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# Inventory reduction in spare part networks by selective throughput time reduction

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ABSTRACT

We consider combined inventory control and throughput time reduction in multi-echelon, multi-indenture spare part networks for system upkeep of capital goods. We construct a model in which standard throughput times (TPTs) for repair and transportation can be reduced at additional costs. We first estimate the marginal impact of TPT reduction on the system availability. Next, we develop an optimization heuristic for the cost trade-off between TPT reduction and spare part inventories. In a case study at Thales Netherlands with limited options for TPT reduction, we find a net saving of 5.6% on spare part inventories. In an extensive numerical experiment, we find a 20% cost reduction on average compared to standard spare part inventory optimization. TPT reductions *downstream* in the spare part supply chain appear to be the most effective.

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## 1. Introduction

Manufacturers of advanced capital goods such as computer systems and medical systems tend to expand their business by offering service contracts for system upkeep during the life cycle (Cohen et al., 2006). Such service contracts typically contain quantified service levels, such as a maximum response time in the case of a failure or a minimum uptime per year. We encountered such contracts at Thales Netherlands, a supplier of naval radar and combat management systems.

At the start of the contract, the supplier and/or the user invests in spare parts to facilitate fast repair by replacement of failed modules, the so-called Line Replaceable Units (LRUs). These (expensive) LRUs are often repaired rather than scrapped. Repair usually consists of diagnosis and replacement of a failed subcomponent, commonly referred to as Shop Replaceable Units (SRUs). Lack of spare SRUs leads to delay in LRU repairs, which increases the need for spare part inventories. Therefore, there is a trade-off between stocking LRUs and (cheaper) SRUs. Possibly, some SRUs are repairable themselves by replacing cheaper parts. So, we have a so-called *multi-indenture* product structure, see Fig. 1. We should decide about the stock levels of all items at all levels in the multi-indenture structure. In the remainder of this paper, we will use the phrases *parent* and *child* to refer to the relations in the multi-indenture structure: in Fig. 1, the supply cabinet is the parent of the power supply, and the power supply and air conditioning assembly are children of the supply cabinet. We use the term *item* for components at any level in the multi-indenture structure (LRUs, SRUs, parts).

Because the installed base is usually geographically dispersed, spare parts may be stocked at various locations. Stocks close to the sites where systems are installed are important for fast supply in case of a failure. This leads to several local stockpoints, each dedicated to a certain geographical area containing a part of the installed base. On the other hand, we may need central spare part stocks to take advantage of the risk pooling effect. Therefore, spare part supply systems usually have a *multi-echelon* structure as shown in Fig. 2. This is an example derived from a case study at Thales Netherlands, where we considered naval radars that are installed onboard of frigates. Spare parts may be stocked onboard, at the shore organization (close to a harbor), or at Thales Netherlands. In the remainder of this paper, we will use the common term *base* for a site where one or more systems are operational. We will use the phrases *supplier* and *customer* for the relations in the multi-echelon structure. In Fig. 2, Thales is the supplier of the Shore, and the Shore is a customer of Thales. Ready-for-use items are moved from the *upstream* part of the service supply chain (Thales) to the *downstream* part (ships).

To optimize the initial spare part inventories, Thales uses a commercial tool based on the VARI-METRIC method (Sherbrooke, 2004). If there is evidence during contract execution that the actual service levels are below target (e.g. in terms of downtime waiting for spare parts), the service provider intervenes. At a tactical level, options are among others (i) buying additional spare parts, (ii) reducing repair shop throughput times, and (iii) reducing transportation times of spare parts. In this research, we focus

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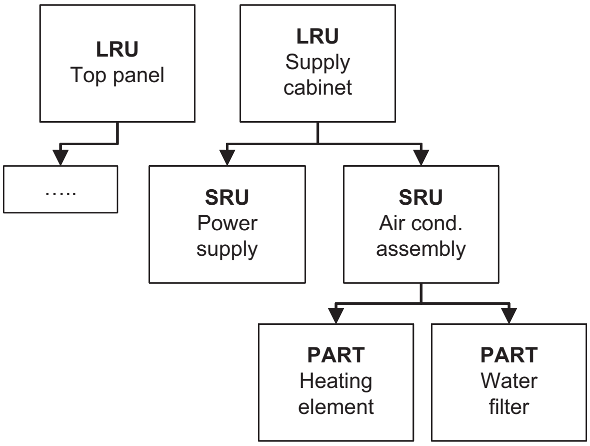


