation result was received by supplier A1.

5.7. Resilient Suppliers

Suppliers and subcontractors are considered to be the main sources of risk that cause massive disruptions in supply chains (Pramanik et al., 2017). Moreover, many supply chain processes are dependent on the supplier. Therefore, selecting resilient suppliers can significantly reduce purchasing costs, delay times, and increase the company's competitiveness and customer satisfaction (Davoudabadi et al., 2020). Supplier resilience assessment is therefore one of the most important ways to enter the world of supply chain resilience, as suppliers are one of the main sources of vulnerability in supply chains.

According to Sheffi and Blayney Rice (2005), resilience in companies and supply chains can be built in three general ways: (1) creating redundancy throughout the supply chain (e.g., additional inventory, low capacity utilization, multiple sourcing), (2) increasing supply chain flexibility (e.g., flexible means of transportation in the event of disruptions, parallel processes instead of sequential, sourcing strategies tailored to supplier relationships), and (3) changing corporate culture (e.g., continuous communication between informed employees, preparation for disruptions).

Table 5.5. Resistance criterion

Resistance Criterion	Explanation
Pollution Control Initiatives	Effort related to pollution minimization initiatives regarding solid waste, water wastage, air emissions etc.
Investment in transmission capacity	A level of safety stock taken into account to minimize the risk of stock-outs due to uncertainty.
Speed of response	The ability of suppliers to respond to market fluctuations in the shortest time possible.
Ability to maintain strategic stockpiles for emergencies	It shows zero availability, losses, replenishment and stock rotation. Strategic stocks must be at a certain level because there are always uncertain demands.
Concluding contracts with backup suppliers	Backup supplier contracting is the process by which a company contracts with suppliers who can provide products or services when primary suppliers are unable to do so. It is a strategy to increase the resilience of the supply chain to disruptions and minimize the risk of supply disruptions.
Mitigation Strategy	Mitigation strategies are actions taken to reduce the negative consequences of supply chain disruptions.
Reserved stock	Reserved inventory is an inventory management strategy in which a company maintains a certain level of inventory that is intended to be used in emergencies or when there are sudden increases in demand.

Source: (Davoudabadi et al., 2020; Suryadi & Rau, 2023)

Hosseini et al. (2019) also pointed out that in supplier assessment, it is worth introducing elements of analysis based on the supplier's resilience capability, which includes three levels of capability:

- absorptive (e.g., excess inventory increases the resilience of the entire supply network to disruptions),
- adaptive (e.g., alternative backup suppliers to quickly adjust the supply network),
- corrective (e.g., rapid recovery of the supplier's lost supply capacity at minimal cost).

Davoudabadi et al. indicated and extended the supplier selection criteria to include sustainable aspects (for example: environmentally friendly materials; technology based on eco-friendly technology; compliance with environmental protection policy; green R&D projects) and resilient ones (Table 5.5).

Thus, resilient suppliers should (1) have the ability to return to an equilibrium state, (2) have the strength and provide some buffering capacity for the system before a disturbance brings the system from stable to unstable conditions, and (3) have the ability to respond to a disturbance.

Chapter Questions

1. What supplier evaluation criteria do you consider to be the most important in the context of managing the financial liquidity of the enterprise and why?
2. What are the main advantages of using the AHP method in the supplier evaluation and selection process?
3. What are the main disadvantages of using the AHP method in the supplier evaluation and selection process?

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6. OUTSOURCING

This chapter is devoted to the most important issues related to outsourcing and make-or-buy analysis used in the outsourcing decision-making process. It contains:

- basic definitions,
- types of outsourcing,
- advantages and disadvantages of outsourcing,
- description of make-or-buy analysis,
- logistics outsourcing.

6.1. Introduction

In today's market conditions, logistics processes, which include the flow of products, materials and information within the company and between organizations, largely influence the fulfillment of consumers' expectations and requests. Logistics determines the creation and maintenance of competitive dominance of current economic entities. Logistics processes are performed within a logistics system that each company has set up in a different way. In order to meet the changing and growing expectations and preferences of customers, companies are currently building very complex logistics systems based on the cooperation of many enterprises from different countries. Logistics processes are becoming more and more complex, burdened with uncertainty and requiring large financial outlays. Companies should not only try to guarantee appropriate customer service and minimize costs, but also reduce the impact of disruptions in logistics processes. (König & Spinler, 2016). The company's logistics system should be adapted to the external and internal conditions of a given organization and should guarantee the effective and efficient implementation of its goals. An inappropriate arrangement of logistics processes may lead to increasing financial outlays of logistics activities and a decline in the quality of consumer service, which results in a decline in the competitive position of the organization (Brzeziński, 2015).

Modern companies are increasingly introducing changes within their organization, especially in the area of management, due to the pursuit of high efficiency of their activities and to achieve goals and market success, because efficiency is a tool for creating their competitive advantage. Constantly increasing market pressure together with the competitiveness of other companies make it impossible for business entities to integrate all resources at all levels of their activity. Therefore, the question arises whether it is necessary to perform all activities in-house for a given organization and consider using outsourcing, that is the services of an external company specialized in a given industry, in order to focus on its fundamental activities?

Henry Ford said that "If there's something we can't do more efficiently, cheaper, and better than our competitors, there's no point in us doing it, and we should hire someone to do that job who can do it better than we can" (Ford, 1923).

6.2. The essence of outsourcing

Generally speaking, **outsourcing** is a management method (concept) that consists in limiting the scope of activities performed directly by a given company (referred to as the parent company) and outsourcing them for permanent implementation by external enterprises (referred to as service companies) (Trocki, 2001).

The concept of outsourcing assumes that for almost every process, area or function that could be performed within the company's typical organizational structure, there is an alternative in the form of services offered by external suppliers (partners) specializing in a given industry. For this reason, outsourcing is defined as a method of permanent external service by specialized enterprises, externalization, external management, or even deconcentration of the functioning of the organization.

Areas that can be successfully outsourced to external companies are presented in Table 6.1.

Table 6.1. Examples of areas that can be transferred to a service company as part of outsourcing

Area	Examples of outsourcing tasks, functions or processes
Production and supply	production of components, semi-finished products and even finished products, product assembly, packaging, design,
Transport and logistics	transport and distribution of products, courier services, warehousing,
Research and development	research and development work, scientific research, implementation work,
Computer science and information technologies	computer network support, data center support, IT infrastructure maintenance services, IT application support, end-user support, security services or internet services,
Finance, accounting and tax and accounting services	accounting, debt management, controlling, audit, financial and analytical services, development of business plans, tax consultancy, taxpayer representation before tax authorities,
Legal suport	legal advice in various fields, or representation in legal matters,
Customer service	telemarketing, running a reception, secretariat, hotline or call center,
Marketing	monitoring changes taking place on the market, researching customer expectations, creating concepts for new products, defining promotional, advertising and distribution strategies, and shaping the public relations sphere,
Staff and human resources,	recruitment and selection of candidates, employee training, creation of motivational systems, personnel management, administration of HR documentation, temporary employment, and payroll settlements,
Management and administration	maintaining buildings and cleanliness, keeping archives, protection of people and property, managerial services..

Source: (Matejun, 2007)

According to another definition, "**outsourcing** is a method of organization and management consisting in a relatively permanent, long-term, contract-based transfer of responsibility for the implementation of specific areas of business activity (tasks, functions or processes) to a specialized external partner, taking into account the dynamic, interactive and partnership nature of cooperation aimed at obtaining economic and qualitative benefits and at the same time the possibility of developing the key competences of the parent company, which allows strengthening its key activities, building a competitive advantage and developing the company" (Matejun, 2015).

The diagram of the evolution and increase in the importance of outsourcing for modern enterprises is presented in Figure 6.1.

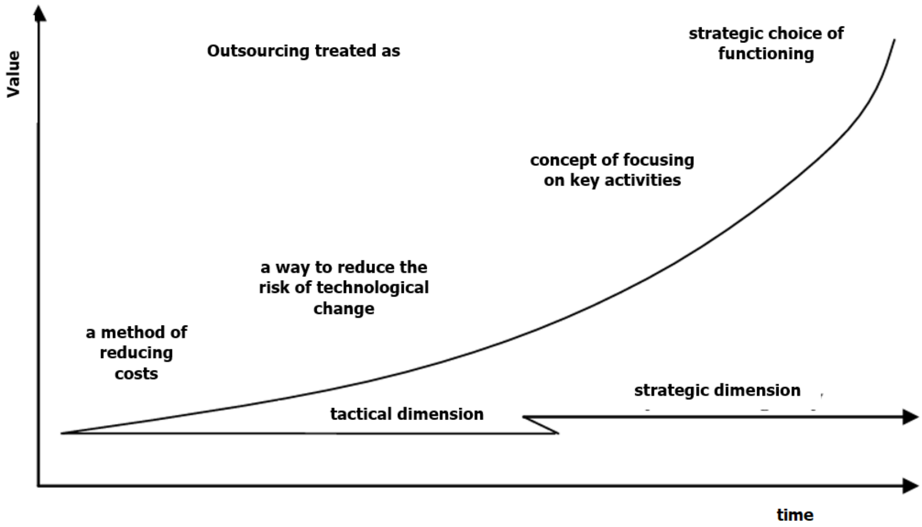


Figure 6.1. Evolution of the outsourcing concept

Source: (Matejun, 2015)

6.3. Basic types of outsourcing

Outsourcing in business practice can take place in two main forms: separation or commission. **Separation** refers to the situation when a given sphere of activity (process, task, function) is performed within the organizational structure of the enterprise, but does not belong to the main competences of the organization, and analyzes related to the costs of its maintenance and the quality, coordination and timeliness of activities show that it does not participate in the process of creating the value of services or products. It is then possible to remove a given area of activity from the organizational structure and outsource its implementation to a service company (Matejun, 2015).

Commission occurs when a specific field of activity has not yet been performed within the company's organizational structure, and the analysis shows that it would be needed due to certain strategic benefits. This area does not include the company's key competencies, and its direct addition to the organizational structure would result the involvement of significant resources that could be allocated to strengthen the basic sphere of operation. This will enable cooperation with an external supplier that provides the desired outsourcing services (Matejun, 2015).

Table 6.2.Variants of capital and contract outsourcing depending on the form of transfer of activities to a service company

Outsourcing / Form of transfer of business activity	Capital outsourcing	Contract outsourcing
	permanent cooperation with an entity related by capital and ownership	permanent cooperation with an entity that is independent in terms of capital
Area separation	**Capital separation** creation of a new subsidiary on the resource base, which begins its independent market existence; it provides services to the parent company as well as to external entities.	**Contractual separation** liquidation of the previously performed function in the enterprise and establishment of formal cooperation with an external, independent supplier who ensures the implementation of tasks; possibility of partial transfer of staff and other resources to the supplier.
Commission an area	**Capital commission** purchase of shares or stocks in a company that provides the required services or performs specific tasks; as a result, a capital takeover takes place and a subsidiary is established	**Contract commission** establishing cooperation with a supplier that is independent in terms of capital and ownership, which begins the implementation of a specific function.

Source: (Matejun, 2015)

It is also possible to separate and commission services in the contract or capital variant. In the **contract variant**, the external supplier, that is the service company, is a capital-independent, specialized enterprise with ties to the parent company only on the basis of a contract. The assumption of the capital variant is to enter into cooperation with a company dependent on ownership and capital. This may be done by creating a new organization (daughter company) or by purchasing shares in an enterprise that already operates on the market and carries out activities needed by the parent company. As a result of the combination of capital and contract outsourcing with two basic methods of outsourcing services to an external service company, four basic variants of this method can be obtained, as presented in Table 6.2.

Table 6.3. Basic types of outsourcing

Division criterion	Types of outsourcing
Type of separated functions	▪ outsourcing of auxiliary functions, ▪ outsourcing of management functions, ▪ outsourcing of basic functions
Type of separated activity	▪ outsourcing of side activities, ▪ outsourcing of auxiliary activities, ▪ outsourcing of core activities.
Type of outsourcing by function	▪ outsourcing of IT services, ▪ financial services outsourcing, ▪ logistics outsourcing, ▪ human resources outsourcing and others
Complexity of separated functions	▪ outsourcing of individual functions, ▪ process outsourcing (BPO), ▪ outsourcing of functional areas.
Purpose of the separation	▪ repair outsourcing, ▪ customization outsourcing, ▪ development outsourcing
Persistence of separation	▪ strategic outsourcing, ▪ tactical outsourcing.
Place of performance of the outsourcing service	▪ services provided centrally, ▪ services provided locally.
Scope of separation	▪ total outsourcing, ▪ partial (selective) outsourcing.

Source: (Matejun, 2006)

In addition to the types of outsourcing presented above, there are many other types of outsourcing in business practice, depending on the adopted criterion, which are presented in Table 6.3.

6.4. Benefits and risks of using outsourcing in modern enterprises

Although the benefits obtained as a result of outsourcing cooperation are often determined by factors related to the size of the enterprise, its industry, the type of outsourced activity or the scale of operations, attention should be paid to many positive aspects for the parent company that can be seen after the implementation of outsourcing, regardless of the above. mentioned factors. The following advantages of outsourcing are most often presented, considered on many levels (Trocki, 2001; Lachiewicz & Matejun, 2012).

I. Direct benefits

1. Legal benefits
   - sense of security resulting from constant cooperation with an external company,
   - sharing the risk between the service company and the parent company,
   - transfer of responsibility for providing services to the supplier.
2. Motivational benefits
   - greater market orientation of management and employees,
   - increased satisfaction and psychological comfort in managing the organization,
   - increasing the motivation of management and employees.
3. Technical and technological benefits
   - Establishing cooperation with partner companies with appropriate qualifications confirmed by certificates,
   - increase in the level of use of enterprise resources,
   - availability of external technological resources (know how),
   - improvement of performance parameters of the spheres of operation outsourced to an external company (their implementation, costs, resource input, quality, time, etc.).
4. Organizational and human resources benefits
   - simplification of the organizational structure and organizational procedures applicable in the company,
   - faster information flow and better communication within the organization,
   - freeing internal resources and saving management time, which can be spent on the development of key activities,
   - reducing the need to engage your own employees to perform certain tasks.
5. Economic and financial benefits
   - increasing financial discipline and increasing control of costs and revenues,

- minimizing financial outlays for the implementation of tasks (primarily by reducing employment and other resources needed to perform them),
- better structure of company expenses,
- transformation of fixed costs into variable costs thanks to payment only for the service provided by an external company, without the need to incur fixed costs for its implementation.

6. Operational benefits
   - improving the quality and efficiency of operational processes in the company,
   - reducing operational problems.
7. Strategic benefits
   - increased strategic flexibility of operations,
   - development of certain areas of the organization without the need to invest - the service provider makes investments on its own in technology and resources necessary to perform specific functions,
   - access to resources or qualifications that the company does not have in its structure or is unable to finance,
   - the economic entity's focus on its core business and the development of key competences (areas of activity).

II. Indirect benefits

- diversification or enrichment of the company's market offer,
- increase in market share,
- acquiring new consumers,
- greater satisfaction and contentment of existing customers,
- better competitive position.

However, outsourcing is not without risks. The most common risks associated with implementing outsourcing according to (Clements et al., 2004; Click & Duening, 2005) include risks:

- human capital management – relate both to the motivation of employees moving to external companies and their ability to adapt quickly to new conditions, and to the loss of their knowledge, competences and potential;
- customer relationship control – outsourcing of business processes can lead to temporary disruptions in customer relationships, especially when the changes involve key service areas;
- in selecting and evaluating service providers – include the difficulty in selecting appropriate external companies, assessing their competence and the need to adapt their resources to the needs of the organization;
- related to quality and timeliness of services – there may be difficulties in ensuring that products and services delivered meet required standards and that agreed deadlines are met;
- limited supplier flexibility – problems may arise from difficulties in adapting the activities of external parties to changes in the parent organization;
- a decline in the quality of customer service – in the short term there may be a reduction in the speed and efficiency with which customer needs are met;
- associated with differences in the goals of the organisation and the supplier – there may be a mismatch between the company's strategy and ambitions and those of the outsourcing partner;
- associated with process reorganisation – refers to the need to adapt organisational structures accordingly to avoid loss of efficiency and productivity;
- loss of effective information exchange – outsourcing can slow down the flow of information and hinder its wide dissemination;
- increased costs in the short term – althoughugh outsourcing is often intended to reduce expenses, it may initially generate additional costs associated with implementing changes;
- legal – arising from potential contractual inaccuracies, regulatory problems and legal disputes.

6.5. Make-or-Buy analysis

One of the most important concepts that justify the use of outsourcing is the concept of **make or buy** dilemmas, which is related to the fundamental problems of the functioning of every enterprise: to make, to do it on its own (make), or to buy, to outsource the work to an external company (buy), but also, whether to carry out a given project alone or together with other organizations (Perechuda, 2000)?

Make (production) – allows the organization to control its activities. It is especially recommended when the company has proprietary products or processes. It is recommended when (www_6.1):

- the product is valuable and not easily replicated,
- the supplier market is not very well developed,
- the environment is stable.

Buy (purchase) – purchasing services and products from external companies in the supply chain contributes to the increase in the company's flexibility and provides it with access to the most modern products. This concept is recommended when (www_6.1):

- environmental instability causes high risk of internal investments,
- we are dealing with competition on the supplier market,
- the product is not treated as strategically important.

Make-or-buy is a key company strategy, which includes, among others:

- introducing a new product to the market,
- production control,
- quality systems,
- human resources,
- production process,
- size of the enterprise and its location,
- measuring efficiency.

The starting point of make-or-buy is the total production and purchase costs calculated for comparable product batches. The basic economic premise is provided by a simple comparison of the unit purchase price with the unit variable production cost. If it is determined that the unit variable cost of production exceeds or is equal to the price of the purchased product, the decision to produce is not economically justified (www_6.1).

In the overall analysis, apart from variable production costs, it is also necessary to analyze what part of the company's fixed costs should be added to the settlement of total production costs? A comparative analysis is presented below, constituting the premise for making the decision "to produce" or "to buy"? (www_6.1).

The calculations of production costs show that:

$$K_p = K_s + X * k_v$$

where:

K_p – total cost of producing x units of goods,

K_s – fixed costs of production,

X – expected production volume,

k_v – unit variable costs.

For purchases:

$$K_z = c * x$$

where:

K_z - cost of purchase,

c - unit price,

x - purchase (production) volume.

X_k is defined as the critical production volume for which the purchase cost is equal to the cost of own production. This is the value below which it is not profitable to undertake production. Only when the X_k value is exceeded is the decision to start production justified. The above calculations were based on the assumption that only the product price is important for the purchase option. However, if the purchase is accompanied by additional financial outlays (e.g. transport costs), then the pattern must be modified by expanding it with appropriate components (Fig. 6.2).

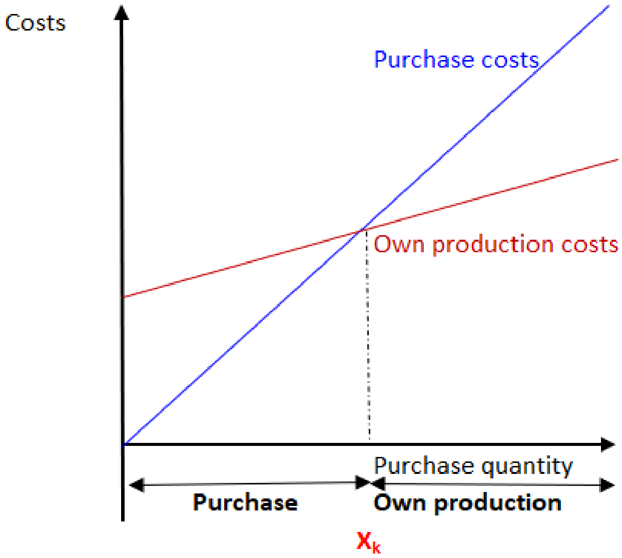


Figure 6.2. Critical production volume

Source: (www_6.1)

You may also face a dilemma: is it worth investing in the production process with production capacity? In this matter, after taking into account all substantive premises that support the investment and do not eliminate the reasonableness of the purchase – the cost analysis should include the components of the investment account (www_6.1).

$$k_i = \frac{r * (1 + r)^m + k_d}{(1 + r)^m - 1}$$

where:

a_0 – volume of investment expenditure,

r – Interest rate,

m – period of use of the investment,

k_d – additional annual costs related to investment management,

k_i – investment costs,

K_p – production cost.

Therefore, the production cost will be calculated according to the formula:

$$K_p = k_i + x + k_v$$

and the purchase cost

$$K_z = c * x$$

If the inequality $K_z < K_p$ is met, there are grounds for making a decision to purchase a given product.

Due to the possibility of changing both the demand volume x and the market price, it is recommended to determine the **critical price c_k** and the **critical production volume X_k** as the values at which the cost of own production and the cost of purchase are equal.

$$c_k = \frac{k_i + x * k_v}{x}$$

In a situation where the initial calculations suggested the advisability of a purchase, the value of the critical price is an indicator to what level the market price can increase without undermining the purchase decision.

$$X_k = \frac{k_i}{C - k_v}$$

Make-or-Buy analysis can be divided into four stages, which are illustrated in Figure 6.3.

Figure 6.3. Outsourcing stages

Source: (www_6.2)

Step 1: Preparation (www_6.2)

First, you should define logistics processes, areas of the company that will be subject to observation in the make-or-buy analysis, as well as aspects that should be particularly focused on in this analysis. There are standard logistics processes, such as transport, storage, shipping, import, export and customs clearance, and supporting logistics processes, which include, for example, preparation, commissioning, packaging, returns and inventory. This division is necessary to decide on the scope of outsourcing as well as the operating model.

When selecting a project team, you should also take into account – apart from the management staff, specialists in the field of operational logistics, as well as issues related to valuations – employees from neighboring departments, such as production or the human resources department, and even the works council, because the decision to outsource will be had a key impact on the functioning of the company. Next, during the kick-off meeting, goals and benefits will be discussed and a project concept will be prepared.

Step 2: Data collection (www_6.2)

The quality of the subsequent analysis results depends only on the correctness of the data. For this reason, it is necessary to collect or store in the company all the necessary data regarding staff and those answering the question whether logistics systems, e.g. industrial trucks or warehouse management, must be transferred or performed by external entities. A catalog of questions that can be divided into important ones can certainly be helpful when making a decision about outsourcing and explaining the logistical situation of a given organization, e.g. how much are the gross employment costs and what exactly do they consist of? What is the weekly working time? etc. and for information questions, e.g. is there a system for employees to submit improvement proposals?

Step 3: Analysis (www_6.2)

In the next stage, the data is assessed and analyzed. The results of make-or-buy analysis are most often carried out using a set of indicator values from comparative analysis (benchmark), which are collected during the operational execution of orders for clients.

Step 4: Comparison of total costs (www_6.2)

Finally, a clear comparison is made between the logistics costs within the company and the logistics costs of the external service provider. In terms of employees, for example, the organization's total personnel costs are compared with the total staff costs of an external entity.

Typically, service provider costs are lower due to more flexible working time regulations. An outsourcing company has the ability to complete the same task with fewer staff. Her expert knowledge also contributes to process optimization, which reduces personnel costs. However, the goal of outsourcing should not be based on the pursuit of savings on employees. In times of shortage of qualified staff, it is more important to effectively assign appropriate positions to employees or increase productivity while maintaining the same number of staff.

When calculating the total costs, it must be taken into account that the decision to outsource usually involves the transfer of part of the organization. This means that selected staff of the parent company will transfer to the external entity's team within a designated period of time. This may be related to severance pay or other conversion costs. This fact should also be taken into account in the comparison of total costs. After obtaining the entire calculation and analysis, you can make a decision for or against outsourcing.

