SENSITIVITY ANALYSIS AND OPTIMIZATION OF DIFFERENT INVENTORY CONTROL POLICIES ALONG THE SUPPLY CHAIN

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ABSTRACT
This paper focuses on the inventory management problem along the supply chain. A three three-echelons supply chain made up of suppliers, distribution centers and retail stores is considered. The analysis of multiple inventory control policies monitored by using multiple performance measures is proposed. To this end a simulation model, capable of recreating the complex supply chain environment, has been developed.

Keywords: sensitivity analysis, inventory control, supply chain

1. INTRODUCTION

According to Lee and Billington (1993), a Supply Chain (*SC*) is a network of different entities or nodes (plants, distribution centers, warehouses and retailers) which provides material, transform them in intermediate or finished products and deliver them to customers in order to satisfy market requests.

Each SC node is identified by two different parameters:

- the demand;
- the productive capacity.

In order to define each parameter a great amount of data have to be collected. Moreover, information and material flow management among SC nodes becomes a very complex task characterized by a number of critical issues related, for example, to demand (volume and production range), processes (machines downtimes, transportation modes), and supply (parts quality, delivery schedules). The Supply Chain Management (SCM) takes care of the above mentioned issues, studying and optimizing the flow of materials, information and finances along the entire supply chain.
The main goal of a supply chain manager is to guarantee the correct flows of goods and information throughout the SC nodes for assuring the right goods be delivered in the right place and quantity at the right time. Among the others, the inventory management problem along the supply chain plays a critical role in terms of supply chain performances. Lee and Billington (1993) consider the inventory control as the only tool to protect SC stability and robustness. In effect, the objective of the Supply Chain Inventory Management (*SCIM*) is to satisfy the ultimate customer demand increasing the quality and service level and decreasing at the same time total costs; inventories affect SC costs and performance in terms of:

- values tied up, e.g. raw materials have a lower value than finished products;
- degrees of flexibility, e.g. raw materials have higher flexibility than the finished products because they can be easily adopted for different production process;
- levels of responsiveness, e.g. products delivery could be made without strict lead times whereas raw materials transformation usually requires stringent lead times.

During the last years a number of research studies on SCIM have been proposed. Minner (2003) proposes a review on Inventory Models (*IMs*) and addresses their contribution to SC performance analysis. In particular, models analyzed concern to:

- different SC configurations (single/multi-echelon systems): Dellaert and De Kok (2004) present an integrated approach for resource and production management of an assembly system; Chen and Lee (2004) implement an analytical model for demand variability, delivery modes, inventory level and total costs in a multi-echelon SC network;
- parameters variability, i.e. demand disruptions: see Qi et al. (2004) who analyze deviation costs of a one supplier – one retailer after demand disruption; order quantity as reported in Zhou et al. (2007) who introduce an algorithm to compute the parameters of a single item-periodic review inventory policy;

- constraints, i.e. De Sensi et al. (2007) propose the analysis of different inventory control policies under demand patterns and lead time constraints in a real supply chain; Longo and Mirabelli (2008) analyze the effects of inventory control policies, lead times, customers' demand intensity and variability in three different supply chain performance measures. Chen and Krass (2001) propose a new inventory approach, based on the minimal service level constraint which consists in achieving a minimum defined service level in each period; Huang et al. (2005) study the impact of the delivery mode on a one-warehouse multi-retailer system, in order to evaluate the optimal inventory ordering time and the economic lot size for reducing total inventory costs. Inderfurth and Minner (1998) investigate an analytical model to determine safety stocks considering as constraint different service levels.

Analytical models for inventory management take into account all the parameters which affect the inventory level. Allen and D'Esopo (1968) in their research work propose a review of the re-order point order-quantity policy introducing a new time parameter, the expedited leadtime, lower than the normal procurement leadtime. Ramasesh et al. (1991) propose a variant of the same policy with parameters related to demand variability and lead times in order to minimize total purchasing, delivery and inventory costs.

