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An adaptive base stock policy for repairable item inventory control

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ABSTRACT

This paper presents an adaptive base stock policy for a repairable item inventory control problem. Base stock level of a repairable item is updated based on the work-in-process (WIP) inventory level in repair facility with update frequency modeled as a separate tactical control parameter together with a standard base stock level. Stock-out situations are handled by emergency shipments, and priority shipments are used when updating the base stock level. A single-item single-location problem is considered, with repair facility having a limited capacity, and the problem is modeled by a two-dimensional continuous-time Markov chain, which is then solved explicitly by using matrix geometric methods. Numerical results are provided that show, for a given downtime target, the new policy achieves substantial reduction in inventory on-hand and significant saving in total cost.

1. Introduction

A repairable item (spare part) is usually a technically complex part of some more complex capital intensive equipment, which is capable of being restored to acceptable operating condition after a failure. Repair service of an item is usually provided either by the original equipment manufacturer (OEM) that manufactures the equipment or outsourced to a supplier of OEM that manufactures this specific item. Customers of OEMs are companies operating usually in capital intensive industries (i.e., chemical industry, construction, semi-conductor manufacturing, aviation, and telecommunications). These companies incur high costs of downtime (due to lost sales, loss of productivity, or dissatisfaction of their customers) when one or more of their equipments are not operating. The cost of downtime is usually very high. As a consequence, customers are demanding high levels of spare part availability in stock. This causes much pressure on an OEM's cost budget for the after-sales maintenance support. Keeping spare parts stock at close locations to customers becomes expensive due to unpredictable, sporadic nature of equipment failures. Backordering is usually not desirable from a customer service perspective, and thus stock-out situations are usually handled via emergency shipments, in which case, a spare part is directly shipped from an external source to the customer. In order to avoid logistical defects, shipments are done via specialized couriers causing high shipment costs for OEMs. Stake holders put the pressure to keep operating costs down, and in contrast, customers demand high service levels. It is the duty of an inventory manager to continuously strive to control and to balance the tradeoff between operating costs and service level commitments. Cutting the operating costs down by meeting the agreed service levels has become important.

We can state the typical characteristics of a repairable item inventory control system as follows: high service requirements, sporadic demand, high inventory costs, high shipment costs, and limited and expensive capacity to perform repair actions. These characteristics set the stage for the tactical design of repairable item inventory control systems. In this paper, we describe a practically intuitive and effective inventory control policy based on these special characteristics of repairable items. Our motivation is based on the existence of priority shipments in repairable item logistics operations of an OEM in semi-conductor manufacturing industry. Planners tend to respond to short-term supply shortages by priority shipments in order to avoid possible future emergencies. Independent of normal replenishment orders in the repair pipeline, a spare part is shipped directly to a warehouse from an external source other than the repair facility, because waiting for repair is considered as risky. This application is equivalent to a situation that, in presence of a stock-out risk, the planner temporarily increases the inventory position by using the priority shipments until the time that the risk is considered to clear out. On the contrary, when the planners foresee excess stock they then tend to decrease the inventory position.

In this paper, we model this state-sensitive behavior by a mechanism that updates base stock levels based on the amount of WIP in the repair facility. If the WIP of an item is getting larger (thus the inventory on-hand becomes less), then the base stock level of that item is increased, and vice versa. We formulate the

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update procedure based on two tactical control parameters: the minimum base stock level and a parameter that refers to the frequency with which the base stock level is updated.

Due to the recent evolutionary advancements in information technologies, monitoring the statuses of proprietary or outsourced facilities has become possible. Thus, revising and updating current plans or tactical control parameters based on the observed operational changes has become a popular practice. Usually, decision making with regard to updating depends on planners' individual assessments, and it is not done in a systematic approach. In this paper, we aim to provide a formal model for this *art of business*, and shed light for practitioners by presenting quantitative insights about the benefits of such approach. Our model is also new for repairable items inventory management literature. By using analytical techniques, we showed how limited updating activities can be put into design of an inventory control policy for repairable items. The primary purpose of this study is to quantitatively evaluate the effectiveness of updating the base stock level of a repairable item based on the WIP level at the repair facility. We will refer to this situation as *the dynamic case*. The alternative case with no updating is called *the static case*.

This paper is organized as follows: in the following, relevant literature is reviewed, and then a detailed formal description of the problem context is provided. In Section 2, a single-item single-location problem is modeled as a continuous-time Markov chain. Then, its stability condition and steady-state solution are provided. Numerical analysis of relevant performance metrics is given in Section 3. In Section 4, the paper is concluded, and ideas for possible extensions for future research are presented.