	A	B	C	D	E	F	G
1	Production (Sales)	92	pcs				
2	Unit price:	10480	$		Break-even point:	31,5	Mg
3	Variable costs:	5600	$			(0+B4)/(B2-B3)	
4	Fixed costs:	153600	$				
5							
6		=$B$1*A8	=B8*$B$2	=B8*$B$3	=$B$4	=D8+E8	=C8-F8
7	Coefficient	Production / Sales	Turnover	Variable costs	Fixed costs	Total costs	Profit
8	0,00	0,0	0,0	0,0	153600,0	153600,0	-153600,0
9	0,09	8,3	86774,4	46368,0	153600,0	199968,0	-113193,6
10	0,18	16,6	173548,8	92736,0	153600,0	246336,0	-72787,2
11	0,27	24,8	260323,2	139104,0	153600,0	292704,0	-32380,8
12	0,36	33,1	347097,6	185472,0	153600,0	339072,0	8025,6
13	0,45	41,4	433872,0	231840,0	153600,0	385440,0	48432,0
14	0,54	49,7	520646,4	278208,0	153600,0	431808,0	88838,4
15	0,63	58,0	607420,8	324576,0	153600,0	478176,0	129244,8
16	0,72	66,2	694195,2	370944,0	153600,0	524544,0	169651,2
17	0,81	74,5	780969,6	417312,0	153600,0	570912,0	210057,6
18	0,90	82,8	867744,0	463680,0	153600,0	617280,0	250464,0
19	0,99	91,1	954518,4	510048,0	153600,0	663648,0	290870,4
20	1,08	99,4	1041292,8	556416,0	153600,0	710016,0	331276,8
21	1,17	107,6	1128067,2	602784,0	153600,0	756384,0	371683,2
22	1,26	115,9	1214841,6	649152,0	153600,0	802752,0	412089,6
23	1,35	124,2	1301616,0	695520,0	153600,0	849120,0	452496,0
24	1,44	132,5	1388390,4	741888,0	153600,0	895488,0	492902,4
25	1,53	140,8	1475164,8	788256,0	153600,0	941856,0	533308,8
26	1,62	149,0	1561939,2	834624,0	153600,0	988224,0	573715,2
27	1,71	157,3	1648713,6	880992,0	153600,0	1034592,0	614121,6
28	1,80	165,6	1735488,0	927360,0	153600,0	1080960,0	654528,0
29							

Figure 6.4. Calculation of data for graphical determination of break-even point

Source: own study

An MS Excel spreadsheet is a tool to support outsourcing decisions in Make-or-Buy analysis. In the case study of a natural cosmetics company, two approaches are presented. The first concerns the determination of the **Break-even Point** using graphical and analytical methods. This point indicates the minimum level of production to cover costs (Fig. 6.4).

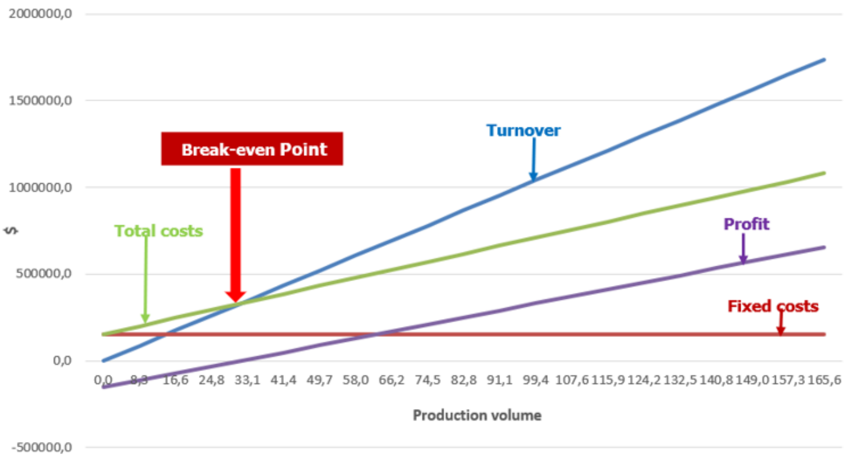


Figure 6.5. Break-even Point Chart

Source: own study

Using the data, a graph of the dependence of fixed costs, total costs, turnover and profit on production volume should be created. The analysis of the profit line reveals the point of intersection, and the analytical determination of the break-even point consists in determining the point of intersection of the turnover and total cost lines (Fig. 6.5), which defines the break-even point.

Based on the results, it can be assessed whether the business is economically viable at current production levels? Changes in parameters such as sales volume (x), price (c), fixed costs (K_s) and unit variable costs (k_v) can then be determined to achieve break-even or planned profit, using the formula:

$$z = x\,(c - k_v) - K_s,$$

where:

x - production level,

c – price,

k_v – unit variable costs,

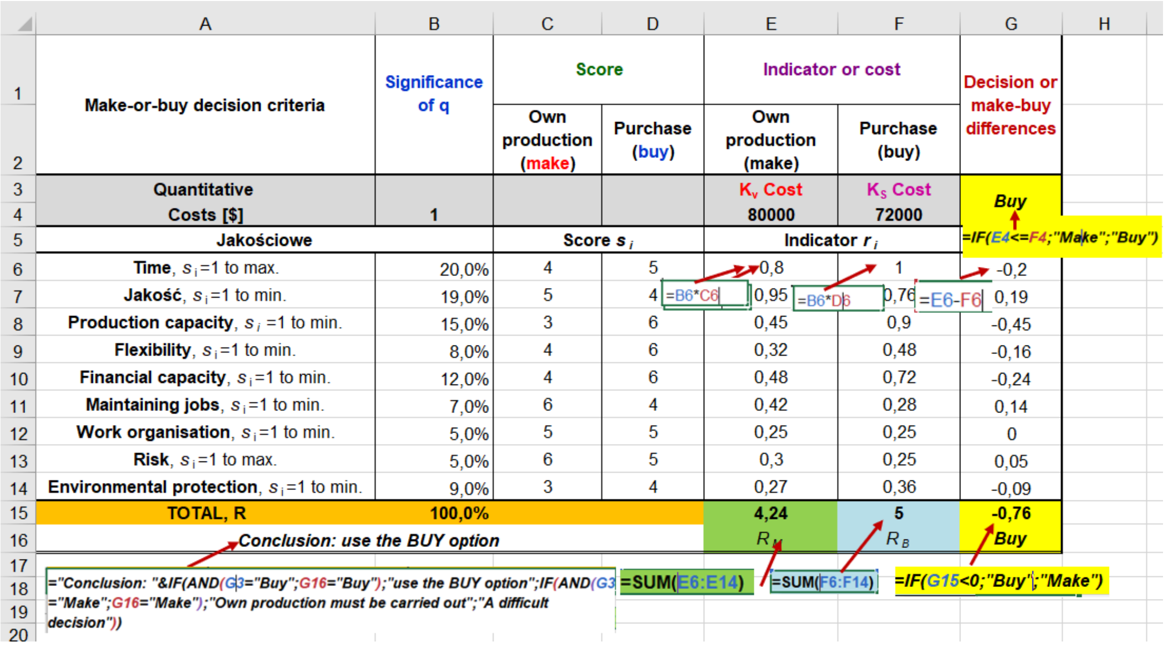
K_s – fixed costs.

The second mode of analysis concerns the Make or Buy decision. Management considered the production of natural essential oils to be too costly, which affects the price of cosmetics. In order to decide whether to continue in-house production or to outsource it, an additional analysis taking into account quantitative and qualitative criteria was carried out.

Key criteria were identified (Fig. 6.6, column A) and assigned weights (q_i, column B). Value judgements (s_i) were made for both options (Make and Buy) using a six-point scale (columns C and D). Relative importance indices were calculated: for in-house production (R_M = 4.24) and for external purchase (R_B = 5.0). A negative final difference of -0.76 confirmed the superiority of the buy option (*Buy*).

For the sake of clarity of the analysis, logical conditions were applied:

- If the costs of in-house production are lower than the costs of purchasing an external service (**K_M < K_B**) and at the same time the importance index of the quality criteria is lower for in-house production (**R_M < R_B**), the *Buy* option should be selected,
- If the in-house production costs are higher than the purchase costs (**K_M > K_B**) and the importance index of the quality criteria is higher for in-house production (**R_M > R_B**), the manufacturing option (*Make*)
- otherwise the decision requires further analysis.



	A	B	C	D	E	F	G
1	Make-or-buy decision criteria	Significance of q	Score		Indicator or cost		Decision or make-buy differences
2			Own production (make)	Purchase (buy)	Own production (make)	Purchase (buy)	
3	Quantitative				K_v Cost	K_S Cost	Buy
4	Costs [$]	1			80000	72000	
5	Jakościowe		Score s_i		Indicator r_i		=IF(E4<=F4;"Make";"Buy")
6	Time, s_i=1 to max.	20,0%	4	5	0,8	1	-0,2
7	Jakość, s_i=1 to min.	19,0%	5	4	0,95	0,76	0,19
8	Production capacity, s_i =1 to min.	15,0%	3	6	0,45	0,9	-0,45
9	Flexibility, s_i=1 to min.	8,0%	4	6	0,32	0,48	-0,16
10	Financial capacity, s_i=1 to min.	12,0%	4	6	0,48	0,72	-0,24
11	Maintaining jobs, s_i=1 to min.	7,0%	6	4	0,42	0,28	0,14
12	Work organisation, s_i=1 to min.	5,0%	5	5	0,25	0,25	0
13	Risk, s_i=1 to max.	5,0%	6	5	0,3	0,25	0,05
14	Environmental protection, s_i=1 to min.	9,0%	3	4	0,27	0,36	-0,09
15	TOTAL, R	100,0%			4,24	5	-0,76
16	Conclusion: use the BUY option				R_V	R_B	Buy

Figure 6.6. Assessment of the Make-or-Buy problem taking into account quantitative and qualitative factors

Source: own study

As the above analysis shows, make-or-buy decisions may turn out to be strategic decisions related to the business and even the future fate of the company. Nowadays, in times of high competition, when companies fight for customers, they strive to produce very good quality products as cheaply as possible. This means that large corporations often stop producing semi-finished products for small companies (www_6.1).

The approach to the issue of make-or-buy is based on qualitative as well as economic and financial factors and is related to the answer to the question whether another business entity can carry out a given task at a lower cost and/or better than the parent company. An incorrectly made decision in this matter may contribute to an increase in operating and production costs, loss of operating efficiency, as well as inefficient use of resources (Platts, Probert & Canez, 2002).

6.6. Outsourcing in Logistics

As part of outsourcing, the most frequently outsourced areas are areas that are not the key competencies of a given company, but only support it. If logistics is not a fundamental activity of the company, then delegating the organization and/or execution of all or part of the logistics processes to competent suppliers specializing in the provision of logistics services may significantly increase the efficiency of logistics processes, which is reflected in the increase in the efficiency of the organization. The idea of logistics outsourcing is to separate resources and use logistics services provided by qualified external companies, which, taking their own risk and usually using their own resources, assume managerial and executive functions. Logistics outsourcing also includes the purchase of various logistics services from external suppliers without meeting the condition of transferring resources (Witkowski, 2008).

The first and most important task for a company before deciding to choose logistics outsourcing is to define the main goals that it plans to achieve by transferring logistics outside the company. Most often, the first and key desired goal is to reduce costs (www_6.3). The decision regarding the scope of logistics outsourcing largely depends on the prices of logistics services, which in turn determine the logistics costs of the economic entity and the prices of products produced and/or sold. As a result of cooperation between the organization and the logistics operator, it is possible to achieve the following goals (Gąsowska, 2016):

- improving the quality of customer service,
- shorter order cycle execution time,
- better quality and delivery guarantee,
- faster flow and increased transparency of information,
- more efficient use of assets.

Outsourcing of logistics processes is also related to the spheres of the company's key logistics activities. Enterprises commission logistics service providers to create a logistics system, model logistics processes, create and implement a logistics strategy. Referring to a logistics entity as a strategic partner may contribute to obtaining and stabilizing a competitive advantage (Jeszka, 2013).

The strategy of the parent company influences the modeling of logistics processes of the logistics service provider. The guarantee of effective cooperation between an organization and an external company specializing in logistics services is communication between the cooperating enterprises. IT systems are increasingly used to support decisions related to flows in the enterprise's logistics system and supply chains. This leads to quick actions that lead to the optimization or transformation of logistics processes, and as a result, to the elimination of the associated risks, minimization of costs, shorter implementation time of logistics processes, increased flexibility and efficiency of the company (Gąsowska, 2016; Liu, Huo, Liu & Zhao, 2015).

Logistics outsourcing improves the company's efficiency if logistics services create the expected correlation of costs with the results of logistics services. The key determinant in the process of deciding on logistics outsourcing should be a precise assessment of this outsourcing in terms of financial savings, non-cost benefits, and risk assessment (Gąsowska, 2016).

Four categories of indicators are used to assess the effectiveness of logistics outsourcing (Szukalski, 2016):

- changes in costs – comparing their changes allows you to assess savings in the area of operating costs that result from logistics outsourcing,
- changes in profitability – their analysis allows you to assess the impact of logistics outsourcing on the profit generated by the business entity,
- changes in turnover – enable the evaluation of the effectiveness of logistics outsourcing, if the separation of logistics processes results in a change in the value of assets,
- changes in the break-even point – analyzing them before and after logistics outsourcing allows you to assess the profitability of outsourcing. A profitable change is to reduce the break-even point.

Risk analysis for logistics outsourcing should be carried out in the following areas (Gąsowska, 2016):

- operational risk, which results from the fear of losing control over logistics processes or an external company's access to confidential information,
- risks associated with selecting a logistics service provider,

- risk regarding the quality of logistics services and the consequences of irregularities in separate logistics processes,
- risks associated with securing confidential company's information,
- risk associated with introducing organizational changes in the enterprise.

The outsourcing process can generally be divided into three phases (www_6.3):

1. **Internal preparations** of the company – the purpose of this stage is to initiate discussions with logistics service providers. It depends primarily on whether the company planning to transfer warehouse functions to a service company is able to collect all information on its warehouse inventory for a period of at least several months and whether the decision-making processes applicable in the organization are defined, as well as the conditions for selecting a logistics service provider. Depending on the level of complexity of logistics processes and the size of the enterprise, it should be assumed that the time of internal preparations to initiate negotiations with logistics specialists may range from one to six months. This phase should end with a tender for logistics services along with all the necessary data, entrusted to a designated group of logistics suppliers.
2. **Inviting external companies** to submit their proposals for logistics services, trade negotiations and selecting the organization that will ultimately take over logistics services. The second part of the process, including conversations and negotiations with selected logistics service providers, may last from three months to about half a year. This is the period needed to develop offers and all other activities accompanying this task: commercial discussions, phased narrowing of the group of service providers in subsequent stages of the tender, until the winner is selected.
3. **Implementation**, i.e. working with the selected business entity to implement the project and physical transfer of warehouse stocks under the operator's management. The third phase usually lasts four to six months. Of course, the implementation period of the operation is the result of many factors and in multi-aspect projects the implementation may take much longer. It is always worth taking into account some time in case of unforeseen circumstances.

Table 6.4. Basic types of outsourcing

Advantages of logistics outsourcing	Disadvantages of logistics outsourcing
Optimizing expenses and reducing investment risk	Employees' fear of dismissal and demotivation
Ability to focus on the right business	Partial loss of control over order execution.
Improving the flow of processes and division of responsibilities	Choosing a partner with a lack of competence
Improving the quality of consumer service	Becoming dependent on a service provider
Increasing competitiveness	Possible problems with coordination and internal communication

Source: (www_6.4)

The increase in the efficiency of logistics processes obtained thanks to logistics outsourcing affects the efficiency of management in the enterprise and the supply chain (Kowalska, 2011). Cooperation of an enterprise with companies providing logistics services may contribute to cost reduction, improvement of financial liquidity, increase in sales profitability, return on assets, return on equity, improvement of indicators (Gąsowska, 2016).

Chapter Questions

1. What are the potential risks associated with outsourcing processes in a company?
2. What are the main factors influencing the decision to choose a "make" or "buy" strategy in the context of the company's operation?
3. What is the key data that should be collected to correctly assess the need for outsourcing logistics systems?

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7. DISTRIBUTION NETWORK OPTIMIZATION USING GRAVITY POINT

The chapter discusses the problem of optimizing the logistics network using Gravity Point (Gravity Model). The supply chain network transforms raw materials into final products and, of course, delivers them to end customers (consumers). It includes different types of objects. Supply chain network design (SCND) is an important issue related to supply chain management (SCM). The most important issues discussed in this chapter include:

- Supply chain network,
- Distribution network,
- Gravity Point.

7.1. Introduction

Supply chain network design (SCND) is an important issue related to supply chain management (SCM). A supply chain is understood as a complex network of enterprises and facilities, most of which are distributed over a large geographical area. This supply chain should synchronize a number of interrelated activities through a network.

The supply chain network transforms raw materials into final products and, of course, delivers them to end customers (consumers). It includes different types of objects. Planning and designing a supply chain network therefore focuses on identifying the number and types of individual links and coordinating activities between them. Typical links in a supply chain network consist of suppliers and subcontractors, manufacturing and assembly plants, distribution centers, warehouses, and customers (Govindan et al., 2017). Typical material flows take place from suppliers to customers. Reverse flows can also be distinguished (so-called reverse logistics). You should also remember about the need to plan and design flows and deal with problems related to many variants/types of products. Analysis related to the location of a given facility in the supply chain is an important issue for the operation of this chain and costs.

7.2. Logistics network

The complexity of the supply chain network is important and influences planning decisions along with classic location allocation decisions to achieve an integrated system (Govindan et al., 2017).

Considering the three levels of decision-making, at the **strategic level**, supply chain decisions need to be made such as: (1) number, (2) location, and (3) capacity of facilities. Strategic decisions typically have a time horizon of about three to five years. Strategic decisions regarding the design of the logistics network influence the effectiveness of customer demand service. Design decisions cannot be made without considering the impact on operational decisions. **Tactical decisions** typically span from three months to three years. For example, pricing decisions are typically placed at the tactical planning level. **Operational decisions** (e.g., vehicle routing decisions) often range from one hour to one trimester (Govindan et al., 2017). Of course, the scope of decisions made may depend on the nature of supply chains.

The selection of the best location for a business facility may be considered in terms of general or specific location. The general location defines a certain area where a given economic facility is to be located.

There are many factors that influence the location of an object in the supply chain. These are among others:

- sources of raw materials and location of markets for production materials (mainly raw materials, components),
- industrial traditions of the region, including accessibility to suppliers and customers (particularly important for the activity of intermediate links),

- labor force (employment opportunities, remuneration, availability, level of qualifications),
- possibilities of supplying energy factors,
- tax regulations and administrative restrictions,
- climate and terrain conditions,
- availability of roads and transport points,
- characteristics of population, socio-political relations,
- infrastructure characteristics (roads, schools, communication),
- possibility of expanding the facility.

However, a detailed location indicates a specific property or area where the facility is to be built. The choice of a detailed location is related to, for example, its technical infrastructure, availability of transport infrastructure (local roads), as well as the local development plan.

In more detail, you should also take into account:

- wage rates in neighboring plants,
- communication options for the crew and travel fees,
- possibility of purchasing the desired plot in a selected region,
- roads, highways and land development with water and gas networks,
- safety zones for odors, noise and pollution,
- terrain enabling the construction of production and auxiliary facilities, parking lots
- possibility of future expansion in accordance with the needs of the production process and the requirements of architectural and construction authorities.

The scope of detailed localization is not covered in this study.

It is important to remember that supply chains operate in a changing environment. It often happens that facilities are closed, opened or reopened more than once within the established planning horizon. Market dynamics force another decision to be made, i.e. the issue of increasing, decreasing or transferring the production capacity of facilities in the logistics network. Another important issue is any type of **disruption** to the functioning of supply chains. A supply chain disruption is an event that may occur in part of the supply chain due to, for example, natural disasters (e.g. earthquakes and floods) and intentional or unintentional human actions (e.g. wars and terrorist attacks). It is identified as an event that interrupts the flow of materials in supply chains, causing the flow of goods to suddenly stop. Even a small disruption can have a devastating impact on the functioning of supply chains as it cascades through the chain (Grzybowska & Stachowiak, 2022). And since supply chains are complex and heterogeneous structures, they are vulnerable to threats and difficult to manage.

The distribution network, often the downstream part of the SC network, consists of product streams from warehouses to customers or retailers. Designing such a network requires solving two difficult combinatorial optimization problems, including determining the location of the facility and the routes of vehicles to serve customers.

7.3. The concept of using the gravity model in a logistics network

Building a reasonable logistics network is the key to the development of regional logistics. The gravity model is derived from Newton's gravity - let us recall: the law of gravity is the law of universal gravitation, the purpose of which is to describe the force with which bodies attract each other.

Gradually, the concept of applying the gravity model was applied to other studies, areas and fields by analogy with physics. In its later expansion, in addition to proving the existence of the gravity model theory itself, it was applied to many disciplines. Among them, the most widely developed research is related to trade, urban spatial connections and logistics:

- Reilly was the first to use the gravity model to study relationships between cities (1929),
- Stewart proposed the concept of the gravity model (1948),
- Tinbergen introduced the gravity model (GM) to international trade (1962),
- Huff proposed the use of the gravity model to estimate market share (1963),
- Bergstrand clarified the supply side of economies, indicating the theoretical foundations of the relationship between the endowment of production factors and trade with Constant Elasticity of Transformation (CET) (1989),

- Kong et al examined the design of green space networks using a gravity model (2010),
- Duanmu et al developed a coupled gravity model and genetic algorithm to study charge distribution (2012),
- Puertas et al. used the gravity model to analyze the logistics network - estimating the logistics efficiency index (2014),
- Zhu & Fan used the gravity model to study the intensity of logistics connections in inland regional logistics (2017).

Distance in Newton's model is an approximation of resistance to motion, i.e. a factor that weakens the force of attraction. This means that the more distant partners are from each other, the less intense their mutual trade is. The main reason for this is the existence of trade transaction costs, which increase with increasing geographical distance. These costs include, among others: transport costs or cargo insurance (Bułkowska, 2018).

Geographical location has always been a factor determining business activity. The meaning and possibilities of transport have changed. Geography is one of the main sources of trade costs, that is, the spatial characteristics of countries that influence their domestic and international transportation costs. Features that are taken into account include geographic distance between facilities or countries. In the case of country analysis, the analysis includes answers to the questions: do the countries have a common border?, are they landlocked countries?, are they island countries? Intuition suggests that greater geographic distance, lack of a common border, and/or greater distance from a trading partner negatively impact transportation costs. Therefore, it has a negative impact on international trade. These consequences can be mitigated through infrastructure development such as the creation of highways, tunnels, airports and ports (Azmi, et al., 2024).

One of the factors in the location of business facilities is the proximity of the sales market. This neighborhood takes on a new and crucial meaning. It is becoming an asset again after the experience of the COVID-19 pandemic and in relation to improving the resilience of supply chains to disruptions.

This applies especially to companies that:

- produce or supply perishable goods,
- are characterized by high price elasticity of supply or services offered,
- produce products that are characterized by high demand variability,
- produce or transport goods that are burdensome to transport.

7.4. Typical decision-making process regarding the location of a facility in the supply chain

In the short term, the manager must operate within the constraints imposed by the location. However, in the long term, location becomes a variable and the manager may make decisions to change the location in order to meet the requirements of customers, suppliers or changes imposed by competitors.

External factors influencing the motivation to analyze the location of a new facility or change the location of a facility are:

- expansion into new markets,
- shifting of residential clusters,
- threats from competition,
- emergence of new supply markets.

The location should meet two criteria: quantitative (cost) and qualitative. Quantitative criteria are considered first. The object location pattern has the form:

$$\boldsymbol{C} = \frac{\sum \boldsymbol{r_i} \cdot \boldsymbol{d_i} \cdot \boldsymbol{S_i} + \sum \boldsymbol{R_i} \cdot \boldsymbol{D_i} \cdot \boldsymbol{M_i}}{\sum \boldsymbol{r_i} \cdot \boldsymbol{S_i} + \sum \boldsymbol{R_i} \cdot \boldsymbol{M_i}}$$

where:

C – center of mass

d_i – distance from point 0 on the grid to the location of the source of raw material i

D_i – distance from point 0 on the grid to the point of location of the source of sales market i

S_i – weight volume of raw materials purchased from supply sources i

M_i – weight volume of finished products sold on market *i*

r_i – transport rate for finished product *i*

R_i – transport rate for raw material *i*.

This is explained by the formula used in Excel:

center of mass = a + b / c+d

a = SUM [transport rate for raw material$_{(i)}$ * distance from point 0 on the grid to the point of location of the source of raw material$_{(i)}$ * weight volume of raw material$_{(i)}$]

b = SUM [transport rate for the finished product$_{(i)}$ * distance from point 0 on the grid to the point of location of the source of the market$_{(i)}$ * weight volume of the finished product$_{(i)}$]

c = SUM [transport rate for raw material$_{(i)}$ * weight volume of raw material$_{(i)}$]

d = SUM [transport rate for finished product$_{(i)}$ * distance from point 0 on the grid to the point of location of the source of the market$_{(i)}$]

7.5. Disaggregated and aggregated gravity models

There are many variants of the gravity model that can be used to simulate flows between retailers and consumers. The choice of model depends on the purpose of its use and on the data available to fit the model. When choosing a gravity model, the level of aggregation is also an important factor. Shopping interactions between consumers and retailers can be represented in a **disaggregated model** that estimates consumer behavior. Can also be presented in an **aggregated model**. In this variant, retail outlets in the zone are assessed collectively (Schlaich, 2020). In aggregate models, the characteristics of individual stores and the exact distances between the consumer and the retailer disappear. On the other hand, aggregation into zones significantly reduces the complexity of the model as the set of destinations decreases.