During the years one of the most important tool for studying inventory management along the supply chain has been the Modeling & Simulation based approach. In effect, the evaluation of the performance of different entities involved in the SC, from suppliers to final customers passing through distribution centers, considering a number of stochastic variable and parameters is a quite complex task in which analytical models often fall short of results applicability.
Bhaskaran (1998) carries out a simulation analysis of SC instability and inventory related to a manufacturing plant: in this case, simulation is used to better understand the effects of different inventory strategies on the SC structure. In this context, artificial intelligence techniques (i.e. fuzzy theory and genetic algorithms) combined with the simulation models support the decision making process.
Gupta et al. (2007) apply the genetic algorithm theory for investigating an inventory model of a system characterized by a single item with undefined inventory costs under the effect of different marketing strategies. Giannoccaro and Pontrandolfo (2002) propose an artificial intelligence algorithm in order to manage inventory decisions at all SC stages (optimizing the performance of the global SC). Huang et al.(2005) solve the ordering and positioning retailer inventories problem at the warehouse and stores, satisfying specific customer demand and minimizing total costs by using neural network approaches. Long et al. (2004) propose a revisited Economic Order Quantity (EOQ) model characterized by the introduction of fuzzy lead times.

Different commercial software and programming languages have been used for developing the simulation models. Lee and Wu (2006) model the reorder point order-quantity and the periodic review order-up policy of a distribution system by using the commercial package eM-Plant™; Al-Rifai and Rossetti (2007) adopt Arena™ for testing a new analytical model for a two-echelon inventory system, whereas Bertazzi et al. (2005) implement in C++ a vendor-managed inventory policy in order to minimize purchasing, replenishment and delivery total costs.

2. THE SUPPLY CHAIN CONCEPTUAL MODEL

The SC considered in this research work is made up by three stages as shown in Figure 1:

- *M* manufacturing plants (*MPs*);
- *N* distribution centers (*DCs*);
- *J* stores or retails (*STs*).

Product demand is defined by the final customer.

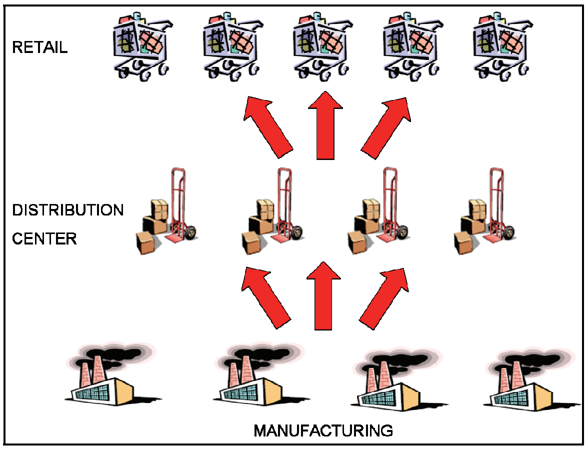

Figure 1: The Conceptual Model of the Supply Chain

2.1. The manufacturing plants

As above mentioned the SC being analyzed has *M* manufacturing plants. Each manufacturing plant has *K* identical processes and it is equipped in order to manufacture *I* different types of products. Variables characterizing the manufacturing plants are:

- the setup time due to plant switching from one product to another;
- the processing time dependent on order size;
- the production capacity.

2.2. The distribution centers

The second SC level is made up by *N* Distribution Centers (*DC*) which store all the *I* products. The inventory control within each DC is as follows. When an order arrives to a DC, the current inventory position (on-hand inventory plus the quantity already on order minus the quantity to be shipped) is checked. If the order is fully satisfied, its status is considered completed and, as a consequence, the inventory level of the DC is decreased of the order quantity, otherwise a lost quantity is recorded. The most important performance measures within a DC are the number of fully satisfied and partially satisfied store orders per period the total lost sales quantity per period to define the service level and the fill rate

2.3. The stores

The third SC level is represented by stores. Each ST works on an eight-hours shift. At the beginning of the day an inventory review is made at each store in order to decide about an order emission at one of the *N* distribution centers. It is necessary to underline that, according to this policy, store orders are delayed until the beginning of the next day so order replenishment is guaranteed by the DC the following day.

