Proposal of Set of Optimization Criteria and Their Specific Calculation for Effective Inventory Management in an Industrial Enterprise

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Abstract – **Currently, there are many mathematical models and tools for inventory management and optimization. Based on the literature review, the authors conclude that inventory management tools and models are mostly one-sided and focused on the cost aspect of the inventory management process. The research goal was to propose a set of criteria for inventory optimization as a basis for the development of an inventory management model whose structure would consider both the economic aspect and the stochasticity of demand and the reliability of delivery. Optimization criteria are based on extensive analyses of influences and correlations between logistic chain subsystems in relation to inventory. The interactions of the subsystems are then mathematically expressed, which represents the main output of the created set of optimization criteria.**

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The defined criteria can be used as a basis for creating a new optimization model of inventory management.

Keywords – **Logistics chain, inventory management process, optimization criteria, inventory costs, commitment of funds, stochasticity of demand, delivery reliability, risk of inventory shortage.**

1. Introduction

Companies look for the optimum level of inventory so that maximum customer satisfaction is ensured while taking into account the economics of the company [1]. For this reason, it is important to consider various factors affecting the level of inventory. Current inventory models and management methods consider only a limited set of criteria focused primarily on the cost side of the inventory management process, with little consideration of the degree of stochasticity of the material flow in the logistics chain [2].

The issue of inventory optimization and management is addressed by many researchers in their scholarly papers. Mandel and Granin [3] describe an inventory control problem related to the optimization of processes that occur in supply chains with multiple unreliable suppliers. Perez *et al.* [4] focus on the inventory management problem addressed for a make-to-order supply chain that has inventory holding and/or manufacturing locations at each node. Online Linear Optimization with Inventory Management Constraints is dealt with in study by Yang *et al.* [5]. Lim and Wang [6] describe a target-oriented robust optimization approach to solve a multiproduct, multiperiod inventory management problem subject to ordering capacity constraints.

Other authors [7], [8] and [9] deal with the mathematical models of inventory optimization and management or there are authors [10], [11] and [12], who present various inventory management and optimization tools.

Most mathematical models used as tools of inventory optimization and management are one-sided and focused on the cost side of the inventory process. Rzepecki [13] focuses on the issue of inventory cost optimization in a construction company. Another example is research by Bojanic et al. [14] dealing with cost optimization of spare parts inventory. Optimization of inventory holding cost is addressed by Gurtu [15].

Some researchers [16], [17], [18] address in their publications a stochasticity of demand and reliability in the supply chain is addressed, however, without any linkage to the economics to inventory management. Alvarez *et al.* [16] focus on a stochastic inventory routing problem under the consideration that both the product supply and the customer demands are uncertain. Chuang *et al*. [17] arrived to the result how help researchers realize inventory models with stochastic ramp type demand. Inventory control systems for stochastic lead time demand are analysed by Mustafid *et al.* [18].

Multicriteria decision-making has been addressed in multiple research studies. In most cases, authors deal with the application of the ABC method, methods of multiple criteria decision making, weighed linear optimization, and risk criteria [19], [20], [21], [22], [23], [24], [25], [26] and [27].

Ramanathan [19] consider multiple criteria and propose a simple classification scheme using weighted linear optimization. Park et al. [20] and Kaabi and Jabeur [21] address a similar scheme. Sobral and Soares [22] propose a methodology based on maintenance data and risk criteria. Mortazavi and Khamseh [23] analysed the issue of risk criteria, while authors [24] and [25] focus on multiple criteria decision making in relation to inventory optimization. Mohamadghasemi et al. [25] specifically use the TOPSIS method as a specific approach to the ABC analysis. Govindasamy and Antonidoss [26] address Multi-Objective Optimization; Zhu *et al.* [27] also deals with it, but all the criteria addressed are cost criteria.