1.1. Literature review

Repairable item inventory control models have attracted much attention in academia, mainly because of their wide application areas in industry. Sherbrooke (1968) is a pioneering study that shed light to this field by introducing the famous METRIC model, where an efficient solution is presented for distributing spare parts in a two-echelon single-depot single-base system. A comprehensive review of literature and a list of the state-of-art models in this field are available at Sherbrooke (2004) and also at Muckstadt (2005).

Much of the research on repairable item inventory control is concentrated on the type of distribution network and the optimization criteria used to decide stock levels of spare parts. The distribution of spare parts can be done through a single or multi-echelon network. The differences between these come from the fact that stock levels at a higher echelon will impose limitations on and govern stocking decisions at a lower echelon. Research on multi-echelon systems such as Graves (1985), Hausman and Erkip (1994), Alfredsson and Verrijdt (1999) elaborate on this interdependency between echelons. Whereas, single echelon models generally concentrate on the exact analysis of the problem (e.g., Archibald et al., 1997; Herer and Rashit, 1999). Further, as stated by field research studies of Cohen et al. (1997) and Ashayeri et al. (1996), single echelon systems are preferred in practice for the sake of better utilization of resources and ease of control in operations.

With respect to the optimization criteria, there are cost-based and service-based models. Cost-based models such as Sherbrooke (1968), Graves (1985) and Rustenburg et al. (2000) minimize expected backorders subject to a budgetary limitation. The changing competitive environment in after sales service business has forced many OEM companies employ a service-based approach. Consequently, most of the recent studies provide models that guarantee a target service level; fill rate or waiting time (e.g., Wong et al., 2007; Kranenburg and van Houtum, 2009; Caggiano et al., 2009). Considering that in most cases equipments waiting for repair are critical for the operations of customers, a waiting time related service level is practically relevant, which is also employed in this paper.

The concept of emergency shipment has become an industry standard because of high service level requirements. It refers to service providers' response against stock-out situations in a way to satisfy any customer request for a spare part in a duration of time that is much shorter than the repair lead time. It can take on various forms such as lateral transshipment between different bases (e.g., Axsäter, 1990; Archibald et al., 1997; Herer and Rashit, 1999), emergency shipment from a depot (e.g., Alfredsson and Verrijdt, 1999), or emergency shipment from an external supplier (e.g., Wong et al., 2007; Kranenburg and van Houtum, 2009). The common feature of these emergency ordering systems is that they all have a reactive and not a proactive approach. They are reactive in the sense that an emergency shipment is issued only after a stock-out occurs, and there are no actions taken for preventing stock-outs. Differently, Verrijdt et al. (1998) presents a continuous review single-item single-echelon system in which failed parts are sent to an emergency repair channel (with shorter lead time) when the net inventory of spare parts is equal to or lower than a given trigger level. The main assumption in Verrijdt et al. (1998) was that repair process is the only supply channel and thus part requests during stock-out are backordered. In this paper, we consider both reactive and proactive actions taken against stock-out situations. In addition to the emergency shipments, we consider the option of using priority shipments to increase stock position once it is foreseen that there is a high risk of stock-out. Further, stock position is decreased when there is a risk of excess inventory.

In repairable item inventory control literature, the most commonly used assumption of independent and identically distributed repair lead times assures the applicability of Palm's theorem to develop required probability distributions. These distributions provide the basis for the tactical models for finding the stock levels of spare parts, and they have been used by Sherbrooke (1968), Axsäter (1990), Kukreja et al. (2001) and many others. In the literature, there has been a lack in the number and the content of studies that deal with the capacitated nature of the repair process, in which parts may queue up in front of the repair facility and thus the repair lead times are no longer independent. Gross (1982) was the first to investigate the effect of this assumption, and showed that the results due to Palm's theorem may become substantially different once a capacitated repair is considered. This idea is further extended by a closed queueing network model of a multi-echelon system in Gross et al. (1983). Recently, Sleptchenko et al. (2002) incorporated capacitated repair shops to multi-echelon multi-indenture systems, and Sleptchenko et al. (2005) further extended this study by also considering item priority rules in the repair shop. It is shown that utilizing item-priority rules (which are state-independent) in a capacitated repair shop can generate significant cost benefits. In this paper, we also consider a capacitated repair facility, where some repairs may take longer or shorter than expected depending on the size of the WIP in the repair facility. Different from the existing literature, we explore a state-dependent tactical planning mechanism.

Another basic assumption in repairable item inventory control literature is the stationary operating environment. Here, our understanding of stationary environment has two dimensions. One dimension is related to the stationarity of demand and repair processes. That is, the distributions of demand for spare parts and of process times in the repair centers have fixed means that are time-independent. Research on non-stationary aspects is quite limited due to analytical complexity – little research is made