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An analytical method for cost analysis in multi-stage supply chains: A stochastic network model approach

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ABSTRACT

This paper studies the cost distribution characteristics in multi-stage supply chain networks. Based on the graphical evaluation and review technique, we propose a novel stochastic network mathematical model for cost distribution analysis in multi-stage supply chain networks. Further, to investigate the effects of cost components, including the procurement costs, inventory costs, shortage costs, production costs and transportation costs of supply chain members, on the total supply chain operation cost, we propose the concept of cost sensitivity and provide corresponding algorithms based on the proposed stochastic network model. Then the model is extended to analyze the cost performance of supply chain robustness under different order compensation ability scenarios and the corresponding algorithms are developed. Simulation experiment shows the effectiveness and flexibility of the proposed model, and also promotes a better understanding of the model approach and its managerial implications in cost management of supply chains.

1. Introduction

With the growing importance of supply chain management (SCM) in enterprise development and in the operation of socio-economic systems, cost management in supply chains has become a strategic business issue in recent years. It involves not only the financial flows but also the associated material flows and information flows among supply chain members. In reality, supply chain cost management has been regarded as a core business activity in processes of supply chain optimization, enterprise resource planning, production scheduling, product quality improving, product diversification, etc. Moreover, it plays an indispensable role in bringing profits and competitive advantage to firms, and consequently receives increasing attention from both supply chain managers and academics.

Activities in supply chain system consist of transforming natural resources, raw materials and components into finished product which be delivered to the end customers. Most these economic activities are also integral parts of the value chain. From this view point, cost management in supply chains is not limited to individual enterprises, but extends to all the purchasing, warehousing, production and distribution activities along the chain. Its goal is to provide a management tool and method to design the integrated chains, to promote its development, to reduce the total cost of supply chain system. This is also the biggest difference between traditional enterprise cost management and supply chain cost management. The change of management perspective has been emphasized in many studies (e.g. [1–3]).

Cost management in supply chains has been given a great deal of attention in SCM. Voluminous amount of published works have addressed this issue either from the enterprise perspective or from the system perspective. Ertogral et al. extend previous joint vendor–buyer models by incorporating transportation cost explicitly into their model [4]. In addition,

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all-unit-discount transportation cost structures with and without over declaration have been considered. Thus their model provides some new insight into the decision-making process in supply chains. Further, Konur and Geunes study the effects of traffic congestion costs on location and distribution decisions in a competitive supply chain [5]. Similar studies can be found in [6,7]. Inventory cost is another important cost component in supply chain operation. Lee and Rhee study the impact of inventory financing costs on coordination and find that trade-credit can be employed as a useful tool for supply chain coordination [8]. The third-party warehouse has been a hot topic in recent years, but Duc et al. find that it does not always help to reduce the inventory costs in a supply chain [9]. In their supply chain design optimization modeling, Bidhandi and Rosnah view the operational costs as a main important factor which affects the final supply chain performance [10]. Production cost is of primary concern in manufacturing [11], and it is also an important part of the total supply chain cost. Faria et al. analyze the performance of industrial production systems based on a joint assessment of cost and service quality [12]. Their work provides a method for analyzing production process in just-in-time supply chains. Boon-itt find an interaction effect between supply chain integration strategies and production cost, and point out that information technology can enhance production cost performance [13]. Mason et al. develop a discrete event simulation model for multi-product supply chain and demonstrate that potential cost benefits can be gained from global inventory visibility which brought about by the integration of warehouse and transportation management systems [14]. Study carried out by Ustundag and Tanyas [15] shows the different effects of product value, lead time, and demand uncertainty on the cost performance of a three-echelon supply chain which integrates the radio frequency identification (RFID) technology.

Various methods have been proposed and used in the cost analysis of supply chain systems. A fuzzy multi-objective linear programming model is proposed by Paksoy et al. to minimize the total transportation costs of supply chain network [16]. Farahani and Elahipanah provide a hybrid non-dominated sorting genetic algorithm which aims to optimize the total cost and service level in just-in-time distribution problem of supply chains [17]. Grover and Malhotra propose that the transaction cost theory (TCT) should be integrated in the supply chain management [18]. Simulation, as that applied in the study of negotiation practices in collaborative supply networks published by Rodriguez-Rodriguez et al. [19], provides a powerful tool to improve management and is also widely used in supply chain optimization [20,21]. One may refer to (e.g. [22–24]) for better understanding of relevant research.

As mentioned above, one important feature of supply chain cost management is its systemic character. In our literature review, however, we found that few studies have addressed the distribution problem of total supply chain operation cost. On the one hand, distribution characteristics of total system cost can provide useful information for the analysis of supply chain dynamics and evaluation. We can also analyze the effect of different supply chain cost components on total cost, and further identify the key links in financial chains. These will be helpful for cost management and for supply chain system optimization. On the other hand, due to the complex supply–demand relationship between members in multi-stage supply chain network system, the cost distribution characteristics of individual supply chain member influence not only the total system cost distribution characteristics but also the supply–demand relationship between members. In reality, the cost distribution characteristics of individual supply chain member are usually stable and can be obtained through some standard measurement method. Consequently, how to estimate the distribution characteristics of total system cost based on these data becomes a challenge to supply chain cost analysis.

In previous studies, the authors have applied the stochastic network theory for analysis of ordering in multi-stage supply chain system, in which a stochastic network mathematical model for order and cost distribution analysis has been proposed [25]. Though the analytical methods applied in this paper are the same as that in the previous study, there are significant differences between these studies in terms of the object of study, the structure of proposed model and the scope of model application: first, from the model characteristics presented in the former study, it is in fact a multi-stage, pull-type supply chain system, namely the downstream demands trigger upstream production and supply activities. So the application of its analysis model is limited to the order process of the same product (mainly constituted by the sale links from manufacturers to final consumers). It can be seen from the model structure that the cost analysis model proposed in this paper contrary to the order model in the former study. This means the new study can be applied to analyze the entire process from the purchases of raw materials to the final product consumption, even with changes in product physical form. From this point of view, the published paper focuses on several links in a supply chain that directly relate to the procurement of certain products, while the new study focuses on the whole capital flows in a multi-stage supply chain system. Second, the published paper focuses on the order quantities in multi-stage supply chains. The basic components of its analysis model are the orders modules. Although cost analysis is also provided, it considers only the ordering cost which is viewed as a dependent variable determined by the order process. Other costs such as the inventory costs, production costs and shortage costs are also mentioned in paper, but they are used as the auxiliary variables in model analysis. In this paper, not only the procurement cost, other supply chain operating costs such as the production cost, the inventory cost and the transportation cost are also introduced into the cost analysis network model framework. According to the needs of research processes, we can choose one, some or all these cost links from the cost analysis model to conduct in-depth research, such as the cost sensitivity analysis, so the new cost analysis model shows more flexibility than the published one.

In this paper, we propose a novel stochastic network mathematical model for analysis of cost distribution in multi-stage supply chain networks. We focus on five important costs: the procurement costs, the inventory costs, the shortage costs, the production costs and the transportation costs. Analytical solution of cost distribution characteristics, such as the expectation and variance, can be obtained from the proposed model. Then, the concept of system cost sensitivity is proposed, together with the corresponding analytical algorithms. Furthermore, the model-based algorithms for cost analysis of supply chain