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## ► To cite this version:

Volker Stich, Daniel Pause, Matthias Blum, Nina Hinrichs. A Simulation Based Approach to Investigate the Procurement Process and Its Effect on the Performance of Supply Chains. IFIP International Conference on Advances in Production Management Systems (APMS), Sep 2016, Iguassu Falls, Brazil. pp.335-342, 10.1007/978-3-319-51133-7\_40 . hal-01615809

**HAL Id: hal-01615809**

**<https://inria.hal.science/hal-01615809>**

Submitted on 12 Oct 2017

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# A Simulation Based Approach to Investigate the Procurement Process and its Effect on the Performance of Supply Chains

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**Abstract.** Influenced by the high dynamic of the markets the optimization of supply chains gains more importance. However, analyzing different procurement strategies and the influence of various production parameters is difficult to achieve in industrial practice. Therefore, simulations of supply chains are used in order to improve the production process. The objective of this research is to evaluate different procurement strategies in a four-stage supply chain. Besides, this research aims to identify main influencing factors on the supply chain's performance. The performance of the supply chain is measured by means of back orders (backlog). A scenario analysis of different customer demands and a Design of Experiments analysis enhance the significance of the simulation results.

**Keywords:** Procurement · Supply chain · System dynamics · Inventory management · Design of experiments.

## 1 Introduction

Today, manufacturing companies are confronted with the influences of a dynamic environment and the continuously increasing planning complexity [1]. Reduced time to markets, rising product diversity as well as complex multi-tier and world-spanning supply chains are faced with growing inter-connectivity of production machinery, enterprise resource planning systems and manufacturing execution systems. Due to globalization, the number of market participants rises resulting in a growing competition amongst the individual companies [2]. In particular, different wage levels in developed and developing countries induce enhanced price pressure on established companies in high-wage countries [3]. In order to remain profitable as a business, the industrial enterprises in high-wage countries must identify cost carrier of the production process in order to reduce unnecessary costs. This is why companies focus on the production steps with a high share of added value and reduce the depth of production [4]. A strong trend towards reduced inventory is sensed so that components are delivered "just-in-time" (JIT) for the production. Accordingly, the process of procurement must be designed in a way which ensures a smooth production. As

part of inter-company value chains the individual view of procurement is not adequate anymore. Rather, the analysis and optimization of the whole supply chain continues to gain importance [5]. This appears to be difficult in industrial practice due to unknown interactions of various parameters in the supply chain (e.g. interactions of the reorder level of the manufacturer on the backlog of the supplier are unknown). Considering these problems, companies lack on an efficient design of their procurement processes. In order to overcome the described issue, this paper presents an approach how to tackle the problem of inefficient procurement processes. Therefore, we designed a simulation model of a four-stage supply chain (sub-supplier, supplier, manufacturer and customer) covering all steps of the procurement process. The aim of simulating a supply chain is to display known interdependencies and phenomena and thus be able to improve the decision making process. In particular, different procurement strategies are investigated and evaluated in this paper. In order to further investigate the interactions of the parameters in the supply chain, a Design of Experiments approach was used. Hereby, the interactions of the parameters are investigated and principles how to design an efficient supply chain are derived.

## 2 State of the Art

Due to the close link between procurement, inventory management and production a separate analysis of these sections is not sufficient. Thus, the emphasis is put on the optimization of all companies involved in the value-added process (supply chain). To investigate the cooperation and acting of a supply chain various research approaches already exist. In the following these approaches are outlined. Moizer et al. (2014) examine the advantages of a close cooperation between the manufacturer and its suppliers of a retail supply chain and the influence of efficiency and performance. A simulation was used on the basis of a trial group consisting of 12 retailers in the US. It was shown that collaboration can cut costs, risks and inventory for both the retailer and their suppliers [6]. Langroodi and Amiri (2016) investigate the choice of the most appropriate region for order placements in a five stage multi-product supply chain, consisting of a customer, an incorporate retailer, manufacturer, material distributor and supplier, in four different regions using a System Dynamics model. A scenario analysis with varying costs and demands was conducted. The model aims to minimize the costs of orders between two stages consisting of transport, price for the product and order placement and thus choose the best supplier [7]. Hishamuddin et al. (2015) analyze disruptions of supply and transportation on the system's total recovery costs and other performance measures in a three stage supply chain with multiple suppliers. Thus, different scenarios of disruptions combined by kind and location of disruption were established to evaluate system costs and stock outs. It was shown that transportation disruptions have more damaging effects than supply disruptions due to the higher lost sales quantity. In addition, disruptions in the earlier stages have a higher negative impact to the supply chain compared to later disruptions [8]. Li et al.