Of all models of spatial interaction in retailing, Huff's (1963) gravity model is one of the most widely used. In its initial form, this model calculates patronage probabilities depending on store size and transportation distance.

In gravity models, an important issue is to determine the variable describing the "power of mutual attraction" of trading partners, i.e. the model explained (dependent) variable. Gravity models provide geographers and economists with a flexible analysis tool.

7.6. Balanced gravity model

The balanced center of gravity method is used to determine the location of a single economic facility (e.g. warehouse). It takes into account sources of demand of various importance and location. The location is determined using coordinates (X, Y), which indicate the position of the point on the map. The importance is related to, for example, the volume of deliveries, the number of people living in a given location or the sales value. You can also use another indicator, it is important that it is properly adjusted to the situation. The described method uses weighted supply point coefficients, thus generating a point on the map marked with coordinates.

For the weighted centroid method, use the model:

$$\boldsymbol{X}^* = \frac{\sum \boldsymbol{W_i} \cdot \boldsymbol{X_i}}{\sum \boldsymbol{W_i}}$$

$$\boldsymbol{Y}^* = \frac{\sum \boldsymbol{W_i} \cdot \boldsymbol{Y_i}}{\sum \boldsymbol{W_i}}$$

where,

X_i, Y_i – coordinates of the i-th source of demand

W_i – weight of the i-th source of demand

The weighted coordinates (X^*, Y^*) calculated using the model indicate the appropriate location of the supply point, taking into account the importance (importance) of individual demand sources.

This is explained by the formula used in Excel:

coordinates of the supply point (X) = SUM [(weighted indicator of the demand source$_{(i)}$ * coordinates X$_{(i)}$)] / SUM coordinates X$_{(i)}$

supply point coordinates (Y) = SUM [(weighted indicator of demand source$_{(i)}$ * Y coordinates$_{(i)}$)] / SUM Y coordinates$_{(i)}$

The balanced center of gravity method allows you to determine the location of one economic facility in a selected geographical area. The method is simple to use and comes down to determining two parameters on a geographical grid.

An extension of this method is the model:

$$\boldsymbol{Coordinates}_{\,(X,Y)} = \frac{\sum \boldsymbol{r_i \cdot d_i \cdot S_i} + \sum \boldsymbol{R_i \cdot D_i \cdot M_i}}{\sum \boldsymbol{r_i \cdot S_i} + \sum \boldsymbol{R_i \cdot M_i}}$$

where,

$Coordinates_{\,(X,Y)}$ – center of gravity

r_i – transport rate for finished product *i*

d_i – distance from point *0* on the grid to the location of the source of raw material *i*

S_i – weight volume of raw materials purchased from supply sources *i*

R_i – transport rate for raw material *i*

D_i – distance from point *0* on the grid to the point of location of the source of sales market *i*

M_i – weight volume of finished products sold on market *i*

Calculations are performed for vertical and horizontal coordinates.

This is explained by the formula used in Excel:

Counter(X) = SUM (transport rate for the finished product$_{(i)}$ *** distance from point 0 on the grid to the location point of the raw material source**$_{(Xi)}$ *** weight volume of raw materials purchased from the supply sources**$_{(i)}$**) + SUM (transport rate for the raw material**$_{(i)}$ *** distance from point 0 on the grid to the point of location of the source of the market**$_{(Xi)}$ *** weight volume of finished products sold on the market**$_{(i)}$**)**

Denominator = SUM (freight rate for finished product$_{(i)}$ *** weight volume of raw materials purchased from supply sources**$_{(i)}$**) + SUM (freight rate for raw material**$_{(i)}$ *** weight volume of finished products sold on the market**$_{(i)}$**)**

supply point coordinates (X) = Numerator$_{(X)}$ **/ Denominator**

Counter$_{(Y)}$ **= SUM (transport rate for the finished product**$_{(i)}$ *** distance from point 0 on the grid to the location point of the raw material source**$_{(Yi)}$ *** weight volume of raw materials purchased from the supply sources**$_{(i)}$**) + SUM (transport rate for the raw material**$_{(i)}$ *** distance from point 0 on the grid to the point of location of the source of the market**$_{(Yi)}$ *** weight volume of finished products sold on the market**$_{(i)}$**)**

Denominator = SUM (freight rate for finished product$_{(i)}$ *** weight volume of raw materials purchased from supply sources**$_{(i)}$**) + SUM (freight rate for raw material**$_{(i)}$ *** weight volume of finished products sold on the market**$_{(i)}$**)**

supply point coordinates (Y) = Numerator$_{(Y)}$ **/ Denominator**

7.7. Gravity model in international trade

Tinbergen (1962) was the first to provide an intuitive explanation of bilateral trade flows in international trade. His discoveries laid the foundation for the modern gravity model, which assumes that trade between nations is directly proportional to the size of their economies and inversely proportional to the costs of trade. This should be understood as follows:

- larger countries are expected to trade more,
- countries that are further apart are expected to trade less (possibly due to higher trade costs).

Since then, the model has been widely used in the industry literature to explain international trade flows. Due to the effectiveness of the gravity model in trade research, we have seen a significant increase in the use of the gravity model to assess various aspects of international trade (Azmi, et al. 2024).

$$\boldsymbol{X_{ij} = \alpha_i + \beta_1 \cdot GDP_i + \beta_2 \cdot GDP_j + \beta_3 \cdot TC_{ij} + \mu_i}$$

where:

X_{IJ} – flow in international trade from country I to country J

GDP_i i GDP_j – gross domestic product of the country of origin and country of destination

TC_{IJ} – the cost of trade between two countries, estimated by the geographic distance between the capital cities

μ_i – random error

α_i – model intersection point

$\beta_1, \beta_2, \beta_3$- coefficients measuring the impact of explanatory variables.

This is explained by the formula used in Excel:

trade flow = intercept + coefficient$_{(1)}$ * income of exporting country + coefficient$_{(2)}$ * income of importing country + coefficient$_{(3)}$ * cost of trade between two countries + random error

Various variants of the presented model are also known. Below is one of them:

$$\boldsymbol{X_{ij} = \beta_0 + \beta_1 \cdot y_i + \beta_2 \cdot y_j + \beta_3 \cdot n_j + \beta_4 \cdot n_i + \beta_5 \cdot d_{i,j} + \beta_6 \cdot D_{ij} + \mu_{ij}}$$

where:

X_{ij} – rade flow (export or import from country *i* to country *j)*

y_i – income of exporting country *i*

y_j – income of the importing country *j*

n_j – population of country *i , j*

$d_{i,j}$ – distance between countries *i* i *j*

D_{ij}– a dummy variable with the value 1 if countries i and j are members of specific preferential trade areas, and 0 otherwise

β_0– represents the intersection point

$\beta_1 - \beta_6$ – coefficients$y_i, y_j, n_j, n_i, d_{i,j}, D_{ij}$ respectively

μ_i – random error.

This is explained by the formula used in Excel:

trade flow = intercept + coefficient$_{(1)}$ * income of exporting country + coefficient$_{(2)}$ * income of importing country + coefficient$_{(3)}$ * population of country j + coefficient$_{(4)}$ * population of country i + coefficient$_{(5)}$ * distance between countries + coefficient$_{(6)}$ * dummy + random error

7.8. Gravity model of locating competitive objects

Most competitive facility location models assume that all available purchasing power is shared among competing facilities.

The leitmotif of all competitive location models is the existence of interconnections between four variables: purchasing power (demand), distance, attractiveness of the facility and market share. The first indicated variables are independent variables, while market share is a dependent variable.

Each competing facility, e.g. a commercial facility, has a "sphere of influence". It is determined by his level of attractiveness. More attractive objects have a larger radius of their sphere of influence. The purchasing power expended by the consumer in the sphere of influence of several objects is divided equally between competing objects (Drezner & Drezner, 2016).

Competitive location models have a number of applications, e.g. they enable the location of shopping centers, stores (e.g. grocery stores, specialty stores - household appliances; footwear; bookstores; computers, jewelry...), restaurants (fast food, cafes, ice cream parlors...), gas stations, bank branches and other.

7.9. Gravity model for intercontinental supply chain

Gravity models can serve as suitable assessment tools for estimating cargo delivery to ports, with time and distance costs playing an important role (Wang & Li, 2021). To analyze the interaction patterns of retail regions associated with different agglomerations, Reilly created a gravity model of goods flows as:

$$\boldsymbol{X_{ij}} = \boldsymbol{\alpha} \frac{\boldsymbol{P_i \cdot P_j}}{\boldsymbol{d_{ij}^2}}$$

where:

X_{ij} – flow in the supply chain

d_{ij} – spatial distance

P_i, P_j – population in the place of origin i and destination j

α – gravity coefficient, constant equal to 1.

This is explained by the formula used in Excel:

flow in the supply chain = gravity coefficient * population in the place$_{(i)}$ * population in the place$_{(j)}$ / spatial distance^2

In this model, the location of all nodal cities is known. The gravitational pull between cities can be determined by the city's size and spatial distance.

Chapter Questions

1. What external factors influence the decision to relocate a facility?
2. What are the main advantages and limitations of using different variants of the gravity model to simulate flows between retailers and consumers?

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8. DEMAND FORECASTING

The chapter discusses forecasting theory. Particular attention was paid to demand forecasting. It is the prediction of future events (related to demand and demand), the aim of which is to minimize the risks associated with making business decisions. The most important issues discussed in this chapter include:

- forecasting principles and trends,
- time series forecasting,
- procedure for developing forecasts based on time series,
- forecasting methods and errors,
- the issue of artificial intelligence in forecasting.

8.1. Introduction

Forecasting is a widely used, multidisciplinary science. It is an important activity that is used to make business decisions in many areas of planning: economic, industrial and scientific (Chatfield, 2001). The built forecast supports making micro- and macroeconomic decisions. It also supports taking actions to activate or oppose some phenomenon. It is also a source of valuable information. Forecasting can be called prediction; predicting future demand, predicting sales or a new trend. Changes in market conditions to which the company must adapt can therefore be predicted.

However, this prediction cannot be based solely on the first and intuition of managers, which are predicted or not based on an improperly prepared basis, which can be triggered by the enterprise device. This is not every prediction is forecasting, because forecasting (also called prediction) is used on **rational, usually scientific grounds**.

Forecasting is inferring about unknown events based on known events (Cieślak, 2005). For example, it can be predicted that: (1) the event will occur because it occurred in the past;

(2) an event will occur because its frequency indicates it; (3) the event will occur because it is related to other events that have occurred (Dittmann, 2003).

Forecasts are developed (built) on the basis of premises of a very different nature. However, taking into account their scientific nature, they are constructed primarily on the basis of statistical and econometric models and using operational research. Forecasts are prepared using historical data - those that occurred in the past. And from the logistics point of view, they are related to data from the recent past. Especially in complex product industries (e.g. automotive industry), but not only, demand forecasts are crucial for the sales area and also for the efficiency of the production system.

The forecast always concerns a specific forecast horizon. The forecast horizon is the interval $\left(T, T_i\right\rangle$, where: T – current moment, T_i – final moment.

Depending on the time horizon, the forecasting problem is generally divided into three areas: short-term, medium-term and long-term forecasting. As mentioned earlier, from the point of view of a logistics manager, **short-term forecasting** is crucial. It covers prediction horizons from one hour to a week. Also interesting from the point of view of a logistics manager's work is medium-term forecasting, which refers to forecasts from one month to a maximum of a year. Finally, we can distinguish long-term forecasts, which are characterized by a prediction horizon longer than one year. They are less important for operational activities related to logistics. Chaos theory has largely shown that long-term forecasting is a wasted effort. Therefore, it can be assumed that for broadly understood logistics activities, the longer the forecast horizon, the lower the probability of the forecast being made. Her confidence is decreasing. Also, forecasting for a product in a longer term than the product's life cycle does not make sense.

The value (importance) of forecasting models is based on their ability to produce accurate forecasts. Therefore, the forecasts are only as good as the assumptions of the model used. It is important to be aware and know what these assumptions are. If any of these assumptions turn out to be incorrect, the forecasts can be re-evaluated, modified and improved. The main problem of forecast accuracy is the unpredictability of economic trends and external events and crises. Therefore, it should be clearly stated that specific forecast values are subject to **error** and **uncertainty**. Thus, the future is determined based on the knowledge we have about the past (Fig. 8.1).

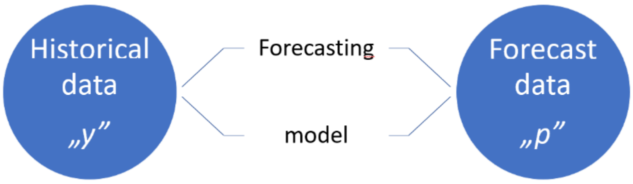


Figure 8.1. Generalized forecasting model

Source: (Dittmann, 2003)

We should not forget about the need to exchange information in supply chain management, which is crucial for the success of demand forecasting (Altendorfer & Felberbauer, 2023). The more accurate the information about demand, the more accurate the forecast will be. Also crucial is the ongoing update of information about demand (it involves changing previous information, e.g. about the size of the order), thanks to which demand is updated in the time horizon and the elimination of information asymmetry. Ali et al. point out that sharing full demand forecasts, rather than the final order quantity, is beneficial to supply chain performance (Ali et al., 2012).

The challenges of successful forecasting are more than just the technical difficulties of developing an accurate forecast model. Forecast models must be developed with a clear understanding of both the nature of the situation for which a forecast is desired and the resources available to produce the forecast. It is important to ensure that the selected variable relates directly to the forecast data needed (Sheldon, 1993). This does not mean that forecasts are useless, but that those who use them should constantly monitor their operating environment to detect any factors that indicate inconsistent or irregular patterns.

Although the forecast is subject to inaccuracies, it constitutes an important guideline for the future operational activities of the company. The justification for creating forecasts in an enterprise is also the cyclicality that occurs in enterprise operations. We predict that if an event occurred in the past, it may also occur in the future. However, if an event occurred in the past with a certain frequency, the probability that it will occur again increases. Despite many uncertainties, a forecast constructed using scientific methods is a prerequisite for making a rational decision regarding the company's operations.

Economic practice also shows that a **simple forecasting method does not automatically mean a worse method** (Kucharski, 2013). As Kucharski points out, naive methods can forecast the same data with similar accuracy. They are much easier to use. As a result of activities related to demand forecasting, it is possible for the organization to obtain many benefits (Table 8.1).

Table 8.1. Benefits of demand forecasting

Identified forecasting benefit	Justification
Better production organization	knowing the forecast sales volume of finished products, the organization can plan the appropriate production volume and the appropriate demand for raw materials and packaging in advance; thus eliminating shortages on the production line
Greater control of safety stock	knowing the forecast sales volume of finished products, you can plan a safety stock that will guarantee the coverage of market demand
More effective reduction of outdated assortment	knowing the forecast sales volume of finished products, you can focus on servicing only the assortment necessary to cover demand; obsolete products can be eliminated and, as a result, the costs of frozen capital in inventory and storage costs can be optimized
Better customer satisfaction and improvement of the organization's image	knowing the forecast sales volume of finished products can ensure that the appropriate level of inventory is maintained in the warehouse
More efficient use of warehouse space	knowing the forecast sales volume of finished products, you can collect only the necessary stocks of products; you can also significantly reduce the storage space used
More effective control and cost minimization	knowing the forecast sales volume of finished products, you can more accurately plan the organization's budget and take steps to control expenses more precisely

Source: (Wojciechowski & Wojciechowska, 2015; Wolny & Kmiecik, 2020)

Several properties of forecasts should be indicated. These are:

1. Forecasts are formulated using the achievements of science (developed and verified mathematical models).
2. Forecasts refer to a specific future.

3. Forecasts are verified empirically (after a specified period of time).
4. Forecasts are acceptable to the person preparing the forecast.

Forecasts support the decision-making process in the company and at the same time fulfill various functions. (Gajda, 2001):

- preparatory – the forecast is an impulse to take a specific action, but it has no influence on the forecasted phenomenon. Only economic decisions are made on its basis,
- activating – the forecast is an impulse to take a specific action and at the same time influences the forecasted phenomenon. Therefore, actions are taken that are aimed at making the forecast realistic (self-fulfilling or favorable forecasts, which trigger actions that favor the realization of the forecasts) or annihilating the forecasts (warning forecasts, which trigger actions that counteract their realization).

However, it is important to remember that the forecasts built can easily break down due to random variables that cannot be incorporated into the model or may be simply wrong from the start. For this reason, forecasting can be dangerous for organizations. There are three problems related to forecasting:

- the data on the basis of which forecasts are made will always be old, relating to historical periods. So there is never a guarantee that past conditions will persist in the future,
- exceptional or unexpected events or external effects cannot be taken into account (example of the COVID-19 pandemic; impact of war and armed conflicts; impact of unforeseen economic crises),
- forecasts cannot take into account their own impact.

Properly conducted forecasting allows entrepreneurs and managers to plan their activities in advance, increasing the chances of remaining competitive on the markets.

8.2. Classification of forecasting methods

There are two basic groups of forecasting methods: quantitative and qualitative (Fig. 8.2). A forecast classified as a quantitative forecasting method takes the form of a specific number (point forecast) or, alternatively, a numerical range (interval forecast).

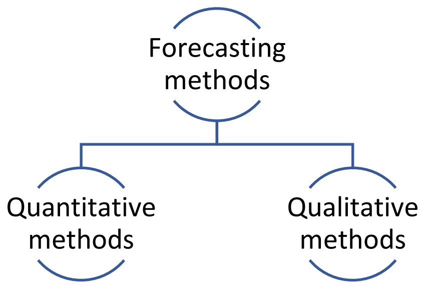


Figure 8.2. Forecasting methods – types

Source: (Dittmann, 2000)

Qualitative forecasts take a non-numerical form. They refer to the analyzed phenomenon in the future and the estimation of its growth, decline or no change. Qualitative forecasts can be treated as based on the opinions of market experts.

From the point of view of a logistics specialist, however, the key forecasts are those that can be defined using numbers, i.e. **quantitative forecasts**. Quantitative forecasting bypasses the expert factor and tries to remove the human element from the analysis. These approaches focus solely on data.

Quantitative forecasts	Time series models
	Econometric models
	Analog models
	Lead variable models
	Cohort analysis models
	Market tests

Figure 8.3. Quantitative forecast methods

Source: (Dittmann, 2000)

Quantitative forecasts can be classified according to the models used (Fig. 8.3). For the purposes of this book, the focus is on **time series models**.

8.3. Time series forecasting

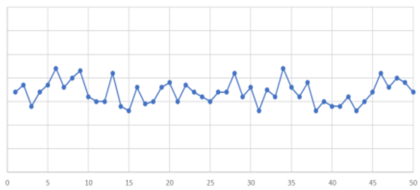
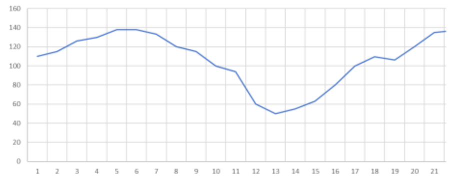
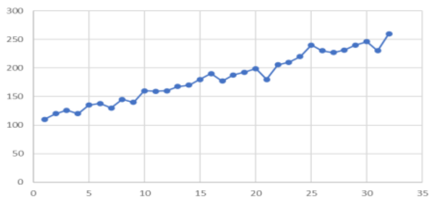
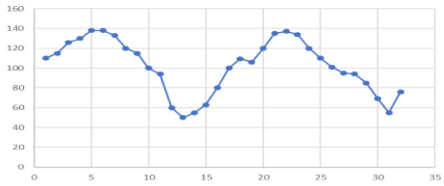
One of the most frequently used forecasting methods for forecasting demand are methods based on time series models. Time series is a methodology for exploring complex and sequential types of data. In time series models, sequential data, which consists of strings of numeric data, is recorded at regular intervals (e.g. per minute, per hour, or per day). The popularity of these methods results from the possibility of obtaining information about the future course of the observed phenomenon through forecasting. Therefore, there is no need to collect and analyze further data from other sources. Forecasting using time series is also often used due to the high probability of its occurrence. Economic practice also shows that forecasts prepared using time series models are not worse than forecasts obtained based on more complicated models. Experience also shows that **time series models have development potential**. Each subsequent modification of the method or subsequent time series forecasting method should, by definition, improve the quality of its results.

8.4. Time series decomposition

Forecasts are built using time series data. This happens regardless of the forecasting method adopted. Time series data (variables) are ordered chronologically, from the oldest data to the newest data. It should be emphasized that the last data does not correspond to the moment of building the forecast. In scientific publications and studies, it is assumed that y_t always determines a specific value of the y series in the period (moment) t.

The components of the time series are random fluctuations, development tendency (trend), cyclical fluctuations and seasonal fluctuations (Table 8.2).

Table 8.2. Time series visualization

random fluctuations 	cyclical fluctuations 
development tendencies (trend) 	seasonal fluctuations 

Source: own study

A few words can be said about each of them (Cieslak, 1997):

- random fluctuations – these are random, accidental and unpredictable changes in a series variable of varying strength, which are observed over time and do not show any clear tendency. They are associated with errors of a statistical or prognostic nature,
- development tendencies (trend) – these are the long-term tendency of series data to one-way (monotonic) changes in the forecast variable. They are of an increase or decrease nature. They most often concern a permanent phenomenon that affects the analyzed data. Time series data may contain both developmental trends and random fluctuations. In order to isolate development trends, more historical data is usually needed. Hence, we observe a rule of thumb: the longer the period of historical data observation, the greater the ability to precisely determine the type of trend. The trend is presented using a linear or non-linear mathematical function,
- cyclical fluctuations – these are long-term, rhythmic fluctuations in the value of a variable around a trend or a constant level, which persist for a long time (longer than a year). They are the result of business cycles. Different cycle

lengths and their dynamics can be observed. Cyclical fluctuations are therefore related to changes in the economic activity of enterprises, crises or economic recovery or the wealth of society. To analyze cyclical fluctuations and build a forecast of future demand, monthly, quarterly or annual historical data from the last few years are needed,

- seasonal fluctuations – these are fluctuations in the value of a time series variable around a trend or constant level, which tend to repeat at regular (seasonal) intervals, not exceeding a year. In such a case, the accuracy of the forecasts built will depend on the type and scale of seasonal fluctuations, the number and type of gaps in the available data, and the forecast horizon.

The identification and analysis of the indicated components of a time series is called **time series decomposition**.

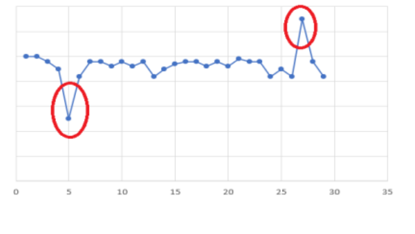
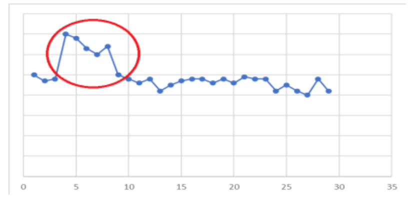
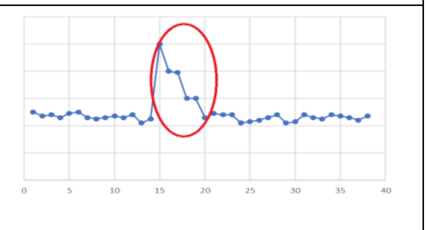
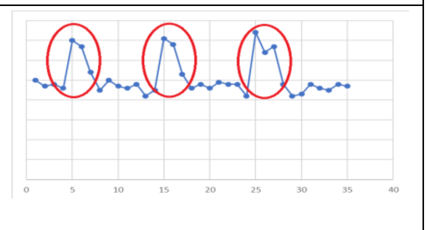
8.5. Preparing time series data

Before taking steps to build forecasts, it is worth performing preliminary data processing, also known as **data cleaning**. They need to be verified to eliminate errors or outliers. Skipping this step may result in distortion of forecast results and, as a result, errors in conclusions. It must be remembered that data related to unusual cases (outliers or rare cases) are true information about which the forecaster has no doubts. They are proven and reliable.

