Chapter 1
Design for a Closed-Loop Supply Chain System With Sensor-Embedded Refrigerators

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ABSTRACT

This chapter presents a methodology to evaluate the benefit of using sensors in closed-loop supply chains. Sensors can be embedded into products to collect helpful information during their use and end-of-life (EOL) phases. This information can subsequently be employed to estimate the remaining lives of components and products and to ensure that proper maintenance is provided to avoid premature failures. The information is also useful in determining the quality of the components and products when planning EOL operations such as disassembly, inspection, and remanufacturing. To statistically illustrate these benefits, discrete event simulation is employed to a case study consisting of regular and sensor-embedded refrigerator systems. A design of experiments study is then employed where experiments are run to compare the two systems. The results reveal that the sensor-embedded systems perform much better than the regular systems in terms of disassembly costs, inspection costs, and EOL profits generated by selling the remanufactured products and components.

INTRODUCTION

For many years, manufacturing processes predominantly focused on profitably producing and selling products. However, strong competition in the market has forced businesses to offer value-added services with their products as a means of attracting more sales. One such service is that of competitive warranties through which manufacturers guarantee they will maintain products for a given period of time. While these warranties do appeal to customers, they also increase manufacturers' costs.

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One of the purposes of this study is to identify methods by which manufacturers can reduce the costs associated with performing maintenance on refrigerators while also enhancing customer satisfaction. It proposes the use of embedded sensors to monitor the performance of the appliance during their use phases, provide information on the condition and use of the components, and help predict possible catastrophic failures. The availability of this information could result in shorter downtimes for the refrigerators in the event of failure and could reduce manufacturers' maintenance costs.

In addition to being beneficial to maintenance processes, sensors can also improve the performance of the refrigerators' end-of-life (EOL) processes. By retrieving critical condition information about the components, manufacturers could enhance the disassembly and inspection processes and, thereby, make EOL processing more profitable (Ilgin & Gupta, 2010b).

Our study introduces a closed-loop supply chain system that aims to enhance the system by which refrigerators are maintained during their life cycle and returned refrigerators are processed for EOL use. The goal of the study is to determine the economic benefit of incorporating sensors into new refrigerators. The study compares regular-refrigerator (RR) and sensor-embedded-refrigerator (SER) systems and tests these systems using discrete-event-simulation models and appropriate design of experiments. The results are compared for their performance measures, and pairwise t-tests are performed to determine the statistical significance of the differences between them.

LITERATURE REVIEW

This section presents a literature review of the studies conducted on remanufacturing, maintenance and sensor-embedded products. Several survey papers (Gungor & Gupta, 1999; Ilgin & Gupta, 2010a; Ilgin et al. 2015) were consulted during the literature review to acquire an in-depth understanding of environmentally conscious manufacturing and product recovery. Gupta and Ilgin (2018) published a book to cover multi-criteria decision making application in environmentally conscious manufacturing and product recovery.

Remanufacturing

Capacity Planning

Capacity planning decisions are essential within remanufacturing processes because attaining profitable utilization levels in remanufacturing systems can be challenging due to uncertainty and variation. Guide and Spencer (1997) suggested the use of rough cut capacity planning for remanufacturing. This planning method employs a bill-of-resources approach and involves the consideration of probabilistic material replacement and routing files. Guide et al. (1997) adapted five different rough cut capacity planning techniques to solve remanufacturing capacity planning problems. These techniques were bill of resources, capacity planning using overall factors, modified bill of resources, bill of resources with variance, and modified bill of resources with variance. They applied these techniques to solve a case study problem and compared the results by simulating the systems.

Georgiadis et al. (2006) and Vlachos et al. (2007) introduced system dynamics models to solve capacity planning problems in remanufacturing. The models considered the demand patterns of the product while it was in use, distribution of the residence time, and changes in remanufacturing capacity.

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