Each store chooses the DC capable of replenishing the maximum order quantity requested. The quantity to order for each product is defined after by checking the current on-hand inventory at the store. At each ST, number of fully or partially satisfied orders, lost sales quantity and total quantity ordered for each product is recorded. These data are then used for performance measure evaluation (e.g. the service level, fill rate, etc.).

3. THE SIMULATION MODEL

The goal of this research work is to analyze the supply chain performance implementing three different Inventory policies in order to estimate the inventory level at each SC stage and, as a consequence, inventory costs.

The simulation model is implemented using the commercial simulation software eM-Plant™ by Tecnomatix Technologies. The simulation model development makes use of an advance modeling approach. The classical modeling approach based on library objects to reproduce static and dynamic entities (materials flow, machines, production line, etc.) is replaced with a new one that substitutes flows of entities with a flow of information stored in tables. To access, update and record such information stored in tables, ad-hoc programmed routines have been implemented. The modeling approach proposed has the advantage to allow high flexibility levels in terms if simulation model modification in order to reproduce several system behaviors under different operative environments (further information can be found in Longo & Mirabelli, 2008). Note that the main disadvantage of the modeling approach being used is the animation: generally animation reproduces the entities flow within the simulation model; in this case, the animation is not considered a priority aspect of the simulation study although model structure allows animation implementation.

3.1. The Manufacturing Plants Model Implementation

The part of the simulation model representing the manufacturing plants, recreates the items production process. If all the machines of a plant are busy when an order arrives, this order is queued waiting for another available resource. The switch from an product type to another requires a set up time. No warehouses are available at each plant (make-to-order system).

DCs select plants to send the order on the basis of lead time and quantity that the plant can refurbish. Figure 2 shows the block diagram of the MP selection process.

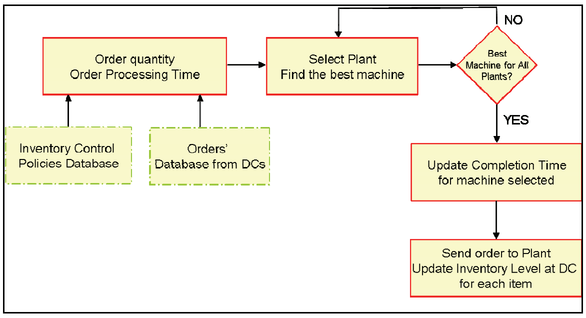

Figure 2: Block diagram for the manufacturing plant selection

The simulation model, according to the DCs orders, evaluates total process times and set up times, then selects the best machine in each plant (capable of processing the order) and finally the best machine among all the plants. The selection of the best machine is made according to the time required to complete waiting orders and to start the new order.

3.2. The Distribution Centers Model Implementation

At the beginning of the day the purchase orders from stores arrive at the DCs. The model checks the inventory levels to verify if incoming orders can be satisfied. In each DC, Items number of incoming orders is compared with the on-hand inventory level. If there is enough on hand inventory, STs demand is totally satisfied and the on-hand inventory level is updated; if demand is partially satisfied or unsatisfied, lost sales are recorded.

Each DC emits purchase orders toward the manufacturing plant on the basis of demand forecast. The main activities that take place within each DC are summarized by the block diagram in Figure 3.

3.3. The Stores Model Implementation

The activities performed by the part of the simulation model representing the stores are quite similar to the activities performed in the DCs. In effect at the end of the day the inventory level is checked in order to evaluate whether or not a purchase order has to be emitted.

