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A new methodology for multi-echelon inventory management in stochastic and neuro-fuzzy environments

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ABSTRACT

Managing inventory in a multi-echelon supply chain is considerably more difficult than managing it in a single-echelon one. A strategy that optimizes inventory one echelon at a time results in excess inventory without necessarily improving service to customer. In this paper, a methodology for effective multi-echelon inventory management is proposed. Subsequently; a neural network simulation of the model is then presented with the support of neuro-fuzzy demand and lead time forecasting, and finally its performance is calculated using performance metrics selected from the SCOR model. The results show that, the inventory is efficiently deployed and uses realistic breakdowns. The proposed methodology aims to provide an important tool for the management of general *N*-echelon tree-structured supply chains that overcomes some of the deficiencies of competing methodologies.

1. Introduction

A manufacturing supply chain is a network of suppliers, factories, subcontractors, warehouses, distribution centers, and retailers, through which raw materials are acquired, transformed, produced, and delivered to the end customers. Such a supply chain network must meet customers' service goals at specified service levels at the lowest possible cost (Bhaskaran and Leung, 1997; Tsiakis et al., 2001; Taskin and Guneri, 2005).

Supply chain inventory management (SCIM) is an integrated approach to the planning and control of inventory throughout the entire network of cooperating organizations from the source of supply to the end user. SCIM goals are to improve customer service, increase product variety, and decrease costs (Giannoccaro et al., 2003). Fig. 1 shows a multi-echelon system consisting of a number of suppliers, plants, warehouses, distribution centers and customers (Axsater, 1990; Andersson and Melchiors, 2001; Axsater, 2003).

An important issue in supply chains (SCs) is the need to make decisions in the face of uncertainty. In addition to demand and lead time fluctuations for a product, the uncertainty is compounded by information delays associated with the manufacturing and distribution processes that characterize SCs (Giannoccaro et al., 2003). To incorporate uncertainty in a supply chain model a suitable means of representing it must be found (Gupta and Maranas, 2003). Three methods are frequently used for representing uncertainty (Gupta and Maranas, 2003; Hameri and Paatela, 2005): First, the uncertain parameters are assumed to have normal distribution with a specified mean and standard deviation; second, the forecast parameters are described as fuzzy numbers defined by their degree of membership; and third, expected outcomes are captured by several discrete scenarios and their associated probability levels (Chen and Lee, 2004).

Examples of all three approaches can be found in the literature (Taskin Gümüs and Güneri, 2007). For example, Gupta and Maranas (2000), Gupta et al. (2000) incorporate uncertain demand in their supply chain model via a normal distribution function, and propose a two-stage solution to the restocking problem. They have recently published a generalization of their model that can handle multi-period and multi-customer problem (Gupta and Maranas, 2003). Tsiakis et al. (2001) use the scenario planning approach to describe demand uncertainties. Petrovic et al. (1999) use fuzzy sets to handle uncertainties in customer demand and the supply of raw materials for manufacturing products. Giannoccaro et al. (2003) also apply fuzzy set theory to model the uncertainties associated with both market demand and inventory costs.

In this paper, Mitra and Chatterjee's (2004) deterministic and stochastic models of supply chain inventories are improved by the addition of neuro-fuzzy demand and lead time forecasting, the incorporation of variable costs and generalization to *N*-echelons. The goal of the work is to improve supply chain performance by minimizing uncertainty.

Mitra and Chatterjee (2004) examine De Bodt and Graves' model (1985), that they developed this model in their paper namely "Continuous-review policies for a multi-echelon inventory

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Nomenclature

K_i	fixed ordering cost at echelon i (includes transportation cost)
A_i	variable cost at echelon i
H_i	installation holding cost at echelon i, which is the cost of keeping a stock unit per time unit at that echelon
h_i	echelon holding cost at echelon i, which is the incremental cost of keeping a stock unit at a given echelon rather than at the upstream one
p_i	expediting cost at echelon i
b	backorder cost at echelon i (same for all retailers because of identity)
l_i	lead time at ith echelon
R_i	reorder point at ith echelon
k_i	safety factor at ith echelon (stock surplus kept to hedge against demand fluctuations)
D_i	demand per unit time at ith echelon
σ	standard deviation of demand per unit time
Q_i	order quantity at echelon i
IP_i	echelon inventory position at echelon i
BO	expected backorders at echelon 1
BO_0	transferred backorders from preliminary cycle
N	cycle number for retailers, integer
X	number of retailers at 1st echelon
y_i	number of installations in the ith echelon

problem with stochastic demand", for fast moving items from the implementation point of view. The proposed modification of the model leads to a reduction of the expected total cost of the system under certain conditions. They assume that the end-item demand is normally distributed and lead time is deterministic. Also their model has a restriction of being appropriate for only two echelon supply chains. Their model can be extended to multi-stage serial and two-echelon assembly systems (Taskin Gümüs and Güneri, 2007).

