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The inventory centralization impacts on sustainability of the blood supply chain

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ABSTRACT

This paper studies the significance of inventory centralization at the second echelon of a two-echelon supply chain with perishable items when the agents of the second echelon use an $(S-1, S)$ inventory policy. The replenishment at the first echelon is considered to be stochastic. The context in which the studied problem exists is in the blood supply network where the first echelon includes a single blood bank that receives stochastic supply from donors. The second echelon contains hospitals receiving external demands (transfusions). In our proposed structure, some of the hospitals in close proximity of each other maintain centralized inventories to serve their demands in addition to the demands by other neighbour hospitals. The results demonstrate that centralization of hospitals' inventory is a key factor in the blood supply chain and can increase the sustainability and resilient of the blood supply chain. Using numerical study, it was observed that reducing the number of hospitals that hold inventory from 7 to 3 decreases outdate and shortage in the supply chain by 21% and 40% respectively.

1. Introduction

The aim of the blood supply chain is supplying adequate safe blood to hospitals. It is paramount that blood is available at hospitals for transfusion purposes since a shortage may endanger the life of patients. In the blood supply chain, replenishment in the blood bank is not fully in control of the decision makers, since replenishment occurs by blood donations. This important property discriminates the blood supply chain from other well-studied supply chains with perishability. The blood supply chain can be modelled as a two-echelon inventory system where the items arrive at the first echelon (the blood bank) stochastically and stochastic demand is realized at the second echelon (the hospitals). The hospitals place orders to the blood bank and there is a lead time for fulfilling the orders. In case of emergencies, the orders are fulfilled immediately with almost zero lead time. Outdates and shortages can occur at the first or second echelon. The outdate in the second echelon is more undesirable (i.e. more costly) than outdate in the first echelon for two reasons: the first reason is that a transportation cost is incurred to an item in the second echelon (the hospitals). The second reason is that an outdated item in hospital "A" could be used in another hospital (hospital "B") if it was not issued to hospital "A" but if an item is outdated in the blood bank it also became outdated in any hospital that it was issued to. This fact is easy to prove as the blood bank and hospitals use a First In First Out (FIFO) policy. It is very hard to say if the cost of shortages in one of the echelon is greater than the other one. The shortage at hospitals is highly undesirable as it is related to patients' lives and puts lots of pressure on the system to immediately deliver blood components. Shortage at the blood bank is also very undesirable since the blood bank may fail to satisfy the required emergency deliveries and consequently risk patients' lives. Furthermore, shortages in the blood bank require calls to external resources or blood banks in other regions that imposes considerable costs to the system. Recent studies show transfusion of fresher red blood cells may lead to better results in some groups of patients. This means not only a blood supply chain should minimize its outdates and shortages, but it also needs to reduce (minimize) the age of transfused items. Therefore, the performance of a blood supply chain can be quantified by the outdate rates, shortage rates and the average age of issues. One way to improve supply chain performance is to reshuffle the structure of the supply chain by centralization of hospitals' inventory in the second echelon as much as possible. For example, assume that there are four hospitals H^1, H^2, H^3 and H^4 at the second echelon of the supply chain; i.e. there are four hospitals that hold the inventory in the second echelon. All of them receive items from the blood bank. We show that if H^1 can receive items from H^2 within a negligible amount of time and H^3 can receive items from H^4 within a negligible amount of time; keeping inventories only in H^2 and H^4

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will significantly improve performance of the supply chain. Note that H^2 and H^4 are two hospitals that hold the inventory in the second echelon.

Here we present four examples to verify the assumption that some of the hospitals are close proximity from each other and it is pragmatic to centralize their inventory:

Example 1: There are three nearby hospitals in Heidelberg, Melbourne, Australia. The Mercy Hospital is located in the same building as Austin Hospital. In addition, The Warringal Private Hospital is located only 400 m away from Austin Hospital.

Example 2: There are four neighbour hospitals in Parkville, Melbourne, Australia. The distance between Royal Children's Hospital (H1) and Melbourne Women's Hospital (H2) is less than 900 m and the distance between Melbourne Women's Hospital (H2) and Melbourne Private Hospital (H3) and Royal Melbourne Hospital (H4) is less than 250 m (according to Google Map).

Example 3: The Women's and Children's Hospital in Adelaide, Australia is located about 350 m away from The Memorial Hospital.

Example 4: The Wellington Hospital in Wellington, New Zealand is located about 650 m away from The Ewart Hospital.

In this paper we systematically consider such centralization in the blood supply chain. The main focus of this study is to shed some lights on the impacts of centralization of blood inventories at the hospitals. One particular issue of interest is to examine how the number of hospitals and variability in the size of hospitals could influence the blood supply chain performance. The insights from our analysis will help to identify those hospitals which should keep their inventory management system intact and those which need to keep zero base stock inventory while satisfying their demands using other nearby hospitals. To the best of our knowledge there is no research on the inventory centralization issue in a two-echelon inventory system with uncontrollable replenishment and perishable items, hence our paper is a novel work in this field.

