European Symposium on Computer Aided Process Engineering – 15
L. Puigjaner and A. Espuña (Editors)

System-Dynamics modelling to improve complex inventory management in a batch-wise plant

Zofia Verwater-Lukszo and Tri Susilowati Christina
Delft University of Technology, Faculty of Technology, Policy and Management
2600 GA Delft, the Netherlands

Abstract

The process industry has to cope with a rigorous competition caused by more short-term dynamics in supply, more unpredictable and turbulent demand patterns, stronger requirements on product variety, delivery lead-time and quality of product. It forces company to spend efforts at improving its competitiveness and productivity. Appropriate strategies or action in the area of inventory management can contribute to survive in these conditions.

This paper describes a novel modelling approach aimed at improving complex inventory management of many product grades in a multi-product batch-wise industrial plant. The simulation model of the internal supply-chain addressing the order acceptance and processing constraints – the cornerstone of the proposed approach - is developed according the System Dynamics methodology. The proposed model implemented in a decision support tool assists the decision maker(s) by providing a systematic structure to arrive at potential improvement options for inventory management. The approach is applied in a chemical multi-product plant producing a number of grades of resins with different priorities.

Keywords: System Dynamics, internal supply chain, decision support

1. Introduction

Inventory holds a crucial but double-sided role in a manufacturing plant. In "rough" situations such as when a plant cannot produce at the desired rate or in moments where suppliers are not reliable, inventory is seen as a saviour, as a survival tool. However, mostly, when everything goes smoothly, inventory is seen as a waste of money, a standing still investment that yields nothing. Inventory management is necessary to create a balance between these two sides. How to manage the inventory to find the right trade-off between both objectives is the basic question addressed in Christina (2004).

Inventory decisions are high-risk and high-impact from the perspective of operations. Commitments on inventory and subsequent shipment to a market in anticipation of future sales determine a number of logistics activities. Without the proper inventory, marketing may find that sales are lost and customer satisfaction will decline. Likewise, inventory planning is critical to manufacturing. Raw material shortages can shut down a manufacturing line, which, in turn, introduces goods shortages. Just as shortages can disrupt planned manufacturing operations, overstocked inventories also create problems. Overstocks increase cost and reduce profitability through added warehousing, working capital requirements, deterioration, taxes, and obsolescence (Bowersox, 1996).

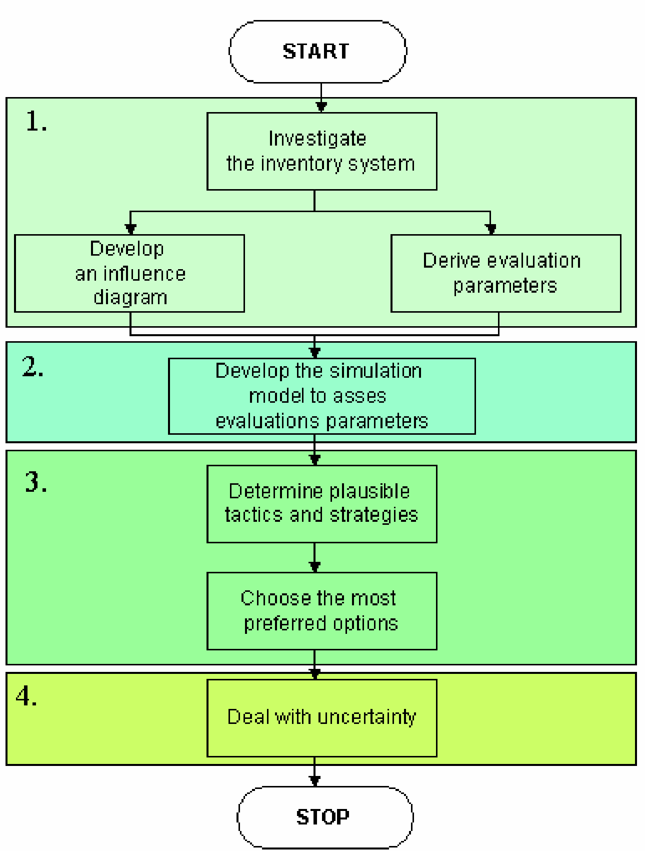


Figure 1. The framework of the decision support system

Designing an effective inventory policy turns out to be a hard task. In order to properly evaluate the different alternatives, which potentially are intended to improve the inventory management, it is necessary to study the impact of the proposed options on the important performance indicators related to the enterprise goals. Two objectives are considered as the most important indicators: the minimization of the inventory costs and the maximization of the customer satisfaction. Therefore, the problem, which arises here, consists of finding the solution that is the appropriate compromise between expected inventory costs and the customer satisfaction level. By searching for the solutions the uncertainty related to strategies, should be taken into account, too (Verwater-Lukszo, 2004).