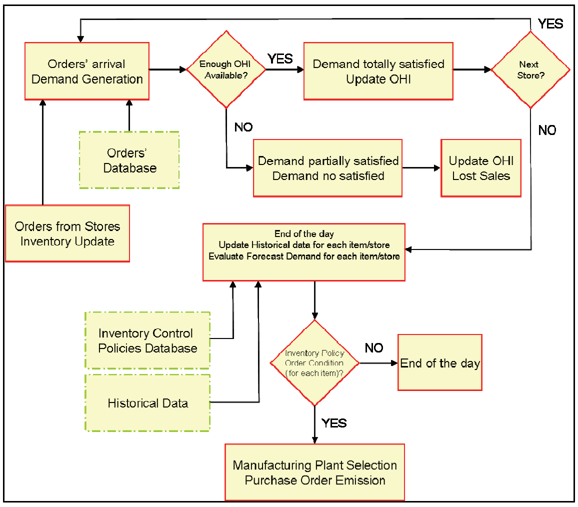

Figure 3: The Distribution Centers Block Diagram

The block diagram in Figure 4 describes the activities performed by the simulation model within each store.

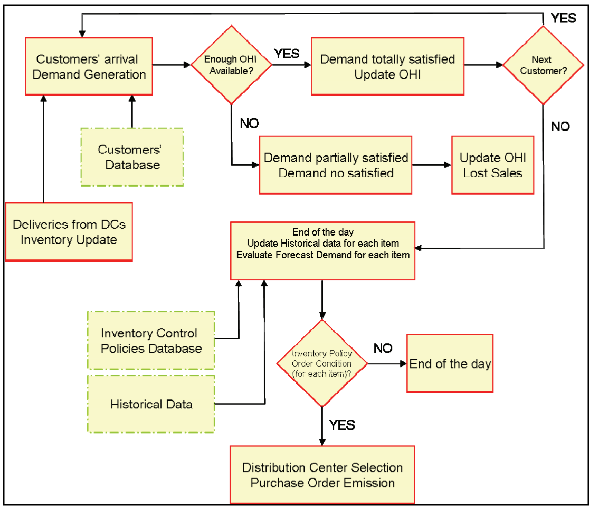

Figure 4: The Stores Block Diagram

4. THE INVENTORY CONTROL POLICIES

In this research work, authors investigate an inventory stocking problem.

In detail, the focus consists in comparing five different Inventory Management Policies (*IMPs*) by using a Modeling & Simulation approach in order to test the performance of the SC analyzed.

According to the SCIM principles, the objective of the inventory control policies is twofold:

- evaluation of the time for purchasing order emission;
- evaluation of the quantity to be ordered.

The inventory control policies implemented in the simulation model within each store and each distribution center are:

- the reorder point-order quantity policy;
- the reorder time-order quantity policy;
- the (s, S) policy;

Before starting to describe each policy, it is necessary to define notation to which authors will refer:

- $s_i(t)$, the re-order level at time t for the item i;
- $S_i(t)$, the target level at time t for the item i;
- $SS_i(t)$, the safety stock level at time t for the item i;
- $DF_i(t)$, the demand forecast at time t for the item i;
- $OHI_i(t)$, the on-hand inventory at time t for the item i;
- $OQ_i(t)$, the quantity already on order at time t for the item i;
- $SQ_i(t)$, the quantity to be shipped at time t for the item i;
- $Q_i(t)$, the quantity to be ordered at time t for the item i;
- $L_i(t)$, the lead time of the item i;
- $DFL_i(t)$, the demand forecast over the lead time for the item i;
- $IP_i(t)$, the inventory position at time t for the item i;

The inventory position $IP_i(t)$ is the on-hand inventory plus the quantity already on order minus the quantity to be shipped. In particular, it is defined as:

$$IP_i(t) = OH_i(t) + OQ_i(t) - SQ_i(t) \quad (1)$$

4.1. The mathematical model

In this section authors derive the mathematical model for each policy presented making reference to a single product *i*.

