

# Inventory Risk Decision-Making Techniques Using Customer Behaviour Analysis

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More recent research shows the significant impact of accurate demand forecasting on the operation of supply chain system and thus on the performance of the company. Inventories in the production process could represent waste, which results in higher storage costs and consequently a higher product price, which in turn reduces company's competitiveness on the market. Nevertheless, a company must implement a lean production process and consequently carefully control storage and inventory costs. The introduction of a lean production process is closely linked to the risk of stock-outs, and knowledge of this risk in relation to customer habits is therefore a useful piece of information for the line manager's decision-making. This paper will present a mathematical model that relates customer demand for a product to the inventory level in the warehouse or between the work operations of the production process and the risk of potential penalties that arises with the introduction of a lean production process. With this model we can simulate, how to improve the production processes with still acceptable risk, with the goal of achieving a balance between stocks and the leanness of the production process. The paper demonstrates the use of a mathematical model on a concrete example from practice for risk simulation when choosing different production scenarios resulting from changed customer behaviour.

**Keywords:** lean production, customer demand, risk simulation, inventory optimisation

## Highlights

- A mathematical model is presented that allows fast and easy simulations of inventory management based on consumer buying behaviour.
- The probability density function of demand was chosen in the mathematical model.
- The changes in the production process can be monitored in terms of inventory costs and the risk that there may be insufficient products available to meet customer needs.
- By simulating three different scenarios, the optimum inventory level was found to be 30,000 pieces, at which the inventory costs are minimal with a moderate risk of 17 %.

## 0 INTRODUCTION

Nowadays, companies decide to implement lean production which aims to reduce costs by eliminating all activities that do not add value [1]. In doing so, companies usually first decide to reduce inventories, that create unnecessary costs, mainly by tying up capital and occupying production areas. Of course, caution should be exercised when reducing inventory, as excessive inventory reduction can lead to business consequences and risks. It is important to determine where the lowest limit of inventory minimization can be and which parameters have a dominant influence. The aforementioned problem can be described with a mathematical model that can serve as a basis for simulating various scenarios that management can predict based on what is happening on the market. This paper presents the results of a follow-up study [2] in which, by using a mathematical model, a significant correlation between a product demand  $E[X]$ , the optimal inventory level  $z_0$  and the average cost of product (ACP), as well as the impact of excess inventory and storage costs  $E[C]$  in the production process on the average cost of product

was demonstrated. An excess inventory level in the production process was found to raise the average cost of product ACP, weaken a company's position on the market and increase the company's inefficiency. To this end, control charts have been developed that can be used to control the inventory level in the work operations of the production process and, consequently, to control the average cost of product ACP. The paper [2] concludes with the measures to be implemented to correct the production flow  $y_0$  and to correct the optimal inventory level  $z_0$  in the production process depending on the changed demand  $E[X]$ .

Introducing lean principles into the production process means making changes to the existing production process, which often entails risks such as interruptions in the production process, non-fulfilment of contractual obligations to customers, loss of goodwill, loss of market, loss of revenue, non-competitiveness, payment of penalties, etc. This paper will therefore focus on identifying a risk  $\beta$  that may arise in the production process as a consequence of inventory level optimisation. A shortage of needed products may mean that customer requirements are not met and the consequences may be penalties, loss

of customers, loss of market share or even loss of market.

Using a mathematical model and simulation, we will demonstrate the possibility of implementing a lean production process using an example of inventory optimisation, so that line management will also have control over the risks associated with inventory optimisation in the production process. The mathematical model allows to simulate different production scenarios according to the customer's requirements and to determine the level of inventories so that the average cost of product is minimised.

The mathematical model can also be extended along the entire supply chain, since every link in the chain, especially the weakest one, is important for the performance, competitiveness and profitability of the entire supply chain.

The aim of this paper is to present a mathematical model and its use in a simulation to find the best ratio between customer demand for a product, the optimal inventory level, including the safety inventory, the optimal storage costs, risk, lean production process due to inventory and the average cost of product ACP. An important advantage of the simulation based on the developed mathematical model is to eliminate those scenarios where the ACP could exceed the market price due to too high storage costs.

