



A queueing-based optimization model for planning inventory of repaired components in a service center



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ABSTRACT

We address the problem of managing repair capacity and repaired component inventory in a service center. With modular products, the repair essentially involves identifying the faulty component in the product and replacing it with a repaired component or a new component, if repaired components are not available in stock. The faulty component is then repaired and used to service a future faulty product that arrives for repair. The problem is modeled as a queueing system with a limit on the queue length. The total cost function involves the steady-state probabilities and queue length of the queueing system. Using the properties of the cost function that we derive, we identify bounds on the decision variables, and use them in developing an algorithm to determine the optimal repair capacity and repaired component inventory. A computational study is carried out to investigate the impact of the various cost parameters on the optimal solution.

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1. Introduction

In an increasingly competitive market place resulting from rapid globalization, firms have shifted their focus towards service activities that can improve customer satisfaction and facilitate increased revenues. This paradigm shift from a product-centric view to a customer-centric view has elevated after-sales service (through service contracts and warranties) from being looked upon as a major part of the firm's cost to a major source of revenue and profit. According to Cohen, Agrawal, and Agrawal (2006), efficient after-sales services can lead to increased customer loyalty as experienced by firms like Caterpillar, GE, and Saturn. There are multiple studies that have inferred that after-sales service supply chain is growing with respect to both revenue and volume. An AMR survey conducted by Bijesse, McCluskey, and Sodano (2002) on manufacturing companies found that service represented a major portion (45%) of their profit and a large portion (24%) of their revenue (Jalil, 2011).

Service contracts ensuring high availability of products or quick turnaround time (TAT) are especially common in the computer industry, where customers expect a replacement product or the service to be completed within the same day. With products that

adopt a modular design, repairs typically involve identifying the faulty component (such as hard disk, monitors, or a particular card or cartridge) and repairing or replacing it. The actual repair of a faulty component takes much longer than the contracted TAT. Therefore, the service centers of firms typically resort to keeping stock of the repaired components for providing quick service through immediate replacement of the faulty component. The faulty component that is removed from the product is sent to the repair center. Of course, repair of faulty components rather than using new components would be practiced only if the cost of repairing a faulty component is significantly lower than that of manufacturing a new component, and the functionality of the repaired component is close to that of a new component. But with greater focus on sustainable operations, and increasing legislation for product take back and pricing on carbon emissions, the economics for using old repaired components instead of new components is getting stronger. For each component of the product that is repaired and serviced, managing the after-sales service requires managing the inventory of the repaired components as well as the returned faulty components that wait in a queue for repair.

In our study, we consider the repaired component inventory system depicted in Fig. 1. What we consider here is only the inventory system for a single component that is used in a family of products. The failed product arrives at the service center. After disassembly and diagnosis, if the particular component in the product is determined to have failed, then this creates a demand

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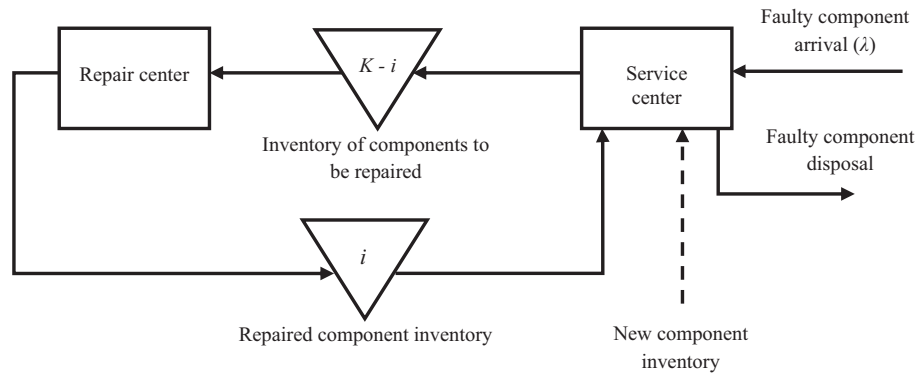


Fig. 1. The repaired component inventory system.

for a repaired component. This demand is satisfied from the repaired component inventory if it is available or with a new component. The model allows for the possibility that a proportion of the faulty components cannot be repaired. The dynamics of the problem where all faulty components can be repaired is significantly different from the problem where some components cannot be repaired. Therefore, we develop two separate models for these two cases (see Section 3 for more details). As the repair/after-sales service system works in conjunction with the product distribution system, we assume that sufficient inventory of new components is always available in the system or can be procured immediately from the supplier of the component.

