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FUZZY ECHELON–A TOOL FOR INVENTORY CONTROL IN SUPPLY CHAIN

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The inventory management policies in a supply chain can be classified according to the criterion i.e. optimization goal, centralized or decentralized control, inventory control frequency, temporal information requirements and spatial information etc. In many industrial sectors, firms are dealing with a demand which is more and more uncertain often due to the supply chain structure. One of the most critical effects of demand uncertainty is the simultaneous increase of inventories and decrease of customer service. To properly model uncertainty several aspects need to be addressed: the causes of uncertainty, the characteristics of both the available (input) and required information (output), and the scale level of the numerical information. So this paper has addressed two key issues of inventory management in SCs, namely the uncertainty associated with market demand and inventory related costs and the need of a tight integration among the SC stages. In particular, a methodology has been proposed to define global inventory management policies that are both easy to be implemented and near optimal for the whole SC. The methodology addresses uncertainty through fuzzy set theory, which is more appropriate than stochastic techniques to deal with market demand and inventory related costs, especially when the environment (e.g. the market) is complex and turbulent. The need of integration is taken into account by the adoption of the echelon concept to measure inventory and the holding costs. The contribution of fuzzy set theory for dealing with uncertainty has been discussed under a theoretical perspective, pointing out its appropriateness to model market demand and inventory costs.

Keywords: Supply Chain Management, Inventory Management, Echelon Stock, Fuzzy Set Theory.

Introduction

In many industrial sectors, due to the supply chain structure firms are dealing with a demand which is more and more uncertain. The effect of demand uncertainty is the simultaneous increase of inventories and decrease of customer service. The differences in customer's size produce demand peaks and thus a very variable and lumpy demand pattern. So the echelon stock concept is adopted to manage the SC inventory in an integrated manner. When we move towards the higher levels of the supply chain, orders show a more variable and uncertain pattern. Different causes of this behaviour are: erroneous demand forecasting, variable supply, longer lead times, batch ordering, price variations and inconsistency of the customers located in the lower levels of the chain (Agrawal and Raju, 1996).

In this work echelon periodic-review control policy is adopted i.e. at each SC stage the echelon stock is reviewed at constant time intervals and an order is issued to the upstream stage to raise the echelon stock up to a target level. Also, real cases (i.e. real SCs) are being analyzed to assess the performance enhancement achievable through the proposed methodology. The methodology is applied on a three stage SC so as to show the ease of implementation. Finally, by adopting simulation, the performance of the three stage SC is assessed and shown to be superior to that, which the adoption of a local inventory management policy would guarantee. There exist different defuzzification techniques. In this paper the moment rule is adopted. Given a fuzzy set, such a rule returns the mean of the set elements that assume the maximum value as the crisp number associated with the set. Further research will address other uncertainty sources, such as supplier's lead times or the quantities they actually deliver.

Supply Chain Inventory Management

Supply Chain Inventory Management is an integration and coordination of business process that manages the flow of material distribution from supplier to customer. Supply Chain system deals with analysis of information from different points on the Supply Chain to reduce operational cost. SCM shows a way to cost optimization all along the chain and it is an integration of facilities and distribution options that performs the procurement and transformation of materials into finished products (Bramel and Simchi, 1997). The SCM mindset should be changed, it should be way of thinking-not techniques and should be culture- not the latest of management tool (Goyal and Szendrovits, 1986).

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FUZZY ECHELON METHODOLOGY FOR SCIM

Several parameters need to be covered to properly model uncertainty: the causes of uncertainty, the characteristics of both the available and required information, and the scale level of the numerical information. If we analyse the case of market demand and inventory costs, uncertainty causes are often confusing, unreliability of statistics, and difficulties in measurement whereas available information is set-or interval-valued or linguistic-type. In these cases probability is not a proper tool (Joglekar, 1988). Values these variables can assume depend on possibilities rather than probability (because statistics are unreliable) (Chatterjee, and Ravi, 1991).

In this paper a fuzzy echelon methodology for SCIM is proposed. Two basic ideas that are used to describe this methodology are, the use of fuzzy set theory to model the uncertainty associated with market demand, inventory holding costs, and backorder costs and the adoption of a global perspective to manage SC inventory (Banerjee, 1986).

INTEGRATION AND THE ECHELON STOCK CONCEPT

According to the echelon periodic-review control policy, at each stage of the SC the echelon stock is reviewed at constant time intervals and an order is issued to the upstream stage to raise the echelon stock up to a target level (Forrester, 1961). Therefore, to completely define the SC inventory policy the optimal review time intervals and the required target levels at every stage need to be defined. The proposed inventory policy can then be specified according to the criteria as reported in Table 1.