## 1 LITERATURE REVIEW

In the study [2], the authors identify the impact of the optimal total inventory level in the production process on the average cost of product ACP. Using a mathematical model, in which customer demand and an intermediate inventory level in the company's production process and storage costs are linked together, a negative impact of excessive intermediate inventory level on the final price of the product can be identified. In this paper, the authors prove the assumption that, in extreme cases, storage and inventory costs can cause the average cost of product ACP to rise even to a price level higher than the price recognised by the market. Seyedan and Mafakheri [3] state that demand forecasting and planning refer to forecasting the quantities and timeframes of customer requirements. They are of the opinion that the objective of such forecasts is to achieve customer satisfaction by meeting customer needs in a timely manner. Accurate demand forecasting could improve the efficiency and robustness of production processes and related supply chains, as resources will be matched to demands, leading to a reduction in inventories and waste.

Uhrin et al. [4] investigated the role of a company's external and internal resources and the impact of their variability on the degree of lean production implementation. They presented an analysis of the effects of environmental risk and past operational performance of a company on the level of lean production implementation. The paper contributes to explaining the circumstances that ultimately lead to the implementation of lean production. As a consequence, the external and internal environment influences a company's commitment to increase lean production. Petropoulos et al. [5] assess that demand forecasting is a prerequisite for decision-making on inventories and plays a key role in supply chain management. How to improve the accuracy of forecasts has always been a focus of research in academia and business, and the study argues that forecasts are designed to help business decisions and should be assessed on the basis of their economic implications. The study compares the performance of several commonly used forecasting methods in terms of achieving inventory control objectives, taking into account a simulation approach. The authors in [6] argue that for any company, in addition to reducing lead times, cost reduction is also a necessity. Therefore, monitoring and controlling manufacturing costs over time can be an important driver for improvement. In [7], the authors use stochastic and hybrid models, which they consider to be very close to reality. They explain the structure of supply chains, the decisions to be taken in a typical supply chain and the models developed for supply chain planning and optimisation. The paper further explores simulation and optimisation to solve stochastic and hybrid models, their applications in the supply chain domain and future research directions arising from the emphasis on sustainability, robustness and resilience of supply chains and opportunities.

Authors in [8] highlight the accuracy of demand forecasting as it has a significant impact on the performance of the supply chain system and thus on the performance of company's business operations. An accurate forecast will allow a company to make the best use of its resources. Synchronisation of customer orders with production is crucial for a timely fulfilment of orders. This paper presents a system that can improve the accuracy of demand forecasting for more efficient inventory management, also in a Smart Industry 4.0 concept. In their study [9], Pusztai et al. presented a method for implementing a risk-adjusted production plan. Two examples of order allocation with inventory costing were presented, one with inventory costing and one without inventory costing. The authors consider that

such information can play a key role in the initial contract negotiations as it also includes potential risks. In their study [10], Perera et al. conclude that the success of a supply chain is highly dependent on the effectiveness of inventory management by taking into account customer behavioural patterns, which is largely neglected by decision-makers in production. In their study [11], Maheshwari et al. pointed out the problem of managing big data also in terms of customer behaviour. The role of big data analysis related to customer behaviour in supply chain management (SCM), logistics (LM) and inventory management (IM) is of paramount importance for inventory optimisation. Soares do Amaral et al. in their study [12] highlight the importance of simulation for evaluating different "what-if" system scenarios to reduce costs and risks especially in industry and service 4.0. The use of modern decision-making support analytical tools and simulation are therefore indispensable to ensure customer satisfaction and cost reduction. In the study [6] and [13], the authors present a framework for value flow optimisation by combining value flow cost and cost-time profiles. Value flow mapping represents a very effective tool for visualising activities within a production flow, focusing on the duration of activities in order to eliminate non-value-added activities. A good cost analysis system is useful and applicable in helping managers to understand the detailed costs of different short-term and long-term activities and processes, which is why stochastic production planning models have been proposed by various authors [14] and [15]. The paper [16] also proposes a stochastic production planning model to reduce risk, for a manufacturing company with seasonal demand and market growth uncertainty, to prevent excess inventory and stockout. In the paper [17] even a two-stage stochastic Linear Programming approach is proposed to investigate a production planning problem where the non-homogeneous characteristics of logs result in random process yields which are modelled as scenarios with discrete probability distributions. Paper [18] focuses on developing a stochastic approach to costing systems that considers the variability in the process cycle time of the different workstations in the assembly line and provides a range of values for the product costs, allowing for a better perception of the risk associated to these costs instead of providing a single value of the cost. The proposed model allows a better analysis of the margins and optimization opportunities as well as investment appraisal and quotation activities. Real production systems are characterised by a high degree of variability and uncertainty, which can have