(2016) examine the dynamic risks effects in a chemical supply chain transportation system. Therefore, a System Dynamics model was built and risk scenarios were established regarding the probability and consequence severity in order to compare order fulfillment rate, transportation and inventory level to measure the performance. The major sources of risks transpired among other as breakdown in core operations, inappropriate choice of service provider and lack of inventory management. The researchers used only a questionnaire as the input for various risk scenarios which could be a source of bias. Thus, it would be necessary to use a more extensive data source [9]. This paper enables the user to evaluate different procurement strategies and interpret the influence of various parameters. The emphasis is put on the interplant relation instead of the internal production itself.

### 3 Methodology

System Dynamics is a methodology for modeling, simulating, analyzing and designing dynamic and complex issues in socio-economic systems. Simulation models based on System Dynamics contain four different types of elements [10]:

1. Levels represent state variables of the system
2. Flow variables symbolize temporal change of the state variables
3. Auxiliary variables are used for decision rules describing casual relations
4. Constants are parameters to be set for the simulation

Supply chains mainly consist of inventory (information or material) as time based variables and flows as activities (transport of material and information). Decisions steer running activities and thus the state of the system [11]. A superior aspect to other simulation models is the possibility of feedback loops within the model. Thus, it is suitable for analyzing complex problems [12]. A common way to analyze a system's behavior using System Dynamics is a scenario analysis. This was done by using the tool Vensim.

## 4 Description of the Simulation Model

### 4.1 Model Structure

The model consists of a sub supplier, a supplier, a manufacturer and a customer (Fig. 1). Between the respective supply chain partners a material flow and an information flow is taking place. The sub supplier serves as an infinite source of order items and the customer is able to create different demand situations. The supplier and the manufacturer are modelled according to a simplified business structure, which is described in the following paragraph. The business structure both of the supplier and the manufacturer are composed of an arrival warehouse for incoming goods, a quality check (QC) for the incoming goods, a

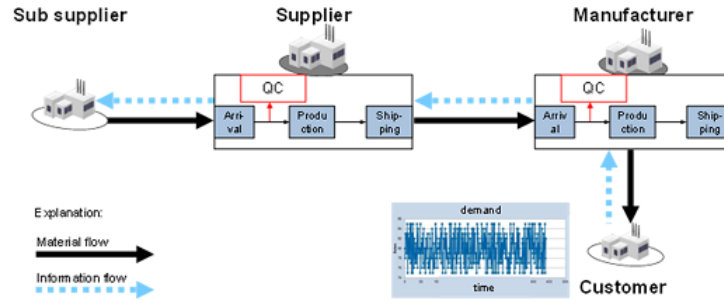


Fig. 1: Model structure

production and a shipping warehouse from which the products are delivered to the customer.

The parameters contained in the model are shown in Table 1. Conducting a scenario analysis target inventory, lead time,  $\alpha$  service level and production rate were defined for both the supplier and the manufacturer.

Table 1: Parameters in the simulation model for the supplier and the manufacturer

Code	Declaration	Setting Range
HB	Target Inventory Supplier	500 - 2000 pieces
HB 0	Target Inventory Manufacturer	500 - 2000 pieces
L	Lead time Supplier	2 - 14 days
L0	Lead time Manufacturer	2 - 14 days
SG	$\alpha$ -Service Level Supplier	90 - 100 %
SG 0	$\alpha$ -Service Level Manufacturer	90 - 100 %
PL L	Production Rate Supplier	500 - 10.000 pieces / day
PL H	Production Rate Manufacturer	500 - 10.000 pieces / day

The customer demand is induced by an Excel based data generator. Thus, based on several parameters different demand situations can be applied to the simulation model. An expected demand and a standard variation need to be specified prior to the simulation as well as the initial situation with regard to a so-called trend, season or a constant demand.

