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ANALYSIS OF A KANBAN CONTROLLED DISASSEMBLY LINE WITH SENSOR EMBEDDED PRODUCTS

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ABSTRACT

The use of sensors in the detection of non-functional or missing components in a product before disassembling it is a promising approach to deal with the high level uncertainty associated with disassembly yield. This study presents a quantitative assessment of the impact of the sensor embedded products on the various performance measures of a kanban-controlled disassembly line. First, two separate design of experiments studies based on Orthogonal Arrays are carried out for the cases with and without sensor embedded products. Then, the results of paired-t tests comparing two cases based on different performance measures are presented.

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 landfill areas and natural resources forces governments to mandate stricter environmental regulations on manufacturers. Some of these regulations even require firms to take back their products at the end of their useful life. 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 parts 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 them increase the importance of product recovery.

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 workstation and disassembly cell is more flexible, the highest productivity rate is provided by a disassembly line. Moreover, the disassembly line is more suitable for automated disassembly [1]. However, the effectiveness of a disassembly line largely depends on the production control mechanism. Similar to assembly lines, there are two commonly used disassembly line control mechanisms: push and pull. Although push system is easier to implement, it results in excessive component and subassembly inventories in a disassembly environment. Pull system involves specific mechanisms in order to achieve lower inventory levels throughout the system. Since these mechanisms were developed originally for assembly lines, their direct applicability in disassembly systems is limited. Therefore, the

modification of traditional pull system mechanisms considering disassembly line characteristics is a popular research issue in the literature.

Kizilkaya and Gupta [2] used discrete event simulation (DES) to test the performance of a novel pull type disassembly line control mechanism called dynamic kanban system for disassembly line which is based on the flexible kanban system originally developed by Gupta and Al Turki for production environment [3]. The main idea of the mechanism is the dynamic change of the number of kanbans with respect to the demand and the capacity of the system. Udomsawat et al. [4] introduce a novel pull type disassembly line control system called Multi-Kanban Mechanism (MKK) which routes kanbans in a dynamic way considering the state of the system. Using a DES model, the authors showed that this mechanism is successful in controlling system's inventory without damaging service level. Udomsawat and Gupta [5] and Udomsawat and Gupta [6] analyzed the applicability of MKK in the case of multiple precedence relationships and component discriminating demands, respectively. The effect of server breakdowns on the performance of a disassembly system controlled by MKK was discussed by Udomsawat and Gupta [7], [8].

All of the above studies analyzed modified pull control mechanisms based on the assumption of perfect yield rate at each station. In other words, they assumed that incoming EOL products do not include any non-functional or missing component. However, in real life, the number of components that can be recovered from a product is highly uncertain. The use of sensor-embedded products (SEPs) is a promising approach to deal with this uncertainty. SEPs involve sensors implanted during the production process. By monitoring critical components of a product, these sensors facilitate the data collection process. The data collected through sensors can be used to predict the component or product failures during product lives while allowing for accurate estimation of remaining lives and conditions of components at the EOL of the product. Moreover, the information provided by sensors regarding any non-functional, replaced or missing component prior to disassembly of an EOL product provides important savings in testing, disassembly, disposal, backorder and holding costs.

In this study, we consider a disassembly line controlled by a kanban-based mechanism. As an extension to the previous kanban-based control mechanisms proposed in the literature, the existence of non-functional or missing component(s) in EOL products is taken into consideration. Moreover, we analyze the use of sensors in the detection of failed or missing components in a product before disassembling it. In order to present the impact of SEPs on system performance, two separate experimental design studies based on Orthogonal Arrays (OAs) are carried out for the cases with and without SEPs. In the calculation of various performance measure values under different experimental conditions, detailed DES models of both cases are used. Then, the results of paired-t tests comparing two cases based on different performance measures are presented. Finally, directions for further research are suggested.