a drastic impact on the price of a product. Uncertainty factors in production processes are mainly demand, cycle time and available resources.

Afonso et al. [18] also used a stochastic approach to product costing in a production process. Based on their work, it is possible to further analyse the variation in costs associated with risks. They consider that the use of descriptive statistics makes sense because it gives the ability to understand and evaluate the behaviour of cycle times and their impact on costs. The approach allows for a better detection of the risks associated with product costs. In his study [19], the author concludes that non-economic theories, such as psychological or psychoanalytical theories, also allow a better understanding of other factors influencing consumer behaviour that need to be taken into account. Consumer behaviour is considered to be a holistic approach and consumer behaviour is based on perceptions towards a product. The theories and models developed in the study can serve as a basis for determining consumer buying behaviour. In [20], Radhakrishnan et al. investigate the effective inventory management in the supply chain and argue that inventory management is one of the important areas of supply chain management. They have developed a novel and efficient approach using a genetic algorithm that clearly determines the maximum possible excess inventory level and the shortage level required to optimise inventory in the supply chain. In the paper [21], Prasertwattana et al. investigate material ordering and inventory control in supply chain systems. The effect of control policies is analysed under three different configurations of supply chain systems. The authors consider that the problem is solvable using an evolutionary optimization method known as differential evolution (DE). The results show that the incentive scheme compliance policy is appropriate and outperforms other policies and can improve the efficiency of the whole system and of all members in the supply chain management framework.

Based on the literature review, a new methodology for decision-making support on inventory levels is proposed in conjunction with an analysis of the changing customer habits based on a mathematical model and simulation. We have not yet found a similar solution in the literature.

## 2 METHODOLOGY

Knowing the purchase behaviour of customer, a probability density function of the product demand can be determined. This information is provided by

the sales department, using data on sales in previous periods and forecasts of future sales.

The probability density function of product demand  $f_X(x)$  is approximated as closely as possible to the actual purchase behaviour of the customer. The chosen probability density function, (Eq. (1)) of the demand  $X$  for product is a good approximation of the behaviour of customer demand in practice [2].

$$X \rightarrow f_X(x) = a^2 x \cdot e^{-ax}. \quad (1)$$

If the function  $f_X(x)$  is multiplied by  $x$  and integrated on the interval 0 to  $\infty$ , mathematical hope  $E[X]$  is obtained. The theoretical mean value of  $E[X]$  (Eq. (2)) is then equated with the mean value  $\bar{x}$  obtained from real customer demand data (Eq. (3)) and the constant production flow  $y_0$  (Eq. (4)).

$$E[X] = \int_0^{\infty} x \cdot f_X(x) dx = \frac{2}{a}, \quad (2)$$

$$\frac{2}{a} = \bar{x}, \quad (3)$$

$$y_0 = \bar{x}. \quad (4)$$

If the probability density function of customer demand  $f_X(x)$  is known, the probability density function of warehouse stock fluctuations  $f_Z(z)$  (Eqs. (5) to (7)) can also be determined.

$$\Delta Z = y_0 - X,$$

$$Z = z_0 + \Delta Z,$$

$$X = z_0 + y_0 - Z,$$

$$Z \rightarrow f_Z(z) = f_X(x) \left| \frac{dx}{dz} \right|, \quad (5)$$

$$f_Z(z) = a^2 (z_0 + y_0 - z) \cdot e^{-a(z_0 + y_0 - z)}, \quad (6)$$

$$f_Z(z) = a e^{-(az_0 + 2)} [(az_0 + 2) - az] e^{az}, \quad (7)$$

where  $\Delta Z$  is inventory fluctuations due to variable demand  $X$ ,  $y_0$  constant production flow equal to the average demand quantity  $E[X]$ ,  $X$  variable product demand,  $a$  parameter of probability density function of customer demand,  $z_0$  initial inventory level, and  $z$  inventory level in warehouse or between working operations.

