Simulation Study of Inventory Management in Supply Chains

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Well-organized management of a supply chain involves the control of inventory levels and fast response to the changing customer demands. Enterprises cannot cope with this problem which contributes to the growing stock levels and therefore increases costs. The main goal of the article is to present a simulation approach to the problem of inventory management in a supply chain. The work shows the use of computer simulation techniques in order to emulate a supply chain system and its stochastic behaviour. The procedure for the usage of simulation modelling was described in a case study containing an analysis of an online store. The simulation results are presented using statistical parameters, which means that managers can get not only information concerning the expected value of the parameter looking decision-making, but also statistics to the characteristics of the risk associated with the decision associated with possible uncertainty.

Keywords: supply chain, inventory management, computer simulation.

1. INTRODUCTION

Efficient management of a supply chain, i.e. the reduction of the inventory levels and fast response to the changing customer demands lead to an optimized inventory. A significant part of the cost of logistics is generated by maintaining stocks. Therefore, to maintain control of inventory level becomes an important issue for supply chain management.

The level of inventory in a warehouse on one side depends on the purchasing process and the other side on sales (demand). Effective inventory management involves finding the optimal size of the inventory level and takes into account purchasing processes and sales. The difficulty lies in the fact that the stock control requires taking into account the different elements of the supply chain. The inventory management is influenced by the nature of demand, depending on whether demand is derived or independent (Narmadha and Selladurai, 2009). Independent demand comes from demand for an end product. End products are found all through the supply chain. By definition, a self-governing demand is uncertain, meaning that extra units or safety stock must be accepted to guard against stock-outs. While managing uncertainty, the objective should be to minimize the inventory levels and also meet customer expectations. Supply chain coordination can reduce the ambiguity of intermediate product demand, in that way reducing inventory costs (Fisher 1997, Dooley 2005).

In this paper there is presented the use of the simulation model of the supply chain, enabling to examine operation of the system experimentally without having to build a physical model and disbursement of additional funding, and allow for optimization of the supply chain and inventory management, especially in terms of uncertain demand.

2. LITERATURE REVIEW AND PROBLEM BACKGROUND

More and more accurate supply chain management is needed to meet growing requirements of the market in terms of customer service - from planning and scheduling, through inventory management to forecasting demand. A key driver of the renewed focus on inventory lies in the recognition that traditional techniques are failing to reign in inventories in the wake of increased supply chain complexity (Scheuffele and Kulshreshta, 2007). This complexity is characterized by increased uncertainty. Demand is more volatile and therefore less predictable.

There are two strategic decisions that companies would face in the supply chain, they are lead time and inventory level (Kristianto, 2011). To increase responsiveness and lower the inventory cost, there are four types of collaboration that can be classified by the level of integration, the capability of integration of supply chain planning, forecasting and replenishment (Christiansen et al., 2007).But the collaboration is difficult to apply in the supply chain that is global and order based, as it has constrains including uncertainty, complexity, location diversity and control limitation (Holweg et al., 2005, Christiansen et al., 2007).

Inventory management is influenced by the nature of demand, including whether demand is derived or independent. Therefore, process of inventory control becomes complicated. Managers of all sizes use such calculations which are part of flow management to manage inventories, schedule deliveries for inputs, and manage capacity. In order to determine the answers to the questions: what, when and how much to order many quantitative models have been developed. Currently, managers making decisions on inventory have an arsenal of methods, ranging from the simplest economic order quantity (EOQ) through flow management software which was evolved from Materials Requirements Planning (or MRP) in the 1960sto the much more complex Enterprise Resource Planning (or ERP) of the 1990s. A flow management system is set in motion by the demand for end products. Independent demand arises from demand for an end product. End products are found throughout a supply chain. By definition, an independent demand is uncertain, meaning that extra units or safety stock must be carried to guard against stock outs (Dooley, 2005). Managing this uncertainty is the key to reducing inventory levels and meeting customer expectations. Supply chain coordination can decrease the uncertainty of intermediate product demand, thereby reducing inventory costs (Houéand Guimaraes 2017, Fliedner 2003). Enterprises, in order to maintain a high competitive position, must identify any hazards and determination of their nature and also try to reduce the impact of any occurred uncertain events. Hence the high importance is given to properly carried out vulnerability analysis (Tubis et al., 2017).