2. SYSTEM DESCRIPTION

We consider an EOL computer disassembly facility. Three components of EOL computers namely memory, hard disk and motherboard are disassembled through a three-station

disassembly line in this facility. Disassembly times at stations, demand inter-arrival times for components and EOL computer inter-arrival times are all assumed to be distributed exponentially. MKK developed by Udomsawat and Gupta [5], [6], [7], [8], [9] is used to control the disassembly line. Kanban levels for components and subassemblies are determined using the formulas given in Udomsawat and Gupta [9]. Following the disassembly, each component is tested. The testing times are normally distributed with the means and standard deviations presented in Table 1.

Table 1 Component Characteristics

Component	Testing Time (min.)		Volume (cft)	Station
	Mean	Std.Dev.		
Memory	2	0.2	0.008	1
Hard Disk	10	2	0.016	2
Motherboard	5	1	0.263	3

A small truck with a load volume of 425 cubic feet is used to dispose excess product, subassembly and components. Whenever the total volume of the excess product, subassembly and component inventories become equal to the truck volume, the truck loaded with excess inventory is sent to a recycling facility. Any product, subassembly or component inventory which is greater than *maximum inventory level* is assumed to be excess. Component volumes are given in Table 1. The volume of an EOL computer is taken as 2.128 cubic feet.

3. USE OF ORTHOGONAL ARRAYS TO SHOW THE IMPACT OF SENSOR EMBEDDED PRODUCTS

The most important drawback of the above system is the highly variable yield rate due to missing or non-functional components. SEPs can eliminate this uncertainty by providing information about the condition of the components prior to disassembly. For instance, if the memory and hard disk of an EOL computer are regarded as non-functional or missing by the sensors, this computer is directly sent to the third station for the disassembly of motherboard. This prevents station 1 and station 2 from wasting time for the disassembly of non-functional memory and hard disk, respectively. Moreover, since the motherboard has been regarded as functional by the sensors, there is no need for testing following the disassembly of motherboard at station 3.

Although the impact of SEPs on disassembly and test times are clear from the above example, there is a need for a comprehensive study to quantify the improvement achieved by the SEPs. That is why, in this study, we compare the case with SEPs against the case without SEPs under different experimental conditions. The factors and factor levels considered in the experiments are given in Table 2. Since there are 26 factors, a full factorial design requires an extensive number of experiments. Therefore, experiments were designed using OAs [10] which allow for the determination of main effects by making a minimum number of experiments. Specifically, L54 OA was chosen since it requires 54 experiments while accommodating 25 factors with three levels and one factor with two levels.

Table 2 Factor Levels

Number	Factors	Levels		
		1	2	3
1	Disposal cost increase factor for EOL computers	0.15	0.20	-
2	Mean demand rate for Memory (<i>components per hour</i>)	10	15	20
3	Mean demand rate for Hard Disk	10	15	20
4	Mean demand rate for Motherboard	10	15	20
5	Mean arrival rate of EOL computers (<i>products per hour</i>)	10	20	30
6	Mean disassembly time for station 1 (<i>minutes</i>)	0.25	0.50	0.75
7	Mean disassembly time for station 2	0.50	0.75	1
8	Mean disassembly time for station 3	1	1.5	2
9	Backorder cost rate	0.40	0.60	0.80
10	Disassembly cost per minute (\$)	1	2	3
11	Holding cost rate	0.10	0.20	0.30
12	Weight for Memory (<i>pounds</i>)	0.1	0.3	0.5
13	Weight for Hard Disk	1	2	3
14	Weight for Motherboard	2	4	6
15	Price for Memory (\$)	10	20	30
16	Price for Hard Disk	25	50	75
17	Price for Motherboard	50	100	150
18	Disposal cost per pound (\$)	0.30	0.40	0.50
19	Maximum inventory level	5	10	15
20	Waste weight Factor	0.20	0.30	0.40
21	Probability of a non-functional Memory	0.10	0.20	0.30
22	Probability of a non-functional Hard Disk	0.10	0.20	0.30
23	Probability of a non-functional Motherboard	0.10	0.20	0.30
24	Probability of a missing Memory	0.05	0.10	0.15
25	Probability of a missing Hard Disk	0.05	0.10	0.15
26	Probability of a missing Motherboard	0.05	0.10	0.15