There are various strategies for dealing with outlier data. This is among other things:

- no action – it involves ignoring atypical data, because some forecasting methods are resistant to the occurrence of atypical data,
- filtering cases with outlier data – this involves removing this data; however, this is not the best strategy,
- replacing unusual data – this is a popular strategy in which outliers are replaced by: (1) a value of *0*, (2) an average value; (3) the maximum/minimum value of the filter or (4) another value determined on the basis of a substantive criterion.

Table 8.3. Selected types of outliers

Additive outlier It appears as a surprisingly large or surprisingly small value for a single observation. It has no effect on subsequent observations – the value of the series does not deviate any further.	
Innovative outlier It occurs as a deviation with further effects on observations. An initial (first) effect with a delay and extension effect on subsequent observations (decreasing or increasing) can be observed. This impact may decrease or increase over time.	
Transient change outlier It occurs when the influence decays exponentially with subsequent observations. Eventually the series returns to its normal level.	
Seasonally additive outlier It appears as a surprisingly large or surprisingly small value that occurs periodically (at regular intervals).	

Source: own study

Leaving atypical data in the time series distorts the result of their analysis and makes it difficult to formulate conclusions, because the atypical data are extremely small or extremely large values. Due to their inconsistency, these values are called **outliers**. As a result, they increase the range in the time series (minimum-maximum range). Therefore, atypical data have a large distorting effect on the forecast value (Table 8.3).

The decision to change the size of an unusual item or remove it is always highly subjective to the forecaster, so it requires caution. Reducing the forecaster's subjectivity when removing atypical cases is possible with quantitative data. For example, you can apply the **standard deviation rule**. This means that if historical data is unusual (e.g. outside the range of the group mean *(x)* plus or minus 2 or 3 standard deviations), it is changed or removed.

It is worth submitting each series of data to the decomposition procedure. Several steps can be specified:

1. Identifying the functional form of the series, which means determining the type of trend.
2. Search for outlier observations and replace them with average values or so-called upper and/or lower filters.
3. Verification whether the last observed data in the series behaves typically; if not cleansing it.
4. Identification of the trend slope coefficient, in order to determine the stability of the main trend observed in the series.
5. Examine the stability of the current short-term trend.

Filters (minimum or maximum) are a good solution when outliers appear (Fig. 8.4).

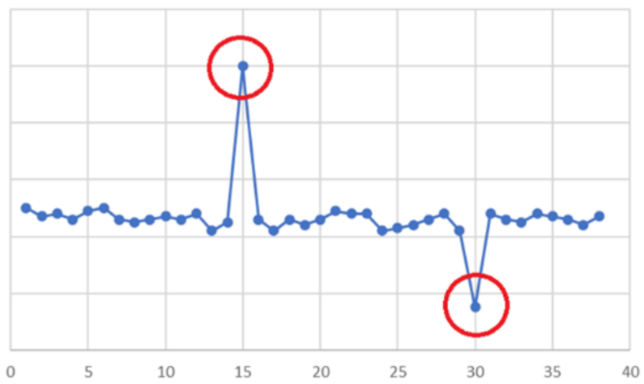


Figure 8.4. Clearly inconsistent values with the general regularity of the time series

Source: own study

The filter is used to correct the data before building the next forecast. A value that deviates from the correct series is replaced with a minimum or maximum filter (Fig. 8.5). Extreme outliers are found above $y_{max} + 3R_q$ or below $y_{min} - 3R_q$. Values suspected of being outliers are included in the ranges $(y_{min} - 1{,}5R_q; y_{min} - 3R_q)$ and $(y_{max} + 1{,}5R_q; y_{max} + 3R_q)$.

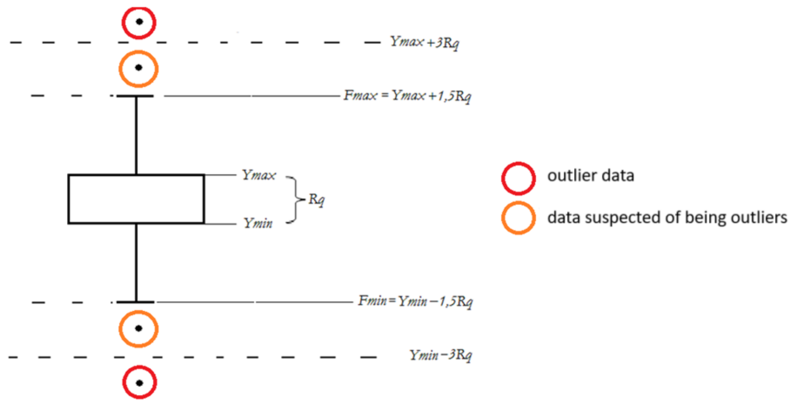


Figure 8.5. Filter values and outliers

Source: (Grzybowska, 2009)

This is represented by the model:

$$F_{min} = y_{min} - 1,5R_q$$

$$F_{max} = y_{max} + 1,5R_q$$

$$R_q = y_{max} - y_{min}$$

where:

F_{min} – minimum filter value

F_{max} – maximum filter value

y_{min} – minimum value determined from the time series

y_{max} – maximum value determined from the time series

R_q – interquartile range.

8.6. Time series forecasting methods

Time series forecasting methods have been divided according to the data trend. Forecasts can be specified for constant demand, trend-like demand (growing or decreasing) and seasonal demand (Fig. 8.6).

Constant demand	Naive methods
	Average methods
	Exponential smoothing method (Brown's model)
	Model ARMA
Trend-like demand	Linear exponential smoothing, LES (Holt's model)
	Simple linear regression method
	Model ARIMA
	Model RW
Seasonal demand	Holt-Winters' seasonal method (Holt-Winters' model)

Figure 8.6. Quantitative methods for time series forecasting

Source: own study

In the presented models, the y parameter always refers to the actual demand values, and the $\check{y}_t$ parameter always refers to the constructed forecast.

Naive methods

Naive forecasting methods are characterized as simple, fast and cheap. They allow the development of forecasts from a small amount of historical data. Naive methods also serve as a reference point for other forecasting methods (Kucharski, 2013).

Naive methods are the simplest mechanical methods. They have been developed on the assumption that there will be no significant changes in demand in the future. They are very suitable wherever there are no large fluctuations in the forecast variable. They are based solely on historical observations. Naive models only have memory of one (last) observation, so they will not filter out noise in the data, but rather copy it into the future.

Naive models consist of simple projective models. This means that they require input from recent observations and no statistical analysis is performed. They are extremely simple and at the same time surprisingly effective. The advantage of these methods is a quick decision about the predicted value. However, the disadvantage is the inability to analyze the cause and effect relationships that underlie the forecast variable.

For the purposes of this study, 3 naive methods will be presented: (1) Naïve Forecast; (2) Seasonal Naïve Method; (3) Drift Method.

Naive forecast

A naive forecast is one in which the forecast value for a given period is simply equal to the value observed in the previous period. This is represented by the formal model:

$$\boldsymbol{\breve{y}_t = y_{t-1}}$$

where:

$\breve{y}_t$ – forecast for the future period

y_{t-1} – actual value of demand from the previous period.

Formula used in Excel:

forecast$_{(t)}$ **= demand**$_{(t-1)}$

Seasonal Naive method

Also, the naive method is useful for data with small seasonal fluctuations. In this situation, each forecast is equal to the last observed value from the same season (e.g. from the same month of the previous year). The forecasts assume the value observed in the previous season. The model is useful when there are small random fluctuations and additive seasonality. This is represented by the formal model:

$$\boldsymbol{\breve{y}_{t+h|T} = y_{t+h-m(k+1)}}$$

where:

$\breve{y}_{t+h|T}$ – forecast for the future period

m – seasonal period

k – część całkowita $(h-1)/m$ (i.e. the number of complete years in the forecast period preceding $T+h$).

The model looks more complicated than it actually is. For example, if a forecast is built based on monthly data, it applies to all future monthly values and is equal to the last observed value for that month of the previous year. For quarterly data, the forecast of all future *Q2* values is equal to the last observed *Q2* value (where *Q2* represents the second quarter). Similar rules apply in other months and quarters and in other seasonal periods.

This is explained by the formula used in Excel:

$$\mathbf{forecast}_{(t)} = \mathbf{demand}_{(t,\ previous\ year)}$$

The forecast for period t is equal to the demand from the corresponding period of the previous year. The seasonal naive method will require a one-year lag.

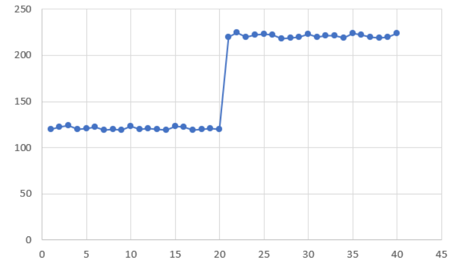
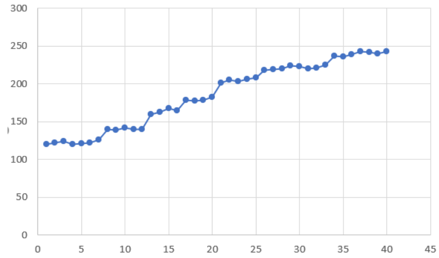
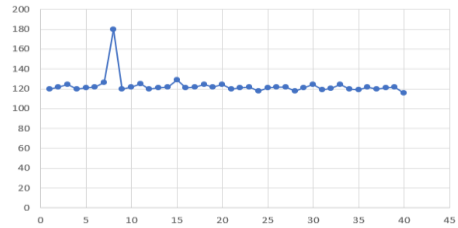
Drift method

A variation of the seasonal naive method, the drift method involves allowing forecasts to increase or decrease over time, where the amount of change over time (called drift) is set to the average change seen in historical data. The method uses an additional component called drift.

Drift refers to the decline in model performance due to changes in data and the relationship between input and output variables. This, however, may result in deterioration of the quality of the forecasting model, resulting in inaccurate forecasts. Variable drift refers to changes in input values, e.g. resulting from sudden changes in sales trends. Changing the input data can be:

- violent (sudden), e.g. due to lockdowns during the COVID-19 pandemic,
- increasing (changing slowly),
- impulse (one-off), e.g. in the case of incorrectly supplied data.

Table 8.4. Types of drift

Change of input data – rapid (sudden)	
Change of input data – incremental	
Change of input data – impulse	

Source: own study

This is represented by the formal model:

$$\breve{y}_{t+h|T} = y_t + h\left(\frac{y_t - y_1}{t-1}\right)$$

where:

$\breve{y}_{t+h|T}$ – forecast for the future period

$h(\frac{y_t - y_1}{t-1})$ – drift component.

This is equivalent to drawing a line between the first and last observation and extrapolating it into the future.

This is explained by the formula used in Excel:

$$\mathbf{forecast}_{(t)} = \mathbf{demand}_{(\text{from the last period of the previous year})} + [h * (\mathbf{demand}_{(\text{from the last period of the previous year})} - \mathbf{demand}_{(\text{from the first period of the previous year})}] / n - 1$$

The forecast for period *t* is equal to the demand from the last period of the previous *year + the drift component*. The drift component contains the number *h*, which refers to the next number of forecasts built, and *t* determines the number of examined periods in the year.

Average methods

Moving average methods act as a filter because they eliminate short-term fluctuations from the data series. To build a forecast, moving average methods use a specific number of adjacent demand data.

As the number of historical data on the basis of which the forecast is built increases, the smoothing effect increases. This means that using more data in the model smoothes the series more strongly. It also causes a slower reaction to changes in the level of the forecast variable. And conversely. Using less historical data helps reflect changes in demand from recent periods more quickly. The forecast then becomes more sensitive to random fluctuations For the purposes of this study, 4 average methods will be presented: (1) Global Mean or Global Average; (2) Simple Moving Average, SMA; (3) Exponential moving average, EMA; (4) Weighted Moving Average, WMA.

Global Mean or Global Average

The forecast, using the global average method, is built on all available historical observations included in the series. This method determines the central tendency, which is the location of the center of the data series in the statistical distribution.

The forecast value using the global average method should be calculated by adding the values of all historical data and dividing the calculated value by the number of analyzed periods.

This is represented by the formal model:

$$\breve{\boldsymbol{y}}_{\boldsymbol{t}} = \frac{\sum_{t=1}^{n} \boldsymbol{y}_{\boldsymbol{t}}}{\boldsymbol{n}}$$

where:

n – number of periods analyzed.

This is explained by the formula used in Excel:

forecast$_{(t)}$ = Σdemand/n

Using the arithmetic mean of the entire series of data distorts the result of the forecast being built. The data used in the method is too outdated, which distorts the correct picture of future demand.

Simple Moving Average, SMA

The simple moving average method uses a typical arithmetic average, but only of a certain amount of historical data. Curated data helps smooth out demand data, reducing the impact of random fluctuations and outdated data. The name moving average means that each forecast is calculated based on data from the previous *x* periods. A simple moving average does not distinguish historical data and does not weight that data.

A simple moving average is an arithmetic moving average calculated by adding the latest demand data and then dividing the resulting value by the number of periods in the calculated average. This is represented by the formal model:

$$\breve{\boldsymbol{y}}_{\boldsymbol{t}} = \frac{\sum_{t+1-m}^{t} \boldsymbol{y}}{\boldsymbol{m}}$$

where:

m – number of periods analyzed.

This is explained by the formula used in Excel:

for a 3-element average:

forecast$_{(t)}$ = AVERAGE(demand$_{(t-1)}$; demand$_{(t-2)}$; demand$_{(t-3)}$;)

To calculate a moving average you can use a simple formula based on the *AVERAGE* function with relative references.

As the formulas are copied down the column, the range changes on each row to account for the values needed for each average.

The longer the moving average, the greater the **lag**. This can be explained as follows:

- The forecast based on 3 historical data is a short-term moving average; it is like a motorboat – agile and quickly changing.
- The forecast based on 50 historical data is a long-term moving average; it is like an ocean tanker – sluggish and slow to change.
- Therefore, the lag factor should be kept in mind when selecting the appropriate number of historical periods (do not use too much data).

Exponential Moving Average, EMA

The exponential moving average method allows you to reduce latency by paying more attention to recent historical data values. This makes the method more responsive to recent data values. An exponential moving average is usually more sensitive to recent changes in demand compared to a simple moving average. This is represented by the formal model:

$$\breve{y}_t = p_{t-1} + \alpha(y_{t-1} - p_{t-1})$$

$$\alpha = \frac{2}{n+1}$$

where:

α – multiplier

n – selected time period.

Calculating an exponential moving average involves three steps:

1. Calculation of a simple moving average for a period (preliminary forecast). The SMA is only required to provide an initial value for further calculations.
2. Calculating a multiplier for weighting an exponential moving average.

   Example: if the forecast is built from 3 periods, the multiplier will be calculated as follows: multiplier = $\alpha = \frac{2}{n+1} = \frac{2}{3+1} = 0{,}5$
3. Calculation of the current forecast according to an exponential moving average

   Reminder: The first forecast calculated is called the preliminary forecast.

This is explained by the formula used in Excel:

forecast$_{(t)}$ = forecast$_{(t-1)}$ + multiplier * (demand$_{(t-1)}$ – forecast$_{(t-1)}$)

The EMA method is used to capture shorter trend moves due to its focus on the latest data and recent forecasts.

Weighted Moving Average, WMA

This is a variant of the Simple Moving Average (SMA). The Weighted Moving Average (WMA) method is a moving average that gives weight to the latest demand values. This means that the latest data has the strongest impact on the forecast value than older data. This is possible by using a weighted factor. The use of weighted coefficients allows for more accurate forecasts. The method is considered more sensitive to changes in demand.

Weighted moving average forecasts are obtained by multiplying each demand value by a predetermined weighted factor and summing the resulting values. This is represented by the formal model:

$$\breve{y}_t = \sum_{t+1-m}^{t} (y_i \bullet \varpi_i)$$

where:

ϖ – weighted coefficient.

To determine their value, remember a few rules:

- The values of the weighted coefficients are in the range $< 0,1 >$,
- Each subsequent weighted coefficient used is greater than its predecessor $\varpi_i < \varpi_{i+1} < \varpi_{i+2}$. This is a very important principle because it differentiates the importance of the historical data used. Older ones have a lower weighted factor, newer data are more important and have a higher weighted factor,
- The sum of all weighted coefficients must equal 1: $\sum_1^n \varpi_i = 1$,
- The number of weighted coefficients depends on the number of analyzed historical periods from the time series.

This is explained by the formula used in Excel

for a 3-element weighted average:

$\text{forecast}_{(t)} = (\text{demand}_{(t-3)} * \omega_{(1)}) + (\text{demand}_{(t-2)} * \omega_{(2)}) + (\text{demand}_{(t-1)} * \omega_{(3)})$

for a 5-element weighted average:

$\text{forecast}_{(t)} = (\text{demand}_{(t-5)} * \omega_{(1)}) + (\text{demand}_{(t-4)} * \omega_{(2)}) + (\text{demand}_{(t-3)} * \omega_{(3)}) + (\text{demand}_{(t-2)} * \omega_{(4)}) + (\text{demand}_{(t-1)} * \omega_{(5)})$

In the weighted moving average method, the value of the smoothing constant should be determined (how many historical periods should be used) and the levels of individual weights of the weighted coefficients should be determined.

Exponential Smoothing methods

Exponential smoothing methods are widely used (Chatfield et al., 2001). There are 15 different methods. Each variant is specified for a different forecasting scenario. The most well-known variants of the exponential smoothing method are Simple Exponential Smoothing (SES) (no trend, no seasonality), Holt's linear method (additive trend, no seasonality), Holt-Winters additive method (additive trend, additive seasonality) and Holt-Winters multiplicative method (additive trend, seasonality). multiplicative) (De Gooijer & Hyndman, 2006). Researchers have proposed numerous variants of the original exponential smoothing methods, e.g., Carreno and Madinaveitia (1990) proposed modifications to deal with discontinuities, and Rosas and Guerrero (1994) looked at exponential smoothing predictions subject to one or more constraints. For the purposes of this study, three exponential smoothing methods will be presented: (1) Simple Exponential Smoothing, SES (model Browna); (2) Linear Exponential Smoothing, LES (model Holta); (3) Holt-Winters' seasonal method (Model Holt-Winters).

Simple Exponential Smoothing, SES (Brown's model)

Simple exponential smoothing is the basic form of exponential smoothing. The exponential smoothing method (Brown's model) is a relatively accurate method of forecasting demand. It takes into account the exponential smoothing factor *(a)*. This coefficient controls the rate at which data influences the forecasts being built. At the same time, the method gives more weight to newer data. It assigns exponentially decreasing weights as the data becomes more distant.

To determine the value of the exponential smoothing factor, remember the following rules:

- the value of the exponential smoothing coefficient is in the range of $\langle 0,1 \rangle$;
- the value of the exponential smoothing coefficient is selected experimentally. The following assumption should be used: the closer the coefficient is to 0, the more the data is smoothed (the forecast is less sensitive to changes in demand), and the more the forecaster trusts the forecast made in the previous period; an indicator closer to 1 means that the forecast is more sensitive to changes in demand, and the forecaster is based on the actual situation that occurred in the previous period.

This is represented by the formal model:

$$\boldsymbol{\breve{y}_t = a \bullet y_{t-1} + (1 - a) \bullet p_{t-1}}$$

where:

a – exponential smoothing factor.

Calculating the forecast using the simple exponential smoothing method involves three steps:

1. Calculation of the naive forecast for the first period (initial forecast). The preliminary forecast is only required to provide an initial value for further calculations.
2. Determining the exponential smoothing factor; Exponential smoothing factor $a = \langle 0{,}1 \rangle$
3. Calculation of the forecast according to the simple exponential smoothing method.

Formula used in Excel:

forecast$_{(t)}$ = alfa * demand$_{(t-1)}$ + [(1 – alfa) * forecast$_{(t-1)}$]

The simple exponential smoothing method is used to forecast based on data without any significant trend or seasonality.

Linear Exponential Smoothing, LES (Holt's model)

The double exponential smoothing method (the so-called Holt model) captures linear trends in the data. It is the right model for demand in which a constant upward or downward trend can be observed. However, there is no seasonality.

The double exponential smoothing model is based on two smoothing factors. One of them refers to the smoothing of the variable level (random fluctuations), and the other to its increase (trend fluctuations). Both coefficients should be within the range: $\langle 0{,}1 \rangle$. This is represented by the formal model:

$$\boldsymbol{\breve{y}_t = L_{t-1} + T_{t-1}}$$

$$L_t = \alpha y_{t-1} + (1-\alpha)(L_{t-1} + T_{t-1})$$

$$T_t = \beta(L_{t-1} - L_{t-2}) + (1-\beta)T_{t-1}$$

where:

α – variable level smoothing factor

β – growth smoothing factor.

According to the model, two starting values L_t i T_t are needed:

$L_t = y_{t-1}$ – according to the naive method

$T_t = y_{t-1} - y_{t-2}$

Formula used in Excel:

forecast$_{(t)}$ = [αlfa * demand$_{(t-1)}$ + (1 – αlfa)(random fluctuation$_{(t-1)}$ + trend fluctuation$_{(t-1)}$)] + [beta * (random fluctuation$_{(t-1)}$ – (random fluctuation$_{(t-2)}$) + (1 – beta) * trend fluctuation$_{(t-1)}$]

Holt-Winters' Seasonal method (Holt-Winters' Model)

The seasonal exponential smoothing method, also called the Holt-Winters model, is very suitable for forecasting demand for data characterized by both trend and seasonality (www_8.1). However, it is necessary to obtain long series of demand data because it is necessary to verify repeated cyclical fluctuations (confirming that there is seasonal demand in the series). Seasonal fluctuations occur in additive or multiplicative versions (Kucharski, 2013).

Additive fluctuations occur when, in individual sub-periods of the seasonality cycle, deviations of the level of the analyzed phenomenon from the average level or trend, in terms of absolute value, can be observed.

This is represented by the formal model:

$$\breve{y}_t = L_{t-1} + T_{t-1} + S_{t-p}$$

$$L_t = \alpha(y_t - S_{t-p}) + (1-\alpha)(L_{t-1} + T_{t-1})$$

$$T_t = \beta(L_t - L_{t-1}) + (1 - \beta)T_{t-1}$$

$$S_t = \delta(y_t - L_t) + (1 - \delta)S_{t-p}$$

where:

α – variable level smoothing factor

β – trend smoothing factor

δ – coefficient of the seasonal component

L_t – level component at time t

T_t– trend component at time t

S_t– seasonal component at time t

p– seasonal period.

Formula used in Excel:

forecast$_{(t)}$ = level component $_{(t-1)}$ + trend component$_{(t-1)}$ + seasonality component$_{(t-p)}$

level component $_{(t)}$ = alpha * [demand$_{(t)}$ – seasonality component $_{(t)}$] + (1 – alpha) * (level component $_{(t-1)}$ + trend component$_{(t-1)}$)

trend component$_{(t)}$ = beta * (level component $_{(t)}$ - level component$_{(t-1)}$) + [(1 – beta) * trend component$_{(t-1)}$]

seasonality component$_{(t)}$ = gamma * (demand$_{(t)}$ – level component $_{(t)}$) + (1 – gamma) * seasonality component$_{(t-p)}$

seasonality component$_{(t-p)}$ for four quarters

seasonality component$_{(1)}$ = demand$_{(1)}$ / average demand$_{(1-4)}$

seasonality component$_{(2)}$ = demand$_{(2)}$ / average demand$_{(1-4)}$

seasonality component$_{(3)}$ = demand$_{(3)}$ / average demand$_{(1-4)}$

seasonality component$_{(4)}$ = demand$_{(4)}$ / average demand$_{(1-4)}$

Multiplicative fluctuations occur when, in individual sub-periods of the cycle, a deviation from the average level or trend by a certain constant relative amount can be observed (Sobczyk, 2006). This is represented by the formal model:

$$\breve{y}_t = (L_{t-1} + T_{t-1})S_{t-p}$$

$$L_t = \alpha\left(\frac{y_t}{S_{t-p}}\right) + (1-\alpha)(L_{t-1} + T_{t-1})$$

$$T_t = \beta(L_t - L_{t-1}) + (1-\beta)T_{t-1}$$

$$S_t = \delta\left(\frac{y_t}{L_t}\right) + (1-\delta)S_{t-p}$$

where:

α – variable level smoothing factor

β – trend smoothing factor

δ – coefficient of the seasonal component

L_t – level component at time t

T_t– trend component at time t

S_t– seasonal component at time t

p – seasonal period.