The proposal of a set of criteria for the inventory process optimization and the specific calculations presented in this paper are based on a holistic approach to inventory management. This means that the proposed set of optimization criteria reflects the synergy of entities, their relationships and linkages within the logistics chain and their impact on the inventory management process.

2. Methodology

Development of a set of criteria and definition of their interrelationships is a prerequisite for the correct definition of equations to calculate the key optimization criteria for the inventory management model.

The rationality of the development of inventory optimization criteria largely depends on a deep knowledge of the subject of the evaluation, as well as a systematic understanding of its structure and functions. The set of criteria must be complete, which is conditioned by a good reflection of the essential characteristics of the subjects evaluated so as not to distort the results of the evaluation of these objects.

The proposal and arrangement of the criteria into the resulting set of criteria is based on the comprehensive view of the whole logistics chain and on considering interactions between the individual subsystems and their mutual synergy in relation to inventory.

The research goal was to find answers to the following questions:

- What influences the size of the order?
- How does the level of inventory maintained in a company influence the ordering process?

The output of the research is the identification of factors affecting or being affected by inventory level. Subsequently, these factors and the identified relationships between them are used for the calculation of optimization criteria so that the results reflect standard technological procedures within each logistics chain and their effect on the efficiency of the inventory process.

By examining the effect of linkages between the logistics chain subsystems on the size of order, the following factors have been identified (Figure 1):

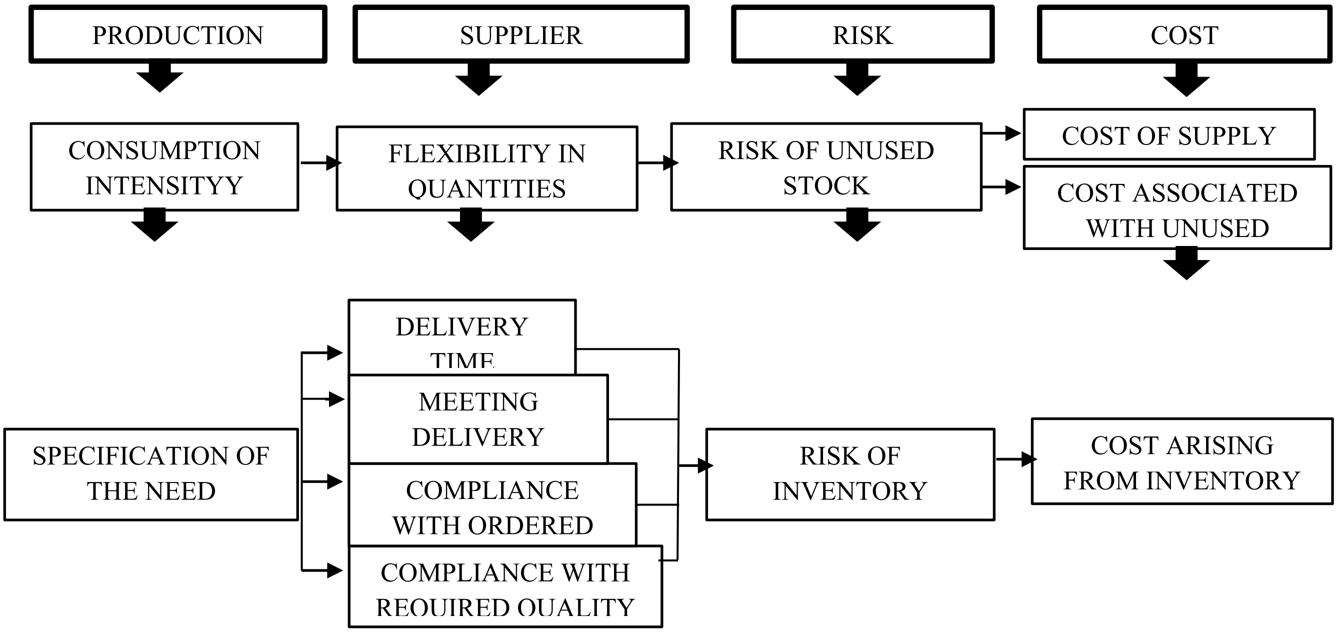

Figure 1. Factors influencing the size of order

By examining the effect of the level of inventory in the company on other logistics chain subsystems, the following factors have been identified (Figure 2):