4.1.1. The reorder point-order quantity policy (RPOQ)

In this control policy the inventory level is continuously checked according to production/demand requirements. According to this policy, if $IP_i(t)$ falls below the $s_i(t)$, the purchase order has to be emitted. The quantity to be ordered can be defined using the Economic Order Quantity (*EOQ)* approach.

$$s_i(t) = DFL_i(t) + SS_i(t) \quad (2)$$

$$Q_i(t) = EOQ_i(t) \quad (3)$$

Such policy should be adopted when inventory level at each SC node is automatically monitored; there are no advantages in using scale economies; purchase orders can be regularly emitted.

4.1.2. The reorder time-order quantity policy (RTOQ)

Unlike the previous control policy, the reorder time-order quantity policy is based on a periodic check. If $T_i(t)$ is the review period of the item *i*, the quantity to order is defined by $S_i(t)$ minus $IP_i(t)$.

The value of $T_i(t)$ can be defined using the inverse formula usually used for evaluating the EOQ. In this policy, $S_i(t)$ represents the target level. This policy should be used when:

- inventory level is not automatically monitored;
- there are advantages related to scale economy;
- orders are not regular.

4.1.3. The ($s_i(t)$,$S_i(t)$) policy

This policy can be derived from the previous policies above mentioned. According to literature, there are two parameters which characterize this policy:

- $s_i(t)$, the re-order level at time t for the item i;
- $S_i(t)$, the target level at time t for the item i.

Authors introduce a new parameter, $K_i(t)$, a constant parameter which represents the average demand of the item *i* over a certain period of time.

The equations expressing $s_i(t)$ and $S_i(t)$ are as follows.

$$s_i(t) = DFL_i(t) + SS_i(t) \tag{4}$$

$$S_i(t) = s_i(t) + K_i(t) \tag{5}$$

Equations 6 and 7 respectively express the re-order condition and the quantity to be ordered.

$$IP_i(t) < s_i(t) \tag{6}$$

$$Q_i(t) = S_i(t) - IP_i(t) = s_i(t) + K_i(t) - IP_i(t) \tag{7}$$

5. INVENTORY POLICIES COMPARISON

Consider for each supply chain node the inventory control policies before described, different values of lead times, different level of demand intensity and demand variability as summarized in Table 1. The values of the lead times, demand intensity and demand variability are expressed as percentage of the actual values.

Table 1: Factors and Levels

Factors	L1	L2	L3
Lead Time	90%	100%	110%
Demand Intensity	90%	100%	110%
Demand Variability	90%	100%	110%

Simulation results, for each factors levels combination, are expressed in terms of average fill rate and on-hand inventory (i.e. the fill rate at store, for each item, is evaluated as ratio between the fully satisfied orders and the total quantity of orders). Simulation results are available for each store and for each distribution center. Let us consider the simulation results regarding one of the distribution center, similar results have been obtained for the remaining distribution center and stores. The following scenarios have been analyzed: (i) comparison of the 90%, 100% and 110% scenarios in terms of demand intensity; (ii) comparison of the 90%, 100% and 110% scenarios in terms of demand variability; (iii) comparison of the 90%, 100% and 110% scenarios in terms of lead times. For each scenario we investigated the behavior of the inventory control policies implemented in the simulation model.

Table 2 reports the simulation results in terms of fill rate for the first scenario.

Table 2: Simulation results comparison of the inventory control policies under different demand intensity – fill rate

Scenarios	RPOQ	RTOQ	sS
90% Demand Intensity	0.831	0.641	0.890
100% Demand Intensity	0.499	0.210	0.539
110% Demand Intensity	0.282	0.058	0.295

The best results in terms of fill rate are provided by the $s_i(t)$,$S_i(t)$ inventory control policy. The lowest value by the *RTOQ* inventory control policy. Note that the higher is the demand intensity the lower is the fill rate (for each inventory control policy). In addition for high demand intensity the *RPOQ* and $s_i(t)$,$S_i(t)$ inventory control policy show similar behaviors in terms of fill rate values.

Table 3 reports the simulation results in terms of on-hand inventory for the first scenario.