Observations of real-world objects belonging to complex systems, like supply chains, prove that they operate in conditions of numerous random factors (Jung et al., 2004, Thierry and Narahari, 2010). Analyzing it in real systems it is not possible. Therefore, a computer simulation is an appropriate tool to study the effect of the variability of demand on the system parameters. Simulation modelling is one of four main types of research approaches (empiricism, morphology, pure theory and modelling) and together with analytical modelling they are part of mathematical modelling (Law and Kelton 2000, Kemme 2013). Banks (1999) defined simulation as the imitation of the operation of a real-world process or a system over time. The discrete-event simulation models processes of a system as a discrete sequence of events in time. Each of these events occurs at a particular instant in time and marks a change of a state in a system (Kostrzewski 2014).

Research in Beamon and Chen (2001) is concerned with the performance behaviour of conjoined supply chains, which typically arise in web-based retail. The study is accomplished via experimental design and simulation analysis, and the results suggest the effects of the various factors on supply chain performance and identify the nature of the relationships among these factors and overall supply chain performance. The authors suggest that the most important issues to deal with in the supply chain are: external demand variability and transportation time variability. Duong et al. (2015) proposed model support to analyze the relationships between input factors such as lifetime, lead time, and substitution ratio to provide better understanding of inventory management in the multi-echelon model for perishable and substitutable products. In Torkul et al. (2016) simulation experiment was carried out to understand the characteristics of the real-time inventory model and to compare it to the re-order point inventory model. Jammernegg and Reiner (2007) performed a simulation study of a three-stage supplier network of a company in the telecommunication and automotive industry. Authors discussed the opportunities and challenges for improving the performance of supply chain processes by coordinated application of inventory management and capacity management. Schmitt and Singh (2012) analyzed the inventory placement and back-up methodologies in a multi-echelon supply chain network using a discrete-event simulation model, showing that systematic proactive planning enables significant reductions in disruption of the risk impact. Park and Kim (2016) proposed a simulation-based evolutionary algorithm approach for deriving the operational planning of global supply chains from the systematic risk management, which proactively deals with the negative consequences of random and hazardous risk events in sourcing, production, distribution, and transportation in an integrated way.

Cost effective supply chain management under various market, logistics and production uncertainties is a critical issue for companies in the chemical process industry. Uncertainties in the supply chain usually increase the variance of profits (or costs) to the company, increasing the likelihood of decreased profit. Demand uncertainty, in particular, is an important factor to be considered in the supply chain design and operations. To hedge against demand uncertainty, safety stock levels are commonly introduced in supply chain operations as well as in supply chain design.

3. SIMULATION OF INVENTORY CONTROL

Uninhibited use of inventory control models, especially those complicated ones, raises the need for a profound knowledge of statistics, econometrics and operational research, and dispose of advanced systems incorporating appropriate algorithms. Only in such conditions there is a guarantee that the adopted method will properly describe the actual logistics system and its surroundings and will lead to a reduction in inventories. Therefore, managers who control inventory, particularly in small and medium-sized enterprises, are often limited to the implementation of basic quantitative models, taking in many cases decisions based on common sense grounds. However, to respond to the needs of customers, suppliers and partners, and at the same time reduce costs and increase revenue is advisable to use specialist software. The moment when intuition and experience of managers no longer are sufficient, one should use the tool that can help with demand forecasting and inventory management.

It seems that the process of inventory control does not have to boil down to two extreme states - to rely on intuition of managers on the one hand or carrying out complex calculations; performed most often based on advanced information systems for planning and scheduling. Solution might be to use simulation modelling software that allows conducting simulations, and even optimize the inventory control under conditions of uncertainty. Simulation modelling permits the evaluation of operating performance prior to the implementation of a system. It enables companies to perform powerful what-if analyses leading them to better planning decisions. Analysis of large and complex stochastic systems, like supply chains, is a difficult task due to the complexities that arise when randomness is embedded within a system. Since testing variability demand in real-world supply chains is absolutely impossible, simulation modelling has often been adopted to evaluate the performance of variability demand. It also as an evaluative tool for stochastic systems has facilitated the ability to obtain performance measure estimates under any given system configuration.