2. Decision support: Performance measurement system

The approach adopted to attain the goal formulated as improvement of the inventory management of the WIP (Work In Progress) materials was aimed at developing a decision support tool that is expected to assist decision maker(s) in revealing the performance parameters (inventory level/costs and service level) behaviour under potential tactics and strategies concerning inventory with regards to uncertainties of the system. The approach is decomposed into four phases, as presented in Figure 1.

The first phase is to get insights of the inventory conditions in the company and to identify the evaluation parameters, which could measure the influence of potential improvement options on inventory management to the achievement of the company's objectives. This is a creative process supported by an influence diagram representing relations between variables in the internal supply chain with regard to customer orders, materials and production resources; see Figure 2.

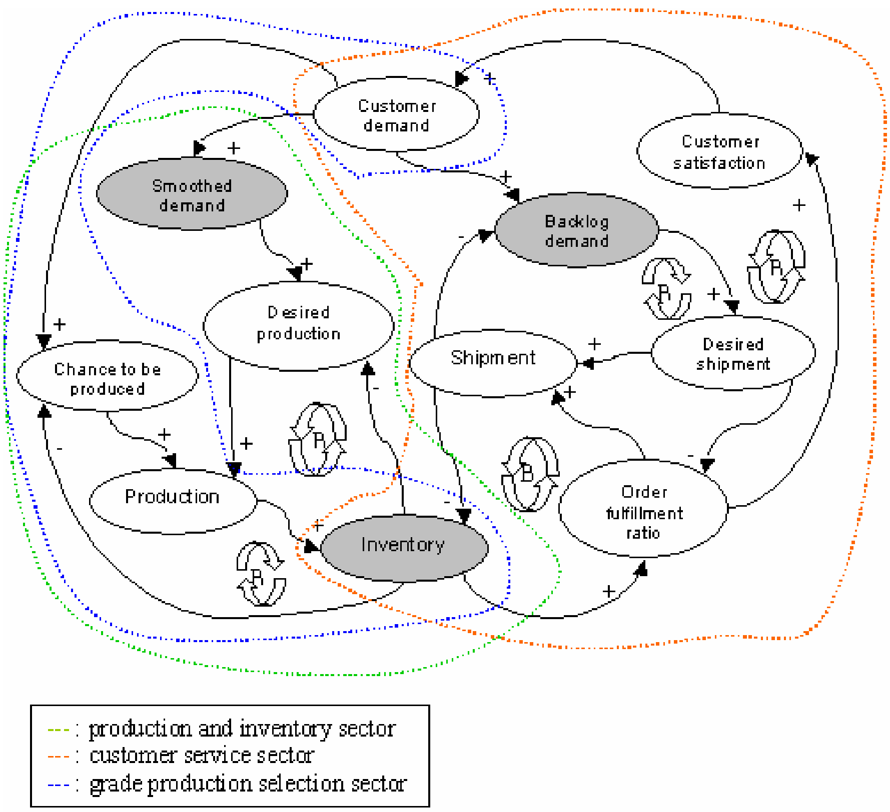
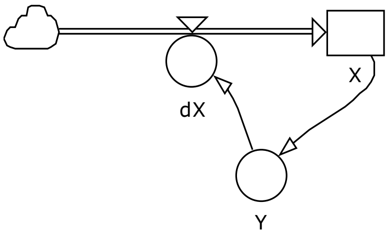


