Evaluating the impact of sensor-embedded products on the performance of an air conditioner disassembly line

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Abstract Increasing consumer awareness towards environmental issues and stricter environmental legislation have forced many manufacturers to set up facilities for product recovery which involves the minimization of the amount of waste sent to landfills by recovering materials and components from returned or end-of-life (EOL) products. Disassembly is an important process in product recovery since it allows for the selective separation of desired parts and materials. EOL products involving missing and/or nonfunctional components increase the uncertainty associated with disassembly yield. Testing, a common solution method, results in high costs. Moreover, if the component is found to be defective, the disassembly time is wasted. Sensor-embedded products (SEPs) can deal with this uncertainty by providing information on the condition of components prior to disassembly. This study evaluates the impact of SEPs on the various performance measures of an air conditioner (AC) disassembly line controlled by a multikanban system which effectively manages material flows considering the stochastic behavior of the disassembly line. First, separate design-of-experiments studies based on orthogonal arrays are carried out for conventional products (CPs) and SEPs. In order to calculate the response values for each experiment, detailed discrete-event simulation models of both cases are developed, considering the precedence relationships among the components of an AC. Then, pairwise $t$ tests are conducted to compare two cases based on different performance measures. The test results show that SEPs improve revenue and profit while achieving significant reductions in backorder, disassembly, disposal, holding, testing, and transportation costs.

Keywords Air conditioner disassembly · Precedence relationships · Sensor-embedded products · Discrete-event simulation · Orthogonal arrays

1 Introduction

Increased rate of advancement in technology coupled with customers’ passion for newer models has resulted in shorter product life cycles and premature disposal of products. The resulting decrease in available landfills and natural resources has forced many governments to mandate stricter environmental regulations on manufacturers. Some of these regulations require firms to take back their products at the end of their useful lives. Manufacturers try to comply with these regulations by setting up specific facilities for product recovery which involves the minimization of the amount of waste sent to landfills by recovering materials and components from returned or end-of-life (EOL) products via recycling and remanufacturing. Moreover, the economic benefits that can be gained by reusing products, subassemblies, and components instead of disposing of them increase the importance of product recovery [13, 16, 44].

The first operation in the recovery of products is disassembly which involves the separation of the desired components, subassemblies, and materials from EOL or returned products. Disassembly operations can be performed at a single workstation, in a disassembly cell, or on a disassembly line. Although a single
The component or product failures during products
production process. By monitoring critical components of a
system. Design-of-experiments study is presented in Section 5.

The number of parts that can be recovered from a product
on a disassembly line is highly uncertain due to missing and/or
nonfunctional components. Since there is generally no
information available about the condition of components
prior to disassembly, components need to be tested following
disassembly at each station. Depending on the testing times,
testing costs can be a significant burden on the profitability of
a disassembly line. Moreover, if the component is slated as
nonfunctional at the end of the testing process, time and
resources spent to disassemble the components are wasted.
This increases the disassembly costs together with the back-

2 Literature review

A literature review on the issues considered in this research is
provided in this section. After presenting a brief review of the
research on product recovery and disassembly, we discuss the
studies on modified kanban systems and sensor-embedded
products.

2.1 Product recovery and disassembly

Gungor and Gupta [6] and Ilgin and Gupta [16] presented
comprehensive reviews of issues in environmentally con-
scious manufacturing and product recovery. Disassembly is
a popular research topic within the area of product recovery.
Researchers have studied different aspects of disassembly
including sequencing [15, 31, 39, 71], scheduling [2, 24,
25, 35], disassembly line [8, 56], disassembly line
balancing [5, 30], disassembly to order systems [17, 34],
and automated disassembly [23, 45, 58]. Researchers also
addressed the issues related to the disassembly of different
types of products, e.g., vehicles [20, 21], electronics [46,
68], and consumer appliances [69]. The interested reader is
referred to a recent book by Lambert and Gupta [33] for
further information on different aspects of disassembly.

2.2 Modified kanban systems

Sudden or large variations in demands greatly reduce the
applicability of traditional kanban system. Several mod-
ified kanban methodologies were developed to deal with
demand variability while preserving the advantages of
traditional kanban system. The algorithm proposed by
Gupta and Al-Turki [9] adjusts the number of kanbans
considering unstable demand. In a follow-up study, Gupta
et al. [12] presented a novel system called flexible kanban
system (FKS). In FKS, the number of kanbans is adjusted
with respect to demand and lead time variations. Gupta
and Al-Turki [10, 11] proved the superiority of FKS to
traditional kanban system by considering the interruptions
caused by the preventive maintenance or breakdown of the
material handling system. In the adaptive kanban system
suggested by Tardif and Maaseidvaag [57], the number of
kanbans is adjusted by considering inventory and backorder
levels. Takahashi and Nakamura [53–55] presented a reactive
kanban system which has the ability of adjusting the number
of kanbans and buffer sizes according to the detected
unstable changes in demand. A reactive just-in-time (JIT)
ordering system was proposed by Takahashi et al. [52] for
multistage production systems which involve unstable
changes in both mean and variance of demands.

Several other studies adapt modified kanban methodol-
gies to disassembly lines. Kizilkaya and Gupta [26] used
DES to test the performance of a novel pull-type disassem-