Fig. 1 shows the inventory cost fluctuations  $p$ ,  $q$ ,  $h$  in a warehouse or between work operations.

Wherein in Fig. 1  $C(z)$  represents storage cost [€],  $C(z) = p$  storage cost of a product when it is not in stock [€/PC],  $C(z) = q$  safety inventory costs [€/PC],  $C(z) = h$  storage cost of a product when it is in stock [€/PC],  $s$  safety inventory [PC], and  $z$  the number

of pieces in stock in the warehouse [PC], and PC represents piece.

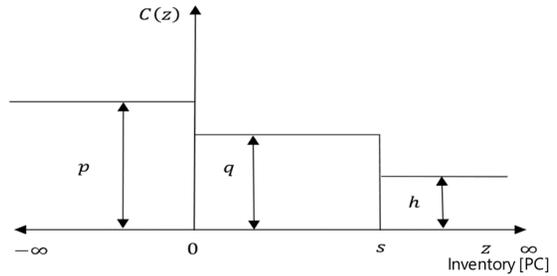


Fig. 1. Cost fluctuations in a warehouse or between work operations

Here, the key question is, of course, how much inventory and how much safety inventory can there be between work operations, and what are the costs and risks of: 1) not paying penalties for not delivering products to the customer on time and 2) having excess production in the warehouse and potentially being uncompetitive because of excessive storage costs?

The simplest solution is to opt for more inventory in the warehouse or between work operations, which means that excess production is created, which in turn, from the point of view of lean principles, represents wastes such as redundant transport, warehousing, processing, poorer product quality, increased warehousing costs, inefficiency, uneconomic and consequently uncompetitive business.

The solution to the problem and the elimination of waste is seen in the introduction of a lean production process with a focus on optimising inventory levels in the warehouse and between work operations. We believe that this is feasible if we have a good knowledge of the customer's buying behaviour and of the risk when interruptions (shortages) may occur in the production process. In this case, we can set an objective that the total waste in the production process or logistics chain should be minimal, which can be achieved by minimising the initial inventory  $z_0$ .

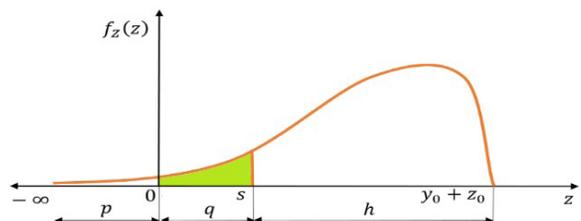


Fig. 2. The figure shows the probability density function of inventory fluctuations

We now define a mathematical algorithm in Eqs. (8) to (10) that will relate the parameters with each other, namely  $z_0$  (optimal initial inventory level), the risk  $\beta$  of being out of stock at a given moment in the warehouse or between work operations due to interruptions in the production process, the storage costs  $E[C]$  as a function of  $p, q$  and  $h$ , the safety inventory  $s$ , the customer buying behaviour  $E[X]$  and the penalties  $Q$  that we will have to pay if we fail to meet demand due to a production failure. Fig. 2 shows the probability density function of inventory fluctuations in the warehouse or between two work operations in relation to the costs  $p, q$  and  $h$ . The mathematical algorithm is given by Eqs. (8) to (10).

$$E[C(z)](z_0) = \left| \int_{-\infty}^0 p z f_z(z) dz \right| + \int_0^s q z f_z(z) dz + \int_s^{y_0+z_0} zh f_z(z) dz + Q\beta, \tag{8}$$

$$E[C(z)](z_0) = hz_0 + \frac{1}{a} e^{(az_0+2)} \cdot \left\{ [p+q+aQ+e^{as}(q-h) \cdot (as-1)] az_0 + 4(p+q) + 3aQ + e^{as}(q-h) \cdot (as-2)^2 \right\}, \tag{9}$$

$$\frac{dE[C]}{dz_0} = 0,$$

$$z_{0optim} = \frac{he^{(az_0+2)} - 3(p+q) - 2ah - e^{as}(q-h) [(as-2)^2 - (as-1)]}{a[p+h+aQ+e^{as}(q-h)(as-1)]} \rightarrow min, \tag{10}$$

To determine the minimum value according to the proposed mathematical method, a simulation model has been developed and is shown in Fig. 3.

