Management of a Disassembly Line using Two Types of Kanbans

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***Abstract*—The continuous growth in consumer waste has seriously threatened the environment. For this reason, environment conscious manufacturing has emerged to be an important attribute that has been embraced by companies to support the environmental laws, social responsibilities as well as profitability resulting in increased awareness of product recovery. One of the first operations in product recovery is disassembly which involves the separation of the desired components, subassemblies, and materials from end-of-life or returned products. A disassembly line is perhaps the most suitable setting for disassembly of products in large quantities. In this paper, a multi-kanban mechanism using two types of kanbans, viz., a component kanban and a subassembly kanban, is used to control the disassembly line. We consider an example from the automobile industry to illustrate the methodology and investigate the fluctuations in components and subassemblies inventories, average waiting times and backorder rates using simulation. The results demonstrate the effectiveness of utilizing the multi-kanban mechanism in a disassembly line.**

***Keywords*—** *Multi-kanban system, disassembly, product recovery, reverse supply chain, environmental issues.*

1. Introduction

The production systems were traditionally designed for economic efficiency. This stance served us well for several centuries because the population on earth was small and people had modest needs. There was abundance of resources and their consumption rates were much smaller than their renewal rates. Consequently, the environment was never threatened and that issue never entered in our decision process. However, gradually things have changed. The manufacturing processes have been significantly improved with the introduction of initiatives such as assembly lines and supply chains. In addition, the aspirations of people have changed, the desire for latest fashions has deepened, competition has increased, and resources have been challenged. All these have resulted in shorter product life cycles and premature disposal of products. The resulting decrease in available landfills and natural resources has compelled many governments to mandate stricter environmental regulations on producers. Some of these regulations require firms to take back their products at the end of their useful lives. Manufacturers have tried to comply with these regulations by setting up efficient reverse supply chains [2], [11] and specific facilities for product recovery [6] 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 [7]. What's more, the economic benefits gained by reusing products, subassemblies and components instead of disposing of them has increased the importance of product recovery [5].

One of the first operations in product recovery is disassembly which involves the separation of the desired components, subassemblies, and materials from EOL or returned products [8]. 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 are more flexible, the highest productivity rate is provided by a disassembly line.

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In addition, a disassembly line is more suitable for automated disassembly [1], [10].

In traditional production lines, there are two types of control mechanisms available, viz., push and pull. The push mechanism works in accordance with a predetermined plan and activity takes place based on anticipated demand of the product. The main disadvantage of this mechanism is excess inventory. On the other hand, the pull mechanism aspires to increase the agility of the line by reducing inventory levels. This is achieved by allowing production only if there is an actual demand for the product. Some of the benefits of pull mechanism include reduction in bottleneck, cycle time and inventory carrying costs. In fact, its popularity has even spread to small companies [4]. A pull mechanism is also most appropriate for a disassembly line where the operations are labor-intensive and the products have limited shelf lives, high carrying costs, or need large storage space.

Kanban is commonly used when implementing the pull mechanism in production lines. It signals the need to move raw materials or perform some process on the line. It essentially acts as a permission slip to produce and a tool to control the inventory level. Kanbans work well if the demands, supplies and processing times are constant [3]. Modifications are needed when these elements are stochastic as they are in a disassembly line. For that reason, we consider a disassembly line that is controlled by a multi-kanban system (MKS), a superior pull-type methodology developed for disassembly lines considering their highly stochastic behavior [12].

The rest of the paper is organized as follows. Section 2 describes the disassembly process for EOL products. The model description is given in section 3. Section 4 describes the kanban mechanism of MKS and the numerical results are presented in section 5. Finally some conclusions are provided in section 6.