How does the simulation software support inventory management from the point of view of logistics strategy?

- makes it possible to analyze the current level of stocks;
- allows identifying potential savings opportunities;
- on the basis of calculations, allows planning inventory management model to optimize inventory levels under uncertainty conditions from the point of view of cost and customer service.

Each computer simulation experiment requires the application of appropriate research procedures. It consists of the following steps:

1. Identifying a research problem
2. Formulating a hypothesis or hypotheses
3. Developing a research project (identification of variables, develop a schedule of research)
4. Defining probability distributions of input data and the disturbance in the model (taking into account uncertainty)
5. Construing of a simulation model
6. Determining the simulation parameters (duration, number of replications)
7. Verifying the simulation model
8. Carrying out simulation experiments
9. Gathering data
10. Analysing statistics
11. Conclusions from research

The first and last three points above procedure are characteristic of most research. From the perspective of simulation modelling different are the construction and verification of the simulation model and carrying out the experiment. Simulation software to conduct simulation experiments makes it possible to build complex models taking into account uncertainty embedded in the system like demand variability. Computer simulations have a much greater flexibility than the analytical models due to the lower number of required assumptions and limitations. Popular tools used to simulate processes are:

- Adonis
- Arena from Rockwell Software
- Aris Simulator
- Matlab Simulink
- VenSim

In this work, it was decided to use Arena software due to the fact that it has special blocks and methods dedicated to logistic processes.

4. CASE STUDY

The following example is a supplement of presented theoretical issues, allowing to formulate the main advantages of the use of simulation modelling in inventory management using Arena – simulation software from Rockwell (version 14). In detail, a discrete event simulation model of the hypothetical supply chain of online RTV store was built. The existing research (Chodak and Latus, 2011) reveals serious lack in the use of tools which can help in inventory management by Polish online stores. In their work they said that only 12% of stores used specialized logistic software, and as much as 85% of stores assume that the best method of forecasting is a salesman's sense and experience. The survey was conducted in 2010 by a survey method on a representative group of 7% of Polish online stores. Authors also indicate the continuing trend for increasing of the safety stock levels. Research in this paper contains a model which is a part of a larger supply chain with two suppliers, one analysed store, three types of product and customers. Figure 1 shows a scheme of analyzed supply chain.

The purpose of this model is to conduct experiments regarding process alternatives. The model can be used to measure relevant performance indicators like safety stock level. In example was decided to choose an online store with electronics as particularly important in the context of maintaining high inventory levels – 36% of online stores in this branch have almost all assortment in store (Chodak and Latus, 2011). For the reason that significant changes in the dynamics of the assortment in this branch keeping in the store electronic equipment may be associated with the loss of its value. In addition, the high value of the stored product causes that it is not reasonable to maintain high inventories.