It is worth remembering that: an additive trend is related to double exponential smoothing with a linear trend, while a multiplicative trend is related to double exponential smoothing with an exponential trend (www_8.2).

Formula used in Excel:

forecast$_{(t)}$ = (level component$_{(t-1)}$ + trend component$_{(t-1)}$) * seasonality component$_{(t-p)}$

level component$_{(t)}$ = alpha * [demand$_{(t)}$ / seasonality component$_{(t)}$] + (1 – alpha) * (level component$_{(t-1)}$ + trend component$_{(t-1)}$)

trend component$_{(t)}$ = beta * (level component$_{(t)}$ – level component$_{(t-1)}$) + [(1 – beta) * trend component$_{(t-1)}$]

seasonality component$_{(t)}$ = gamma * (demand$_{(t)}$ / level component$_{(t)}$) + (1 – gamma) * seasonality component$_{(t-p)}$

seasonality component$_{(t-p)}$ for four quarters

seasonality component$_{(1)}$ = demand$_{(1)}$ / average demand$_{(1-4)}$

seasonality component$_{(2)}$ = demand$_{(2)}$ / average demand$_{(1-4)}$

seasonality component$_{(3)}$ = demand$_{(3)}$ / average demand$_{(1-4)}$

seasonality component$_{(4)}$ = demand$_{(4)}$ / average demand$_{(1-4)}$

Autoregressive methods

Among the forecasting models, models of stationary ARMA series (AutoRegressive Moving Average) and non-stationary ARIMA series (AutoRegressive Integrated Moving Average model) have a special place. These are models based on the phenomenon of autocorrelation, created by integrating the AR autoregressive model (AutoRegressive model) and the MA (Moving Average) model (Grzelak, 2019).

For the purposes of this study, 3 autoregressive methods will be presented: (1) Autoregressive Moving Average (ARMA); (2) Autoregressive Integrated Moving Average (ARIMA); (3) Random Walk (RW).

The ARMA and ARIMA models have many similarities. The components AR(p) – general autoregressive model and MA – general moving average model MA(q) are the same. What distinguishes both ARMA and ARIMA models is the difference. If there are no differences in an ARMA model, it simply becomes an ARIMA model.

Autoregressive Moving Average, ARMA

The requirement for forecasting according to the ARMA method is a series of data that is characterized by stationarity. It means that in this series we can distinguish a constant mean, a constant variance and a constant covariance, which depends only on the time interval between the values (Schaffer et al., 2021).

According to the ARMA model, the forecast value at time t depends on its past values and on the differences between the past actual values of the forecast variable and its values obtained from the model – forecast errors. This model is referred to as the **ARMA(p,q)** model, where p refers to the order of the autoregressive polynomial and q is the order of the moving average polynomial. This is represented by the formal model:

$$\boldsymbol{\breve{y}_t = \varepsilon_t + (\alpha y_{t-1} + \varepsilon_t) + (\beta y_{t-2} - \alpha y_{t-1} + \varepsilon_t) + (\varepsilon_t + \alpha \varepsilon_{t-1})}$$

where:

α – parameter of the autoregressive model

β – parameter of the moving average model

ε – model error (white noise).

Formula used in Excel:

forecast$_{(t)}$ **= model error**$_{(t)}$ **+ component**$_{1}$ **+ component**$_{2}$ **+ component**$_{3}$

Model error$_{(t)}$ **= NORM.S.INV(rand())**

component$_{1}$ **= alfa * component1**$_{(t-1)}$ **+ model error**$_{(t)}$

component$_{2}$ **= beta * component2**$_{(t-2)}$ **– alfa * component2**$_{(t-1)}$ **+ model error**$_{(t)}$

component$_{3}$ **= model error**$_{(t)}$ **+ alfa * model error**$_{(t-1)}$

Autoregressive Integrated Moving Average, ARIMA

In the case of ARIMA models, attention is paid to the non-stationarity of the series. There are three parameters in the model: the autoregressive parameter *(p)*, the moving average parameter *(q)* and the order of differentiation *(d)*. The ***ARIMA(p,q,d)*** model is also described using numbers, for example: *(1,1,0)*, which means that in the series *p=1* there is a single autoregressive parameter, *q=1* there is a single moving average parameter and *d =0*, no differentiation occurs (Malska & Wachta, 2015). For the given example, the formal general model is as follows:

$$\breve{y}_t = \alpha + y_{t-1} + \beta_1(y_{t-1} - y_{t-2})$$

where:

α – parameter of the autoregressive model

β – moving average parameter.

Formula used in Excel:

forecast$_{(t)}$ **= alfa + demand**$_{(t-1)}$ **+ beta * [demand**$_{(t-1)}$ **- demand**$_{(t-2)}$**]**

Random Walk, RW

The Random Walk model is a subcategory of the ARIMA model. In a simple RW model, each forecast is assumed to be the sum of the last observation and a random error term. It therefore assumes that the latest observation is the best indication for building the nearest next forecast. This model is quite simple to understand and implement. It is used when a development trend is observed in the data sequence. This is represented by the formal model:

$$\breve{y}_t = y_{t-1} + \varepsilon_t$$

$$\varepsilon_t = y_{t-1} - y_{t-2}$$

where:

ε – model error (white noise).

Formula used in Excel:

forecast$_{(t)}$ **= demand**$_{(t-1)}$ **+ [demand** $_{(t-1)}$ **– demand** $_{(t-2)}$**]**

It has been observed that many complex forecasting methods based on linear structure are unable to beat the naive RW model (Adhikari & Agrawal, 2014).

Regression methods

In regression models, it is not possible to talk about the influence of one variable on another. By means of a variable or a set of variables, another variable is explained. To apply regression methods, a larger amount of historical data is needed – the longer the observation period of historical data, the greater the possibility of precisely determining forecasts.

Many variants of regression models are known: linear regression, non-linear regression, logistic regression, stepwise regression, ordinal regression. The formula for the general form of regression is:

$$\breve{\boldsymbol{y}}_{\boldsymbol{t}} = \boldsymbol{f}(\boldsymbol{X}, \boldsymbol{\beta}) + \boldsymbol{\varepsilon}_{\boldsymbol{t}}$$

where:

X – explanatory, predicting variable

β – regression coefficient

$f(X, \beta)$ – regression equation

ε_t – random error.

For the purposes of this study, three exponential smoothing methods will be presented: (1) Trend Projection Method; (2) Simple linear regression method; (3) Multiple linear regression method.

Trend Projection Method

The Trend Projection method is a variation of the straight line method. Jet is the most classic business forecasting method that deals with the movement of variables over time. A distinction can be made between the **graphical method** – in which the data is displayed on a graph and a line is drawn manually through it. The line is drawn maintaining the smallest distance between the designated points and the line; **trend equation fitting method** using data and a straight or exponential line equation.

Simple Linear Regression Method

The linear regression method is the simplest variant of regression. The purpose of the linear regression method is to fit a straight line to the data. Therefore, you need to find a solution that will allow you to find the optimal straight line that will best show the relationship between the data. In the simple linear regression method, the forecasting model is based on a linear tendency. To determine the regression line, and therefore the values in the linear regression model, you need to calculate the straight line coefficients *a* and *b*. This is represented by the formal model:

$$\breve{y}_t = an + b$$

where:

a – value of the variable in the analyzed period

b – value of the increase or decrease in the dependent variable

n – serial number of the analyzed and forecast period.

To determine the parameters *a* and *b*, you need to calculate a system of two equations. It has the following form:

$$\begin{cases} a\sum_{1}^{n} t_i^2 + b\sum_{1}^{n} t_i = \sum_{1}^{n} t_i \bullet y_i \\ a\sum_{1}^{n} t_i + b \bullet n = \sum_{1}^{n} y_i \end{cases}$$

where:

t_i – the ordinal number of the period (t = 1, 2, 3, ...), which is the value of the independent time variable

y_i – dependent variable (e.g. demand for a given good in a given time period)

a – value of the variable in the analyzed period

b – value of the increase or decrease in the dependent variable

n – number of all analyzed periods.

However, the quickest way to calculate the above regression coefficients is to use the LINEST function.

Syntax**: LINEST(known_y,[known_x],[constant],[statistics])**

Multiple linear regression method

Multiple linear regression allows you to build models of linear relationships between many variables. The multiple linear regression method is used in data analysis to examine complex relationships between multiple variables. This is represented by the formal model:

$$\boldsymbol{\breve{y}_t = a + b_1 y_1 + b_2 y_2 + \cdots + b_i y_i + \varepsilon}$$

where:

a – value of the variable in the analyzed period

b – value of the increase or decrease in the dependent variable

ε – model error (white noise).

8.7. Forecast errors

To assess forecast accuracy, forecast errors must be measured. Given that there is no guarantee of perfect prediction of future demand (Hopp & Spearman, 1999), every forecast is subject to error.

Researchers distinguish between systematic and unsystematic effects of forecast errors (Zeiml, et al., 2019). The performance of a forecasting system is typically measured using various measures of forecast error (Table 8.5).

Table 8.5. Selected forecast errors

Forecast error	Model	Interpretation
Mean Squared Error (MSE)	$MSE = \frac{\sum(y_t - p_t)^2}{n}$	The mean squared error can only be positive and its value should be as small as possible. The value of this error, which is *0*, indicates excellent forecast accuracy.
Root Mean Squared Error (RMSE)	$RMSE = \sqrt{\frac{\sum(p_t - y_t)^2}{n}}$	The error value should be as close to *0* as possible. The lower the root mean square error value, the better the model. And the perfect model has a value equal to *0*.
Mean Absolute Percentage Error (MAPE)	$MAPE = \frac{\sum\frac{\lvert E_t - A_t\rvert}{A_t}}{n}$	This is one of the more popular measures of error. A value of *0* indicates that the model has no mean error, meaning the value should be as close to *0* as possible. For the same forecast errors, smaller actual values make the relative error larger.
Mean Percentage Error (MPE)	$MPE = \frac{100\%}{n}\sum\frac{a_t - f_t}{a_t}$	This is the average percentage error (or deviation). It informs how much the deviation from the actual value will be on average during the forecast period. MPE is useful because it allows you to check whether a forecast model systematically underestimates (more negative error) or overestimates (positive error).
Mean Absolute Deviation (MAD)	$MAD = \sum\frac{[x_t - \bar{x}_t]}{n}$	It is a simple extension of absolute variance. The mean absolute deviation is used as a measure of the variation in the data.

Source: (Hyndman & Koehler, 2006; Zeiml, et al., 2019)

8.8. Advantages of forecasting in Excel

Microsoft Excel can be used for forecasting. Using developed algorithms and based on collected data from the past, you can prepare forms to build forecasts and, as a result, make the right decisions in business. Excel is the basic tool for forecasting.

Table 8.6. Selected Excel Features

Function	Explanation
=AVERAGE	This function allows you to calculate an average based on existing values.
=SUM	The function allows you to calculate a sum based on existing values.
=FORECAST	The function allows you to predict future value from existing values using linear regression..
=FORECAST.ETS	Calculates or predicts future value based on existing (historical) values using a version of the exponential smoothing algorithm (ETS).
=LINEST	Calculates statistics for a line using the least squares method.
=FORECAST.LINEAR	Calculates or predicts future value from existing values using linear regression.
=TREND	It will be used to determine the linear trend.
=FORECAST.ETS.SEASONALITY	Calculates the length of the seasonal pattern based on existing values and timeline.

Source: own study

Excel is used in forecasting by many companies, small, medium and large (including corporations), because it has a number of appropriate tools at its disposal. Data can be easily stored and calculated in an Excel workbook. Excel can visualize the acquired and processed data in various ways, which is useful and helps in making forecasts easier (www_8.3).

After all, Excel uses many formulas that can be used in the program's workbook to help calculate predicted values. Excel supports several different functions that allow you to use the software in a practical way (Table 8.6). Understanding them is key to getting the most out of Excel.

The disadvantages of Excel include the need to manually synchronize data and manually update data. Another common problem is the possibility of making mistakes as a result of incorrectly performed data import or as a result of interruption of the formula. Because Excel is a manual data entry program, the data used for forecasting is not real-time data.

8.9. Artificial intelligence in forecasting

Supply chain data is multidimensional and generated at multiple points in the chain, for multiple purposes, in large volumes (due to the multitude of suppliers, products, and customers), and at high speed (reflecting the many transactions continuously processed across supply chain networks). This complexity and multidimensionality of supply chains is causing a shift away from conventional (statistical) approaches to demand forecasting, which are based on the identification of statistically average trends (characterized by mean and variance attributes) (Michna, i in., 2020), towards intelligent forecasts that can learn from historical data and intelligently evolve to adapt to anticipate ever-changing demand in supply chains.

The answer to new needs and challenges is anticipatory logistics, which supports processes such as demand forecasting. At its core lies the possibility of using artificial intelligence (AI). It is a combination of modern technologies such as Big Data (BD), machine learning (ML) and artificial intelligence (Sczaniecka & Smarzyńska, 2018). Technological advances in recent years have led to the increasingly frequent generation and storage of huge amounts of data. This data is captured over time at different points (e.g. at different links in the supply chain) and stored in different places. They should therefore be processed efficiently to extract useful and valuable knowledge from them (Galicia et al., 2019).

Big Data refers to dynamic, high-volume, high-velocity, and high-variety data sets that exceed the processing capabilities of traditional data management approaches (Chen et al, 2014). Big Data can provide a wealth of unique insights into things like market trends, customer purchasing patterns, and maintenance cycles, as well as ways to reduce costs and make more targeted business decisions (Wang et al, 2016). Research indicates that Big Data Analytics (BDA) can provide a way to obtain more accurate forecasts that better reflect customer needs, facilitate supply chain performance assessment, improve supply chain efficiency, shorten response times, and support supply chain risk assessment (Awwad et al, 2018).

Big Data Analytics (BDA) in Supply Chain Management (SCM) is gaining increasing attention (Seyedan & Mafakheri, 2020). Supply chain data analysis has become a complex task due to (Awwad et al, 2018):

- increasing number of SC entities,
- increasing variety of SC configurations depending on homogeneity or heterogeneity of products,
- interdependencies between these entities,
- uncertainty about the dynamic behavior of these components,
- lack of information regarding supply chain entities,
- networked production entities due to their increasing coordination and cooperation to achieve high level of customization and adaptation to different customer needs,
- increasing use of supply chain digitalization practices (and use of Blockchain technology) to track supply chain activities.

Artificial intelligence methods are being developed very intensively around the world, both theoretically and in terms of application (Trojanowska & Malopolski, 2004). Among the artificial intelligence methods, artificial neural networks are used for forecasting. Neural networks have a number of features that are useful for analyzing and forecasting time series. Their effectiveness is primarily related to tuning the adopted structure based on data. The process of building a neural model involves exploring available data sets and enables automatic model estimation. An additional advantage of neural networks is their ease of adaptation to changing market conditions (Ciężak et al, (2006).

Unlike traditional model-based methods, **artificial neural networks** (Artificial Neural Networks, ANNs) are self-adaptive data-driven methods. They learn from examples and capture subtle functional relationships between data, even if the underlying relationships are unknown or difficult to describe. Artificial neural networks can generalize (Hornik et al., 1989). After examining the presented data, they can infer the unseen part of the population, even if the sample data contains noisy information. They also have more general and flexible functional forms than traditional statistical methods (Zhang et al., 1998).

Chapter Questions

1. What are the limitations of using time series methods in demand forecasting?
2. What are the main components of a time series and what is their importance in the forecasting process?
3. What are the different strategies for dealing with outlier data?

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9. INVENTORY MANAGEMENT

The chapter presents the most important issues related to inventory management. Particular emphasis was placed on the analysis of logistics data, for which a spreadsheet can be used. You will find here:

- customer service level,
- functions and division of inventories,
- inventory costs,
- basic inventory classification models,
- basic replenishment models.

9.1. Introduction

In the current conditions of functioning global supply chains, the key factor determining competitiveness is the time it takes to introduce a product or service to the market. Organizations aspiring to gain or maintain a competitive edge should implement solutions characterized by both speed and adaptability in responding to customer demand and market fluctuations. Before the COVID-19 pandemic, many companies leaned towards a just-in-time (JIT) strategy, minimizing inventory levels and maximizing efficiency by delivering raw materials and components exactly when needed in the production process. Flexibility was important, but not always a priority, as the key was to maintain low inventory levels and minimized order fulfillment time.

After the COVID-19 pandemic, the emphasis on flexibility and resilience of systems significantly increased. Companies that had previously relied on just-in-time delivery began to revise their approach towards greater security and diversification of supply chains to be better prepared for future disruptions. It became clear that inventory management systems needed to be more dynamic to quickly respond to unexpected changes in demand and availability of raw materials or components. As a result, many organizations started to maintain higher safety stock levels and invest in advanced analytical technologies and artificial intelligence, which allow for better forecasting and real-time response to changes.

Traditional forecasting methods, although widely used, are not always effective because forecast errors may lead to the need to store additional inventories. Therefore, a more effective solution is to use actual data on customer consumption, which allows for better adaptation of logistics systems and reduces dependence on forecasts. However, care should be taken to maintain the maximum Customer Service Level (CSL) while limiting costs and reducing assets frozen in the supply network (Cyplik & Hadaś, 2012).

Inventory is the amount of goods stored by an enterprise to meet current and future needs (Brunaud et al., 2019). Inventories are tangible components of current assets. The inventory has a specific location, storage place, and its size can be expressed in quantitative and valuable measures (Niemczyk et al., 2011)

Inventories take up space and tie up capital. Therefore, inventory management is essential to minimize to ensure business continuity. **Inventory management** refers to the process of supervising and controlling the level of stocks, warehouse levels and their storage in an enterprise. This involves deciding how much inventory to hold, when to reorder or restock, and how to optimize inventory utilization to meet demand while minimizing costs and maximizing efficiency (Song et al., 2020). Effective inventory management includes tasks such as forecasting demand, tracking inventory levels, replenishing inventories, optimizing warehouse space, and reducing inventory or excess inventory (Jain et al., 2022).

The goal of inventory management is to ensure that the right products are available in the right quantities, at the right time and in the right place to meet customer needs while avoiding out-of-stock, over-inventory and associated costs (Jain et al., 2022; Matusiak, 2022).

9.2. Customer Service Level

Customer service is a broad concept, which makes it difficult to formulate a clear definition. This term covers all aspects of the interaction between the supplier and the consumer, including both intangible and tangible elements (Strojny, 2008). Therefore, customer service is often considered from three different perspectives (Bowersox & Closs, 1996):

- customer service as specific activities – this is a specific set of tasks that the company must perform to meet customer expectations, e.g. processing orders, issuing invoices, handling returns and complaints,
- customer service as a measurement of the performance of activities – this means assessing through the prism of various performance indicators, such as the percentage of orders delivered on time and completely and the speed of order processing,
- customer service as a philosophy – involves creating an environment and organizational culture that aims to ensure the highest level of customer satisfaction through optimal service at all levels of the company's operations.

In the context of inventory management, a key task in formulating and maintaining safety stock is to guarantee an appropriate level of customer service. Therefore, it is necessary to define the **customer service level** (CSL) that from the point of view of a single product range can be considered (Bowersox & Closs, 1996; Cyplik & Hadaś, 2012):

- probabilistically – as the probability of no shortage occurring in stock in a given replenishment cycle,
- quantitatively – as the degree of quantitative demand fulfilment.

The **probabilistic customer service level** means that the probability that from the moment an order is placed, i.e. the replenishment process begins, until the received shipment becomes available for use (which means the replenishment cycle ends), all needs can be met without stock being out of stock. This is defined as the Probabilistic Service Level, which is expressed as a percentage (Bowersox & Closs, 1996; Cyplik & Hadaś, 2012). The probabilistic customer service level can be calculated from the formula:

$$PSL = (l_d - l_{dn}) / l_d \times 100\%$$

where:

PSL – probabilistic service level,

l_d – number of inventory replenishment cycles during the examined period,

l_{dn} – number of inventory replenishment cycles in which shortages were recorded during the examined period

</> Formula used in Excel:

$$\text{PSL} = \frac{\text{[number of inventory replenishment cycles]} - \text{[number of inventory replenishment cycles in which shortages were recorded]}}{\text{[number of inventory replenishment cycles]}} * 100\%$$

> The **PSL** (probability of meeting demand within the replenishment cycle) of 95% means that 95 times out of 100, when customers want to purchase the product, the company will be able to fulfill their orders without delays and without having to wait for delivery.

The quantitative customer service level refers to the execution of orders in quantitative terms. Demand Fill Rate (DFR) – determines what percentage of the demand reported by customers was released from stock (Bowersox & Closs, 1996; Cyplik & Hadaś, 2012).

The Demand Fill Rate can be calculated using the formula:

DFR = (PR – NB) / PR

where:

DFR – Demand Fill Rate,

PR – demand , total number of units ordered,

NB – number of deficiencies.

</> Formula used in Excel:

$$\text{DFR} = \frac{\text{[demand]} - \text{[no of deficiencies]}}{\text{[demand]}}$$

The **DFR** (Demand Fill Rate) of 0.95 means that for all orders placed by customers, 95% of them will be filled directly from available inventory, and only 5% may require additional time to restock or will not be fulfilled from due to out of stock.

Regardless of the definition adopted, it is obvious that the relationship between the level of customer service and inventory investments is characterized by an exponential relationship (Fig. 9.1). This means that with high percentages of the customer service level (PSL), each further increase in this indicator leads to an exponential increase in inventory investment (Cyplik & Hadaś, 2012).

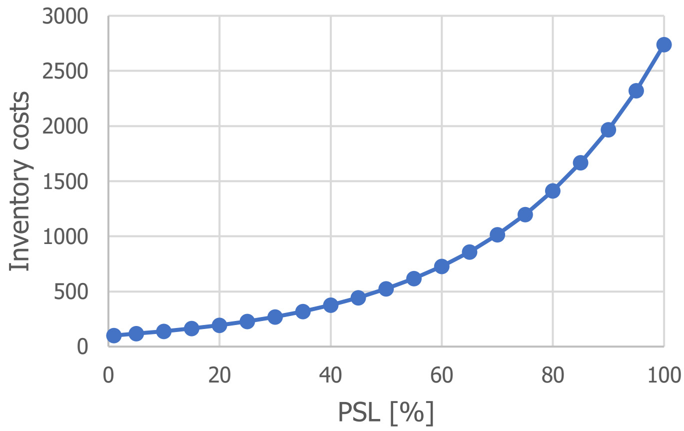

Figure 9.1. The relationship between PSL and inventory costs

Source: own study

Improving logistic customer service is a complex and systematic process. The following elements are most commonly analyzed and divided into three phases (Powell Robinson & Satterfield, 1990):

- pre-transactional – aims to prepare the organization for customer service: e.g., customer service policy, organizational structure, standards, procedures and instructions, customer service training,
- transactional – direct customer contact with the company and finalization of the transaction according to his requirements: e.g., percentage of unfulfilled orders,

order information, ease of placing an order, frequency, reliability, completeness, accuracy of deliveries,

- post-transactional – allows the company to maintain further contact with the customer: e.g., installations, warranties, repairs, product tracking, handling customer complaints, returns, exchanging defective products, providing replacement products.

Currently, the greatest emphasis is placed on the transactional elements of logistic customer service. They can be categorized into four main groups related to (Papiernik-Wojdera & Sikora, 2022):

- time, the customer wants to receive the order as quickly as possible, hence the effort to shorten the order fulfillment time,
- reliability, considered in three dimensions: assurance that the order will be completed without shortages and damages in transport, completeness of the received order in accordance with the specification included in the contract, punctuality of order fulfillment,
- convenience related to the availability of products, the degree of service individualization depending on customer needs, the comprehensiveness of the offer, the frequency of deliveries, the minimum batch size for delivery, communication convenience (location, infrastructure),
- communication, which includes the competence of the staff, ease of placing orders, availability of information about the order status, information and advice on after-sales services, clarity, understandability and completeness of documentation, means of communication and IT tools supporting communication with the customer.

It should be noted that there is a balance that the company must find between the cost of service and customer satisfaction in order to maximize profit (Fig. 9.2). Too low a level of service can limit revenues, while too high can excessively increase costs, which lowers profits (Placencia et al., 2020). After exceeding the equilibrium point, additional costs associated with further increasing the level of service outweigh the increase in revenues, leading to a decrease in profit.