2. Disassembly Process for EOL Products

Consider an example of a disassembly line where EOL products, consisting of any combination of four components, A, B, C and D, are disassembled (see Figure 1). The line consists of three workstations. Component A is disassembled at workstation 1 (WS1), component B is disassembled at workstation (WS2) and components C and D are disassembled at workstation 3 (WS3). Arriving EOL products to the disassembly line may consist of different combinations of the four components. Thus, the four components considered here could produce up to 11 possible product combinations (viz., AB, ABC, ABCD, ABD, AC, ACD, AD, BC, BCD, BD, CD). However, in real life situation, not all combinations exist in EOL products. In fact, only a very small subset of these combinations may exist. The workstation where an EOL product enters the disassembly line depends on the type and combination of the components in the product. Thus for example, a product arriving at the disassembly line consisting of components B, C, and D does not have to go to workstation 1 at all. It could enter the disassembly line directly at workstation 2. Similarly, if an arriving product consists of components A, C, and D, it will enter workstation 1 and then skip workstation 2 entirely. Thus, EOL products with different combinations of components must be processed through the workstations in different sequences.

Another unique characteristic of a disassembly line is that the demand can occur at any station of the disassembly line. This creates a disparity between the number of demanded components and the number of partially disassembled products. Thus, if the system responds to every request for components, it would end up with a significant amount of extra inventory of components that are in low demand. All this creates chaos in the system. Since service level is important and is necessary to maximize, it becomes necessary to develop a good methodology to control the system and find a way to manage the extra inventory produced.

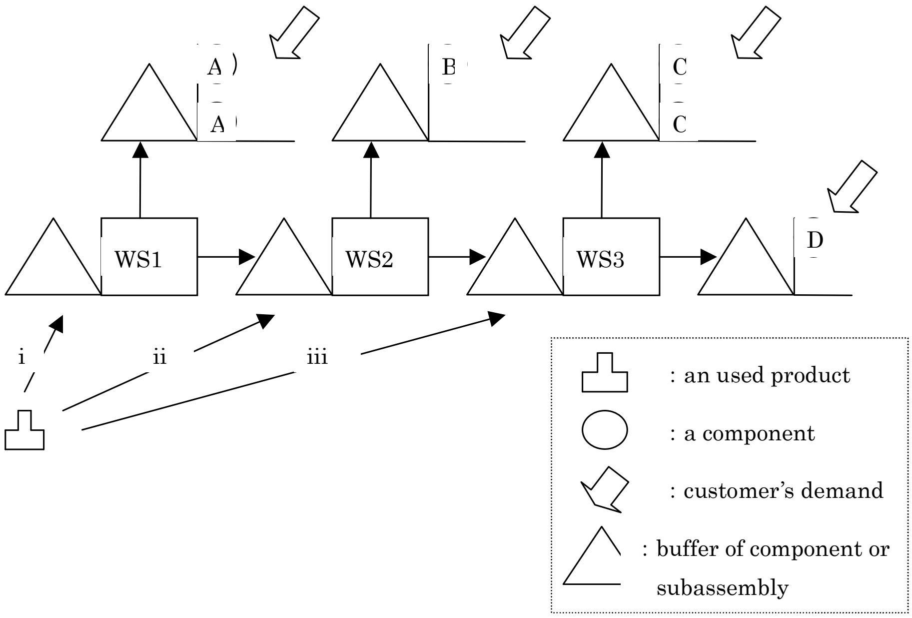

Figure 1. A general disassembly line (3 workstations)

3. The Model Descriptions

In this section, we consider and model part of a disassembly line based on an actual EOL vehicle disassembly factory [9]. The component structures of used products and subassemblies are given in Tables 1 and 2 respectively. Six types of products and eight types of subassemblies consisting of combinations of seven different parts make up the set of used products and subassemblies. Figure 2 shows the positions of workstations, products buffers, subassemblies buffers and components buffers. EOL products, P1-P6, arrive from outside at the appropriate workstations as shown in Figure 2. The customers demanding components arrive at the components buffers, A-F. Kanbans are attached to components and subassemblies. The disassembly of products and subassemblies are controlled by the kanbans.