An algorithm procedure using simulation

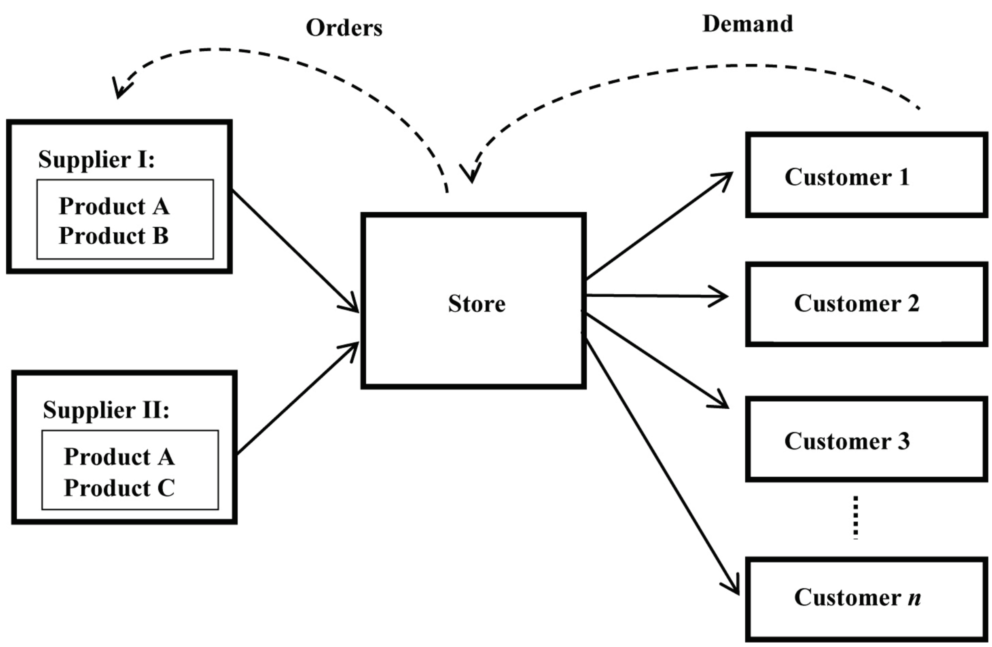

Fig. 1. Scheme of the analyzed supply chain.

experiments in the Arena environment of an analyzed supply chain is shown in Figure 2. This environment can simulate any complex system, taking into account possible uncertainty. The aim of this consideration is to examine how changes in the plan of ordering goods affect stock levels in the store. The use of a simulation model to investigate this problem allows testing of logistics processes occurring in the supply chains without interfering with the real processes. Any analysis is carried out only in the computer, and using the appropriate methodology for the preparation of a simulation model provides a close correlation between the results obtained using the simulation model and the results that can be achieved by conducting similar research on a real supply chain.

Table 1. Simulation parameters – delivery amounts.

Supplier		Product type	Delivery amount [items per 7 days]
I	A	300	
	B	180	
II	A	300	
	C	4,000	

In real supply chains there are many stochastic components. In this case random probability distributions are used to represent uncertainty in demand. Table 2 presents parameters for customers' orders - values given according to normal distribution. Normal distribution is a good description of the distribution of demand for fast-selling items (Krzyżaniak, 2009).

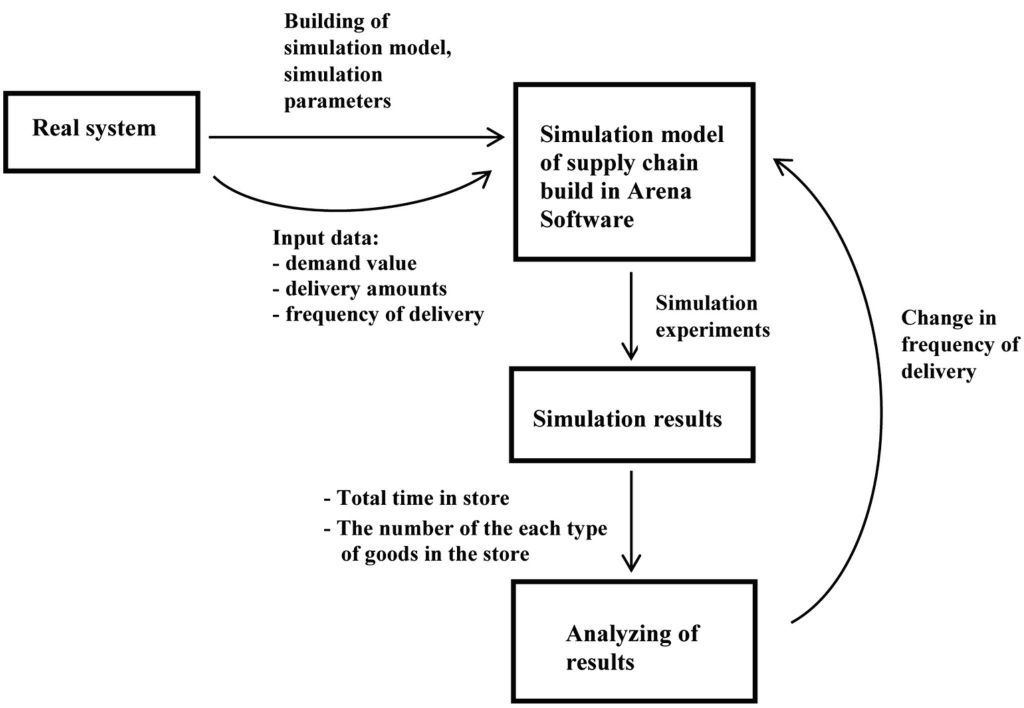

Fig. 2. An algorithm procedure using simulation experiments.