DES models of both cases were developed using Arena 11 to determine profit value together with various cost and revenue parameters for each experiment. Each DES experiment was carried out for 60480 minutes, the equivalent of six months with one eight hour shift per day. Equation (1) presents the formula used in the DES models for the calculation of profit value.

$$\text{Profit} = \overbrace{(SR+CR)}^{\text{Total Revenue}} - \overbrace{(HC+BC+DC+DPC+TC+TPC)}^{\text{Total Cost}} \tag{1}$$

The different cost and revenue components used in Equation (1) can be defined as follows. *SR* is the revenue generated by the component sales during the simulated time period (STP). *CR* is the revenue generated by the collection of EOL computers during the STP. *HC* is the holding cost of components, EOL computers and subassemblies during the STP. *BC* is the backorder cost of

components during the STP. *DC* is the disassembly cost during the STP. *DPC* is the disposal cost of components, EOL computers and subassemblies during the STP. *TC* is the testing cost during the STP. *TPC* is the transportation cost during the STP.

In order to calculate the disposal cost of a product, subassembly or component, the weight in pounds is multiplied by the *disposal cost per pound*. Disposal cost for subassemblies and products are increased by a factor called *disposal cost increase factor for EOL products*. While calculating the weight of a product or subassembly, the weights of cd-rom, floppy disk, power supply, and case are taken as 2 lbs, 0.8 lbs, 4 lbs, and 10 lbs, respectively. In order to determine the weight of other components such as screws, adaptors and cables, total weight of the computer is multiplied with a *waste weight factor*. While calculating the testing cost for the case with SEPs, the time required to retrieve information from the sensors prior to disassembly is assumed to be testing time. The duration of this retrieval process is taken as 15 seconds per EOL computer. For both cases, the testing cost per minute is assumed to be \$0.5. In the calculation of transportation cost, the operating cost associated with each trip of the truck is assumed to be \$50. For each EOL computer, the facility demands a \$30 collection fee.

4. RESULTS

Based on the results of experimental design studies, various paired-t tests were carried out on different performance measures. Table 3 presents the 95% confidence interval, t-value and p-value for each test. According to this table, SEPs achieve statistically significant savings in holding, backorder, disassembly, disposal, testing and transportation costs. Moreover, there are statistically significant improvements in total revenue and profit in case of SEPs.

Table 3 Paired-t Test Results for Various Performance Measures

Performance Measure	95% Confidence Interval on Mean Difference (Sensor –No Sensor)	t-value	p-value
Holding Cost	(-42.3731, -23.5391)	-7.02	0.000
Backorder Cost	(-20201.7, -8473.1)	-4.90	0.000
Disassembly Cost	(-36635.5, -26913.9)	-13.11	0.000
Disposal Cost	(-20483.8, -13521.9)	-9.80	0.000
Test Cost	(-134668, -114139)	-24.31	0.000
Transportation Cost	(-116.996, -86.893)	-13.58	0.000
Total Cost	(-206436, -168871)	-20.04	0.000
Total Revenue	(55762, 147797)	4.44	0.000
Profit	(228842, 350023)	9.58	0.000

5. CONCLUSIONS

There is a high level uncertainty associated with disassembly yield due to non-functional or missing components in EOL products. Sensors embedded in products can deal with this uncertainty by providing information about the condition of the components prior to

disassembly. In this study, we analyzed the impact of the SEPs on the various performance measures of a kanban-controlled disassembly line. First, two separate design of experiments studies based on OAs were carried out for the cases with and without SEPs. Then paired-t tests were carried out in order to compare two cases for different performance measures. The test results indicate that SEPs can achieve significant reductions in holding, backorder, disassembly, disposal, testing and transportation costs while increasing total revenue and profit. As a future research, the study can be extended by considering precedence relationships among the components.

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