European Journal of Operational Research 244 (2015) 498–510

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Production, Manufacturing and Logistics

Last time buy and repair decisions for spare parts

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ARTICLE INFO

Article history:
Received 1 October 2013
Accepted 2 February 2015
Available online 11 February 2015

Keywords:
Inventory
Stochastic processes
Spare parts
Last time buy
Repair

ABSTRACT

Original Equipment Manufacturers (OEM's) of advanced capital goods often offer service contracts for system support to their customers, for which spare parts are needed. Due to technological changes, suppliers of spare parts may stop production at some point in time. As a reaction to that decision, an OEM may place a so-called Last Time Buy (LTB) order to cover demand for spare parts during the remaining service period, which may last for many years. The fact that there might be other alternative sources of supply in the next periods complicates the decision on the LTB. In this paper, we develop a heuristic method to find the near-optimal LTB quantity in presence of an imperfect repair option of the failed parts that can be returned from the field. Comparison of our method to simulation shows high approximation accuracy. Numerical experiments reveal that repair is an excellent option as alternative sourcing, even if it is more expensive than buying a new part, because of the option to postpone the repair until the parts are needed. In addition, we show the impact of other key parameters on costs and LTB quantity.

1. Introduction

In this paper, we consider the spare parts supply for advanced capital goods. Examples of these goods are mainframe computer systems, aircrafts, chemical plants, and medical systems. These systems are very expensive and can be in use for a long period (5–30 years). Often, these systems are highly downtime critical, that is, downtime has serious consequences in terms of costs, quality of service, and safety risks.

The customers of these systems are often not just interested in acquiring such systems at an affordable price, but far more in a good balance between the resulting Total Cost of Ownership (TCO) and the system availability throughout its lifetime. Often, the support costs for system upkeep during its lifetime constitute a large part of the TCO. For customers however, system use is their core business, and not the system upkeep. Therefore, customers often prefer to outsource major parts of system upkeep, either to an OEM or to a specialized service provider, if they can provide a good balance between system uptime and costs of system upkeep. A service contract specifies the services provided and the corresponding service level agreements, such as a maximum problem resolution time, or a minimum system uptime per year. To achieve a high uptime, capital goods are often repaired by replacing failed parts by ready-to-use parts from inventory. Therefore, service providers should offer high spare parts availability.

Due to technological developments and the introduction of new systems, the demand for specific spare parts may significantly drop after some time, causing the manufacturer of these parts to decide that it is not profitable anymore to produce them. This point in time may be many years before the time that service obligations end. As a result, the service provider has to decide how to cover future demand until the end of the service period. This decision is inevitably hard, due to the long remaining period and the high level of uncertainty in demand, arising from uncertainty in the size of the installed base and the parts failure rate.

Placing a large final order, a so-called Last Time Buy (LTB) order, is common in industry. Often, the LTB order quantity is very large to attain a high service level, which also yields high obsolescence levels at the end of the service period. Therefore, companies try to mitigate these risks and the costs involved by considering alternative sourcing options. Examples are (i) repair of failed parts that are returned from the field, (ii) strip phased-out systems for reusable spare parts, (iii) buy second-hand parts on the open market, (iv) substitute by a compatible part, and (v) system redesign avoiding the need of the specific spare part.

A key advantage of using such alternative supply options is that either the decision to supply parts from alternative options can be postponed, thereby reducing the level of uncertainty to deal with ((i), (ii), (iii)), or that an LTB order is not needed at all ((iv) and (v)). Even though companies use these alternative supply options, they lack decision support tools to make rational trade-offs between the various supply options.

In this paper, we construct a model to determine the LTB quantity by making trade-offs between one alternative supply option, namely

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http://dx.doi.org/10.1016/j.ejor.2015.02.003
0377-2217/

Table 1
Overview of the existing literature on LTB problem for capital goods.

Literature	Supply option: LTB	Repair of failed parts	Retrieve parts from dismantling	Perform extra production runs	External market
Moore (1971)	☑				
Ritchie and Wilcox (1977)	☑				
Fortuin (1980)	☑				
Fortuin (1981)	☑				
Klein Haneveld and Teunter (1998)	☑				
Hong, Koo, Lee, and Ahn (2008)	☑				
Leifker, Jones, and Lowe (2012, 2014)	☑				
Teunter and Fortuin (1998)	☑		☑		
Teunter and Fortuin (1999)	☑		☑		
Kleber et al. (2012)	☑		☑		
Inderfurth and Mukherjee (2008)	☑		☑	☑	
Inderfurth and Kleber (2013)	☑		☑	☑	
Pourakbar, van der Laan, and Dekker (2014)	☑		☑		
Teunter and Klein Haneveld (2002)	☑				☑
Krikke and van der Laan (2011)	☑	☑	☑		
Van Kooten and Tan (2009)	☑	☑			