The rest of the paper is organized as follows. Section two reviews the related literature. Section three provides approximation formulas for the performance measures of a blood supply chain. Section four investigates the optimal value of base-stock level (S) as the decision variable in a blood supply chain. Section five discusses how the number and configuration of the hospitals could influence the performance of a blood supply chain. Section six offers conclusions and some directions for future research.

2. Literature review

The research on the perishable supply chain with focus on ordering policies is copious. For a few examples refer to Yu et al. [32]; van Donselaar and Broekmeulen [30] and Herbon et al. [15]. However, there is little research considering the situation of the blood service with stochastic replenishment. There is a literature survey of the blood supply chain by Belien and Force [6] that reviews and classifies 98 papers published in the area of the blood supply chain in last three decades. Moreover, Nahmias [20] published a book on perishable inventory management in which the last chapter of the book is dedicated to blood inventory management. Here we also concentrate on research on the blood service supply chain. Most of the studies in this area consider a single inventory system and their focus is either on the blood bank or on the hospitals. For instance, Zhou et al. [33]; Schmidt and Nahmias [25] and Gunpinar and Centeno [13] studied single level inventory models for perishable items in hospitals. In the single inventory setting for the blood bank the arrival to and demand from the inventory are stochastic, so queuing framework is often used for modelling the system. Keilson and Seidmann [16] provided formulas for the outdate rate, the shortage rate and the average age of issues in a single perishable inventory system with stochastic replenishment under both the first-in-first-out (FIFO) and the last-in-first-out (LIFO) policies. Abbasi and Hosseinifard [1] proposed a modified FIFO policy for a single perishable inventory system in the blood bank with stochastic replenishment and showed that, when designed properly, it can outperform the FIFO and LIFO policies. Atkinson et al. [5] also combined the FIFO and the LIFO policies and proposed a new issuing policy for issuing red blood cells to hospitals. Abouee-Mehrizi et al. [3] presented the theoretical analysis of the issuing policy proposed by Atkinson et al. [5].

Since replenishment and demand are both stochastic in a blood bank with a single perishable inventory system, the base-stock level and ordering policy are not decision variables in the system. Most of the studies on inventory policies and optimal inventory stocks in the blood supply chain focus on hospitals as a single echelon system. As a result, the replenishment is in control of hospitals when placing orders to the blood bank. In such cases, Schmidt and Nahmias [25] studied a single perishable inventory model under continuous review policy for perishable items with lost sales representing unmet demands. Olsson and Tydesjo [23] extended Schmidt and Nahmias's model to allow for backordering. Sheopuri et al. [26] and Song and Zipkin [27] considered dual sourcing for replenishment which utilizes regular replenishment and expedited replenishment.

There are a few studies that model the supply chain for perishable items as a two-echelon system. Yen [31] studied the two echelon inventory system for perishable products but without stochastic replenishment. He assumed a periodic review is used in which the orders are placed to fill up the inventory to the level of S at the review points. Other related studies in this area with periodic review are Prastacos [24]; Cohen et al. [8]; Lystad and Alexopoulos [18] and Nahmias [19]. However, the continuous inventory review is more appropriate for perishable items. Nowadays, continuous reviewing of inventory and tracking each individual item is affordable by using new technologies. Olsson [22] studied the two echelon inventory system with continuous review policy for perishable items. He applied an $(S-1, S)$ policy to both echelons of the supply chain. Olsson [22] worked under the assumption that the unmet demand is backordered. He defined a cost function and derived optimal S's i.e. base- stocks in each location. To the best of our knowledge the only research that considers the two echelon system with perishable items and stochastic replenishment is Abbasi and Seidmann [2]. Their model analyses the impact of reducing shelf life on the blood supply chain performance. Furthermore, Blake et al. [7] and Fontaine et al. [12] used a simulation model to analyse the impact of shortening of the shelf life for red blood cells in the blood supply chain.

A part of the past research in the domain of two or multi-echelon supply chain considers lateral transshipment policies. This means agents in the same echelon are allowed to transfer items to each other. The transshipment can be allowed in one or two directions. As noted by Andersson and Melchiors [4] the analysis of the supply chain with transshipment policies is very complicated. There are numerous studies considering transshipment policies in the supply chain. Federgruen and Zipkin [11] found the optimal inventory with assumption of instantaneous and costless transshipment opportunities within an echelon for non-perishable items. Tagaras [29] also studied the transshipment policies among retailers for non-perishable items. For more details on the transshipment policies we refer to Dennis et al. [9]; Lien et al. [17]; Olsson [21]; Dong et al. [10]; Gong and Yücesan [14] and Tai and Ching [28].

However, there is no research on transshipment policies in a two echelon supply chain with the perishable items or in a supply