2. Literature on multi-echelon inventory management

The analysis of the multi-echelon inventory systems that pervade the business world has a long history (Chiang and Monahan, 2005; Routroy and Kodali, 2005), extending back to the development of the economic order quantity (EOQ) formula by Harris in 1913. Research on multi-echelon supply chain models has gained importance over the last decade mainly because modern information technology has made it feasible to study them (Rau et al., 2003; Diks and de Kok, 1998; Kalchschmidt et al., 2003). Clark and Scarf (1960) were the first to study a two-echelon inventory model (Diks and de Kok, 1998; Bollapragada et al., 1998; van der Vorst et al., 2000; Tee and Rossetti, 2002; Rau et al., 2003; Dong and Lee, 2003; Chiang and Monahan, 2005). Bessler and Veinott (1965) extended the Clark and Scarf (1960) model to include general tree structures. Eppen and Schrage (1981) analyzed a model with a stockless central depot that immediately shipped orders to the warehouses (van der Heijden, 1999). Sherbrooke (1968) constructed the multi-echelon technique for recoverable item control (METRIC) model, which identifies the stock levels that minimize the expected number of backorders at lower echelons, subject to a budget constraint. For detailed literature review of multi-echelon models please see Taskin Gümüs and Güneri (2007).

Mitra's (2009) work that we are extending relaxes several assumptions available in literature on multi-echelon systems with returns base, as non-existence or non-relevance of set-up and holding costs at different levels. A two-echelon system with returns under more generalized conditions is considered. A deterministic model as well as a stochastic model under continuous review for the supply system with returns is developed.

In the papers cited above and also in Mitra's studies (Mitra, 2009; Mitra and Chatterjee, 2004), demand and lead times are assumed to have probabilistic distribution functions, product costs are assumed to be fixed and a two-echelon serial system is analyzed generally. The basic difference between our model and the others seen in the literature is that our model is generalized to N-echelons. Additionally, the variable and expediting costs are included in cost computations, and a neuro-fuzzy forecasting is used in order to treat demand and lead time uncertainties in a more realistic way. We analyze a three-echelon system as an illustrative example. The basic differences and contributions of the proposed methodology can be seen in Table 1.

3. The proposed methodology and related models

This section describes our methodology for developing total cost models for supply chains. The technologies our methodology exploits, such as artificial neural networks, neuro-fuzzy

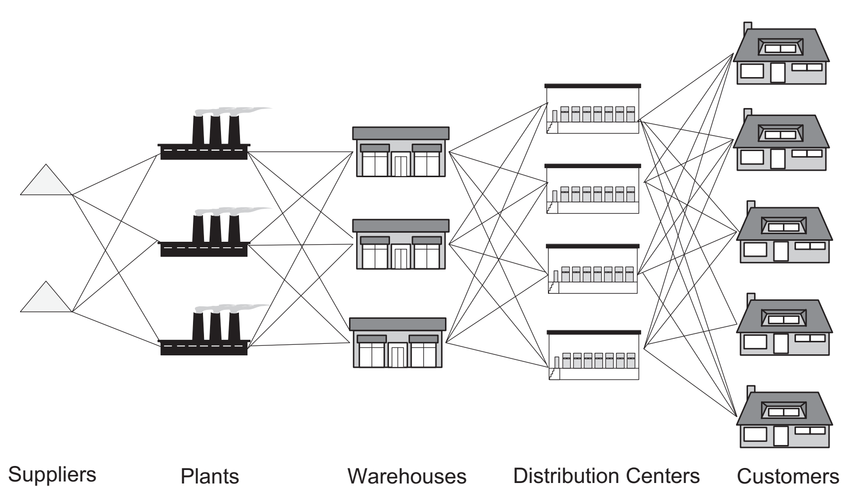

Fig. 1. A multi-echelon inventory system.