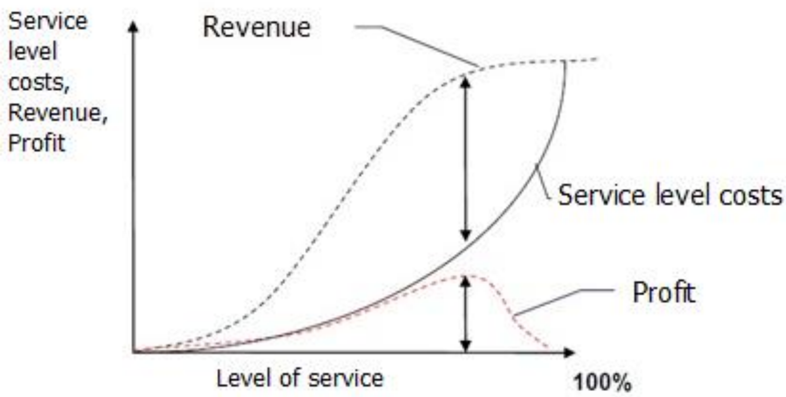

Figure 9.2. The relationship between the level of customer service and revenue and profit

Source: own study

9.3. Functions and types of inventories

Logistics processes taking place both in enterprises and in supply chains are constantly accompanied by the creation of inventories. Inventories are created to equalize the difference in the intensity of flows of goods. Therefore, the following **functions of inventories** can be indicated (Bril & Łukasik, 2013; Hachuła & Schmeidel, 2016):

- ensuring the availability of goods when demand occurs,
- protection against random fluctuations in independent demand and material needs in the enterprise,
- protection against unexpected changes in order processing time,
- protection against price increases,
- obtaining lower prices due to a larger scale of purchases,
- lower transport costs due to larger scale of purchases,
- the need to purchase seasonal goods,
- the need to season some materials for technological reasons.

Many factors influence **the level and structure of inventories** in an enterprise. These include the following (Bril & Łukasik, 2013):

- production scale and rhythm,
- frequency of deliveries and volume of one-time delivery of materials,
- differences in transport costs of large and small batches of supplies and storage costs,
- length of the period of preparing materials for production,
- the degree of expansion of the product offer,
- development of information technologies,
- development of the transport services market,
- inventory planning and management methods used.

Inventories in an enterprise can be divided according to various criteria. For the purposes of settlements in the area of accounting and their place in the supply chain, a distinction is made (Selivanova et al., 2018):

- materials – raw materials, basic and auxiliary materials, semi-finished products of foreign production, packaging, spare parts and waste,
- finished products – finished products, services provided, completed works, including construction and assembly works, scientific and research works, design works, geodetic and cartographic works, etc.,
- semi-finished products and products in progress – unfinished production, i.e. production (services, including construction works) in progress and semi-finished products (semi-finished products) of own production,
- goods – tangible components of current assets purchased for resale in unchanged form; advance payments for supplies of supplies.

However, in the area of inventory management, the division of inventories according to the quantitative structure of inventories (according to the turnover rate): rotating stock, non-rotating stock, stock not showing movement (excess stock, emergency stock) or inventory functions – reason for creation: cyclic stock (current, working stock), safety stock, seasonal stock, speculative stock, strategic stock (Bril & Łukasik, 2013; Matusiak, 2022; Wild, 2017; Kryżaniak & Cyplik, 2008; Fertsch, 2006; Krzyżaniak, 2015).

The elements of the inventory structure are:

- **cyclic stock**, rotating stock, it is inventory that the company uses in the course of normal production or distribution and recreates in the routine ordering process; Cyclic stock in a certain period is equal to half the average shipment volume in that period:

$$S_C = \frac{1}{2} \times \overline{DS}$$

where:
S_C – cyclic stock,
$\overline{DS}$ – average delivery size.

Formula used in Excel:

S_C = 0,5 * [average delivery size] = 0,5 * [AVERAGE([cell range])]

- **excess stock** is defined as non-rotating, redundant or dead stock, it has no value for the company, which should get rid of such stock, maintaining this stock is an unjustified cost for the company. Excess stock is the excess of inventory beyond needs defined by average demand during the replenishment cycle and the assumed level of customer service. It is calculated from the formula:

$$S_E = S_{AV} - S_S - S_C$$

where:
S_E – excess stock,
S_{AV} – *medium stock,*
S_S – safety stock,
S_C – *cyclic stock.*

Formula used in Excel:

S_E = [medium stock] - [safety stock] - [cyclic stock]

The parameters of the replenishment systems are:

- **safety stock**, non-rotating stock is intended to prevent emergency downtime in production or distribution, and is a buffer for delays in deliveries and order fulfilment, depends on the level of customer service in a probabilistic approach (PSL). Safety stock for historical data requires the following information: average demand per unit of time, average replenishment cycle time, standard deviation of demand, standard deviation of replenishment cycle time. Safety stock for forecast data requires: demand forecast, contracted replenishment cycle time, standard error of forecast, assumed lead time delay. Regardless of the time perspective, data on the adopted customer service level, the applied inventory replenishment system, and the available budget are needed. Safety stock may change with fluctuations in demand and delivery times. It is calculated as follows:

  $$S_S = \omega(PSL) \times \sigma_{DT}$$

  where:

  S_S – safety stock,

  $\omega(PSL)$ – safety factor depending on the level of customer service and the type of distribution describing demand variability in the replenishment cycle; normal distribution is most often assumed in the literature and in practical applications and it is read from the statistical tables for a given POP level,

  σ_{DT} – standard deviation of demand in the replenishment cycle, is calculated from the formula:

  $$\sigma_{PT} = \sqrt{\sigma_T{}^2 \cdot D^2 + \sigma_P{}^2 \cdot T}$$

  where:

  σ_P – demand deviation,

σ_T – replenishment cycle time deviation,

D – average demand,

T – replenishment cycle time.

Formula used in Excel:

S_S = [safety factor] * [standard deviation of demand in the replenishment cycle]

- **information stock** is used in systems: inventory renewal based on the information level, min–max, periodic with a specific information level and fixed delivery volumes, periodic with a specific information and maximum level and variable delivery volumes. The information stock is calculated using the formula:

  $$S_I = D \times T + S_S$$

  where:

  S_I – information stock,

  D – average demand in the adopted time unit (e.g. day, week),

  T – restocking cycle time,

  S_S – safety stock.

Formula used in Excel:

S_I = [average demand] * [restocking cycle time] + [safety stock] = [AVERAGE([cell range])] * [restocking cycle time] + [safety stock]

- **minimum stock** is used in the so-called stock renewal system, min–max, is replenished in the system when its level drops below the designated minimum value, it is always replenished to the designated maximum stock level. The minimum stock is calculated using the formula:

  $$S_{MIN} = p_{MAX} \times T_d$$

  where:

S_{MIN} – minimum stock,

p_{MAX} – maximum planned consumption,

T_d – delivery time.

Formula used in Excel:

Z_{MIN} = [maximum planned consumption] * [delivery time]

- **maximum stock** is used in inventory renewal systems: based on periodic review, min–max, periodic with a specific information and maximum level and variable delivery volumes. The maximum stock is calculated using the formula:

$$S_{MAX} = D \times (T + T_0) + S_S$$

where:

S_{MAX} – maximum stock,

D – average demand per unit of time (e.g. day, week),

T – replenishment cycle time,

T_0 – time of the regular inspection cycle,

S_S – safety stock.

Formula used in Excel:

S_{MAX} = [average demand] * ([replenishment cycle time] + [time of the regular inspection cycle] + [safety stock] =
= [AVERAGE([cell range]) * ([replenishment cycle time] + [time of the regular inspection cycle] + [safety stock]

- **free stock**, or available stock, is stock that is available for release to customers (external or internal) at present or in the foreseeable future; stock is taken into account that has been ordered from suppliers but has not yet been delivered, but will be delivered in the foreseeable future and will increase the stock level; goods that have been purchased by an external customer or reserved by an internal customer, but have not yet physically left the warehouse, will not be included in the available inventory. Free stock is calculated as follows:

$$S_F = S_W + S_O - S_R$$

where:

S_F – free stock,

S_W – stock in warehouse,

S_O – stock ordered but not delivered,

S_R – stock reserved but not released from stock.

Formula used in Excel:

S_F = [stock in warehouse] + [stock ordered] - [stock reserved]

Stocks according to the cause of creation criterion are as follows:

- **work-in-progress stock** are materials and semi-finished products in the production area and inventories in transit, are valued according to the cost of production, which, in accordance with the Accounting Act, includes costs directly related to a given product and a justified part of the costs indirectly related to the production of the product,
- **seasonal stock** is created to meet demand throughout the year, but is produced only seasonally (agricultural products, fruit), is intentionally created, resulting from the difference between the sales volume and the production volume in a given period,
- **promotional stock** is maintained during a marketing promotion and built up before the promotion date, it is inventory that is maintained in order for the logistics system to quickly respond to a marketing or price promotion,
- **speculative stock** is created in anticipation of price increases, changes in exchange rates or changes in the socio-political dimension.

9.4. Basic replenishment systems

The basic inventory replenishment models in logistics encompass several commonly used systems that help organizations manage inventory levels to minimize costs and ensure product availability. These include:

- ROP (Reorder Point) system with information stock – orders are placed when inventory levels reach a predetermined point (the reorder point), ensuring that products are replenished before they run out, thereby minimizing the risk of stockouts,
- ROC (Reorder Cycle) system with maximum stock – orders are placed at set intervals, and their quantity takes into account the current inventory level, with the goal of replenishing to a maximum level,
- JIT (Just-In-Time) system – inventory is replenished only as needed, often to reduce storage costs. This system is used in production environments that aim to minimize inventory,
- Kanban system – orders are triggered by physical signals (such as cards), ensuring a continuous flow of materials, this model provides flexibility in replenishing inventory as demand changes,
- EOQ (Economic Order Quantity) system – determines the economic order quantity to minimize ordering and holding costs, it is typically used in stable environments where demand is predictable,
- MRP (Material Requirements Planning) system is used to plan material requirements based on forecasted demand and production schedules.

The above models are used depending on the needs and operational characteristics of the enterprise. Each has its own advantages and is chosen based on factors such as demand variability, inventory holding costs, and supply chain complexity. Due to their widespread use, the basic inventory replenishment systems: ROP and ROC, are described.

The **ROP (Reorder Point)** system refers to making ordering decisions based on the available inventory level: if the inventory falls below the information stock level, an order is triggered. The reorder point is defined as the level of inventory at which an order must be placed to prevent stock from running out before the next delivery arrives. Safety stock is added to minimize the risk of stockouts. This system is most commonly used for inventory items classified in groups A and B, according to the ABC classification, due to the smallest stock levels it creates in the warehouse (Cyplik, 2005). Reorder point is calculated from the formula:

$$ROP = D \times T + Z_B$$

where:

ROP – reorder point,

D – average demand in the adopted unit of time (e.g. day, week),

T – replenishment cycle time,

S_S – safety stock.

The ROP system is effective in environments where demand is relatively stable and the inventory replenishment cycle is well-defined. It helps minimize the risk of stockouts while maintaining optimal inventory levels. The basic rules for using the ROP system are as follows:

- **define the reorder point**, which is the inventory level at which a new order is triggered; it should consider the expected demand and safety stock during the lead time,
- it is assumed that **safety stock** is maintained to prevent stockouts in case of sudden spikes in demand or delays in deliveries,
- **regular monitoring of inventory levels** is required to initiate the ordering process at the right time,
- exceeding or dropping below the reorder point indicates the need to **place a new order** to maintain supply continuity and avoid production or distribution interruptions,
- it relies on **demand forecasting**, so it is essential to use reliable historical data and forecasts to determine the average demand and estimate variability to accurately set the reorder point.

The **ROC (Reorder Cycle)** system involves placing orders within a specified cycle with a fixed review period. The order quantity is variable and derived from the difference between the maximum stock level and the current available inventory. The order size is determined using the lot-for-lot method to cover the entire cycle's demand. The maximum stock level is set based on the expected demand during the cycle, considering the safety stock. The order cycle is predefined, allowing for regular deliveries, but it may require larger safety stocks due to the risk associated with irregular demand. This system is applicable for inventory items classified in group C, according to the ABC classification (Cyplik, 2005). The order size in the ROC system is calculated using the formula:

$$Q = S_{MAX} - S_F$$

where:

Q – order size,

S_{MAX} – maximum stock,

S_F – free stock (current).

The ROC system is suitable for environments with a fixed delivery schedule, where demand can be forecasted over the cycle period. It provides stability in inventory management and can be applied in situations where the regularity of orders is a priority. The basic rules for using the ROC system are as follows:

- it is based on placing **orders at regular, predetermined intervals** (cycles), when setting the order cycle, consider the demand and replenishment time to ensure the appropriate frequency of orders,
- a **maximum stock level** is defined, which serves as the target for each order, the maximum stock level should account for the expected demand during the cycle and safety stock,
- orders are placed in **regular cycles**, but the **order quantity can be flexible**, adjusting to current inventory levels and expected demand, allowing for responsiveness to demand changes without changing the order schedule,
- **regular monitoring** of inventory levels is essential to ensure that the order cycles and quantities are appropriately adjusted to changing demand and supply availability.

9.5. Inventory costs

Inventory costs are an important factor in managing production capacity and inventory. Holding inventory ties up capital and incurs costs related to ordering, storage and potential shortages. Businesses must carefully plan inventory levels to minimize these costs and optimize overall supply chain performance (Song et al., 2020).

The concept of costs has various aspects and numerous definitions can be found in the literature. Generally, **costs** are an economic category that describes them as the consumption of specific resources to produce an item or provide a service. Costs are characterized by the following features (Matusiak, 2022):

- present the consumption of production factors in a valuable way,
- were incurred for a specific purpose,
- they can be assigned to precisely defined periods,
- it is possible to compare costs with revenues,
- are integrated with the company's normal operations.

Inventory costs result from the need to use financial resources at various stages of their accumulation and storage. They include expenses related to the entire life cycle of inventories, starting from the purchase of raw materials, through their storage, to production and distribution processes (Śliwczyński, 2008).

The costs arising in the enterprise and the supply chain related to inventories can be divided into three categories (Skowronek & Sarjusz-Wolski, 2012):

- stock replenishment costs,
- inventory holding costs,
- shortage costs.

The process of generating inventory-related costs begins with conscious steps to select a supplier and prepare a purchase order, and ends with the receipt of materials or products into the company's resources. In the context of warehousing activities, it is the act of recording the receipt of goods and issuing an appropriate warehouse document, called an external receipt document.

Stock replenishment costs can be divided into ordering costs and transportation costs. The following components can be distinguished in **ordering costs** (Krzyżaniak & Cyplik, 2008; Śliwczyński, 2008):

- fixed costs – remuneration costs in procurement or purchasing departments, infrastructure costs (rooms, equipment, IT systems), fixed costs of ICT connections, subscriptions to use purchasing platforms, fixed costs of software licenses used by the supply or purchasing departments,

- variable costs – variable costs of using shopping platforms, variable components of telephone costs, overtime costs. Formula to calculate Variable Replenishment Costs:

$$VRC = n_d \times c_d$$

where:
VRC – variable replenishment costs,
n_d – number of deliveries in the period considered,
c_d – cost associated with one delivery.

</> Formula used in Excel:

VRC = [number of deliveries] * [cost of delivery]

The largest component of restocking costs is **transportation costs**. The following components can be isolated in it (Krzyżaniak & Cyplik, 2008; Śliwczyński, 2008):

- fixed costs – for own transport, these are the costs of vehicle depreciation and insurance, driver remuneration costs, vehicle inspection costs; for outsourced transport, these are the remuneration costs of employees ordering and supervising the provision of transport services,
- variable costs – for own transport, these are the costs of fuel and vehicle operation, costs of traveling on toll road sections, insurance costs, allowances and overtime costs of drivers; for outsourced transport, these are the costs of transport carried out by service providers and insurance costs.

Inventory holding costs are the expenses associated with owning and storing goods in a warehouse or other storage locations. They are physically registered in the enterprise from the moment of accepting materials, goods and products into inventory and issuing the PZ document. Inventory maintenance costs include storage costs and impairment costs. The following components can be distinguished in **storage costs** (Krzyżaniak & Cyplik, 2008; Śliwczyński, 2007):

- fixed costs – for own warehouse these are the costs of depreciation of buildings and warehouse equipment, costs of operating buildings and warehouse equipment, costs of insurance of warehouse infrastructure, costs of remuneration of warehouse workers (permanent); for an external warehouse, these are the remuneration costs of employees commissioning and supervising the provision of warehouse services by the logistics operator,
- variable costs – for own warehouse these are the costs of frozen capital, remuneration costs of seasonal workers, energy costs (lighting, cooling, powering forklifts); for an external warehouse, these are storage costs calculated on the basis of the number of pallets stored, storage time and the operator's price list. Formula to calculate Variable Holding Costs:

$$VHC = \mu_0 \times S \times P$$

where:

VHC – variable stock holding costs,

μ_0 – periodic stock holding cost coefficient,

S – stock in quantitative terms,

P – purchase price; in the case of production, it is the total cost of producing a unit of inventory.

Formula used in Excel:

VHC = [periodic stock holding cost coefficient] * [stock] * [purchase price]

The inventory maintenance cost factor μ_0 indicates what percentage of the average inventory value translates into its maintenance cost. It can be calculated as the ratio of inventory holding costs to the average inventory value. The value of the μ_0 coefficient can vary within a wide range (from 0.05 to 0.20) and depends on the conditions of inventory storage, the principles of its financing and the type of stored goods (Krzyżaniak & Cyplik, 2008).

Storage costs are relatively fixed, to a large extent independent of the size and turnover of warehouses due to constant employment and warehouse infrastructure, and depend mainly on the period of inventory storage.

The costs of capital frozen in inventories are financial costs resulting from the freezing of capital. They depend on the size of this capital (inventory value) and the freezing time (inventory maintenance time). The costs of freezing capital in inventories are hypothetical costs and represent alternative costs that the company incurs by unproductively freezing capital in inventories, instead of, for example, placing capital in a bank (as a deposit).

Loss of value costs only have a variable part. The following cost categories can be distinguished among them (Krzyżaniak & Cyplik, 2008; Śliwczyński, 2007):

- loss of value costs are caused by their changing price on the market, they arise as a result of depreciation of the stock, i.e. loss of their current value as a result of aging: physical – as a result of loss of functional properties and changes in physic-chemical characteristics caused by long-term storage or economic (moral) – in as a result of changes in fashion trends and new market designs, customer preferences and rapid scientific and technological progress,
- disposal costs if the goods kept in stock have a limited shelf life or shelf life,
- costs of damage, theft, etc.

Stockout costs reflect lost benefits, in particular profits that the company could have realized if it had had stocks in the right place, time, quantity and range. Inventory shortage results in disruptions in production, which forces the reorganization of the production plan for other products for which raw materials are available, as well as the need to rearrange production machines, which translates into temporary downtime and often work overtime or on days off. In the context of contract performance, lack of stocks may result in the need to pay contractual penalties for failure to deliver goods. However, the most serious effect is the loss of the company's reputation and its competitive position on the market, which is the result of the lack of product availability in line with customer expectations (Śliwczyński, 2008). Formula to calculate Stockout costs:

$$SOC = FSOC + VSOC = C_{SO} \times p(SO) \times N_R + N_{SO} \times c_{SO}$$

where:

SOC – stockcout costs,

FSOC – fixed stockout costs,

VSOC – variable stockout costs,

C_{SO} – cost incurred due to a stockout,

p(SO) – the probability of a stockout occurring in a given inventory replenishment cycle,

N_R – number of inventory replenishment cycles in the considered period,

N_{SO} – average (expected) number of stockouts in the considered period,

c_{SO} – cost incurred in the event of a single unit stockout.

Formula used in Excel:

SOC = [fixed stockcout costs] + [variable stockcout costs]

SOC = [cost incurred due to a stockout] * [probability of a stockout] * [number of inventory replenishment cycles] + [average number of stockouts] * [unit shortage cost]

The costs of lost benefits in their fixed part refer to the estimated value of the lost margin after the end of cooperation with the client (if the cessation of cooperation with the client was caused by a lack of stock). In the variable part, it is the value of the lost margin caused by failure to deliver a certain number of items ordered by the customer (Krzyżaniak & Cyplik, 2008).

Contractual penalties in the fixed part include the cost of emergency purchase, the cost of downtime of the production system, and penalties depending on the fact of failure to deliver (regardless of the number of undelivered units). The variable part consists of penalties depending on the number of items not delivered in accordance with the order specifications (Krzyżaniak & Cyplik, 2008).

In addition, there may also be **excess inventory costs** associated with exceeding a certain inventory level. Fixed costs of excess inventory may result, for example, from the need to rent an additional warehouse. Variable costs depend on the amount of excess and are related to (Krzyżaniak & Cyplik, 2008):

- costs of renting additional warehouse space from a logistics operator,
- contractual penalties for detaining means of transport (e.g. railway tank cars),
- costs resulting from the increased risk of inventory expiration.

In summary, controlling inventory-related costs is important for effectively managing production and inventory levels. By implementing appropriate inventory management methods, companies are able to reduce operating costs and increase the efficiency of the entire supply chain (Song et al., 2020).

9.6. Basic inventory classification models

ABC analysis is based on the "80-20" rule, known in economics, formulated by the Italian economist Vilfredo Pareto. According to its main assumptions, approximately 20% of the elements determine the effects of a given issue in 80% – this is a classic division. The Pareto principle is an important decision aid for the classification of physical goods. The use of ABC analysis, in the classical approach, divides all assortment items into three classes (A, B, and C) taking as the criterion of this division the share of individual assortments in the total sales value (Pandya & Thakkar, 2016; Tanwari et al., 2000). The procedure for dividing product items according to the ABC analysis is based on a clear classification criterion, which is a specific percentage of the turnover value (Krzyżaniak & Cyplik, 2008).

The ABC method includes the following steps (Cyplik & Hadaś, 2012):

[1] Calculation of the annual consumption value of each product item,

[2] Sorting consumption values in descending order,

[3] Adding up the value of all items,

[4] Calculation of the share of the consumption value of each item in the total consumption value,,

[5] Calculation of accumulated percentages,

[6] Determining the division into groups A, B and C.

Formula used in Excel:

[1] Calculate [consumption value of the assortment] = [purchase price]*[consumption volume]

[2] Sort descending for [product consumption value]

[3] Summarize the entire column [product consumption value] using the SUM([product consumption value])

[4] Calculate the [share] of each item as [stock consumption value]/SUM([stock consumption value])

[5] Calculate the cumulative percentage for each assortment as [cumulative percentage item n+1]=[cumulative percentage item n]+[cumulative percentage item n+1]

[6] Assign the assortment to groups A, B, C using the function: =IF([cumulative share item 1]<80%;"A"; IF([cumulative share item 1]<95%;"B";"C"))

In the **ABC analysis**, products classified as A are the most valuable and require special attention and frequent reviews. Group B products require moderate control, group C products are the least valuable and can be managed using simpler procedures.

Distinguishing 80% of the consumption value determines the items qualifying for group A, which will include approximately 20% of the items. These are the materials that account for the largest share of sales and are generally few in number. The next 15% of the consumption value will determine the items qualifying for group B. The remaining items will form group C – the most numerous. This assortment contributes only to a small extent to the total sales value (Cyplik & Hadaś, 2012), (Chu et al., 2008). It should be noted, however, that such a division is conventional and, depending on the operating conditions and the results obtained, different limits for separating product groups are adopted. The classic shape of quantity-value relations consistent with the Pareto principle is shown in Figure 9.3.

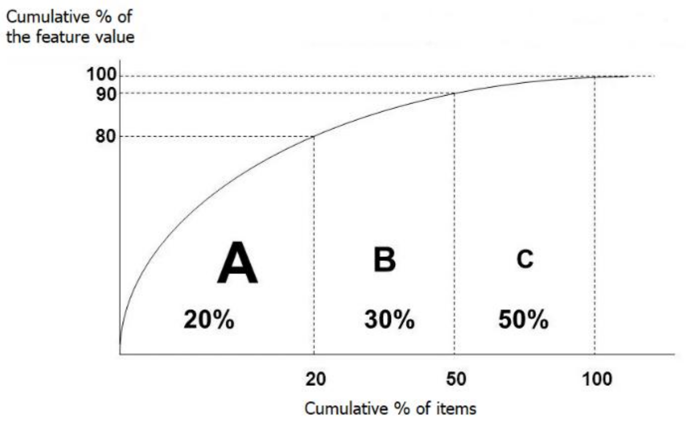

Figure 9.3. ABC Analysis curve

Source: own study

XYZ analysis aims to assess fluctuations in demand or consumption of an assortment (Pandya & Thakkar, 2016). It focuses on the quantitative movement of part of the inventory (Al-dulaime & Emar, 2020). XYZ analysis is performed on inventory, which can vary significantly in each month for which the analysis is performed because the results can be influenced by various external factors such as lost or delayed sales orders and deliveries (Dhoka & Choudary, 2013).