The decision variables in this problem are the maximum inventory (of repaired components and the faulty components), K , and the number of servers, c , as they determine the total cost incurred by the system. The expected total cost function utilizes the steady-state probabilities and the expected queue length for the underlying queueing model. We derive properties of the total cost function, and obtain useful bounds on the decision variables, which were then beneficially employed to develop efficient algorithms to obtain optimal inventory level of the repaired components as well as the number of servers at the repair facility. The major contributions of this paper are to innovatively combine queueing theory with optimization to model and solve the problem, and successfully exploit the bounds identified for the two decision variables in the development of the optimal algorithms.

The rest of the paper is organized as follows. Section 2 presents a review of the related literature on reverse logistics, repair & remanufacturing systems and service logistics systems. In Section 3, we develop the queueing-based optimization models for the two scenarios, as well as analyze these models and develop algorithms to determine the solution to the problem. In Section 4, we present the numerical results while the conclusions are presented in Section 5.

2. Literature review

The problem under consideration in our study falls under the broad area of reverse logistics. Reverse logistics involves “full coordination and control, physical pickup and delivery of material, parts, and products from the field to processing and recycling or disposition, and subsequent returns back to the field where appropriate (Blumberg, 2005).” There is a huge body of literature related to reverse logistics, and interested readers are referred to review papers by Fleischmann et al. (1997), Bazan, Jaber, and Zanoni (2016) and Govindan, Soleimani, and Kannan (2015). The streams of research in reverse logistics that are related to our problem can be broadly classified into three main areas, namely, (1) repairable item inventory systems, (2) inventory systems with product returns, (3) inventory systems with remanufacturing.

The repairable item inventory system (RIIS), also popularly known as the METRIC system (Sherbrooke, 1968), is a closed system containing a fixed number of items, such as tanks (in military), cranes, and earthmoving equipment (in construction). These items might be positioned at different locations or depots. In addition to the items that are being used, inventory of spare items is also maintained. When a failure occurs to an item being used, it is sent for repair and replaced with a spare item. When there are no spare items available, the repair orders are backlogged. The objective of the problem is to determine the number of spare units to be held at different locations, so as to minimize the total cost (comprised of the holding and backorder cost). From the perspective of spare item inventory, the RIIS system is equivalent to a normal multi-echelon inventory system with $(S - 1, S)$ policy with a stochastic lead time that is dependent on the inventory level of the spares and the time required for repair.

One of the first papers dealing with RIIS was the METRIC model developed by Sherbrooke (1968), that studied a multi-echelon network model for US Air Force that comprised of multiple bases and a central depot. Other papers that addressed the RIIS models or its refinements or variations include, Graves (1985), Sherbrooke (1986), Gross, Gu, and Soland (1993), and Rappold and Van Roo (2009). The models developed by Sherbrooke (1968) and Graves (1985) assumed ample capacity for repair (ample repair facilities and large parts population), while capacitated repair facility (modeled using either a closed queueing network or a multi-server queue) was considered by Rappold and Van Roo (2009) and Gross et al. (1993). For a more detailed review on RIIS, the reader is referred to Guide and Srivastava (1997) and Basten and van Houtum (2014). Mirzakhosseinian and Piplani (2011, 2013) studied an inventory model for a repairable parts system operating under a performance-based logistics contract in which the service provider is compensated for the performance delivered by the system under contract. van Jaarsveld, Dollevoet, and Dekker (2015) studied spare parts inventory control for an aircraft component repair shop, where inventory of each component is controlled using independent (s, S) inventory policy. The cost minimization problem was formulated as an integer program with fill rate constraints, and column generation was applied to solve the optimization problem.

Although our problem might seem to have some similarities with the RIIS model considered in the literature, there are some differences as well. In the RIIS model, the arrival of faulty products comes from a small base of the installed items within the system. In our model, the arrivals of faulty components come from a large installed base of products/customers in the region. Therefore, the arrival rate of the failed components is independent of the number of components in repair. Due to the high service requirements, customers/products that arrive with a failed component are immediately provided with a replacement item, either a repaired

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