Figure 2. The overall inventory system influence-diagram

Having insight into the inventory, the second step is to construct the model that can be used to simulate the behaviour of performance parameters under the implementation of the decisions (improvement options). A System Dynamics (Sterman, 2000) approach is used to capture the dynamic relationships and feedback structures, as presented in Figure 3. In the developed model the internal supply chain is divided here into three sectors: production and inventory sector; customer service sector (including shipment) and grade production sector. These sectors are related to each other as visualized in the influence diagram presented in Figure 2.



$$X(t) = \int dX.dt + X(0)$$
$$dX = f(Y(t))$$
$$Y(t) = g(X(t))$$

Figure 3. Basic buildings blocks for System Dynamics diagram
X(0) means the initial state of the stock value. The stock level X(t) accumulates by integrating the flow rate (dX). Auxiliary variables (Y) control or convert other entities (g(X(t))).

It should be mentioned here, that production and inventory sector as well as customer service sector and apply similarly for all grades in their own ‘private’ model. However, these ‘private’ models don’t work independently of each other. They interact through the grade production selection. Grade production selection is a very important decision moment in a batch-wise multi-product plant: very often one grade may be produced in different types of equipment, the importance of grades for business values may be different and the (expected) frequency the grades have to be produced can be very diverse. Basically, a grade needs to be produced if its inventory level is not sufficient to fulfil the demand. Therefore, less inventory and higher demand increases its chance to be produced. Importance of the grade symbolizes a need for priority rule in determining which grade should be produced. This happens in the grade selection sector.

As already mentioned, the influence diagrams as presented in Figure 2 and their decomposition into the interconnected sub-models are translated into quantitative relations and implemented in a System Dynamics simulation model using the software tool Powersim Studio. The idea was to develop a general model, which can be easily adapted to specific industrial situations. The developed model is capable to simulate physical and informational aspects of the inventory-management in real batch plants and to predict the behaviour of the system if influenced by new decisions.

After satisfactory model is available, the determination of the plausible tactics and strategies (improvement options), can be performed in the third phase. The model is used then to analyse which options are promising to be further studied to improve the system’s behaviour. These options are then utilized as tactics, e.g. eliminating safety stock for shutdown, and strategies, which are a combination of tactics.

The fourth step is to treat the uncertainty in one of the three types: external uncertainty, system response uncertainty and value uncertainty (Walker, 2000). External uncertainties, e.g. the expected orders, are inputs that are beyond the control of decision maker. System response uncertainty is related to the system responses to the external uncertainties. Finally, value uncertainty is related to the uncertainty about the valuation of system outcomes e.g. due to changes of decision makers’ preferences. In this study, employing scenario analysis treats external uncertainty. Scenarios related to the market growth and plant disruption are investigated. Then, robustness of strategies is evaluated under the proposed scenarios by judging the impact of scenarios to performance parameters. This concludes the analysis, so that the most robust options for inventory improvement, e.g. reducing safety stock level by x%, can be recommended.

3. Case study in a chemical plant

The presented approach is applied in a chemical plant producing 7 grades of resins, whereby two grades, say X1 and X5 may be produced in two production lines, but the other grades may be only produced in the dedicated line. Each line has its own speed, which can be different for each grade. Currently, resin production is determined by the silo level and demand. Operator looks at the silo level and if it reaches minimum level, the particular resin will be produced. The most common grade produced in line 1 is grade X1, and X3 for line 2. Production is also adjusted to the current situation, i.e. demand and line condition. For example, if there is an urgent need (i.e. rush demand) for grade X7, then X7 will be produced in line 1, and line 2 will produce other grade depending on the priority settings. Moreover, every grade change in the production line generates transition (twilight) material, which should be minimized. Furthermore, there is only limited amount of silos available on-site, and not each silo has blending capability, which is needed when twilight material is produced.

3.1 Simulation model

Having the necessary assumptions about the plant situation and data, the general model, as presented in Figure 4, is adapted to simulate the real condition of the plant.

