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Approximate evaluation of order fill rates for an inventory system of service tools

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ABSTRACT

This paper deals with the analysis of a single-location, multi-item inventory model for service tools, in which coupled demands and coupled returns occur. We distinguish multiple Poisson demand streams. Per stream there is a given set of tools that is requested per demand. We are interested in the order fill rates, i.e., the percentage of demands for which all requested tools are delivered from stock. Requested tools that are not on stock are delivered via an emergency channel. For the warehouse under consideration, they may be considered as lost sales. Delivered tools are returned to the warehouse after a deterministic return time, that is equal for all tools. We show that the full multi-item evaluation problem decomposes into evaluation problems for small sets of service tools. For the resulting subproblems, we develop three approximate models for the order fill rates, which are all based on Markovian models. One approximate model has appeared to give an underestimation in all computational tests, while the second approximate model has led to an overestimation in all instances tested. The last approximate model combines the other two. This approximate model is very accurate and can be computed efficiently for representative instances based on data from an Original Equipment Manufacturer with whom we collaborated for this research.

1. Introduction

Original Equipment Manufacturers (OEMs) produce expensive machines that are critical in the production process of their customers. Therefore, customers often have service contracts with the OEM in which the availability of the machine is agreed upon. To make sure this performance is met, the OEM performs preventive maintenance. Furthermore, in case of a defect, corrective maintenance is performed, for which the company needs spare parts, service engineers, and service tools. These resources are positioned in a global network consisting of central and local customer service points. The company's objective is to meet the agreed system performance against minimal costs. Total costs consist of procurement costs, inventory holding costs, transportation costs for regular, lateral and emergency shipments of spare parts and service tools, import taxes, and the costs for employing service engineers.

The OEM has to decide how much stock is needed at which location, both for spare parts and service tools, and how many service engineers should be hired to meet all service targets. In practice, the system performance demanded by customers is decoupled into separate targets for engineers, spare parts and service tools, and the minimization problem is solved for each resource separately. In this paper we focus on the subproblem involving service tools. So far, the stock planning of service tools has received only little attention in literature. However, since prices of service tools can be very high, and service tools may lead to large investments for OEMs, optimization of stock levels of service tools is an important issue.

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The situation described occurs for many OEMs, among which a company in the semiconductor supplier industry, with whom we collaborated for this paper. This company already uses sophisticated methods to optimize stock levels for spare parts. For service tools, however, the company is still in need of a model to determine the optimal stock levels. The service tools at this company are stored at local warehouses at close distance of the semiconductor factories. When tools are needed for a maintenance action (corrective actions in general) in a semiconductor factory, they are taken from the warehouse to which the factory has been assigned, and after usage they are returned to this local warehouse. Service tools can also be obtained from and lent to other warehouses, but after usage they do return to the warehouse they belong to. The problem is to determine how many service tools of each type are needed to meet the service levels agreed upon with the customers. This problem is typically considered per local warehouse, where interactions with other local warehouses are modeled in a straightforward way.

In order to optimize the stock levels of service tools, first an evaluation model is needed. In this paper, therefore, we study an evaluation model for a single-location, multi-item inventory system for service tools. Different demand streams occur following a Poisson process, where for each demand stream a given set of tools is requested. When a demand occurs, all available tools are sent to the customer, and the other tools are sent from a warehouse in another region or from a central warehouse that serves as a backup. For the latter shipments, the fastest available transport mode is usually used to avoid long down-times of machines. For the warehouse under consideration, the demand for these tools may be considered as lost. Tools that are sent to the customer, return to their original location after a deterministic return time. We evaluate the *order fill rate*, i.e., the percentage of orders for which all requested tools are delivered from stock.

Currently, the evaluation of the order fill rates for service tools is done by ignoring the coupling between the demands of different tools (and thus the positive correlation between inventory levels for different items). This way of analyzing may lead to a significant underestimation of the service offered to customers (see Section 4). Our objective is to find an accurate and efficient evaluation procedure for the order fill rates. We aim at a procedure that is sufficiently efficient to be used in an optimization procedure for multi-item service tool models (in which case many evaluations have to be executed). For these optimization procedures, we may think of similar procedures as developed for multi-item spare parts models; see e.g., Wong et al. (2005) and Kranenburg and Van Houtum (2007).

In spare parts research this usage of building blocks to come up with more sophisticated models can also be recognized. Already in 1963, Hadley and Whitin (1963) studied a model very similar to ours, namely an $(S-1, S)$ policy for spare parts with a Poisson arrival process, arbitrary supply lead time distributions and lost sales. However, a difference between spare parts and service tools is that service tools are often demanded in combination with other service tools, i.e., we have *coupled demands*, while spare parts fail one at a time in general. The first model by Hadley and Whitin (1963) has been used a lot in other spare parts inventory models; see Kennedy et al. (2002), Sherbrooke (2004), and Muckstadt (2005) for an overview of the developments in this field.

The service tools problem is also related to assemble-to-order systems. In those systems several subassemblies are demanded and all have to be available before an order can be assembled. Song and Zipkin (2003) give an overview of research on assemble-to-order systems. In most of the studies backlogging is assumed, but there are also a few papers where the lost sales case is considered. Song et al. (1999) study a generalized model that has both complete backlogging and lost sales as a special case. In addition, they distinguish total order service, which means that an order is fulfilled completely or rejected as a whole, and partial order service, which means that partial fulfilment occurs as in our service tools problem. Song et al. (1999) derive an exact matrix-analytic solution for the order-fulfillment performance measures. The supply system in this paper is modeled as a single-machine exponential production facility per item. Iravani et al. (2003) extended this work by introducing flexible customers, i.e., customers that are willing to compromise on the requested items. Dayanik et al. (2003) study computationally efficient performance estimates for the same problem. When comparing our model to these assemble-to-order models, we observe the same structure for demand streams, and the return times in our model are like the lead times in an assemble-to-order system. In the terminology of assemble-to-order systems, the supply system in our model is modeled as an ample server system with equal deterministic service times for all tools. I.e., tools demanded together will return together after an equal deterministic return time for all tools, or, in other words, we have *coupled returns*. In essence, it is because of these coupled returns that the type of solutions for the assemble-to-order systems described above does not work for our problem.

Another problem related to ours is the repair kit problem; see e.g., Brumelle and Granot (1993), Mamer and Smith (1982, 1985), and Mamer and Shogan (1987). In this problem, repairmen travel around to repair machines with a repair kit containing several items. One or more items are needed to repair a machine. Thus, for a repair a subset of tools or spare parts is needed, as in our problem. The problem is to determine the optimal set of items to include in the repair kit. However, in most literature studying the repair kit problem, each repair is studied independently, which means that all tools are restocked again directly after usage, while we study demand over an infinite horizon, including the effect that tools are not readily available after usage because of the return times. More recently, Teunter (2006) studied the problem in which a repairman visits multiple locations before his repair kit is restocked. However, in this work every tour is considered separately, which means that also in this paper lead times are not considered.