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:

$$\textbf{PSL} = \frac{\text{[number of inventory replenishment cycles]} - \text{[number of inventory replenishment cycles in which shortages were recorded]}}{\text{[number of inventory replenishment cycles]}} * 100\%$$

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:

$$\textbf{DFR} = \frac{\text{[demand]} - \text{[no of deficiencies]}}{\text{[demand]}}$$

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).

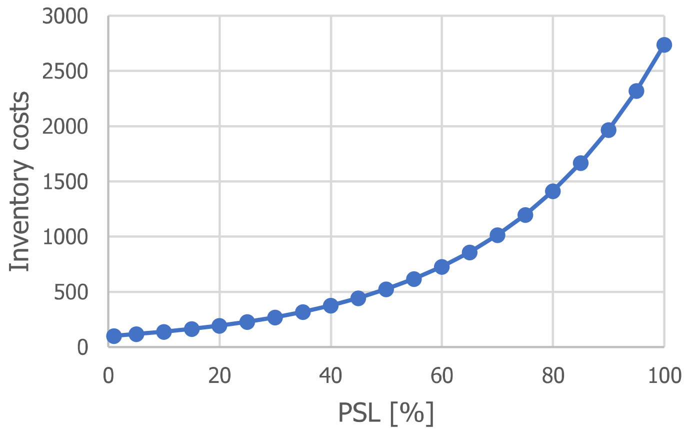

Figure 9.1. The relationship between PSL and inventory costs

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.

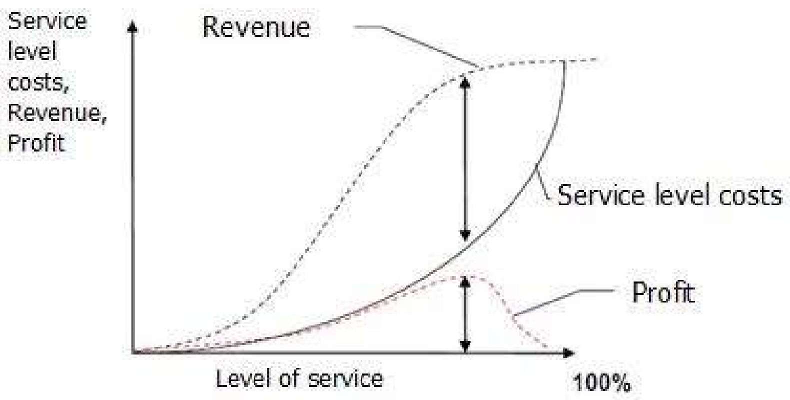

Figure 9.2. The relationship between the level of customer service and revenue and profit

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.

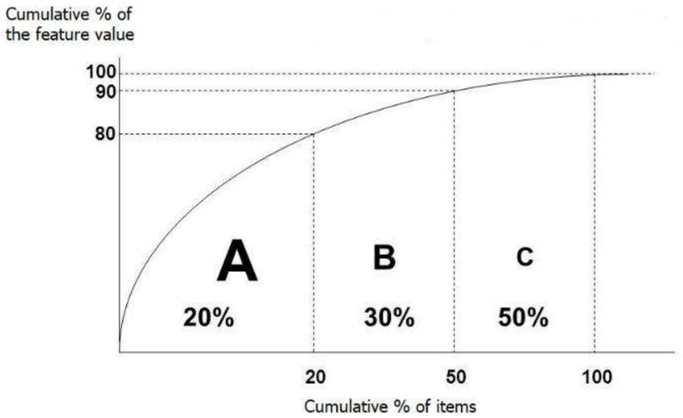

Figure 9.3. ABC Analysis curve

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?

REFERENCES

Al-Dulaime, W., & Emar, W. (2020). Analysis of Inventory Management of Laptops Spare Parts by Using XYZ Techniques and EOQ Model–A Case Study. Journal of Electronic Systems. 10(1).

Bowersox, D. & Closs, D.J. (1996). Logistical Management: The Integrated Supply Chain Process, 4th ed., McGraw-Hill, New York, NY.

Bril, J., & Łukasik, Z. (2013). Metody zarządzania zapasami. Autobusy: technika, eksploatacja, systemy transportowe, 14(3), 59-67.

Brunaud, B., Laínez-Aguirre, J. M., Pinto, J. M., & Grossmann, I. E. (2019). Inventory policies and safety stock optimization for supply chain planning. AIChE journal, 65(1), 99-112.

Chu, C. W., Liang, G. S., & Liao, C. T. (2008). Controlling inventory by combining ABC analysis and fuzzy classification. Computers & Industrial Engineering, 55(4), 841-851.