Table 1
The Adopted Global Policy

Inventory management criteria	*Policy*
Optimization goal	Global
Control type	Centralized
Inventory control	Periodic
Temporal information requirement	Instantaneous
Spatial information requirement	Echelon

Consider a serial production system of N stage. Each stage has been modeled as a stock (inventory collection) point that feeds the downstream stage and is fed by the upstream stage. The Nth stage is assumed to be fed by an external supplier with unlimited stock. Market demand at stage 1 is expressed as the fuzzy set about x unit per time unit. When market demand exceeds the available stock the difference is backordered. The objective of the inventory policy is to minimize the average total SC cost over an infinite time horizon. The considered costs are: (i) a fixed order cost L_n at every stage n, which includes the transportation cost and occurs any time stage n issues an order; (ii) the installation holding cost I_n at every stage n, which is the cost of keeping a stock unit per time unit at that stage; (iii) the backorder cost p at stage 1, which is a per unit and per time penalty incurred when market demand can not be immediately satisfied.

In particular, holding costs have been calculated with regard to the echelon rather than the installation stock. The echelon holding cost h_n at stage n is given by:

$$h_n = I_n - I_n + 1 \tag{1}$$

h_n is the incremental cost of keeping a stock unit at a given stage rather than at the previous one. When the echelon stock is used as a basis for charging holding costs, the average total cost in an N stage serial system is given by

$$C(\bar{T}) = \sum_{n=2}^{N}\left[L_n / T_n + 1/2\lambda I_n T_n\right] + \left[L_1 / T_1 + 1/2\lambda(I_0 - I_2)T_1\right] \tag{2}$$

Being $\bar{T} = (T_1, \ldots.., T_n), \lambda,$ is the demand rate [unit/time], h_n is the echelon holding cost at stage n [cost/(time × unit)], In is the installation holding cost at stage n [cost/(timeunit)], is the backorder cost at stage 1 [cost/(time unit)], $I_0 = pI_1 / (p + I_1)$, L_n, is the per order cost at stage n [cost].

It mainly takes into account the value added to the product when moving it from a stage to another closer to the customer. In particular, all the coefficients in Equation 2 are crisp values obtained by defuzzification through the moment rule, after that any necessary arithmetic operation (sum, subtraction, product, and division) is effected over the fuzzy sets according to fuzzy mathematics.

FUZZY THEORY CONCEPTS

First, let us note that in the fuzzy theory literature the term crisp usually refers to deterministic objects (i.e. deterministic sets, quantities, and numbers) as opposed to fuzzy ones. Given a set Q consisting of some elements, a fuzzy subset C of $Q(C \subset Q)$, is characterized by the membership function μ_C:

$Q \to [0,1]$ Such that: $\forall_x \in Q$:

$\mu_C(x) = 0$ if $x \notin C$

$\mu_C(x) = [0,1]$ Otherwise

Let C and D be two fuzzy subsets of ($C \subset QandD \subset Q$), R the set of all real numbers, and $R0$ the set of all non-zero real numbers. The following relations hold:

The complement of B is the fuzzy set $\bar{C}$ such that

$$\mu\bar{C}(x) = 1 - \mu_C(x) \quad \forall_x \in Q$$

The union of C and D is the fuzzy set $E = C \cup D$ such that

$$\mu_E(x) = \max(\mu_C(x), \mu_D(x)) \quad \forall_x \in Q$$

The intersection of C and D is the fuzzy set $F = C \cap D$ such that

$$\mu_F(x) = \min(\mu_C(x), \mu_D(x)) \quad \forall_x \in Q$$

The opposite fuzzy set of C is the fuzzy set–C such that

$$\mu_{-C}(x) = \mu_C(-X) \quad \forall_x \in Q$$

The reciprocal fuzzy set of C the fuzzy set $1/C$ such that

$$\mu_{1/C}(x) = \mu_C(1/x) \text{ for } x \neq 0 \quad \forall_x \in Q$$

$$\mu_{1/C}(x) = 0 \text{ for } x = 0$$

The defuzzification of C consists in the conversion of the set into a crisp number. There exist different defuzzification techniques. In this paper the moment rule is adopted. Given a fuzzy set, such a rule returns the mean of the set elements that assume the maximum value as the crisp number associated with the set.

CONCLUSION

This paper has covered two key issues of inventory management in SCs, namely the uncertainty associated with market demand and inventory related costs and the need of a tight integration among the SC stages. In particular, a methodology has been proposed to define global inventory management policies that are both easy to be implemented and near optimal for the whole SC. The need of integration is taken into account by the adoption of the echelon concept to measure inventory and the holding costs. The contribution of fuzzy set theory for dealing with uncertainty has been discussed under a theoretical perspective, pointing out its appropriateness to model market demand and inventory costs.

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