The basis for the division according to the XYZ classification is the nature of consumption – sales (Cyplik & Hadaś, 2012):

- from items issued in large quantities, of a mass nature – group X,
- by medium-sized consumption (in quantitative terms) – group Y,
- for items published sporadically, individually – group Z.

The division into XYZ groups is also related to the criterion of regularity of demand and forecasting accuracy. According to this take (Krzyżaniak & Cyplik, 2008):

- group X includes items consumed in large quantities, characterized by regular demand, with small fluctuations, with high forecasting accuracy,

- group Y are items with lower quantitative demand, with seasonal fluctuations in demand, or showing a clear demand trend, for which forecasts are of average accuracy,
- group Z includes slowly moving items with irregular demand and low accuracy of demand forecasts.

For XYZ analysis, the following steps are involved in the calculation (Dhoka & Choudary, 2013):

[1] Calculating the sum of squares,

[2] Calculation of standard deviation,

[3] Calculation of the coefficient of variation,

[4] Establishing the division into groups X, Y and Z

Formula used in Excel:

[1] Sum of squares calculation: =SUM(([range of cells]-AVERAGE(([range of cells])^2)

[2] Standard deviation calculation: =STDEV.S([cell range])

[3] Calculation of CV as the ratio of the standard deviation to the mean, expressed as a percentage, it is calculated from the formula: =(STDEV.S([range of cells]) / AVERAGE([range of cells]))*100

In **XYZ analysis**, items classified as X have consistent, predictable demand, which allows for easier planning and minimization of safety stock. Y items are moderately predictable and require a more flexible approach to inventory management, while Z items are the least predictable and may require the largest safety stocks.

ABC classification (Pandya & Thakkar, 2016; Cyplik & Hadaś, 2012). Conducting a combined **ABZ/XYZ analysis** allows dividing the considered assortment into 9 groups for which various solutions can be taken regarding maintaining and replenishing the stock (Krzyżaniak & Cyplik, 2008). The characteristics of these groups are presented in Table 9.1.

The field in the matrix is a combination of ABC and XYZ analysis. Assigning the assortment in two dimensions enables the adoption of a good inventory management strategy and gives better control over them (Pandya & Thakkar, 2016). For example, you can indicate:

- rationalization potential for AX, BX and AY groups,
- control complexity for AY, AZ and BZ groups.

Table 9.1. The 9-box approach to the ABC-XYZ relationship

	A	B	C
X	High value of goods turnover, high accuracy of demand forecast	Average turnover value goods, high accuracy demand forecasts	Low turnover value goods, high accuracy demand forecasts
Y	High turnover value product, average accuracy of demand forecast	Average turnover value product, average accuracy of demand forecast	Low turnover value product, average accuracy of demand forecast
Z	High value of goods turnover, lack of accuracy of demand forecast	Average value of goods turnover, lack of accuracy of demand forecast	Low turnover value goods, lack of accuracy demand forecasts

Source: (Pandya & Thakkar, 2016)

The ABC/XYZ classification, along with determining the Probabilistic Service Level (PSL) or the Demand Fulfillment Rate (DFR), constitutes the key foundations for developing an effective inventory replenishment model. These methods allow for the identification and prioritization of inventory based on their value and demand predictability, which is essential for optimizing ordering processes and warehouse management. Consequently, they enable a more targeted and effective approach to inventory management, increasing the operational and financial efficiency of the enterprise.

For classifying inventory to better manage and optimize supply chains, besides the ABC and XYZ methods, the following can also be used (Mitra et al., 2015; Pandya & Thakkar, 2016; Sirisha & Kalyan, 2022):

- HML – classification based on the unit price of the product, where H (High) denotes products with a high unit price, M (Medium) with a medium, and L (Low) with a low,
- VED – classification based on the criticality of products, where V (Vital) denotes indispensable products, E (Essential) important, and D (Desirable) desired,
- GOLF – classification based on the frequency of use and location, where General denotes general products, Occasional – occasional, Local – local, and Fast-moving – quickly rotating,
- SDE – classification based on the availability of products, where Scarce denotes rare products, Difficult hard to obtain, and Easy easy to obtain,
- FSN – classification based on the rotation speed, where Fast denotes quickly rotating products, Slow slowly rotating, and Non-moving non-rotating,
- SOS – classification based on the cyclicality of demand for a given product: Seasonal products have high demand in a specific season or time period, Off-Seasonal – have even demand throughout the year or their demand increases in periods that are not considered the peak season for the product category.

Chapter Questions

1. What is a probabilistic customer service level?
2. What are the basic models of logistics replenishment?
3. What is the main assumption of the Pareto principle?

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10.TRANSPORT OPTIMIZATION

This chapter is devoted to the most important issues related to transport optimization. It includes:

- basic definitions of the transport system,
- the nature and importance of transport system optimization,
- description of the application of the transport issue in practice.

10.1. Introduction

Transport and forwarding processes play a dominant role in the distribution phase. It is important to note that their increasing importance generates the need for innovations concerning the organization of the movement of cargo using appropriately selected means of transport and mode of transport (Krawczyk, 2001). Methods and tools are therefore being sought to provide precise answers to key questions regarding transport and forwarding processes. One may wonder whether any changes need to be made and, if so, what financial results will result? The challenge, as well as the need of the modern company, is to combine the economic benefits of maintaining a high quality of customer service with the reduction of transport costs, which is also a function of customer service. In doing so, the issue of cost minimization takes on a strategic dimension (Christopher, 2000).

Transport belongs to the field of production of material services, performs transportation of people and goods, provides distribution and supply of raw materials and products of industry and agriculture to all regions of the world. at home and abroad. The main task of transport is to fully and timely meet the transport needs of the national economy and population, to increase the efficiency and quality of the transport network. Given the leading role of transport in the market economy, transport management is assigned to a separate field, called transport logistics. Transport logistics includes a number of elements, the main ones being (Yahiaoui, 2019; Vakulenko & Evreenova, 2019):

- loads,

- consolidation stations,
- transport hubs,
- transport network,
- rolling stock,
- handling equipment,
- logistics process participants,
- transport containers,
- packaging.

The main reserves for improving the transport and logistics process lie in the rational organization of supply chain participants' interactions, coordination of their interests and the search for mutually beneficial and appropriate solutions. Advances in information technology can significantly improve the efficiency of transportation logistics, and information and IT support have a rightful place among key logistics functions (Liu, Zhang & Wang, 2018; Sun, et al., 2019).

Advances in information technology have contributed to increased transport efficiency. The use of the latest information technology makes it possible to automate all the IT activities of transport companies that are involved in the processes of organising freight traffic. The automation of transport logistics provides increased efficiency and optimization of transport. With the introduction of automated routing, billing and planning systems in transport enterprises, transport logistics reaches a new level (Dekhtyaruk, et al. 2021).

10.2. The nature and importance of transport system optimization

Transport system optimization research and work is linked to important transport policy issues, playing an important role in the development of transport economics theory. The development of optimization work and research is stimulated by the economic practice of transport, indicating the most relevant issues to be solved, as well as determining the scope and directions of methodological research. On the other hand, the topic of transport system optimization has inspired researchers to implement the achievements of systems theory and cybernetics to solve economic transport problems. This has contributed to favourable developments in the aspect of scientific research methodology, as well as sparking interest in aspects of transport economics of a methodological nature (De Maio & Vitetta, 2015).

An optimal transport system is understood as a system that fully and correctly secures the service of the existing transport needs (volume, types, area dispersion) with the lowest social labour input, while making rational use of the features and characteristics (technical, operational and economic) of individual transport modes. By the idea of this definition adopted in the literature, the issue of optimizing the transport system is reduced to the total and proper service of transport needs with the criterion of minimizing social labour input (Wong, et al., 2016).

Optimization in transport is a very broad concept that covers a variety of processes. Their aim is to improve the situation of the parties involved in transport (shippers, receivers, employees). Most often, aspects relating to optimization and forwarding can be found in the literature. Usually it is a question of reducing transport and delivery costs. In practice, however, the issue is multi-criteria. Less common criteria are also relevant, among which one can mention comfort, ecology, quality of transport services, customer satisfaction and even road wear and tear. Cost and time, however, are the dominant factors. Logistical processes should be considered from a strategic as well as an operational perspective. The strategic perspective refers to long-term planning and the design of a company's vision. The operational perspective deals with the current situation. These aspects of optimization should be linked to each other as well as supported by various logistics management systems. The topic of transport optimization, even if limited to cost minimization, involves a whole sequence of activities concerning the complete supply chain. The most important is the creation of an efficient distribution network, concerning the identification of the location of customers and their needs, which potentially change over time, and the optimal location of distribution centres, distribution terminals and warehouses. It is also important to choose the right fleet (size of vehicles, split between own and external fleets, as well as their capacities such as lifting, crane, refrigeration, cargo space), as an inadequate fleet can significantly reduce the potential of a transport company. The transport optimization process should also analyse different product flow scenarios, as well as a global identification of bottlenecks and profit-reducing factors for the company (www_10.1).

The advantages of a properly conducted optimization process include increased safety, better service quality and greater availability of goods and services. The integration of systems and the application of predefined standards, together with a skilful selection of optimization techniques, is helpful for national and regional transport and is also conducive to increasing the competitiveness of the enterprise. The most important benefits of optimization, when carried out correctly, are illustrated in Figure 10.1. The following figure shows the changes occurring through the implementation of optimization processes.

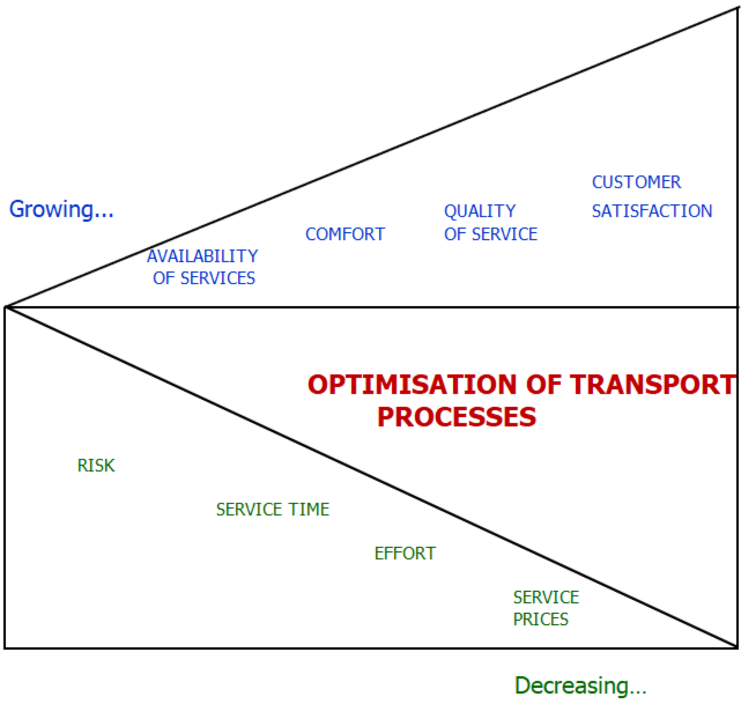

Figure 10.1. Changes resulting from the use of optimization of transport processes

Source: (Zajdel & Filipowicz, 2008)

Several optimization issues can be mentioned. The most important of them in the group of small shipments are:

- choice between indirect and direct carrier,
- distribution potential planning,
- consider local distribution.

The acceptance of transportation orders always raises the question of choosing between direct suppliers and the use of a distribution network. Making a decision regarding the transport of a shipment depends on terminal and delivery costs. This problem concerns the dimensions of the shipment. A large shipment and a long delivery distance encourage you to choose direct transport. If the shipment is a single shipment, the issue becomes easy to solve because it is enough to compare transportation costs using the terminal system. However, it should be borne in mind that combining a shipment with other items reduces the costs of indirect transport. Designing a distribution network for small parcels is a strategic issue. The total cost of the system can be calculated using the following formula (Milewski, 2011):

$$\boldsymbol{K_{CSD} = \sum_{j=1}^{n} K_{d-O_j} + K_{T_j} + K_{P_j},}$$

where:

K_{CSD} – total cost of the distribution system,

K_{d-O_j}- transport and disposal costs of the *i*-th terminal,

K_{T_j} – terminal costs of the *i*-th terminal,

K_{P_j} – costs of linear transport of the *i*-th terminal,

n – number of terminals.

An operational problem is planning parcel transport routes within the framework of strategic arrangements. The total cost of transporting shipments along a given route can be expressed using the formula below (Milewski, 2011):

$$\boldsymbol{K_{CDL} = \sum_{k=1}^{O} K_{i,k} * d_k\,,}$$

where:

K_{CDL} – total cost of local distribution,

$K_{i,k}$ – transportation cost (delivering or distributing) of shipments on route *k*,

d_k - route length *k*,

o – number of routes.

The main goal of optimization methods and models is to solve problems. The optimization criterion is usually the shortest possible transport time or the shortest route. This approach is sufficient assuming that the total cost depends directly on the length of the routes. Therefore, the route should be selected so that it is "as short as possible or the travel time along it is as short as possible." At this point, attention should be paid to the optimization model of the transport macrosystem (Milewski, 2011). Its task is to develop an appropriate number of indicators and measures necessary in the process of rational transport management during the logistic implementation of operational activities. The more precisely the model reflects the tested reality, the more effective the control capabilities are. Depending on the similarity, the optimization model can be used to directly create a business strategy in the transport services sector. The optimization model of the transport system provides methods and scientific tools for controlling the transport system. It can be written in the form of the following expression (Ficoń, 2010).

$$MDE_{ST} =< Z_{ST}, P_{ST}(t) \text{ II } G_{ST}, F_{ST}, H_{ST} > \xrightarrow{maxSTO_{ST}} minS_{ST},$$

where:

Z_{ST} – a set of operational (logistic) resources of the *ST* system,

P_{ST} - a set of operational (logistics) processes of the *ST* system,

G_{ST} – a set of constraints and boundary conditions of the *ST* system,

F_{ST} – ST system operation criterion function,

H_{ST} – a set of acceptable operating schedules for the *ST* system,

S_{ST} – global costs of functioning of the *ST* transport macrosystem,

STO – logistic customer service standards by the transport sector.

The concept of optimization modeling of the transport system is presented in Figure 10.2.

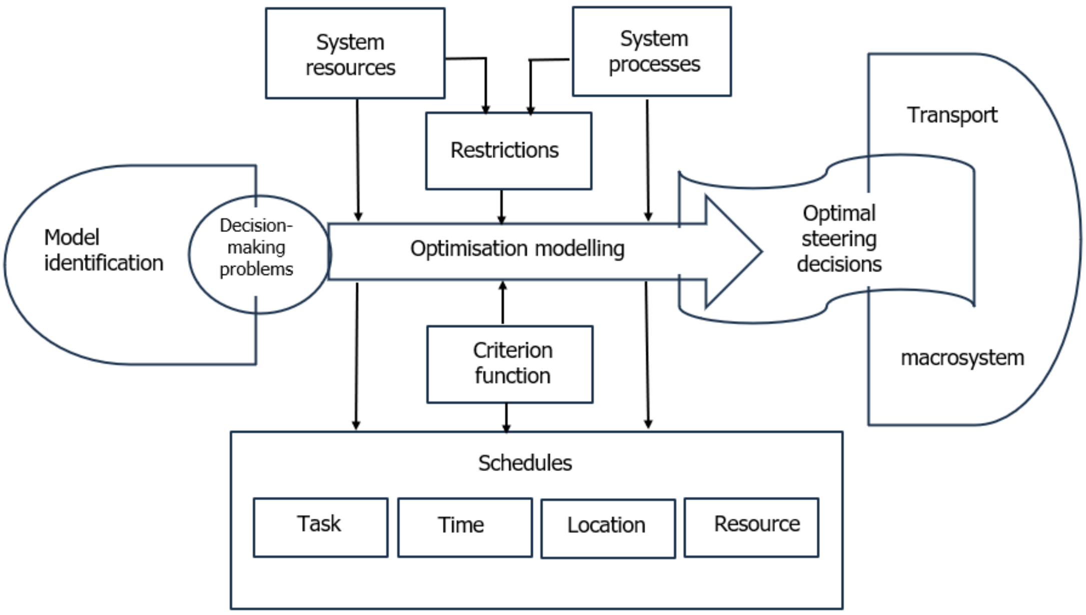

Figure 10.2. The concept of optimization modeling of the transport system

Source: (Ficoń, 2010)

There are, of course, other models to help solve optimization problems in transport There are many more transport optimization issues. There are differences between them depending on the company, its size and the products at its disposal.

10.3. Transport optimization issues in practice

One of the basic components of transport optimization is **route optimization**. This involves designing routes for the vehicles used to transport goods in order to optimize profits and customer service. For the company, this usually means a reduction in costs and transport time, while for customers it means lower costs and on-time delivery. These objectives are achieved by minimizing the distance travelled, being able to adapt transport schedules to changing conditions and new situations over time, synchronizing transport with warehouse operations, and being able to optimize frequently and quickly in order to update the current plan. Although the most common goal in transport tasks is to reduce transport costs to a minimum or strive to minimize distances, in the case of transporting products, mainly foodstuffs, that can quickly become out-of-date, products that quickly lose their useful properties or those that are delivered according to the just-in-time principle due to limited storage capacities or excessive storage costs at the recipient's premises, or late deliveries by previous links in the supply chain, the priority objective is to minimise the lead time for all deliveries. Shorter delivery times make it possible to meet customers' expectations regarding delivery times, as well as to preserve the use value of the transported products, which can compensate for the expenses that result from the involvement of transport means. In the above cases, the most important consideration is therefore the reduction of the longest transport time in a given delivery system, i.e. the calculation of the shortest time in which deliveries could be completed (Gaspars-Wieloch, 2011).

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From an IT perspective, route optimization in transport and logistics is closely related to the **traveling salesman problem** (TSP) and the marshalling problem (VRP, Vehicle

Routing Problem). The traveling salesman problem is a classical combinatorial optimization problem, which involves planning the shortest and least expensive transportation route, passing through n specified sending and receiving points, with given travel costs between each pair of points. The VRP problem is a generalisation of the TSP problem. In it, it is possible to have multiple commuters (multiple vehicles), with the possibility of returning to the base multiple times before reaching all n locations. For both the TSP and the VRP problem, there are many generalisations and additional practical constraints, which can include time windows, sequential restrictions on the locations visited, different vehicle and driver capabilities, or capacity constraints, which are useful for delivery and collection (www_10.2).

In order to solve the TSP task, it is necessary to specify: the level of product stock at each sending point, the volume of demand at each receiving point, as well as the transport costs from each sending point to each receiving point (Vinichenko, 2009). If only one product is involved, then the demand of the receiving points can be supplemented from one or more sending points. The intention of such a plan is to calculate the amount of products shipped from each sending point to each receiving point in order to minimise the total transport cost (Stachurski & Wierzbicki, 2001).

If the cost of the journey is directly proportional to the quantity transported, we are dealing with a linear transport task. Otherwise, if this condition is not met, the transport task becomes a non-linear task. One of the most popular optimization methods is linear programming (Silaen, et al., 2019; Gass, 2013). The greatest usefulness of this method is noted when creating a network of facilities, with the constraining conditions for the model being the size of demand and supply for production facilities, distribution centres or individual markets. With a given objective function, assuming, for example, a reduction in total cost, linear programming is helpful in creating an optimal facility deployment pattern that takes into account demand-supply constraints. Although the linear programming method is quite practical, there are limitations to its use, as the problem to be solved using it must be formulated deterministically, as well as the problem should be subjected to a linear approximation. In addition, the fixed and variable operating costs of logistics facilities cannot be taken into account in linear programming (Coyle, et al., 2002).

A large number of scientific papers can be found in the logistics literature on the theory and practice of organising an optimal transport system using various models and methods. Publications (Lai & Bierlaire, 2015; De Maio & Vitetta, 2015; Manley, Orr & Cheng, 2015; Vitetta, 2016) present route optimization studies according to the criterion of minimum delivery time.

In the articles (Hess, et al., 2015; Nyrkov, Sokolov & Belousov, 2015) methods based on alternative sampling were used to determine the optimal route. In contrast, the authors of publications (Zhilenkov, Nyrkov, & Cherniy, 2015; Omelianenko, et al., 2019; Tomashevskiy, 2007; Cheng & Wu, 2020; Zaychenko, 2014) have used fuzzy logic-based route modelling methods for transport systems. In the publications (Shang, et al., 2020; Shramenko & Shramenko, 2019) their authors, in order to plan the optimal route, used a heuristic model, while in the articles (Maleev, et al., 2019,; Skvortsov, Pshonkin & Luk'yanov, 2018,) a quantum model for determining the optimal route in transport systems was described.

The results of modelling the selection of optimal routes using **Global Positioning System** (GPS) data focused on trucks making long journeys can be consulted in publications (Khripach, et al., 2018; Navrodska, et al., 2019; Fialko, et al., 2020).

In the following, the individual steps in solving a transport task are presented in detail using a practical example of a transport problem with a time criterion for optimising the supply of a supermarket chain, which was described in the article (Gaspars-Wieloch, 2011).

Problem characterisation of the transport problem with a time criterion for optimising the supply of a supermarket chain

In the transport optimization issue described, a supermarket chain distributed in different parts of the country is considered. A new range of goods is developed for each week, which, in addition to the always-on range, which includes groceries, drugstore products, are only sold to customers for six days from Monday to Saturday or until stocks run out. The week's offerings include white goods, paper products, clothing, toys, tools or gardening items, among others. Often, the product offer is tailored to the season and holidays such as Christmas, Easter, Valentine's Day, All Saints' Day, First Holy Communion, etc. The week's offerings are determined well in advance and the products they cover are stocked in wholesalers spread across the country. Depending on the possibilities available to the suppliers, the different types of goods are delivered to the wholesalers a week in advance on different days (including Saturday mornings) before they go on sale. Wholesalers are required to prepare product kits for each shop. An example kit might include 20 napkins, 30 televisions, 40 buckets, 20 pairs of flip-flops, 30 pots, 20 teddy bears, 30 pairs of trousers, 60 hand creams, 50 balls and 40 notebooks.

As the kits may not be completed until the end of the week, and due to insufficient storage space in the supermarkets, the company is keen to deliver the week's range to all shops on the night of Sunday to Monday and spread them out on the shelves without delay.

Each lorry that leaves the warehouse delivers sets of products immediately to several or even a dozen supermarkets, forming a sector. The supermarkets in a sector are located fairly close to each other (e.g. in the same town). The time taken to supply a sector depends on which wholesaler a vehicle is diverted to it from. The key objective of the company is to minimise the longest delivery time.

Mathematical model of the transport task

The general form of a model describing a closed transport problem with a time criterion can be presented as follows (Gaspars-Wieloch, 2011):

$$\max_{x_y>0}\{t_{ij}\} \rightarrow min \qquad (1)$$

$$\sum_{j=1}^{n} x_{ij} = a_i \quad (i-1,\dots,m) \qquad (2)$$

$$\sum_{i=1}^{m} x_{ij} = b_j \quad (j=1,\dots,n) \qquad (3)$$

$$x_{ij} \geq 0 \qquad (4)$$

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j \qquad (5),$$

where:

x_{ij} – volume of goods transported from *i*-th supplier to *j*-th customer,

t_{ij} – transport time of the goods from *i*-th supplier to *j*-th consignee,

n – number of recipients,

m – number of suppliers,

a_i – supply of the *i*-th supplier,

b_j – *j*-th customer demand.

When there is no equality between total supply and total demand, the last formula (5) is not taken into account and the supply conditions (2) or demand conditions (3) turn into inequalities. The mathematical model described above is applicable to circumstances where the decision-maker does not assume other considerations, such as insufficient supply vehicles, a required minimum level of demand satisfaction or a difference in the nature of transport time and unloading time.

In scientific papers (Sikora, 2008), an algorithm was presented to solve the previously described transport problem. The subsequent steps of the course of action according to the said algorithm are listed below (Gaspars-Wieloch, 2011):

1. The first step is to determine the admissible base equation using the minimum matrix element method, known as the MEM method based on a table of times.
2. in the second step, it is important to determine the maximum delivery time (T^k) for a particular solution based on the formula (6):

$$\boldsymbol{T^k} = \max_{x_{ij}>0}\{\boldsymbol{t_{ij}}\}, \qquad (6)$$

where:

T^k – maximum delivery time in the k-th iteration.