Cyplik, P. (2005). Zastosowanie klasycznych metod zarządzania zapasami do optymalizacji zapasów magazynowych–case study. LogForum, 1(3), 4.

Cyplik, P., & Hadaś, Ł. (2012). Zarządzanie zapasami w łańcuchu dostaw. Wydawnictwo Politechniki Poznańskiej.

Dhoka, D. K., & Choudary, Y. L. (2013). XYZ inventory classification & challenges. IOSR Journal of Economics and Finance, 2(2), 23-26.

Fertsch, M. (ed.) (2006). Słownik terminologii logistycznej. ILiM. Poznań.

Hachuła, P., & Schmeidel, E. (2016). The Model of Demand and Inventory in a Decline Phase of the Product Life Cycle. Folia Oeconomica Stetinensia, 16(1), 208-221.

Jain, N., & Tan, T. F. (2022). M-commerce, sales concentration, and inventory management. Manufacturing & Service Operations Management, 24(4), 2256-2273.

Krzyżaniak, S. (2016). Próba uogólnienia formuły na obliczanie zapasu zabezpieczającego dla klasycznych metod odnawiania zapasu. Zeszyty Naukowe Politechniki Śląskiej. Seria Organizacja i Zarządzanie. No. 99, 245-259.

Krzyżaniak, S., & Cyplik, P. (2008). Zapasy i magazynowanie : podręcznik do kształcenia w zawodzie technik logistyk. T. 1, Zapasy. Instytut Logistyki i Magazynowania.

Matusiak, M. (2022). Logistyka zaopatrzenia. Skrypt akademicki. Część 1 Wykład. Wydawnictwo Uniwersytetu Łódzkiego.

Mitra, S., Reddy, M. S., & Prince, K. (2015). Inventory control using FSN analysis–a case study on a manufacturing industry. International Journal of Innovative Science, Engineering & Technology, 2(4), 322-325.

Niemczyk, A., Cudziło, M., Kolińska, K., Fajfer, P., Koliński, A., Pawlak, R., Sobótka, J. (2011). Podręcznik dla nauczycieli do laboratorium spedycyjno – logistycznego i magazynowego. T.II. Wyższa Szkoła Logistyki. Poznań 2011.

Pandya, B., & Thakkar, H. (2016). A review on inventory management control techniques: ABC-XYZ analysis. REST Journal on Emerging trends in Modelling and Manufacturing, 2(3).

Papiernik-Wojdera, M., & Sikora, S. (2022). Ocena logistycznej obsługi klienta w przedsiębiorstwie Cargonet sp. z o. o. [in] ed. Fajczak-Kowalska A. Problemy i wyzwania współczesnej logistyki. Wydawnictwo Rys. Poznań.

Placencia, I. A., Partida, D. S., Olivos, P. C., & Flores, J. M. (2020). Inventory management practices during COVID 19 pandemic to maintain liquidity increasing customer service level in an industrial products company in Mexico. Advances in Science, Technology and Engineering Systems, 5(6), 613-626.

Powell Robinson, E. & Satterfield, R.K. (1990). Customer Service: Implications for Distribution System Design. International Journal of Physical Distribution & Logistics Mngmnt, 20(4), 22–30.

Selivanova, N., Bubilich, S., & Popko, Y. (2018). Features of formation of the accounting policy of the enterprise in a part of accounting of manufacturing reserves. Економіка: реалії часу, 5(39), 89-96.

Sirisha, T., & Kalyan, D. N. B. (2022). Inventory management pattern of manufacturing sector in India. Available at SSRN 4165201.

Skowronek, Cz., Sarjusz-Wolski, Z. (2012). Logistyka w przedsiębiorstwie. PWE. Warszawa.

Śliwczyński, B. (2007). Controlling w zarządzaniu logistyką: Controlling operacyjny, controlling procesów, controlling zasobów. Wyższa Szkoła Logistyki.

Śliwczyński, B. (2008). Planowanie logistyczne: podręcznik do kształcenia w zawodzie technik logistyk. Instytut Logistyki i Magazynowania.

Song, J. S., Van Houtum, G. J., & Van Mieghem, J. A. (2020). Capacity and inventory management: Review, trends, and projections. Manufacturing & Service Operations Management, 22(1), 36-46.

Strojny, S. (2008). Przesłanki standaryzacji interpersonalnej obsługi klienta. LogForum, 4(1), 1-8.

Tanwari, A., Lakhiar, A. Q., & Shaikh, G. Y. (2000). ABC analysis as a inventory control technique. Quaid-E-Awam University research journal of engineering, science and technology, 1(1).

Wild, T. (2017). Best practice in inventory management. Routledge.