**Fig. 1.** A multi-indenture structure.

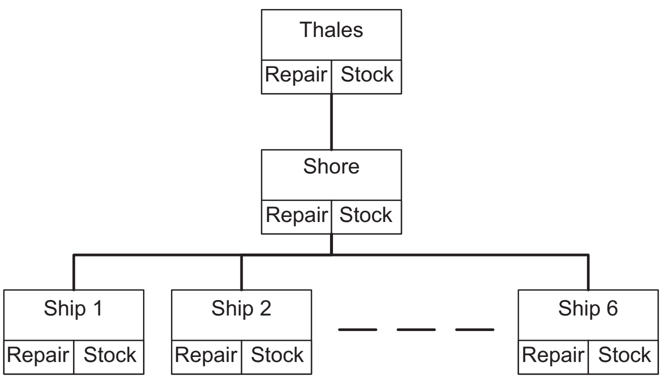


**Fig. 2.** A multi-echelon structure.

on throughput time (TPT) reduction (of repair and transportation) as alternatives to spare part investment for multi-indenture, multi-echelon spare part networks. At Thales Netherlands, such reductions are feasible at extra costs. It is well known that influencing repair TPT for specific items may have a large impact on the total costs (Sleptchenko et al., 2005; Adan et al., 2009).

To gain insight on the impact of TPT reductions, we first develop expressions for the marginal backorder reduction of LRUs at operating sites as a function of the marginal reduction in TPT of each repair and transport in the network. We use these expected backorders as criterion, because their minimization is approximately equivalent to maximizing operational availability (Sherbrooke, 2004). If pipelines are Poisson distributed, we need only the fill rates of all items in the multi-indenture structure at all locations in the multi-echelon networks for this purpose. Combining these marginal values with a certain discrete step size for the TPT reductions, we develop a heuristic optimization method to balance the investment in TPT reductions to investment in extra spares. In a numerical experiment, we show that a trade-off between spare part inventories and TPT reductions may yield considerable cost savings (20% on average). We find that TPT reductions *downstream* in the service supply chain are particularly interesting. TPT reductions of low level items (SRUs and subcomponents) upstream in the network make little sense. We illustrate our approach using a case study at Thales Netherlands.

In this paper, we first discuss related literature and state our contribution (Section 2). We define our model in Section 3. Section 4 shows how we estimate the impact of TPT reduction for given spare part stock levels. This is input for our optimization heuristic (Section 5). In Section 6, we discuss numerical results from both the case study at Thales Netherlands and a large set of theoretical problem instances. We end up with conclusions and directions for further research in Section 7.

## 2. Literature

There is a vast extent of literature on optimization of slow moving spare part inventories in multi-echelon, multi-indenture supply chains (Sherbrooke, 2004; Muckstadt, 2005). These models contain many parameters, some of them resulting from underlying decisions. Examples are the location and allocation of repair activities, repair and transportation lead times, and item failure rates. In the last decades, several models have been developed that consider some of these decisions jointly. Öner et al. (2010) consider the joint decision of mean time between failures (which can be influenced during product design) and the costs of spare parts during the life cycle for a single item. Joint decisions for spare parts inventories and repair locations, taking into account the costs of resources required, are discussed by among others Alfredsson (1997) and Basten et al. (under review a). Rappold and Van Roo (2009) combine the spare part stocking problem with facility location. Focusing on the relation between spare part inventories and TPTs, there are two streams of literature:

- analysis and optimization of spare parts and repair and supply processes at a *tactical* level, where a selected subset of items is given high priority in repair;
- *operational* optimization of spare part networks by dynamic priority setting in repair and supply, given fixed spare part stock levels and resource capacities.

Within the stream focusing on the *tactical* level, we distinguish the selective use of emergency repair and supply in case of low stocks, and priority setting models with finite repair capacities. In the first area, Verrijdt et al. (1998) use a single item model to show the impact of emergency repairs if the stock level drops below a certain threshold value. Perlman et al. (2001) consider a single-item, two-echelon model with finite capacity repair shops and assume that emergency repair is applied with a certain probability. Van Utterbeeck et al. (2009), on the other hand, focus on supply flexibility, i.e., the performance improvement if emergency shipments and lateral transshipments are allowed. They use simulation optimization to search the optimal system design and stock allocation, again for a single item.

The models with finite repair capacities usually model the repair shops as single or multi-server queues with exponentially distributed repair times (Gross et al., 1983; Diaz and Fu, 1997; Sleptchenko et al., 2003). An important issue in this line of research is the trade-off between repair capacity and spare part inventories: limited capacity leads via high utilization and long TPTs to more spare part stocks. Sleptchenko et al. (2005) introduce priority queueing models for the repair shop where the items are assigned to two priority groups (high or low priority). They show that appropriate priority assignment may lead to a significant reduction in the spare part inventory investment. The idea is to prioritize repair of items with high value and small repair times, so that the work-in-process of these items is reduced with limited impact on other items. A similar idea has been used by Adan et al. (2009), who consider multiple priority classes ( $>2$) in a single-location, single-indenture problem. They develop a method for exact cost evaluation.

At the *operational* level, various priority rules have been examined. These models assume that all resources are given (spare part inventories, repair capacities) and search for efficiency gain using (i) repair priorities (if a server becomes idle, which item from the queue should be repaired first?), and (ii) dispatch priorities (if an item has been repaired and there are multiple outstanding orders for this

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