Simulation experiment

The experiment design is described in the following section followed by a discussion of results. Simulation model imitates hypothetical supply chain of online store with RTV products. Store has two suppliers (I and II) and sells three main types of goods: computer monitors (A), big television sets (B) and some small size RTV goods (radios, record players) (C). Fixed model parameters are shown in table 1. The number of items is calculated taking into account the transport with 24 ton capacity trucks.

Table 2. Simulation parameters – uncertainty in demand.

Product type	Demand value [items per 7 days]	
	Average	Standard deviation
A	550	100
B	160	30
C	3,500	700

According to the accepted parameters in the literature, which ensure reliable results the following simulation runs parameters were determined:

- The basic unit of time in the simulation = 1 day
- Warm-up time =10 days
- Replication length = 365(one year)
- Number of replications = 3

The resulting parameters to be analyzed:

- Total time spent by the goods in the store
- The number of the each type of goods in the store

Results from simulation experiment are presented in table 3.

Table 3. Simulation results.

Product type	Total time in store [days]	
	Average	Maximum
A	16.3	62.6
B	17.2	67.9
C	12.7	50.0

From table 3 one can observe that the average value of total time in store is about two weeks. But the maximum values of are much higher – reason is the variability of demand (about 20% differ from the average weekly demand). This confirms the need to minimize the total times and thereby high stock levels.

24 additional simulation runs (8 scenarios x 3 replication each) were conducted to evaluate the effects of the supply chain process alternative scenarios (scenarios from 2 to 9 – table 4). Managers can see how are changing the analyzed parameters with changes in the ordering plan (change in frequency of delivery – table 4), as well taking into account the possible uncertainty in the demand. Individual scenarios differ in the frequency of delivery. Usually these are changes in 1 day in relation to 7 days between deliveries to a given product, to show decision makers how small changes in orders can change storage times. The aim is to determine such changes in the ordering plan to minimize the total time the goods in the store while providing the availability of goods. Table 4 and figure 3 shows the results of the following most relevant scenarios.

Table 4. Simulation results – alternative scenarios.

Scenario no.	Product type	Frequency of delivery [number of days between delivers]		Total time in store [days]		Minimum value of stored goods [items]
		Supplier I	Supplier II	Average	Maximum	
1	A	7	7	16.3	62.6	194
	B	7	-	17.2	67.9	25
	C	-	7	12.7	50.0	478
2	A	8	7	11.1	42.7	50
	B	8	-	6.5	25.9	3
	C	-	7	12.7	49.7	450
3	A	7	8	11.2	43.6	180
	B	7	-	17.2	67.9	25
	C	-	8	2.0	8.0	0
4	A	8	8	5.3	20.6	51
	B	8	-	17.2	67.9	30
	C	-	7	12.7	49.7	368
5	A	8	8	5.3	20.6	50
	B	7	-	6.5	25.9	3
	C	-	7	12.7	49.7	478
6	A	9	9	1.5	6.5	0
	B	7	-	17.2	67.9	41
	C	-	7	12.7	49.7	412
7	A	9	7	6.9	26.9	99
	B	9	-	2.0	8.6	0
	C	-	7	12.7	49.7	387
8	A	7	9	6.8	26.7	56
	B	7	-	17.2	67.9	28
	C	-	9	1.9	8.0	0
9	A	7	9	16.3	62.6	194
	B	8	-	6.5	25.9	3
	C	-	8	1.9	8.0	0