Table 1. Components Structures of Products

		EOL Product					
	Component	P1	P2	P3	P4	P5	P6
A	Tire	X	X	X	X	--	--
B	Car navigation system	X	X	--	--	--	--
C	Bumper	X	X	X	X	--	--
D	Lead acid battery	X	X	X	X	X	X
E	Ni-MH battery	X	–	X	--	X	--
F	Engine	X	X	X	X	X	X
G	Body	X	X	X	X	X	X

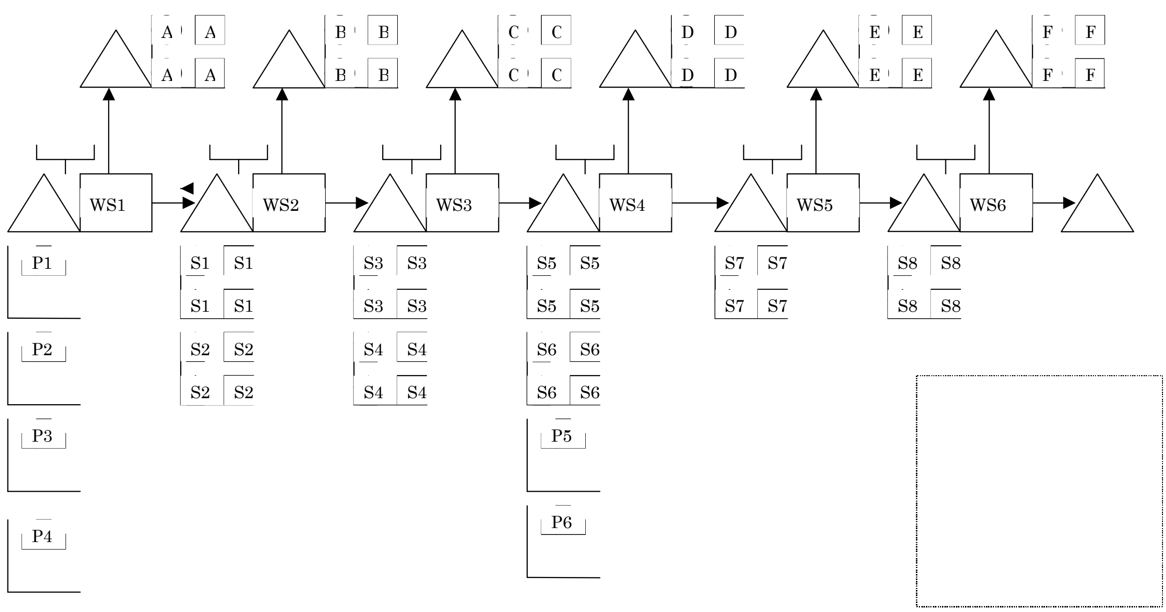

Figure 2. Disassembly line of EOL vehicle

Table 2. Components Structures of Subassemblies

		Subassembly							
	Component	S1	S2	S3	S4	S5	S6	S7	S8
A	Tire	–	–	–	–	–	–	–	–
B	Car navigation system	X	X	–	–	–	–	–	–
C	Bumper	X	X	X	X	–	–	–	–
D	Lead acid battery	X	X	X	X	X	X	–	–
E	Ni-MH battery	X	–	X	–	X	–	X	–
F	Engine	X	X	X	X	X	X	X	X
G	Body	X	X	X	X	X	X	X	X

4. Operations Management using Kanbans

In a multi-kanban system (MKS), two types of kanbans, viz., a component kanban and a subassembly kanban, are used. A component kanban is attached to a component at the component buffer. Similarly, a subassembly kanban is attached to a subassembly at the subassembly buffer. When a component or a subassembly with kanban is withdrawn by customer or subsequent WS, the kanban is detached from it and is sent to an appropriate WS. Two or more WS candidates can exist for delivery of the kanban. The kanban is sent to most appropriate WS based on the inventory level and shortage of stock situations.

(1) Component kanban
Figure 3 shows the movement of component kanban. Normally, the component kanban is delivered to the WS where the component is detached from a product or a subassembly. However, other actions could also be taken to minimize unnecessary accumulations on the line. Each step of movement of component kanban is explained below.

- When a demand occurs for a component, the component is withdrawn from its buffer. The kanban attached to the component is sent to the kanban post of WS where the component was detached from a subassembly.
- Disassembly of a component takes place when there is a component kanban at the kanban post. If there are two or more types of subassemblies that can be disassembled to obtained this component, MKS looks at the inventory levels of the buffer of the subsequent residual subassembly obtained by such disassembly. The subassembly chosen for disassembly is the one that will generate a residual subassembly where the inventory level is

low at the subsequent WS. For example, at WS2 in Figure 3, S1 can be dissembled into component B and subassembly S3, and subassembly S2 can be disassembled into component B and subassembly S4. Since inventory levels of S3 and S4 are two and one respectively at WS3, S2 will be disassembled in order to raise the inventory level of S4 to two.