The simulation is carried out using the standard software tool MS Excel and is therefore easy to use, so that the line management can use it whenever there is a change in the input parameters, which depend mainly on market conditions.

The following variables appear in the simulation model,  $z_0$  is initial inventory level [PC],  $s$  safety inventory level [PC],  $\beta$  risk [%],  $E[C]$  average storage cost as a function of  $z_0$  [€], and  $Q$  penalties that have to be paid due to unfulfilled requests to the customer [€].

### 3 CASE STUDY

In the selected company, we have carried out a material value flow analysis in the production process of a Basic hinge (Fig. 4). We have focused on the cold forming and surface protection operations. Using the proposed model, we want to determine how much inventory should be held to keep the process lean and to identify the risk  $\beta$  that may arise from optimising the inventory level  $z_0$ . The capacity of the Basic hinge assembly system is 68,500 PC per day, which corresponds to the customer demand ordering an average of  $y_0 = E[X] = 50,000$  PC of hinges.

The input data of the model shown are  $p, q, h, s, Q, z_0$  and  $x$ . The parameter  $a$  depends on customer buying behaviour, so cannot be influenced, and  $x$  represents actual monthly orders. When we enter the

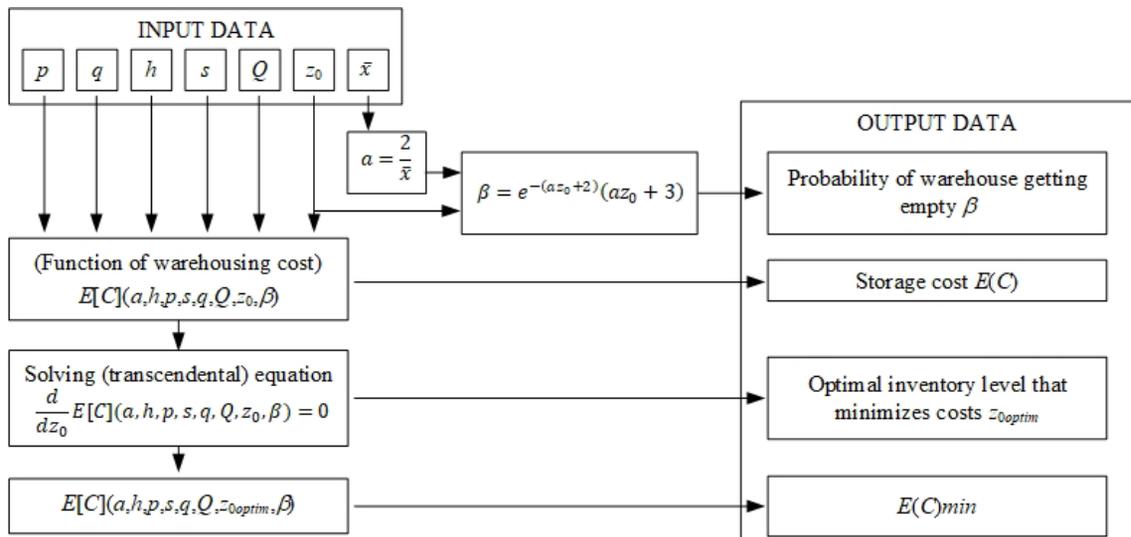


Fig. 3. Mathematical algorithm for simulation in Excel

input data into the Excel software using our algorithm, we get the output data  $\beta$ ,  $E[C]$  and  $z_0$ .

When we solve the equation  $dE[C]/(dz_0) = 0$  using numerical calculation methods, we obtain the optimum  $z_{0optim}$ , where the cost  $E[C]$  is a minimum. In the simulation we use the "What if experiments". In our example we are interested in the function  $E[C](a, h, p, s, q, Q, z_0, \beta)$ .  $\beta$  depends indirectly on  $a$  and  $z_0$ . Using this function, in addition to  $z_0$ , we can simulate the behaviour of the cost for different values of  $a, h, s, q, p, Q$  and  $\beta$ .