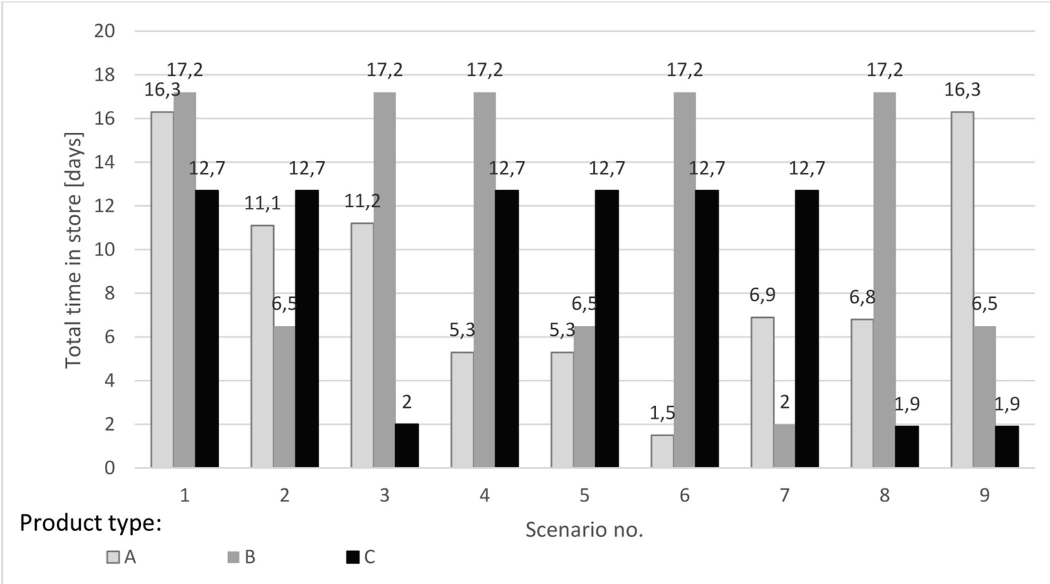

Fig. 3. Average total time (days) in store – alternative scenarios.

The analysis results are presented in tabular form and on a graph that allows managers to compare the inventory levels related to all the investigated scenarios. The results of the simulations show that the decision to choose the best ordering plan is not easy, especially if we assume the uncertainty in the supply chain which is reflected variability in demand. One can observe that the best results of total time in store for all products are for scenario 7, but in this scenario there are cases in which the article B is missing, i.e. television sets. If we consider only those scenarios when you are never short of any kind of product then good results are obtained in scenario 2 or 4. The problem thus presented becomes a bi-criteria problem. Managers should decide which of these criteria is more important from their point of view. Simulation experiments help in providing data so that they can make decisions not only on the basis of intuition. In addition, one can notice that all the scenarios show better effects compared with scenario 1 (standard orders once a week). Managers seeing this combination can make decisions not only based on intuition or simple calculations, but also specific data, which also include a certain level of demand uncertainty.

5. CONCLUSION

Inventory management is an important component of supply chain management. Supply chain management in any industry is always burdened with certain risks and uncertainties, because in such a complex system one can often come across events and phenomena bearing signs of randomness, which to the end cannot be predicted due to unknown causes of them.

This paper shows the interaction among characteristics of inventory management, taking into account uncertainty in demand. The author described simulation modelling as a useful tool to assist and verify the decision regarding inventories undertaken in conditions of uncertainty. A simulation model of a supply chain for online store was build and analyzed in Arena environment which is simulation software that has special blocks and methods dedicated to logistic processes. A properly constructed simulation model makes it possible to examine the operation of a system by experiment (computing) without having to build a physical model. This approach allows any modification of the model parameters; types and values of the input quantities and to set the output that interest us in a way that does not require additional funding.

In this paper an efficient and simple methodology is proposed – the one that uses simulation modelling to precisely determine low inventories levels in the supply chain in such way that the total supply chain cost can be reduced. The results of the numerical experiments illustrate that the different variants in the ordering plan can generate lower levels of inventories while providing the availability of goods in the store. Managers can easily make changes to the simulation model and analyze the results in terms of reducing inventory also taking into consideration the variability of demand.

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