Transportation Research Part E 76 (2015) 34–44

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

An inventory pooling model for spare units of critical systems that serve multi-companies

Wenbin Wang [a,b,*], Shuai Yue [a]

[a] Donlinks School of Economics and Management, University of Science and Technology Beijing, 100083 Beijing, China
[b] Faculty of Business and Law, Manchester Metropolitan University, UK

ARTICLE INFO

Article history:
Received 29 August 2014
Received in revised form 21 December 2014
Accepted 2 February 2015
Available online 23 February 2015

Keywords:
Inventory pooling
Centralization
Spare units
Cost analysis

ABSTRACT

In this paper, we present an inventory pooling model for spare units of critical systems that serve multi-companies. Companies located in the same geographical area can benefit from a coalition to share the storage cost of such spare units, which may be stored as one unit at only one company's location. In our model, we combine the storage cost, replacement costs and downtime cost into a unified cost function, giving the expected cost per company per unit time as our objective function. We use two decision variables: the number of companies in the coalition; and the threshold to determine whether to place an emergency order or not, compared with the remaining ordinary order's arrival time. We obtain an optimal solution with regard to these two decision variables under a certain cost structure. Our simulation method verifies the correctness of the model. A series of sensitivity analyses are also conducted to show which variable has the most influence on the expected cost.

1. Introduction

Companies that have critical and expensive systems in service are confronted with two conflicting problems. On the one hand, they want to have a high availability of the spare units for such systems when they are requested. On the other hand, they want to reduce the cost related to system replacement and the storage cost of such spare units (Fritzsche, 2012). An insufficient stock of spare units can lead to an excessive downtime cost, but maintaining an excessive number of spare units increases the amount of capital tied up in spare unit inventories (Wong et al., 2005). These systems are very expensive, critical, and generally have long lead times and high values of the MTBF (mean time between failure). In general, companies which have such systems at most store one unit spare part. However, the cost to hold such a spare part is huge. Firstly, the expensive system ties up capital in spare part inventories; and secondly, they are subject to very infrequent failures, the spare system will be idled in the warehouse for a long time, so the storage cost is very high. The systems are critical, and if each company needs a spare part that it is not available in the warehouse; it would takes too long to wait for a normal replenishment from the supplier, which will incur a heavy lost of production. Therefore all companies want to have a high availability of the spare units for such systems when they are requested. Due to the above characteristics of the system, it is obvious that keeping such spare units in each company's warehouse may not be a viable option in practice. Since inventory holding and shortage costs are much higher than transportation costs among companies, inventory pooling of such systems among companies is an effective inventory strategy (Karsten and Basten, 2014; Wanke, 2012). Rational companies will agree

* Corresponding author at: Donlinks School of Economics and Management, University of Science and Technology Beijing, 100083 Beijing, China. Tel.: +86 10 62332744; fax: +86 10 62333582.
E-mail address: wangwb@ustb.edu.cn (W. Wang).