## 4.2 Procurement Process

In the beginning of the simulation a certain stock is available in the shipping warehouse from which the demand is satisfied. As soon as the stock reaches the reorder level a new order is placed with the supplier. Between the time of

ordering and the time of delivery the order quantity is put in the open purchase quantity. Before a new order is placed both the stock amount in the shipping warehouse and the amount in the open purchase quantity is checked if the stock moved below reorder level. The order quantity varies depending on the order policy investigated. This paper puts emphasis on a variable order point ( $s, S$  and  $s, Q$  order policy), because the order policies using a fix order point are mostly obsolete today [13]. The reorder level  $s$ , at which a new order is placed, establishes a link between the inventory level and the stochastic character of the demand. While the order quantity varies using a  $s, S$  strategy due to the stock replenishment up to a set target inventory a  $s, Q$  strategy purchases a fix quantity every time [14]. However, in this study the order quantity using a  $s, Q$  strategy can vary by the size of the backlog. In case the company is not able to meet the full demand in one period this amount is considered for the following order placed at the supplier. The reorder level is defined by the safety stock and the material which is used for the daily production. The daily production is determined by the moving average production of past periods in order to avoid a high volatility. The safety stock depends on the volatility of the demand. When the demand fluctuates substantially, a greater safety stock is necessary to ensure a smooth production. Depending on the delivery reliability towards the customer a greater safety stock has to be held. Another factor that influences the safety stock is the time it takes to restock the warehouse, defined as lead time.

## 5 Results of the Simulation

Different scenarios of demand situations have been investigated to identify the best order policy. The results were compared by evaluating the quantity of the backlog. This variable is linked to the service level which in turn has a direct influence on the customer's satisfaction and thus the supply chain's long-term success. In the following the scenario of a seasonal demand is exemplarily presented. Fig. 2 illustrates the comparison of the ordered parts and delivered parts over time. Whereas the delivered parts do not vary between  $s, Q$  and  $s, S$  order policy, it is obvious that the backlog using the  $s, Q$  order policy is lower than the backlog of the  $s, S$  order policy. The  $s, Q$  order policy reorders the amount of backlog as well as the usual quantity and is thus able to better react on unstable demand situations. Figure 2 also indicates that the backlog of the supplier occurs more often and in a higher quantity than the backlog of the manufacturer.

Based on the simulation results a Design of Experiments analysis was conducted to visualize and identify the factors that influence the backlog of delivered parts most. The main effects charts in Figure 3 illustrate the examined factors (also see Table 1) and indicates if it has a positive or negative impact on the backlog when changing from a predefined minimum to a maximum value.

A horizontal line implies that there is no effect on the backlog, the steeper the line the greater the influence on the backlog. It is obvious that the greatest influence on the backlog of the manufacturer and supplier are the lead time

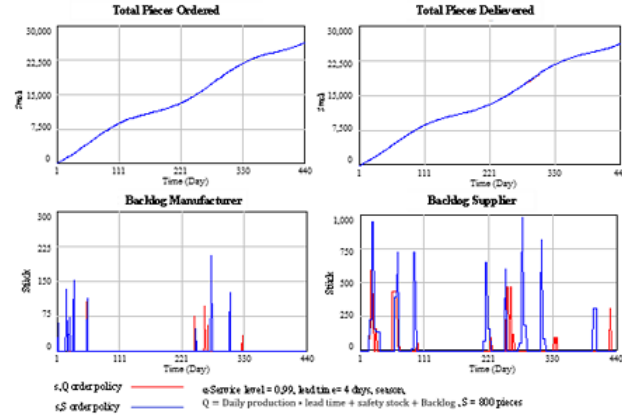


Fig. 2: Results of the scenario analysis on the basis of a seasonal demand structure