repair of the failed parts that are returned from the field. In this research, we collaborated with two industrial partners (computer machinery and printing machines). We noticed that typically only a certain fraction of the failed parts will be returned and diagnosed to be suitable for repair, the so-called return yield. As we observed in practice, the return yield may depend on the willingness of the users to send the broken parts back. In those cases, incentives such as a payment for a returned part will increase the return yield. In several real applications in our industrial partners, we observed an average return yield between 60 percent and 80 percent showing that the return flow is potentially a significant source of supply. In addition, we observed high repair yields (80 percent–90 percent) in practice. Not all returned parts can be repaired from a technical point of view.

We assume a pull policy for the repair of failed parts (i.e., repair on demand), as this is known to be effective (Krikke & Van der Laan, 2011). We aim to minimize the sum of LTB procurement costs, holding costs of ready-to-use parts, repair costs, and shortage costs minus the salvage value. In addition, we aim to evaluate service levels in terms of fill rate and probability of not running out of stock. We develop accurate approximations for performance evaluation and efficient heuristics to optimize the key decisions: the LTB quantity and the repair policy (time-dependent inventory levels).

In the next section, we discuss the related literature and specify our contribution. Next, we present our model in Section 3. Section 4 shows the performance analysis and the optimization heuristic when repairs are assumed perfect. Section 5 extends the model to the case with imperfect repairs. We validate the accuracy of our approximations as well as our optimization heuristic in Section 6. There, we also show the impact of the key input parameters in a numerical experiment. Finally, we summarize our main conclusions and give promising directions for future research in Section 7.

2. Literature review

Research on the LTB problem exists in the area of: (1) consumer products, and (2) capital goods. For consumer products that have relatively low value, it is an option to replace the failed product by a new or similar product (Pourakbar et al., 2012; Van der Heijden & Iskandar, 2013; Shen & Willems, 2014). This is however not a realistic option for advanced capital goods that may have a product value of several millions of euros. Therefore, such systems are repaired by replacing failed parts of modules by spares.

The literature within the field of spare parts management is extensive and covers several decades of research (Sherbrooke, 2004; Muckstad, 2005). The specific literature in the area of LTB decisions for spare parts can be classified according to the sourcing options that are used to satisfy demand after stopping the production of spare parts. Early papers solely focus on finding the LTB order quantity for several model variants. More recent papers take into account other sources of supply, in particular, the repair of failed parts, the retrieval of parts from dismantling complete systems that are phased-out, setting up dedicated production runs at higher costs, or ordering from the external market at higher prices (if possible). In Table 1, we give an overview of papers according to this classification and discuss them in more details.

Among the papers that consider the *LTB as the only source of supply*, Moore (1971) is the first to propose a method to forecast the all-time-requirement of service parts. His method does not incorporate stochastic demand. As a result, neither safety stocks nor service levels or stock-out costs can be computed. The latter aspects have been analyzed by Ritchie and Wilcox (1977); Fortuin (1980,1981); Klein Haneveld and Teunter (1998); and Hong et al. (2008) for several model variants. Leifker et al. (2012) study LTB problems in a continuous setting without any service period restriction, while there is limited information on the customers, and the only alternative is buying a part. Leifker et al. (2014) consider possibilities for service contract extension when computing the final order quantity.

Table 1 shows that retrieving parts from *dismantling phased-out systems* has received the most attention as alternative source in the literature. A key characteristic in this case is the correlation between demand for parts and supply from dismantling: if systems are phased-out and dismantled, the size of the installed base decreases and thus the number of system failures which initiate the demand for spare parts decreases. At the same time, the supply from dismantling increases. Teunter and Fortuin (1998, 1999) assume that dismantling can be done at negligible costs, which justifies the use of a push policy to dismantle every returned system immediately. They apply dynamic programming and propose an approximation based on newsvendor equations. They determine a dispose-down to level for the excess parts above that level in order to avoid high inventory levels. Pourakbar et al. (2014) propose a model using a finite horizon Markov decision process to find the LTB quantity and non-stationary inventory control levels. They consider retrieving parts from phased-out systems, where timing and quantity of the phase-outs are uncertain as well as repair time. Kleber et al. (2012) consider buying back failed systems to retrieve spare parts. They study possible benefits of buying back broken systems compared to other sourcing options such as LTB and trade-in campaigns to exchange old systems with