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The multi-sourcing location inventory problem with stochastic demand

Mehdi Amiri-Aref[a], Walid Klibi[a,b,*], M. Zied Babai[a]

[a] The Centre of Excellence in Supply Chain (CESIT), KEDGE Business School, France
[b] Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT), Canada

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ABSTRACT

This paper deals with a multi-period location-inventory optimization problem in a multi-echelon supply chain network characterized by an uncertain demand and a multi-sourcing feature. The aim of the paper is to propose a generic modeling approach to integrate key features of the inventory planning decisions, made under a reorder point order-up-to-level (s, S) policy, with the location-allocation design decisions to cope with demand uncertainty. Given the hierarchical structure of the problem, a two-stage stochastic mathematical model that maximizes the total expected supply chain network profit is proposed. This optimization model is intractable due to its non-linearity. Therefore, a linear approximation is proposed and a sample average approximation approach is used to produce near-optimal solutions. Numerical experiments are conducted to validate the proposed modeling and solution approaches. The results show the efficiency of the linear approximation of the (s, S) policy at the strategic level to produce robust design solutions under uncertainty. They underline the sensitivity of the design solution to the demand type and the impact of the inventory holding costs and backorder costs, especially under non-stationary processes.

1. Introduction

In today's business environment shaped by an increased volatility (Christopher & Holweg, 2011) and by disruptive extreme events (Klibi, Lasalle, Martel, & Ichoua, 2010), designing the Supply Chain Network (SCN) and planning for its activities is becoming inevitably a complex decision-making process. Supply Chain (SC) factors such as customers demand, sales price, exchange rates, deliveries lead-time and cost, sourcing price and availability, and capacities are uncertain and could vary considerably along the companies' future business horizon. At the strategic level, the uncertainty of these factors impacts on the SCN resources to deploy and it conditions the sourcing, production and inventory policies to set in order to operate the SC efficiently. It is thus clear that anticipating these factors' uncertainty as well as the appropriate SC policies and operations, at the SCN design time, would generate more robust design solutions. Klibi, Martel, and Guitouni (2016) studied the impact of transportation anticipation on the location and allocation decisions, and their results revealed the sensitivity of the customers' assignment to demand uncertainty. It is clear that the strategic assignment of customers to distribution resources will condition the mission of these resources and thus the inventory and distribution policies that will be decided along time. However, as reported in Shapiro and Wagner (2009), the integration of location-allocation and inventory decisions under uncertainty is not a common practice in the current literature.

In a distribution context, the tactical and operational decisions such as inventory Planning and Control (P&C) are usually taken independently from the SC strategic decisions such as the Distribution Centers (DCs) location and the customers' allocation to DCs decisions, despite the fact that facilities deployment over the territory and inventory deployment within these facilities are interrelated problems. For instance, in a make to stock context, the inventory decisions define the replenishment and distribution policies at the DCs in order to reach the highest service level at minimum inventory-dependent cost. However, the inventory policy selection depends strongly on the number and location of these DCs, since these latter decisions drive the inbound lead-times, throughput and storage capacities, and the outbound distribution schemas. Such independency assumption, could dismiss key dimensions of the inventory problem, such as the inventory policy and level, the sourcing policy (i.e. single vs multi-sourcing allocation), and the inventory deployment model (i.e. one echelon vs multi-echelon). Therefore, optimizing location-allocation decisions at the strategic level with the anticipation of the revenues and costs incurred by

* Corresponding author at: The Centre of Excellence in Supply Chain (CESIT), KEDGE Business School, France.
E-mail address: walid.klibi@kedgebs.com (W. Klibi).

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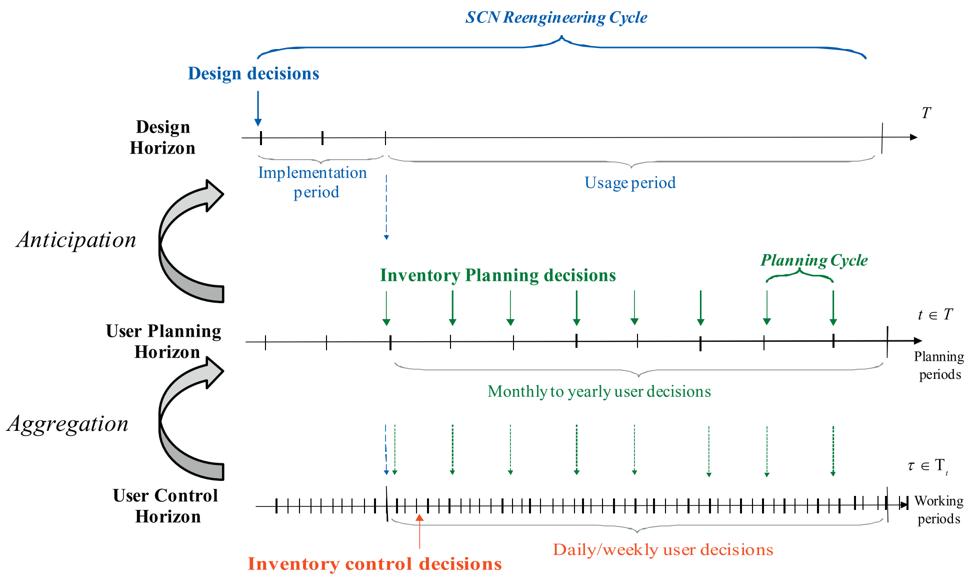