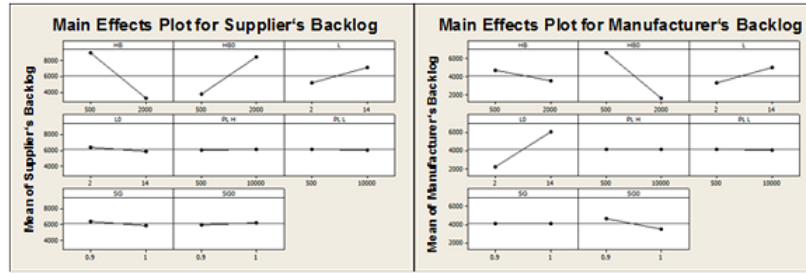


Fig. 3: Main effects charts for supplier's and manufacturer's backlog

(L, L0) and the target inventory (HB, HB0). The backlog of the supplier increases with a greater lead time and a decreasing target inventory. The target inventory of the manufacturer and the lead time of the supplier have a positive influence on the backlog. A higher manufacturer's target inventory comes along with greater order quantities which leads to a higher backlog because the supplier is not prepared for these orders. The supplier can react by storing more inventories due to the negative effect as seen in the left graph (HB). Another fact which is seen in Fig. 3 is that the manufacturer's backlog is not much influenced by the actions of the supplier (lead time and target inventory). The line of the production rate between 500 and 10,000 pieces per day (PL L and PL H) as well as the  $\alpha$ -service level (SG and SG0) in both plots are almost horizontal indicating a low influence on the backlog. After identifying the lead time and the target inventory (HB) as the major influencing factors, an analysis of the interaction between these parameters was conducted (Fig. 4). An interaction plot shows the interdependencies between particular factors when changing

specific factor settings. Because an interaction can magnify or diminish main effects, evaluating interactions is extremely important.

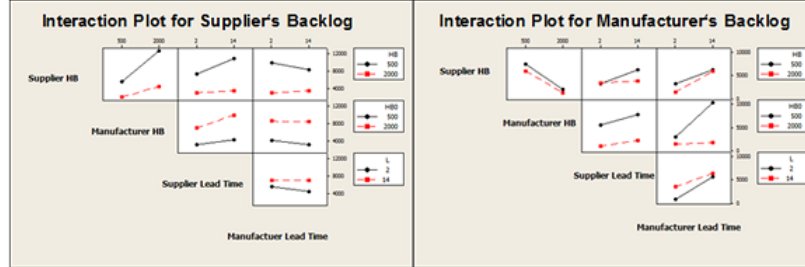


Fig. 4: Interaction between target inventory (HB) and lead time

The lines in Fig. 4 are indicating the strength of the interaction between the parameters. If the lines are parallel to each other, no interaction occurs. The more nonparallel the lines are, the greater the strength of interaction is. Evaluating the supplier's backlog it stands out that there is a great influence between the target inventories (HB) of the manufacturer and the supplier. Due to this fact it would be advisable that the supplier and the manufacturer make arrangements on their target inventories for the purpose of a decreasing backlog. Apart from that only slight interactions are seen in the plot of the supplier's backlog. On the contrary the manufacturer's backlog shows almost no interaction between the target inventories (HB) of the manufacturer and the supplier. Even greater is the interaction between the manufacturer's target inventory (HB) and its lead time. It would therefore be advisable to choose the proper target inventory based on the lead time to the customer.

## 6 Conclusions and Outlook

In this paper, a simulation of a four-stage supply chain was presented and different order policies were compared. After introducing the basics of procurement and inventory as well as System Dynamics, the model structure was explained and two order policies were chosen for a comparison. It was shown that the lead time and target inventory are main causes for the supply chain's performance measured on the basis of the backlog. Due to the dependency of the backlog of the supplier by actions of the manufacturer, a close cooperation between all companies involved is advisable. The vendor managed inventory where the supplier manages the inventory and orders of the manufacturer is a method trying to decrease the backlog. In further investigations this method could be considered and implemented in the simulation model. Additionally, further parameter could be added to the model, which might influence the supply chain's performance. e.g. costs for inventory and procurement in order to



further specify decision rules. Moreover, instead of using the backlog as a main measuring unit for the supply chain performance further objectives such as costs or average inventory level could be considered.

## Acknowledgements

The presented research is a result of the Cluster of Excellence (CoE) on “Integrative Production Technology for High-Wage Countries” funded by Deutsche Forschungsgemeinschaft (DFG). Within the CoE “Integrative Production Technology for High-Wage Countries” several institutes at RWTH Aachen University are conducting research on fundamentals of a sustainable production strategy. The authors would like to thank the German Research Foundation DFG for the kind support within the Cluster of Excellence Integrative Production Technology for High-Wage Countries.

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