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Inventory control for returnable transport items in a closed-loop supply chain

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A R T I C L E I N F O

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A B S T R A C T

An inventory control model for returnable transport items (RTI) where the manager selects the optimal length for inspection, repair, and purchase cycles is described. Repaired and newly obtained RTI are used in combination to satisfy current production requirements. Uncertain returns are incorporated into the model by determining a satisfactory safety stock level to buffer the inventory of used and repairable containers. The minimum cost solution is obtained when inspection and repair runs begin simultaneously. Cycle times are a function of the expected return rate and repairable percentage, while variability in these random assumptions affects the required safety stock.

1. Introduction

Returnable transport items (RTI) are containers used multiple times by manufacturers to avoid the cost of purchasing new shipping material each time their product is distributed to a customer location (Twede and Clarke, 2004). RTI include such packaging types as kegs, pallets, roll cages, barrels, trolleys, and refillable liquid or gas containers (ISO, 2007). The investment in RTI can be necessitated by the need to reduce the costs in a supply chain versus employing one-way packaging items, and is also attractive for reducing environmental impacts (Kroon and Vrijens, 1995; Twede and Clarke, 2004; Hellström, 2009). While acknowledging the potential cost reduction through material savings associated with RTI, McKerrow (1996) also outlines additional benefits of reusable packaging that include improved handling and storage.

This paper proposes a model for determining inventory control policies for the inspection, repair, and purchase of RTI in a closed-loop supply chain (CLSC). Motivation for the system presented is the determination of inventory policies for a beverage manufacturer that utilizes returnable kegs. The product is delivered through distributors, who eventually collect and return the containers to the manufacturer. Returned kegs are processed and inspected to determine whether they can be repaired and reutilized for future shipments. The inspected containers are transferred to a repair station where parts are replaced as necessary and the kegs are cleaned and sanitized. Once the repair process is completed, the containers are added to an inventory of serviceable containers that are ready to be refilled. The workflow in the facility and the proximity of the inspection and repair functions is such that the containers can be continuously transferred between the inventory queues once each process is completed. Inspection and repair are performed on containers in batches, so the manufacturer

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must establish effective cycle lengths and corresponding lot sizes for these functions. Only a fraction of the containers are returned from distributors, so the company must also decide when to purchase new containers and set an order quantity.

This research contributes to the current models available to manufacturers for managing their collections of RTI. Decisions regarding the purchase, inspection, repair, and transportation of RTI affect the costs of distributing products to customers (Thoroe et al., 2009; Kim and Glock, 2014). Kelle and Silver (1989a,b) and Buchanan and Abad (1989) developed methods for forecasting RTI returns and determining optimal purchase quantities for replacement of lost containers. Witt (2000) notes that decisions affecting the ability of the company to recollect RTI quickly are also important because these determined the number of containers needed in a fleet. In a study of an engine manufacturer in Brazil, Silva et al. (2013) found that once logistics policies were established to reduce the time-to-return of reusable packaging to satisfactory levels, both positive economic and environmental impacts were realized. Accorsi et al. (2014) study both the environmental and economic effects of deploying a fleet of RTI in a food catering supply chain. They note that the reduced environmental impact is significant, but that the economic returns can be negative if the distribution system is not configured properly.

Managing the collection of RTI owned by a manufacturer can be aided by setting inventory control policies for processing used containers and returning them to the production system. The model in this paper seeks to minimize total expected inventory costs of the closed-loop RTI supply chain when the percentage of containers returned in each production lot and the percentage of repairable containers are random variables. The design of the system is similar in some respects to the method proposed by Kim and Glock (2014); however, the prior model is implemented in a single-supplier, single-retailer supply chain where containers are collected by the retailer and returned in a batch to the supplier. In the system proposed here, containers return to the manufacturing facility continuously.

This research makes the contribution of providing optimal inspection, repair, and purchase intervals for a CLSC under the following assumptions that are not simultaneously permitted in current methodology:

1. Containers are continuously returned by distributors to the manufacturer.
2. Both the return rate of RTI and the percentage of returned containers that are repairable are allowed to be random variables.
3. Returned containers travel through separate inspection and repair processes at finite rates.
4. Safety stock is established to buffer against uncertain container return and repairable container rates.

The next section reviews relevant research in the area of management of RTI and remanufactured inventory. Section 3 defines the CLSC model that will be utilized to determine RTI inventory policies for the manufacturer. Section 4 shows the calculation of the optimal inventory control parameters and presents a safety stock model needed to buffer against uncertain returns and an uncertain percentage of repairable containers. Section 5 provides analysis of the solution and managerial implications. Section 6 provides a case study that applies the model to decisions made by a beverage manufacturer. Section 7 concludes the paper by discussing limitations and future research.

2. Literature review

The prior work that is most closely aligned with this paper is a collection of studies that offer methods for jointly determining optimal policies for remanufacturing used inventory while also purchasing or producing new items, with both sources of inventory (or RTI) used to satisfy demand. Relevant work is summarized in Table 1 with further explanation below. The work reviewed here includes methodology for systems with deterministic, stationary demand where either repair or remanufacturing is required to return RTI to serviceable condition. A review by Guide and Van Wassenhove (2009) cites other applications that develop inventory policies other under sets of assumptions.

The work of Schrady (1967) first considered joint optimal repair and purchase lot sizes for repairable inventory items. Replenishment of inventory through either repair or purchase is assumed to occur instantaneously. This is referred to as an "infinite" purchase rate and repair rate in Table 1. The terms repair and recovery are both used in this stream of research to mean the process by which used inventory is repaired to reusable condition after it is returned to the manufacturer.

The solution developed by Schrady (1967) was extended by Nahmias and Rivera (1979) to consider fixed storage capacity for repaired and purchased items, with repairs occurring at a finite, non-instantaneous rate. Mabini et al. (1992) presents a variation on a model for determining repair and purchase lot sizes by incorporating returns of multiple types of items that share a finite repair capacity. Teunter (2001) presents a deterministic model to calculate optimal manufacturing and recovery batch sizes for reusable inventory items where recovery and production rates are assumed to be infinite. Batches of recovered items are alternated with newly produced items, or vice versa. Thoroe et al. (2009) study the effect of improving the return rate of RTI through RFID tracking on a model with similar characteristics to that of Teunter (2001). Richter (1996a,b) also solves a repair and production lot sizing with alternating new and used batches of inventory items, but includes a disposal option for items that cannot be repaired.

Koh et al. (2002) extended the model of Nahmias and Rivera (1979) to consider the case where the demand rate exceeds the repair rate. The policies developed are of two types. The first alternates one lot of recovered items with multiple purchase lots of new products. The second alternates one lot of new inventory with multiple batches of recovered items. Teunter (2004) incorporates finite and infinite production and recovery rates into a model designed to calculate optimal production