If we want to obtain the optimal value  $z_{0optim}$  immediately, it can also be obtained by the exact mathematical Eq. (10) and the given parameters  $a, h, s, q, p$  and  $Q$  without simulation. In our case,  $s$  can also be referred to as the strategic stock necessary for the smooth running of the production process.

In this paper, we have limited ourselves to presenting three scenarios using a practical example. There are many possible combinations, and the choice of the best balance between inventory, costs and risks is in the hands of management. We have found some similar studies in the literature that indicate that solving the problem from the point of view of the balance between inventory, costs and risks is important and at the same time interesting for the academic community. We believe that the proposed model is therefore interesting and useful for practice.

It can be seen from Fig. 4 that the quantity of products transported daily between the two operations, or the daily quantity demanded by the customer ( $Q_{td}$ ) is  $Q_{td} = 50,000$  PC/Wd, where Wd represents work day. The quantity of products between the two operations and the quantity of products in transition between the two operations ( $Q_{bo}$ ) is  $Q_{bo} = 466,666$  PC. Other used variables in Fig.4 are:  $W$  represents number of workers at the workplace,  $WP$  workplace number,  $TP$  process time,  $Tc$  cycle time,  $Ts$  setup time,

$A$  availability,  $Tps$  process time for series,  $Qs$  quantity in one series processed and  $S$  scrap.

The status between the two operations is an interesting data point for us, because it is clearly an overproduction which represents a cost or waste for the company. We will verify the claim that waste is in question here by applying the proposed mathematical model (Eqs. (8) to (10)). Let us assume that the daily storage cost of the cup semi-finished product is  $h = 0.5$  €/PC, the cost of storing the safety inventory of the cup semi-finished product  $q = 1$  €/PC, the cost of the cup semi-finished product when it is not in stock  $p = 2$  €/PC, the quantity of the safety inventory of the cup  $s = 1,000$  PC, and the penalties to be paid if there is an interruption in the production process and we are not able to fulfil the customer's order  $Q = 10,000$  €. The customer's average daily order is  $E[X] = 50,000$  PC of Basic hinges.

The following findings are also important for the simulation, including the data that represent limitations in the optimisation process.

The inventory level of the cup semi-finished product  $z_0$  between the cold forming and surface protection operations in the existing production process is excessive and is in fact overproduction and waste. This is in contrast to a lean production process.

Since the inventory level is excessive, the risk  $\beta$  of production failure is practically non-existent or negligible.

The storage costs of excessive quantities of the cup semi-finished product are high and therefore increase the average cost of the cup semi-finished product, raising the price of the finished Basic hinge product and thus weakening the product's position on the market. Excessive inventories generate a range of different wastes (transport, additional storage space, redundant processing, increased changeover times, questionable quality and increased defect volumes).

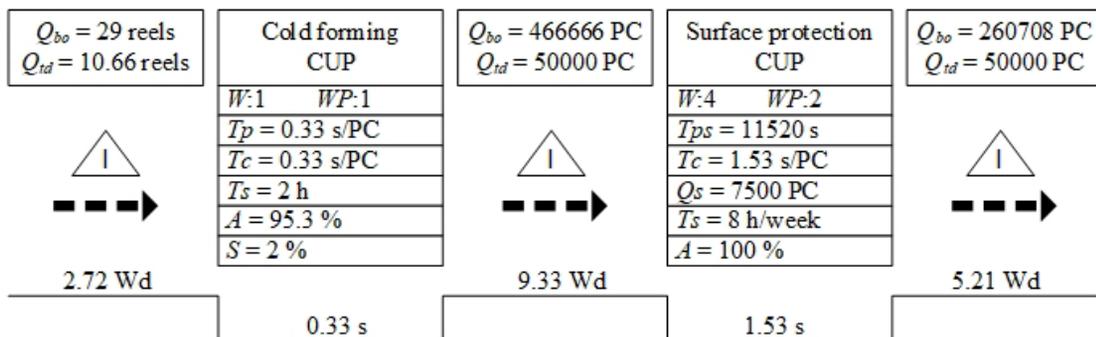


Fig. 4. Material value flow for the Basic hinge

4 ANALYSIS AND DISCUSSION

We have selected three scenarios to analyse the lean production process by varying the inventory level between the cold forming and surface protection operations. The simulation was carried out in MS Excel environment.