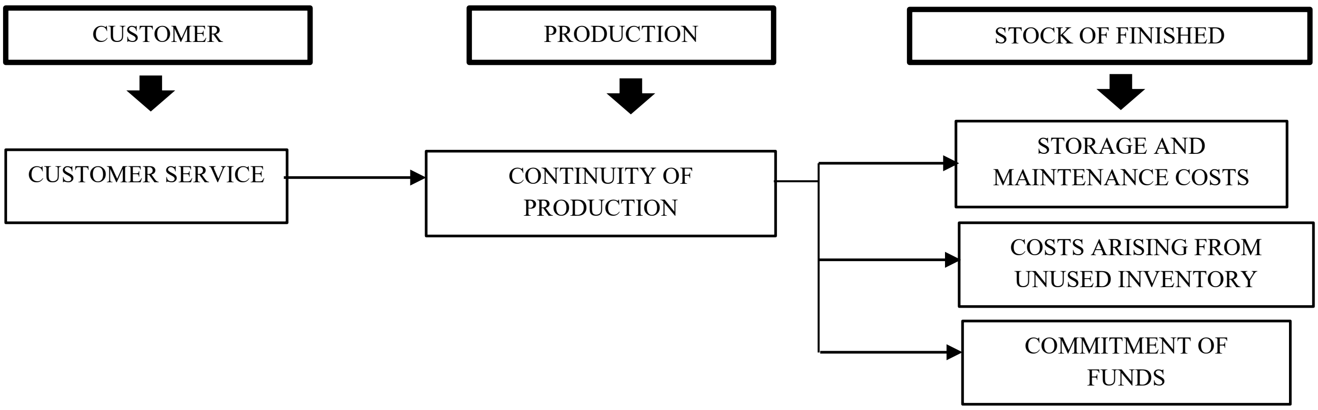

Figure 2. Effect of the level of inventory on logistics chain components

In order to optimize the inventory process by using relevant optimization criteria, a specific way of expressing is proposed for each key criterion so that it corresponds to the real effect of the sub-factors on the inventory.

These factors influence the economic efficiency of inventory management as well as ensuring of adequate level of provided customer service, which is an important prerequisite of company´s competitiveness. The level of inventory must correspond with the ability of the company to meet the deadlines for delivery and to respond flexibly to casual customer requirements. Table 1 presents the specification of the key criteria by means of subfactors influencing the level of inventory.

Table 1. Proposed model criteria

Optimization criterion	**Factors influencing the level of inventory**
Annual delivery costs	➢ Warehouse capacity ➢ Cost of delivery ➢ Length of consumption period ➢ size of order ➢ daily intensity of consumption ➢ number of consumption periods per year ➢ cost of delivery per one transport unit ➢ capacity of transport unit
Commitment of funds	➢ intensity of consumption ➢ length of delivery period ➢ reliability of delivery ➢ purchase price of stock ➢ storage cost
Loss arising from inventory shortage	➢ percentage of sales ➢ selling price of the final product

3. Results

The following chapters are devoted to the creation of the specific calculation of the main variables in the area of inventory management. Specifically, it is a calculation of annual costs of stock delivery, calculation of commitment of funds in inventory, and calculation of loss arising from inventory shortage.

3.1. Calculation of Annual Costs of Stock Delivery

Adequate inventory optimization is conditional on considering the specific behaviour of costs of delivery depending on the growth in the size of order. These costs are included in step-fixed costs [28]. This means that they experience a change when a certain threshold is exceeded. For the purposes of the model, the given threshold is the capacity of the transport unit.