http://dx.doi.org/10.1016/j.tre.2015.02.002
1366-5545/

and pool their inventories if this leads to an increasing profit for themselves (Braglia and Frosolini, 2013). For example, Guajardo et al. (2012) showed that a large energy company, which currently holds its inventory separately, could obtain an annual inventory storage cost saving of 44% if pooling is used. In the airline industry, the intuitive way of accumulating the demand for spare parts is to pool the inventories together and use the pool to satisfy the demand from several aircraft fleets operated by different airlines (Kilpi and Vepsäläinen, 2004). Pooling can be achieved in numerous ways. The two most commonly used pooling methods are lateral transshipments and inventory centralization. Extensive researches have considered the inventory control for networks consisting of multiple local warehouses, where spare parts of expensive capital goods are kept in stock. When, in such a network, a demand occurs at a local warehouse but is out of stock at that moment, one often applies a lateral transshipment from another local warehouse (Kranenburg and van Houtum, 2009). In an overview, Wong et al. (2006) categorized the literatures of lateral transshipments in terms of the number of echelons, the number of items, periodic or continuous review, inventory control policy, the type of analysis done, exact or approximate evaluation, and optimization or approximation. Lateral transshipments can either be restricted to take place at predetermined times before all demand is realized, or they can take place at any time to respond to stockouts or potential stockouts. These methods are referred to by Paterson et al. (2011) as "proactive transshipments" and "reactive transshipments", respectively. In proactive transshipment models, lateral transshipments are used to redistribute stock amongst all stocking points in an echelon at predetermined moments in time. Reactive transshipments respond to situations where one of the stocking points faces a stock-out while another has stock in hand. This kind of lateral transshipment is suitable in an environment where the transshipment costs are relatively low compared to the costs associated with holding large amounts of stock and of failing to immediately meet demands. In our paper, the inventory control for such inventory pooling consists of multiple similar companies located in the same geographical area. Spare part of an expensive system is stored only one unit at one company's warehouse. This is a very special case that except the company which stores the one unit spare part, the other companies have to apply a lateral transshipment when a demand occurs. This inventory pooling method can be classified as a reactive lateral transshipment or inventory centralization. In concept, inventory centralization is different from pooling, but it does have some similarity since storage sharing is also the main mechanism for centralization. Inventory centralization physically consolidates stock at a limited number of locations (often a single facility) from which all demands are satisfied (Wanke and Saliby, 2009). Managers interested in inventory pooling, however, some authors have voiced skepticism about the potential benefits of decentralization, stating it may deter managers from implementing a centralization plan (Abdul-Jalbar et al., 2003). Wanke (2009) showed that the consolidation decision requires an in-depth understanding of the stock saving structure. Some authors deduced ways for deciding whether and how inventories should be pooled under different variable factors. Chang and Lin (1991) considered when it is beneficial for such a system to actually operate as a more centralized system by using transshipments. They compared a decentralized model with a centralized model and deduced some properties that, if met, showed that costs would be reduced if the operations share resources. Das and Tyagi (1997) presented a formal analysis of the inventory centralization decision on determining the optimal degree of centralization as a tradeoff between inventory and transportation costs. The optimal degree of centralization for minimum costs thus depends on the relative magnitudes of transportation vs. inventory costs. Abdul-Jalbar et al. (2003) concerned with a multi-echelon inventory/distribution system considering one warehouse and N retailers. The retailers are replenished from the warehouse. The optimal reorder policy which minimizes the overall costs can be derived. They concluded that as the number of retailers increases so does the number of instances where the decentralized policy is better. They only showed the degree of preference to centralization or decentralization policy under different N. In our paper, we found an optimal number of companies should coalesce to form a pool. Wanke and Saliby (2009) developed a framework for deciding whether and how inventories should be pooled in light of different products, lead time, and demand characteristics. The sensitivity analyses performed via mathematical expressions and simulation indicated that the inventory holding costs impact remarkably on this decision in terms of the degree of inventory centralization. Kilpi et al. (2009) specified cooperative strategies for the availability service of repairable aircraft systems and found out which factors contribute to the emergence of a particular cooperative strategy.

The literature surveyed above provides an overall understanding of the role of inventory pooling. However, none of the existing relevant papers discuss the problem of how many companies should coalesce to form a pool to centrally hold the spare units of the system under discussion. This is a problem faced by the manager of a large steel company who discussed it with us. They want to know how many companies should be involved, and which key variables attention should be paid to. For their company, critical systems such as crankshafts and inverters are subject to random and very infrequent failures. They want to find ways to reduce their high spare unit holding costs. Intuitively, it makes sense for companies in the same geographical area to pool common spare systems, forming contracts with other companies to store such spare systems at only one user's location and thus share and save on the storage cost. Because the system is so expensive and has experienced very infrequent replacements to our knowledge, and particularly there will not be many companies nearby to use the same system so it is practical and economical for the companies to store just one unit of such spare system. If they store more than one spare units, more companies may be required to share the storage cost and the capital tied up to the spare units inventories, which may not be feasible due to limited users of such systems. So we assume in this paper that these companies only store a maximum of one spare system at only one user's location. Once the replacement of a system is required from any of the users in the contract, this spare system is taken from storage, if it is available. When the spare system is taken, an ordinary order is placed at once to replace the spare system; this order has an ordinary order lead time. Sometimes, the companies may require this spare system before the ordinary order has arrived. At this point, the companies should consider