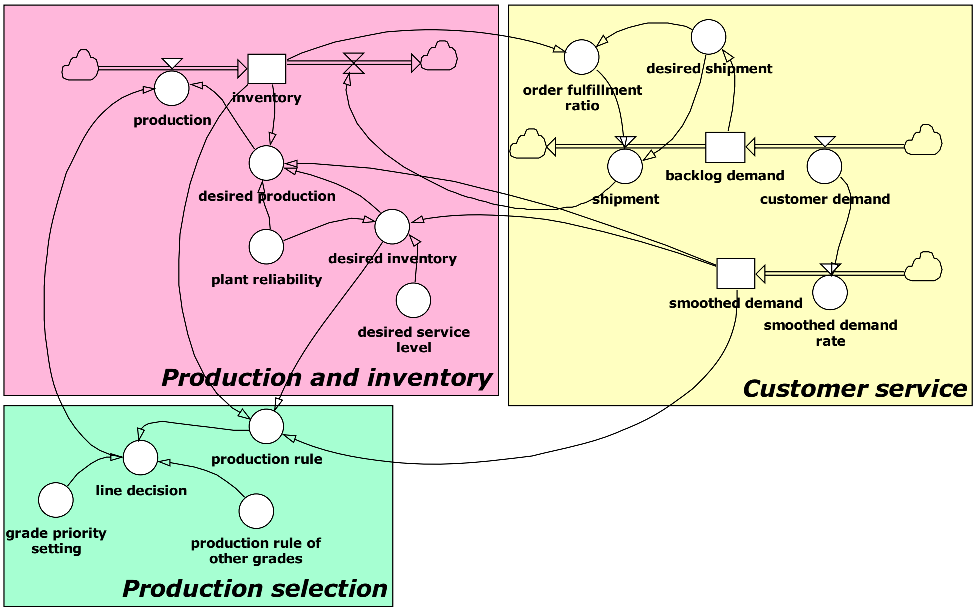


Figure 4. Overall picture of the model

3.1 Tactics and strategies as improvement options

Tactics analysed in this study are derived from discussion with the company and from the results of the sensitivity analysis of the simulation model. These are: (1) increasing plant reliability, (2) eliminating safety stock for shutdown, (3) reducing safety stock, and (4) reducing desired service level. Performance of each of these tactics is appraised through their capability to influence the performance indicators of inventory management of the company, which are inventory level, which has to be minimized and order fulfilment ratio (service level), which has to be maximized. Next, the tactics are combined to two strategies: "change safety stock policy" (tactics 2,3,4) and "entitlement strategy" (all tactics). A qualitative result of each strategy can be seen in Table 1, which pictures the result compared with base case.

Table 1. Result of strategies. Effects are calculated based on average value relative to the average value of the base case simulation

Performance indicator	**Change effect to base case**	
	Strategy 1	**Strategy 2**
Inventory level		
X1 inventory	-54%	-60%
…		
X7 inventory	-53%	-57%
Total inventory	**-54%**	**-59%**
Order fulfillment ratio (OFR)		
…		
X6 OFR	-3%	-4%
X7 OFR	-9%	-8%

Taking into account the model assumptions, we can conclude that the first strategy developed could lower inventory by 54% with 9% decrease in service level. Second strategy reduces 59% lower average inventory with less than 8% decrease in the service level.

4. Final remarks

Multipurpose batch plants often operate in a very dynamic environment with a high variability of demand. Determination of appropriate safety stock levels and possible options for the improvement of inventory management are difficult tasks. Capturing the complexity of inventory management through an aggregate model, which can accurately simulate the effects of improvement options and take into account the production and capacity constraints helps to find a trade-off between inventory costs and customer satisfaction level. This creates conditions for the coming order acceptance and scheduling as well as processing tasks.

References

Bowersox, D.J., David J. Closs, 1996, Logistical Management: The Integrated supply chain process, McGraw-Hill Companies, Inc.

Christina T.S., 2004, System Dynamics Model as a Decision Support Tool for Inventory Management Improvement, Master Thesis, Faculty of Technology, Policy and Management, TU Delft

Sterman. J.D.,2000, Business Dynamics: Systems thinking and modeling for a complex world, Irwin McGraw Hill, Boston

Verwater-Lukszo Z., H. Roeterink, 2004, Decision Support System for Planning and Scheduling in Batch-wise Plants, IEEE International Conference SMC 2004, the Netherlands

Walker, W.E., 2000, A systematic approach to supporting policy making in the public sector, Journal of Multicriteria Decision analysis, Vol. 9(1).