3. a cost table (c_{ij}) for the k-th solution must be presented in turn according to formula (7):

$$c_{ij}^k = \begin{Bmatrix} 0 & & t_{ij} < T^k \\ 1 & \text{if} & t_{ij} = T^k \\ 10 & & t_{ij} > T^k \end{Bmatrix} \qquad (7)$$

4. The next step is to check the optimality of the solution based on the cost table. In the case of non-negativity of the optimality criteria (Δ_{ij}) for all base routes, the procedure ends at this stage. If the optimality criteria are negative, follow the steps in step five.

$$\boldsymbol{\Delta_{ij}^{k}= c_{ij}^{k} - \alpha_{i}^{k} - \beta_{j}^{k}}, \qquad (8)$$

where:

α_i^k, β_j^k – dual variables, i.e. potentials in the *k*-th iteration.

5. the acceptable base solution should be redetermined, taking into account the most negative optimality criterion, and then return to step two.

The above algorithm is based on the so-called potential method, which has been described in many publications, e.g. (Leonard, 1997). If there are other assumptions in a specific decision problem, concerning the limited packing capacity of the means of transport, then the procedure discussed should additionally refer to the principles that were adopted in the course of the procedure for a transport task with limited route capacity (Codeca & Cahill, 2022; Sanz & Escobar Gomez, 2013).

The algorithm can be used as a manual procedure when dealing with tasks with a small number of suppliers and customers. For problems of greater complexity, it is recommended to use an appropriate programme created for the algorithm in any programming language.

Another option for the procedure presented can be a developed optimization IT tool, an example of which is Solver, included in Microsoft Excel. However, it should be taken into account that the version of Solver has an impact on the type of tasks that can be solved. With each newer version, more possibilities are offered in terms of the number of conditions or variables in the task, the time required to solve the problem and the type of functions used. In the standard version of Solver, no „if", „max{}" or „min{}" function can be used. The „max" function appears in the mathematical model, described by formulas (1)-(5), so it seems that the task cannot be solved using the standard version of Solver. In order to carry out the calculations, an example with specific numerical data is considered below, for which an appropriate mathematical model has been formulated. The example concerns a supermarket chain comprising three wholesalers, P (in the south of the country), Z (in the west of the country) and PW (in the north-east of the country), and 50 shops, divided into 8 differentiated sectors, denoted by letters (A, B, C, D, E, F, G and H). Based on the products transported, 18 kits can be drawn up by each wholesaler. The demand for kits per sector is as follows:

$$\mathbf{Z_A = 6; Z_B = 7; Z_C = 9; Z_D = 6; Z_E = 8; Z_F = 5; Z_G = 4; Z_H = 5, \text{ whereby } \sum_{j=1}^{8} 50.}$$

The time taken by the delivery vehicles to serve each sector is formed by the travelling time from the wholesaler to the sector, which is not dependent on the number of shops in the sector, as well as the unloading time in the sector itself, which is dependent on the number of shops, as illustrated in Tables 10.1 and 10.2. It has been assumed that the transport time in a sector, which in practice is determined by the distance between the shops in the sector, is taken into account in the unloading times of the assortment in each shop. The aim is to minimise the delivery time taking the longest.

Table 10.1. Approximate journey time (t_{ij}^{p}, in hours)

Sectors / Wholesalers	A	B	C	D	E	F	G	H
P	9	6	3	3	6	9	12	7
Z	5	4	5	6	9	12	9	7
PW	8	5	11	5	3	3	4	3

Source: (Gaspars-Wieloch, 2011)

Table 10.2. Average unit unloading time (t_i^r, in hours)

Sectors	A	B	C	D	E	F	G	H
t_i^r	1/3	1/2	1/3	2/5	1/2	2/5	1/4	2/5

Source: (Gaspars-Wieloch, 2011)

The example presented above with numerical data has a slightly higher degree of complexity than a standard transport problem with a time criterion. Therefore, the exact notation of the optimization task that applies to the example in question is only fragmentarily similar to the general mathematical model, as illustrated by formulas (9)-(21). The objective function for minimising delivery time can be written as follows (Gaspars-Wieloch, H. in: Szymczak, M. (ed.), 2011, pp.17-18):

$$\max\{(9\min\{x_{11},1\}+\frac{1}{3}x_{11}),\left(6\min\{x_{12},1\}+\frac{1}{2}x_{12}\right),\left(3\min\{x_{13},1\}+\frac{1}{3}x_{13}\right),(3\min\{x_{14},1\}+ +\frac{2}{5}x_{14}),\left(6\min\{x_{15},1\}+\frac{1}{2}x_{15}\right),\left(9\min\{x_{16},1\}+\frac{2}{5}x_{16}\right),\left(12\min\{x_{17},1\}+\frac{1}{4}x_{17}\right),(7\min\{x_{18},1\} +\frac{2}{5}x_{18}),\left(5\min\{x_{21},1\}+\frac{1}{3}x_{21}\right),\left(4\min\{x_{22},1\}+\frac{1}{2}x_{22}\right),\left(5\min\{x_{23},1\}+\frac{1}{3}x_{23}\right),(6\min\{x_{24},1\} +\frac{2}{5}x_{24}),\left(9\min\{x_{25},1\}+\frac{1}{2}x_{25}\right),\left(12\min\{x_{26},1\}+\frac{2}{5}x_{26}\right),\left(9\min\{x_{27},1\}+\frac{1}{4}x_{27}\right), \left(7\min\{x_{28},1\}+\frac{2}{5}x_{28}\right),\left(8\min\{x_{31},1\}+\frac{1}{3}x_{31}\right),\left(5\min\{x_{32},1\}+\frac{1}{2}x_{32}\right),\left(11\min\{x_{33},1\}+ \frac{1}{3}x_{33}\right),\left(5\min\{x_{34},1\}+\frac{2}{5}x_{34}\right),\left(3\min\{x_{35},1\}+\frac{1}{2}x_{35}\right),\left(3\min\{x_{36},1\}+\frac{2}{5}x_{36}\right),\left(4\min\{x_{37},1\}+ \frac{1}{4}x_{37}\right),\left(3\min\{x_{38},1\}+\frac{2}{5}x_{38}\right)\}\to min \quad (9)$$

The conditions that relate to sectoral demand are written as follows (Gaspars-Wieloch, 2011):

$$x_{11}+x_{21}+x_{31}=6 \quad (10)$$

$$x_{12}+x_{22}+x_{32}=7 \quad (11)$$

$$x_{13}+x_{23}+x_{33}=9 \quad (12)$$

$$x_{14}+x_{24}+x_{34}=6 \quad (13)$$

$$x_{15}+x_{25}+x_{35}=8 \quad (14)$$

$$x_{16}+x_{26}+x_{36}=5 \quad (15)$$

$$x_{17}+x_{27}+x_{37}=4 \quad (16)$$

$$x_{18}+x_{28}+x_{38}=5 \quad (17)$$

The conditions that apply to the supply of wholesalers are presented below (Gaspars-Wieloch, 2011):

$$x_{11}+x_{12}+x_{13}+x_{14}+x_{15}+x_{16}+x_{17}+x_{18}\leq 18 \quad (18)$$

$$x_{21}+x_{22}+x_{23}+x_{24}+x_{25}+x_{26}+x_{27}+x_{28}\leq 18 \quad (19)$$

$$x_{31}+x_{32}+x_{33}+x_{34}+x_{35}+x_{36}+x_{37}+x_{38}\leq 18 \quad (20)$$

The condition having to do with the integrability of the decision variables has the form (Gaspars-Wieloch, 2011):

$$x_{11}, x_{12}, \dots, +x_{38} \in N, \quad (21)$$

where:

x_{11} – number of sets transported from warehouse P to supermarket A,

⋮

x_{38} – number of sets transported from the PW warehouse to the supermarket H.

The example discussed is one of the rather convoluted ones, not only due to the lack of direct possibility to solve optimization problems containing the „max{}" and „min{}" functions in the standard version of Solver. Further complications include the two types of time introduced: the arrival time at each sector, and the discharge time at the sector. This was necessary because products transported by truck are not unloaded in one place, but in several shops. There is therefore a correlation between unloading times and the number of supermarkets served. The algorithm described earlier should not be directly applied to this type of problem.

Design of the Excel spreadsheet in the presented example of a transport task

Figure 10.3 shows how to enter the data in the Microsoft Excel spreadsheet of the transport task example discussed. The cells with addresses C8-J10 are the fields where the optimal values of the decision variables (x_{11}, x_{12}, …, x_{38}) will be shown. The summed field values of the corresponding columns of table C8-J10 were calculated in the row with the number 11. They represent the left-hand side of conditions (10)-(17). The formulated demand is included in the row with number 12. The added values from cell ranges C8:J8, C9:J9, C10:J10 are shown in the column labelled K. They contain the total number of sets transported from wholesalers P, Z, PW respectively, i.e. the left-hand side of supply constraints (18)-(20). The supply values of the individual wholesalers are shown in column L.

	B	C	D	E	F	G	H	I	J	K	L
4											
7	Wholesalers and sectors	A	B	C	D	E	F	G	H	Total at a given wholesaler	Supply
8	P									0	18
9	Z									0	18
10	PW									0	18
11	Sector total	0	0	0	0	0	0	0	0		
12	Demand	6	7	9	6	8	5	4	5		
13											
16	Travel time to sector	9	6	3	3	6	9	12	7		
17		5	4	5	6	9	12	9	7		
18		8	5	11	5	3	3	4	3		
19											
20	Unloading time	0,33	0,50	0,33	0,40	0,50	0,40	0,25	0,40		
21											
24	Total unloading time	0	0	0	0	0	0	0	0		
25		0	0	0	0	0	0	0	0		
26		0	0	0	0	0	0	0	0		
27											
30	Total journey time (fixed) and unloading time (variable)	9	6	3	3	6	9	12	7		
31		5	4	5	6	9	12	9	7		
32		8	5	11	5	3	3	4	3		
33											
36	Base and non-base routes	0	0	0	0	0	0	0	0		
37		0	0	0	0	0	0	0	0		
38		0	0	0	0	0	0	0	0		
39											
43	Total time on base routes	0	0	0	0	0	0	0	0		Objective function
44		0	0	0	0	0	0	0	0		0,0
45		0	0	0	0	0	0	0	0		

Figure 10.3. Data entered into the spreadsheet in this example of a transport task

Source: (Gaspars-Wieloch, 2011)

Rows 16-45 present a summary of the parameters and formulas needed to determine the objective function. The data from Tables 10.1 and 10.2 are presented in rows 16-18 and 20. The total unloading time from the *i*-th wholesaler to the *j*-th sector in rows 24-26 has been calculated by multiplying the unit unloading time from row 20 by the number of delivered sets in rows 8-10, as shown in Figure 10.4.

24	Total unloading time	=C20*C8	=D20*D8	=E20*E8	=F20*F8	=G20*G8	=H20*H8	=I20*I8	=J20*J8
25		=C20*C9	=D20*D9	=E20*E9	=F20*F9	=G20*G9	=H20*H9	=I20*I9	=J20*J9
26		=C20*C10	=D20*D10	=E20*E10	=F20*F10	=G20*G10	=H20*H10	=I20*I10	=J20*J10

Figure 10.4. Calculation of total unloading time

Source: compiled on the basis of (Gaspars-Wieloch, 2011)

The method of determining the total travel time and unloading time in rows numbered 30-32 is shown in Figure 10.5.

30	Total journey time (fixed) and unloading time (variable)	=C16+C24	=D16+D24	=E16+E24	=F16+F24	=G16+G24	=H16+H24	=I16+I24	=J16+J24
31		=C17+C25	=D17+D25	=E17+E25	=F17+F25	=G17+G25	=H17+H25	=I17+I25	=J17+J25
32		=C18+C26	=D18+D26	=E18+E26	=F18+F26	=G18+G26	=H18+H26	=I18+I26	=J18+J26

Figure 10.5. Calculation of total unloading time

Source: compiled on the basis of (Gaspars-Wieloch, 2011)

The purpose of writing „$min\{x_{ij}, 1\}$" in formula (9) is to extract the underlying routes. In the standard version of Solver, it is not possible to solve tasks where the function 'min{}' is present. Therefore, the base routes must be determined differently. If the quotient in formula (22) has a value close to the number 1, then this route can be referred to as the base route. If, on the other hand, the quotient is equal to zero, then the transport on the examined route will not take place, as shown in Figure 10.6.

$$\frac{x_{ij}}{x_{ij} + 0{,}00001} \qquad (22)$$

36	Base and non-base routes	=C8/(C8+0,00001)	=D8/(D8+0,00001)	=E8/(E8+0,00001)	=F8/(F8+0,00001)	=G8/(G8+0,00001)	=H8/(H8+0,00001)	=I8/(I8+0,00001)	=J8/(J8+0,00001)
37		=C9/(C9+0,00001)	=D9/(D9+0,00001)	=E9/(E9+0,00001)	=F9/(F9+0,00001)	=G9/(G9+0,00001)	=H9/(H9+0,00001)	=I9/(I9+0,00001)	=J9/(J9+0,00001)
38		=C10/(C10+0,00001)	=D10/(D10+0,00001)	=E10/(E10+0,00001)	=F10/(F10+0,00001)	=G10/(G10+0,00001)	=H10/(H10+0,00001)	=I10/(I10+0,00001)	=J10/(J10+0,00001)

Figure 10.6. Determination of base and non-base routes

Source: compiled on the basis of (Gaspars-Wieloch, 2011)

Using the method described, only the times for the base routes can be included in the final step. The formulae for calculating the total time on the base routes can be found in Figure 10.7. and can be found in rows 43-45. The cells in lines 43-45 are the successive arguments of the {max} function that appears in formula (9). The objective function itself is contained in cell L44.

43	Total time on base routes	=C36*C30	=D36*D30	=E36*E30	=F36*F30	=G36*G30	=H36*H30	=I36*I30	=J36*J30
44		=C37*C31	=D37*D31	=E37*E31	=F37*F31	=G37*G31	=H37*H31	=I37*I31	=J37*J31
45		=C38*C32	=D38*D32	=E38*E32	=F38*F32	=G38*G32	=H38*H32	=I38*I32	=J38*J32

Figure 10.7. Determination of total cost on base routes

Source: compiled on the basis of (Gaspars-Wieloch, 2011)

Solving the problem in the presented transport task

To obtain the optimal solution, the Solver window still needs to be completed (Figure 10.8). The non-negativity of variables must be selected in the options, and then the "Solve", "Store Solution" and "Ok" commands selected.

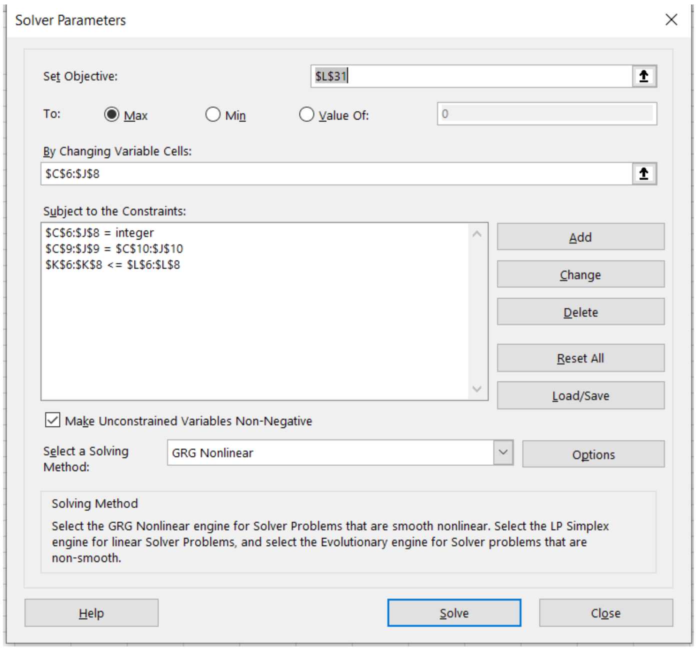

Figure 10.8. Formulas in the Solver window

Source: compiled on the basis of (Gaspars-Wieloch, 2011)

The resulting calculations are presented in Figure 10.9. However, they should be approached with caution, as the creation of the worksheet only managed to avoid the use of functions of the type „min{}", while the function „max{}"still remained. The results should therefore be looked at more closely. The transport of products on the route that connects wholesaler P to sector F currently has the longest duration, i.e. 9.8 hours, and needs to serve two shops ($x_{16} = 2$). Therefore, an attempt should be made to find a more favourable scheduling of deliveries by adding the condition $x_{16} \leq 1$, i.e. $H$6≤ 1. This will reduce the transit and discharge times to a maximum of 9.8-0.4=9.4 hours, resulting in a more favourable solution.

Wholesalers and sectors	A	B	C	D	E	F	G	H	Total at a given wholesaler	Supply
P	0,0	3,0	7,0	2,0	3,0	2,0	0,0	0,0	17	**18**
Z	6,0	1,0	2,0	4,0	0,0	0,0	1,0	1,0	15	**18**
PW	0,0	3,0	0,0	0,0	5,0	3,0	3,0	4,0	18	**18**
Sector total	6	7	9	6	8	5	4	5		
Demand	**6**	**7**	**9**	**6**	**8**	**5**	**4**	**5**		
Travel time to sector	9	6	3	3	6	9	12	7		
	5	4	5	6	9	12	9	7		
	8	5	11	5	3	3	4	3		
Unloading time	0,33	0,50	0,33	0,40	0,50	0,40	0,25	0,40		
Total unloading time	0	1,5	2,31	0,8	1,5	0,8	0	0		
	1,98	0,5	0,66	1,6	0	0	0,25	0,4		
	0	1,5	0	0	2,5	1,2	0,75	1,6		
Total journey time (fixed) and unloading time (variable)	9	7,5	5,31	3,8	7,5	9,8	12	7		
	6,98	4,5	5,66	7,6	9	12	9,25	7,4		
	8	6,5	11	5	5,5	4,2	4,75	4,6		
Base and non-base routes	0	1	1	1	1	1	0	0		
	1	1	1	1	0	0	1	1		
	0	1	0	0	1	1	1	1		
Total time on base routes	0,0	7,5	5,3	3,8	7,5	9,8	0,0	0,0		Objective function
	7,0	4,5	5,7	7,6	0,0	0,0	9,2	7,4		**9,8**
	0,0	6,5	0,0	0,0	5,5	4,2	4,7	4,6		

Figure 10.9. First solution to an optimization task

Source: (Gaspars-Wieloch, 2011)

The second plan is included in Figure 10.10. In it, it is worth including the condition $x_{28} \leq 2$, i.e. $\$J\$9 \leq 2$, as it will then contribute to reducing the delivery time on the Z-H route by at least 0.4 hours (the unloading time for products in the H sector will then be 8.2-0.4=7.8 hours).

Wholesalers and sectors	A	B	C	D	E	F	G	H	Total at a given wholesaler	Supply
P	0,0	3,0	8,0	1,0	3,0	0,0	0,0	1,0	16	**18**
Z	6,0	2,0	1,0	4,0	0,0	0,0	0,0	3,0	16	**18**
PW	0,0	2,0	0,0	1,0	5,0	5,0	4,0	1,0	18	**18**
Sector total	6	7	9	6	8	5	4	5		
Demand	**6**	**7**	**9**	**6**	**8**	**5**	**4**	**5**		
Total time on base routes	0,0	7,5	5,6	3,4	7,5	0,0	0,0	7,4		Objective function
	7,0	5,0	5,3	7,6	0,0	0,0	0,0	8,2		**8,2**
	0,0	6,0	0,0	5,4	5,5	5,0	5,0	3,4		

Figure 10.10. Second solution to an optimization task

Source: (Gaspars-Wieloch, 2011)

The third solution is illustrated in Figure 10.11. The time on the Z-H route actually decreased to 7.5 hours, but the longest time was recorded on the P-E route (8 hours). One might be tempted to see if adding the criterion $x_{15} \leq 3, czyli\ \$G\$8 \leq 3$ would improve the final result?

	B	C	D	E	F	G	H	I	J	K	L
4											
5	Wholesalers and sectors	A	B	C	D	E	F	G	H	Total at a given wholesaler	Supply
6	P	0,0	2,0	8,0	4,0	4,0	0,0	0,0	0,0	18	18
7	Z	6,0	4,0	1,0	2,0	0,0	0,0	0,0	2,0	15	18
8	PW	0,0	1,0	0,0	0,0	4,0	5,0	4,0	3,0	17	18
9	Sector total	6	7	9	6	8	5	4	5		
10	Demand	6	7	9	6	8	5	4	5		
11											
29											
30	Total time on base routes	0,0	7,0	5,6	4,6	8,0	0,0	0,0	0,0		Objective function
31		7,0	6,0	5,3	6,8	0,0	0,0	0,0	7,8		8,0
32		0,0	5,5	0,0	0,0	5,0	5,0	5,0	4,2		

Figure 10.11. The third solution to the optimization task

Source: (Gaspars-Wieloch, 2011)

In the fourth solution, shown in Figure 10.12, the longest delivery time is already only 7.5 hours. After introducing constraints on the routes, which now determine the value of the objective function: $x_{12} \leq 2, czyli\ \$D\$8 \leq 2\ i\ x_{15} \leq 2, czyli\ \$G\$8 \leq 2.$

Figure 10.13 shows the fifth most optimal solution. Even if further constraints are added, they will no longer improve delivery times.

	B	C	D	E	F	G	H	I	J	K	L
4											
5	Wholesalers and sectors	A	B	C	D	E	F	G	H	Total at a given wholesaler	Supply
6	P	0,0	3,0	4,0	6,0	3,0	0,0	0,0	1,0	17	18
7	Z	6,0	3,0	5,0	0,0	0,0	0,0	0,0	1,0	15	18
8	PW	0,0	1,0	0,0	0,0	5,0	5,0	4,0	3,0	18	18
9	Sector total	6	7	9	6	8	5	4	5		
10	Demand	6	7	9	6	8	5	4	5		
11											
29											
30	Total time on base routes	0,0	7,5	4,3	5,4	7,5	0,0	0,0	7,4		Objective function
31		7,0	5,5	6,6	0,0	0,0	0,0	0,0	7,4		7,5
32		0,0	5,5	0,0	0,0	5,5	5,0	5,0	4,2		

Figure 10.12. Fourth solution to an optimization task

Source: (Gaspars-Wieloch, 2011)

	B	C	D	E	F	G	H	I	J	K	L
4											
5	Wholesalers and sectors	A	B	C	D	E	F	G	H	Total at a given wholesaler	Supply
6	P	0,0	2,0	4,0	6,0	2,0	0,0	0,0	1,0	15	18
7	Z	6,0	5,0	5,0	0,0	0,0	0,0	0,0	1,0	17	18
8	PW	0,0	0,0	0,0	0,0	6,0	5,0	4,0	3,0	18	18
9	Sector total	6	7	9	6	8	5	4	5		
10	Demand	6	7	9	6	8	5	4	5		
11											
29											
30	Total time on base routes	0,0	7,0	4,3	5,4	7,0	0,0	0,0	7,4		Objective function
31		7,0	6,5	6,6	0,0	0,0	0,0	0,0	7,4		7,4
32		0,0	0,0	0,0	0,0	6,0	5,0	5,0	4,2		

Figure 10.13. Fifth solution to an optimization task

Source: (Gaspars-Wieloch, 2011)

The assumption for the optimal solution to the task is that the longest delivery time of 7.4 hours will be recorded on the two routes: P-H and Z-H. Each sector will be supplied with kits in line with reported demand. The supply of PW wholesalers will be used to the maximum. 13 trucks will be required to supply the supermarket chain.

Comparing the results obtained in the fourth and fifth solutions, one could actually end up implementing the fourth option due to the slight difference in time (7.5-7.4=0.1 h). It is worth noting here that in the fourth plan, in addition to a slightly longer delivery time, as many as 14 goods vehicles would have to be dispatched. The result obtained is of course not the only optimal solution. Different simulations may lead to different conclusions.

The analysis of the scientific works that were mentioned in the earlier sections of this article shows that the researchers' studies use different analytical approaches to the organisation of freight traffic and the modes of operation of facilities, as well as the modes of operation of individual elements and parts of logistics systems. This makes it possible to choose a method with which to optimize the transport system, which is an extremely important component of logistics processes in a company, affecting the profitability of the company.

Chapter Questions

1. What are the main transport policy problems related to the optimization of the transport system?

2. What are the main goals of route optimization for the company and recipients?
3. What is the traveling salesman problem (TSP) and how is it related to route optimization?

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