Fig. 1. Decision-time hierarchy in the SC.

the tactical/operational inventory control decisions motivates our work with the aim to improve the quality of SCN design solutions. The importance of integrating the strategic level decisions with the tactical and operational levels is discussed in Sabri and Beamon (2000) and Klibi et al. (2016).

Furthermore, due to the temporal hierarchy between strategic and tactical decisions, the timing between these decisions as well as the distinct time-horizon granularity should be taken into account. This timing structure between the SCN design and the inventory control is illustrated in Fig. 1 as a three-layer planning & control system. The lower layer of Fig. 1 corresponds to the SC operational level in which we assume that, the horizon is composed of a set of discrete periods where the SC users make daily or weekly decisions. This time granularity corresponds also to the demand occurrence from customers. At the tactical level, at each planning cycle, P&C decisions such as the inventory policy, the inventory location and network flow planning are made/revised. It corresponds to the multi-period horizon illustrated by the intermediate layer of Fig. 1. The granularity of planning periods necessitates the aggregation of operational periods and also an aggregate modeling of the operational level decisions. At the upper layer, long-term design decisions are made to cope with future business operations during the usage period of the SCN, which may last several years. Once the network structure is implemented, the deployed platforms are used on a daily basis to perform SC operations under the inventory policy and SC management rules that are planned on a monthly-to-yearly basis. It is clear that the inclusion of these latter at the strategic level would improve the quality of the design decisions. The inventory considerations in the integrated design model may take the form of decision variables, data parameters, or evaluation functions. The time lag between the design decisions and their usage period implies that these decisions are obviously made under uncertainty. With this hierarchical setting, the revenues and expenses generated by a SCN along its usage period are directly related to these P&C decisions. Optimizing the location-allocation decisions with the hierarchical integration of the periodic inventory policy and inventory replenishment decisions leads to an *integrated location-inventory problem*. This problem must not be confused with the class of problems known as *joint location-inventory problems*, which in fact optimizes the location and inventory decisions simultaneously as pointed out in Sabri and Beamon (2000).

With this in mind, few papers that studied the joint location-inventory problems are discussed hereafter. The first research work that deals with a joint location-inventory problem can be viewed as an extension of the traditional uncapacitated fixed-charge facility location (UFL) problem (Daskin, Coullard, & Shen, 2002). Next to that, Shen and Qi (2007), Shen, Coullard, and Daskin (2003) and Shen (2007) have proposed similar models of the joint location-inventory problem with a static setting and non-hierarchical relation between these decisions (i.e. simultaneous decisions). They have shown the cost savings that can be obtained by associating the location and inventory decisions. Furthermore, Atamtürk, Berenguer, and Shen (2012), Ozsen, Daskin, and Coullard (2008, 2009) also stressed the potential benefits that a company can achieve by allowing its retailers to be multiple-sourced in a location-inventory problem. Escalona, Ordóñez, and Marianov (2015), Puga and Tancrez (2017) and Ross, Khajehnezhad, Otieno, and Aydas (2017) emphasized the influence of distribution decisions integration on the economics of network costs. Note that the above-described literature has considered an (r, Q) inventory control policy based on a Normal demand assumption and the standard economic order quantity (EOQ) model.

Further works have considered alternative control policies for the joint location-inventory problems. Nozik and Turnquist (2001) have applied the base-stock replenishment policy (S-1,S), which is useful for systems that operate with one-for-one replenishment. Using the same inventory control policy, Candas and Kutanoglu (2007) have compared the solutions obtained from the simultaneous optimization of the inventory and location model with the decoupled one and have shown the substantial additional cost incurred by optimizing a model that ignores inventory and location association. A considerable cost saving is reported by Berman, Krass, and Tajbakhsh (2012) and Yao, Lee, Jaruphongsa, Tan, and Hui (2010) as a result of the integration of inventory and location decisions in the SCN design problem adopting a periodic order-up-to level (R, S) review policy. Aside, integrated models of the transportation-inventory problem (Shu, Teo, & Shen, 2005; Teo & Shu, 2004), the location-transportation problem (Klibi et al., 2010) and the inventory-routing problem (Archetti, Bianchessi, Irnich, & Speranza, 2014) have been proposed.

Despite the contribution of the abovementioned models regarding the interdependency of inventory and location decisions in the SC, two main shortcomings are reported when compared to the