Table 3: Simulation results comparison of the inventory control policies under different demand intensity – on hand inventory

Scenarios	RPOQ	RTOQ	sS
90% Demand Intensity	100	113	54
100% Demand Intensity	105	121	69
110% Demand Intensity	154	194	134

Concerning the on-hand inventory the $s_i(t)$,$S_i(t)$ performs better than the other policies.

Table 4 reports the simulation results in terms of fill rate for the second scenario.

Table 4: Simulation results: comparison of the inventory control policies under different demand variability – fill rate

Scenarios	RPOQ	RTOQ	sS
90% Demand Variability	0.511	0.219	0.569
100% Demand Variability	0.496	0.205	0.533
110% Demand Variability	0.487	0.190	0.520

The *RTOQ* inventory control policy gives the worst performance. Note the similar behavior of the *RPOQ* and $s_i(t),S_i(t)$ policies. The policy based on the review period shows a better behavior in correspondence of low demand variability. In effect the higher is the demand variability the higher is the demand forecast error. The best policy with low demand variability is the $s_i(t),S_i(t)$, with the actual demand variability *RPOQ* and $s_i(t),S_i(t)$ show similar behavior, finally with high demand variability $s_i(t),S_i(t)$ allows to obtain the highest fill rate values.
Table 5 reports the simulation results in terms of on-hand inventory for the second scenario.

Table 5: Simulation results: comparison of the inventory control policies under different demand variability – on hand inventory

Scenarios	RPOQ	RTOQ	sS
90% Demand Variability	101	112	67
100% Demand Variability	104	113	69
110% Demand Variability	111	117	73

Concerning the on-hand inventory, once again, the $s_i(t),S_i(t)$ performs better than the other policies.

Table 6 reports the simulation results in terms of fill rate for the third scenario.

Table 6: Simulation results comparison of the inventory control policies under different lead time values – fill rate

Scenarios	RPOQ	RTOQ	sS
90% Lead Time	0.510	0.247	0.544
100% Lead Time	0.496	0.205	0.533
110% Lead Time	0.447	0.152	0.526

Such scenario investigates the effect of different lead times on the fill rate. Note that the higher is the lead time the lower is the fill rate (for each inventory control policy). The fill rate reduction passing from 90% to 100% lead time and from 100% to 110% are as follows: (i) 1.1% and 3.9% for the RPOQ control policy; (ii) 3.3% and 4.2% for the RTOQ control policy; (iii) 0.9% and 0.5% for the sS control policy. Consequently the $s_i(t),S_i(t)$ policy performs better than *RPOQ* and *RTOQ*.

Table 7 reports the simulation results in terms of on-hand inventory for the third scenario.

Table 7: Simulation results comparison of the inventory control policies under different lead time values – on hand inventory

Scenarios	RPOQ	RTOQ	sS
90% Lead Time	84	92	50
100% Lead Time	104	113	69
110% Lead Time	121	121	78

The simulation results analyzed in this section regard one of the distribution center. The variation of the demand intensity, of the demand variability and of the lead time allows to compare the different behaviors of the inventory control policy in order to find out the best policy in each situation both in terms of fill rate and in terms of on-hand inventory. Similar results have been obtained for each supply chain node, both retailers and distribution centers, analyzing the inventory systems along the supply chain.

6. CONCLUSIONS

The authors implemented a simulation model of a three echelons supply chain for studying the inventory management problem along the supply chain. Three different inventory control policies have been implemented in each node of the supply chain (on each store and distribution center excluding the manufacturing plant that work as make to order system without warehouse). The inventory control policies have been compared under different conditions in terms of demand intensity, demand variability and lead times, observing the variation of the fill rate and of the on-hand inventory. In particular three different values have been considered for the demand intensity, three for the demand variability and three for the lead time (in each case the middle value is the actual value). The simulation results analysis shows that the variation of the factors considered strongly affect the behavior of the inventory control policies, for each scenario the most suitable inventory control policy should be used. Further researches are still on going applying the genetic algorithms for evaluating optimal values for the parameters of both the demand forecast models and of the inventory control policies.

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