Scenario 1: Since the daily demand is 50,000 PC, the line manager in the first scenario has decided on an initial inventory  $z_0 = 30,000$  PC, i.e., 60 % of the daily safety inventory, which can be considered as an optimistic decision because in this case there should be no production failure of more than half a day.

Scenario 2: In the second scenario, the manager has increased the initial inventory to 60,000 PC, which represents 110 % of the daily safety inventory, which can be considered a plausible scenario. Even if there is a slight change in demand, there is still one day's safety inventory if a production failure occurs.

Scenario 3: In the third scenario, the initial inventory was further increased to 100,000 PC, which represents 200 % of the daily safety inventory, which can be considered a pessimistic decision because in this case there is a safety inventory for two days of production failure.

Using the mathematical model and the simulation software developed in MS Excel, the line manager in charge of production found out very easily what the storage costs  $E[C](z_0)$  and the risk  $\beta$  are for each scenario chosen.

Fig. 5 shows a possible choice between the optimal inventory  $z_0$ , the storage costs  $E[C](z_0)$  and the risk costs  $\beta$ . The coloured boxes show the values for the selected values for the 3 scenarios previously proposed that could allow a lean production process

in the case of reducing the inventory level of the cup semi-finished product between the cold forming and surface protection work operations.

$z_0$	$E[C](z_0)$	$\beta$
0	43,037.95	0.40
10,000	36,480.39	0.30
20,000	32,865.68	0.23
30,000	28,247.71	0.17
40,000	29,563.30	0.12
50,000	31,868.36	0.09
60,000	34,910.93	0.06
70,000	38,497.64	0.04
80,000	42,482.45	0.03
90,000	46,756.48	0.02
100,000	51,239.37	0.01
110,000	55,872.31	0.01
120,000	60,612.57	0.008
130,000	65,429.28	0.006

Fig. 5. Possible choice between the inventory  $z_0$ , the storage costs  $E[C](z_0)$  and risk costs  $\beta$

Fig. 6 shows the results from Fig. 5 in graphical form. Fig. 6 clearly shows where the minimum value  $E[C](z_0)$  is, and hence the optimal inventory level  $z_0$  is

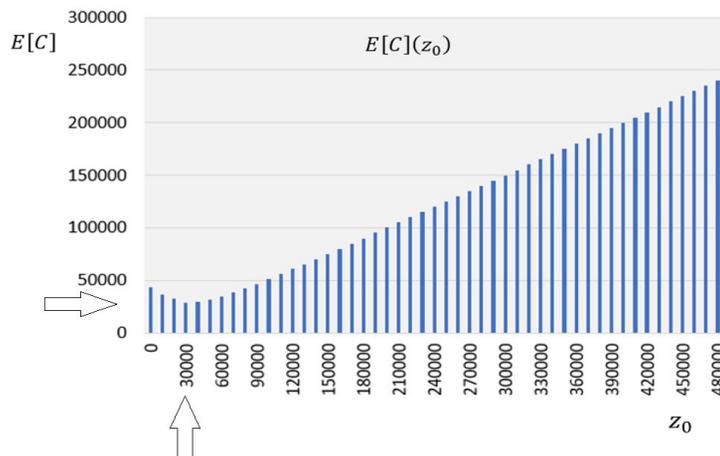


Fig. 6. Storage cost fluctuations  $E[C](z_0)$  as a function of the selected inventory level  $z_0$

determined. A more detailed analysis of the simulation results for all 3 scenarios is as follows:

Scenario 1: The storage costs are the lowest,  $E[C](z_0) = 28,247.71$  €. As a consequence, there is a slightly higher risk of production failure  $\beta = 17$  %. In Fig. 5, Scenario 1 is indicated by the red box and in Fig. 6 it is indicated by the arrows.