The costs per delivery while considering the capacity of the transport unit are determined as follows (1):

$$N_{dod}^{PJ} \times \frac{Q^N}{k^{PJ}} \text{ [p.j.]} \quad (1)$$

where:
Q^N – size of order [u.m.],
N_{dod}^{PJ} – costs of delivery - one transport unit [t.u.],
k^{PJ} – capacity of transport unit [u.m.].

Based on formula (1), it can be stated that the amount of delivery cost increases with exceeding the capacity of the transport unit, which means that the larger the order size, the higher the cost of delivery.

However, the annual cost of delivery depends on the number of executed orders per year. The larger the delivery size, the lower the number of orders executed during the year [29]. This implies that in some cases, larger delivery can be more advantageous from the perspective of economic efficiency.

To determine the number of deliveries per year, it is necessary to know the intensity and nature of consumption (2):

$$\frac{r}{Q^N/I} \times R \text{ [-]} \quad (2)$$

where:
r – length of consumption period [in days],
R – number of consumption periods per year [-],
Q^N – size of order [u.m.],
I – intensity of consumption per day [u.m.].

The annual costs of delivery while considering the above facts is calculated as follows (3):

$$N_{dod}^{R} = \frac{r}{Q^N/I} \times R \times \left(N_{dod}^{PJ} \times \frac{Q^N}{k^{PJ}}\right) \quad (3)$$

where:
N_{dod}^{R} – annual costs of delivery [t. u.],
r – length of consumption period [-],
Q^N – size of order [u.m.],
I – intensity of consumption per day [u.m.],
R – number of consumption periods per year [-],
N_{dod}^{PJ} – cost of delivery per one transport unit [t.u.],
k^{PJ} – capacity of transport unit [u.m.],
k^S – warehouse capacity [u.m.].

3.2. Calculation of Commitment of Funds in Inventory

The size of delivery influences the level of inventory, which causes a certain level of commitment of funds. Such funds could be used for other purposes; therefore, it is beneficial for the company to keep the inventory level as low as possible. On the other hand, keeping a certain inventory level in the company is essential to ensure the continuity of the production process, especially in the event of an inventory shortage on the side of a supplier. Such a shortage is most often caused by insufficient supplies, e.g., due to delayed delivery or inadequate delivery in terms of quality or quantity.

When deciding on the level of inventories in the company, it is necessary to consider the above facts besides the degree of funds commitment. Therefore, determining the degree of reliability of the company´s individual suppliers is essential, whether in terms of meeting the delivery dates, the quantity ordered, or the adequate quality of delivery.

The degree of meeting delivery deadlines can be expressed by means of the ratio of material delivered on time to the total material delivered. Material delivered relative to material ordered indicates delivery accuracy, while material received relative to material delivered indicates delivery quality.

The overall delivery reliability including all the above aspects is expressed by equation (4). It can take values ranging from 0 to 1, with 1 indicating 100% reliability of the given supplier.

$$DS = 3 - \left(\frac{M^{DL}}{M^C} + \frac{M^{DP}}{M^O} + \frac{M^{DK}}{M^{DP}}\right) \text{ [-]} \quad (4)$$

where:
M^{DL} – value of material delivered in time [t.u./u.m.],
M^{DK} – value of material received [t.u./u.m.],
M^O – value of material ordered [t.u./u.m.],
M^{DP} – value of material delivered [t.u./u.m.],
M^C – total value of material delivered [t.u./u.m.].

With the growth of the size of order, the amount of inventory that may be lacking in the case of an unreliable supplier also increases, and so does the necessary level of inventories in the company. The level of inventory is also influenced by the nature of a given inventory. The larger fluctuations in the consumption, the higher the level of inventory maintained in the company needs to be.