Scenario 2: It represents higher storage costs  $E[C](z_0) = 34,910.93$  € but a lower risk of production failure,  $\beta = 6$  %. In Fig. 5, scenario 2 is indicated by a black box.

Scenario 3: It represents even higher storage costs  $E[C](z_0) = 51,239.37$  € but the lowest risk of process disruption  $\beta = 1.7$  %.

Given the target function, the optimal decision is at  $\min z_0$ . This target is reached in the first scenario, where the selected quantity of the initial inventory is 30,000 PC and the cost  $E[C](z_0) = 28,247.71$  €. According to the production management, a risk of 17 % is acceptable.

Hypothetically, bearing the lean production principles in mind, we should have opted for a production without inventories, but in this case the costs are 43,037.95 € and the risk is 40.6 %, which is too high a risk. We have noted that in the mathematical model, and therefore in the simulation, the dominant variable is  $Z$  or  $z_0$  (optimal value), since this variable affects both the cost  $E[C]$  and the risk  $\beta$ . The larger the inventory  $Z$ , the higher the cost and the lower the risk, and vice versa. Thus, the management's decision depends mainly on the developments on the market. The greater the competition, the leaner the production process must be (because of lower costs) and the quantity  $Z$  must be close to  $z_0$ , even if the risk is higher. If the risk is higher, it means that the market situation must be closely monitored, and the simulation must be run again with the proposed model to choose a new inventory strategy adapted to the conditions.

Since we did not find a similar approach to inventory minimization in the literature, it is not possible to compare the results with other similar studies. Therefore, the management of the company in question has analysed the results in detail and found that they are useful for decision making regarding the level of inventory.

## 5 CONCLUSIONS

Inventory management is an important aspect of managing the production process and the entire logistics chain. This paper presented a mathematical model that allows fast and easy simulations of inventory management based on consumer buying

behaviour. For the mathematical model, the probability density function of demand  $f_X(x)$  was chosen which, in our opinion [1], best approximates the actual real-life customer buying behaviour. Based on the chosen function  $f_X(x)$ , the changes in the inventory fluctuation  $z_0$ , the storage costs  $E[C](z_0)$  and the risk costs  $\beta$  can be calculated in the production process as a function of the changed customer demands.

This paper is a follow-up to a previous study, which presented the negative effects of too high inventory levels of semi-finished products per time unit of observation on the average cost of the ACP product and thus on the final price of the product. This time, we have extended and additionally focused on the risk that may arise when deliberately reducing inventory levels between the work operations of a production process with the aim of approaching the desired lean production process. Logically, reducing the inventory level between work operations increases the risk of interrupting the quantities available to supply the customer and, of course, vice versa. In the practical case under consideration, the proposed model was used to simulate three possible scenarios of a lean production process on an example of inventories, storage costs and risk costs. Only two work operations have been chosen, cold forming and surface protection, as an example, but the model could be extended very easily to the whole logistics chain.

In the present case, there was clearly overproduction and thus waste. Between the two work operations observed, an inventory of as many as 466,666 PC was determined. By simulating three different scenarios, the optimum inventory level was found to be 30,000 PC, at which the inventory costs are minimal with a moderate risk of 17 %. The presented simulation method, based on a mathematical optimisation model, is a simple tool that provides the line management with an efficient decision-making support regarding the quantities to be produced in a given time interval, depending on the customer behaviour. The simulation can also be useful for the sales management to analyse, during the negotiations with customers, what the desired quantities mean for the production costs and to negotiate the selling price accordingly.

The scientific contribution of the presented model and simulation for decision-making support is that by analysing consumer buying behaviour, the changes in the production process can be monitored in terms of inventory costs and the risk that there may be insufficient products available to meet customer needs. There are few useful solutions in the literature for solving these problems, which are every-day

problems in manufacturing. The limitation of the study is that the proposed method is only suitable for batch production.

Our further research will focus on the development of a cost, analysis stream map (CASM) model that will offer a detailed overview of the entire production process in terms of demand, average cost of product ACP and risk. By incorporating CASM, the proposed method will be suitable for the optimisation of lean processes depending on customer behaviour also in industry 4.0. and can be integrated in the ERP or MES companies.

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