On the basis of the above, two methods of determining the level of stocks can be used. The first method is suitable for stocks whose consumption is continuous and whose function in the company is "only" to compensate for stock shortages caused by the supplier (5).

$$H^N = Q^N \times DS \text{ [m.j.]} \quad (5)$$

where:
H^N *– level of stock reserve [u.m.],*
Q^N *– size of order [u.m.],*
DS – delivery reliability [-].

The second method of determining the level of inventory in the company is intended for inventories that are consumed at irregular time intervals. In such a case, it is suitable to maintain a level of inventory that compensates for fluctuations in supply caused by the supplier but also the time gap between the execution of the order and the physical delivery of stock. The calculation is as follows (6):

$$H^N = I * d + Q^N \times DS \text{ [m.j.]} \quad (6)$$

where:
H^N *– level of stock reserve [u.m.],*
I – intensity of consumption [u.m.],
d – length of delivery time [in days],
Q^N *– size of delivery [u.m.],*
DS – delivery reliability [-].

When the level of inventory in the company, cost of storage, and the purchase price of given inventory are known, the parameter W can be calculated (see Equation 7 below):

$$W^H = H^N \times (n_{skl} + C^N) \text{ [t.u.]} \quad (7)$$

where:
W^H *– commitment of funds in inventories [t.u.],*
C^N *– purchasing price of inventory [t.u.],*
H^N *– level of stock maintained for ensuring* Q^N *[u.m.].*

3.3. Calculation of Loss Arising from Inventory Shortage

Determining the level of stock considering only the commitment of funds, a loss may arise caused by an inventory shortage. The amount of such a loss depends on the percentage share of inventory on the total sales of the company. As in the case of commitment of funds, the degree of inventory shortage risk depends on the level of inventory kept in the company. However, it shall be noted that the commitment of funds grows with the level of inventory, and the risk of inventory shortage decreases. This can be expressed as follows (Eq. 8):

$$S^N_{ned} = \left(\frac{F}{100} \times C_p\right) - H^N \times \left(\frac{F}{100} \times C_p\right) \text{[p.j.]} \quad (8)$$

Where:
F – percentage share of sales [%],
C^P *– selling price of the finished product [t.u.],*
H^N *– level of inventory for given* Q^N*.*

4. Discussion

Currently, there are many tools for the optimization and management of the supply chain. Even a separate scientific discipline focused on inventory optimization has emerged, namely inventory theory, which deals with the creation of mathematical models of inventory management. However, existing tools for inventory management consider only a limited number of criteria, with the main focus on the economics of inventory management.

This has led to the intention to develop a set of criteria for efficient inventory management that would consider both inventory-related costs and a wide range of criteria focusing on other facts, factors, and entities that influence the inventory process.

The analysis of the influence of individual components and subsystems of the logistics chain on order sizing, as well as examining the effect of inventory levels on other components of the logistics chain represent an important tool to identify specific factors affecting inventory management. A key step in the development of an appropriate set of criteria for inventory management is the mathematical expression of the interaction of the determinants in relation to inventory.

Such a set of criteria increases the reliability of the inventory process with regard to all components involved in the transport of material, ranging from the producer to the company itself, and thus represents a suitable basis for the development of a mathematical model of inventory management.

5. Conclusion

Current inventory management tools are limited to two to three criteria considered, with a focus on inventory-related costs. The objective of the paper was to propose a set of inventory optimization criteria, which could serve as a basis for a multicriteria model of inventory optimization considering not only costs but the whole course of the inventory process.

The set of criteria was proposed to consider all existing factors influencing the inventory management process within the logistics chain, which was achieved by means of thorough analyses of the logistics chain from various perspectives. Individual analyses were focused on the effect of the behaviour of the individual subsystems within the logistics chain on the order size on the one hand; on the other hand, there was examined the impact of a certain size of the inventory level in the company on the other subsystems of the logistics chain.

The output is a mathematically defined set of criteria that reflects the interaction of the logistics chain subsystems in relation to inventory.

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