- When the disassembly is completed, the component and its kanban are sent to the component buffer and the residual subassembly is forwarded to the buffer in the subsequent WS without the kanban.

(2) Subassembly kanban

Figure 4 shows the movement of subassembly kanban associated with subassembly S8. Normally, the subassembly kanban is delivered to the preceding WS from where the component is detached from a product or a subassembly. However, other actions could also be taken to minimize unnecessary accumulations on the line. Each step of movement of subassembly kanban is explained below.

- When disassembly begins at WS6, subassembly S8 is taken from the buffer. At this time, if subassembly kanban of S8 is detached and is sent to WS4 or WS5 depending on the size of their component buffers. The subassembly kanban is sent to the WS where the inventory level of component is lower. Priority is given to WS that is downstream when the component inventory levels are the same. In Figure 4, S6 is disassembled to component D and subassembly S8 in WS4, and S7 is also disassembled to component E and subassembly S8 in WS5. When subassembly kanban of S8 is detached at subassembly buffer in WS6, because inventory levels of component D and E are two and one respectively, the subassembly kanban will be sent to WS5.
- Disassembly of a component takes place when there is a subassembly kanban at the kanban post. Here, it is not necessary to select subassembly because subassembly kanban specifies only one type of subassembly to disassemble.
- When the disassembly is completed, the subassembly and its kanban are sent to the subassembly buffer. The component detached is sent to the component buffer without the component kanban.

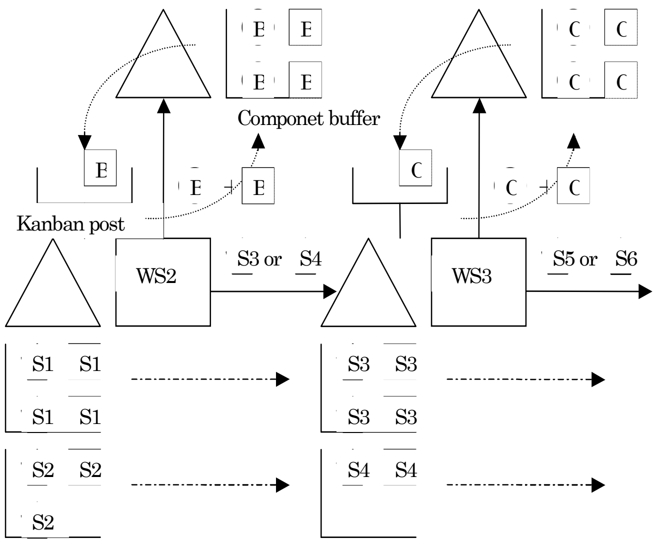

Figure 3. Movement of Component Kanban

5. Numerical Experiments

We conduct numerical experiments to evaluate the performance of the MKS system, given in Figure 2. The following five performance measures and graphs of inventory level are obtained using simulation.

- Average inventory levels of component at component buffer
- Customer's average waiting time at component buffer
- Occurrence number of back order of component
- Rate of back order of components
- Average inventory level of subassembly at subassembly buffer

The characteristics of the simulation experiments are as follows:

- Simulation model is an EOL vehicle disassembly line as depicted in Figure 2 and in Tables 1 and 2.
- Simulation is of discrete type.
- Arrival intervals of EOL products and subassemblies to the system are exponentially distributed.
- Arrival intervals of demand are also exponentially distributed.
- Disassembly times at each WS are uniformly distributed with interval [2, 4] and mean 3.
- The delivery lead times of components, subassemblies and kanbans are considered to be zero.
- Arrival intervals of EOL products to the system are exponentially distributed with means shown in Table 3.
- The simulation periods for the experiments are, T = 1500000, while the average values are based on the periods during 70000-1265000. Inventory level graphs are plotted at every 5000 period intervals during periods 5000 - 1265000.

- Two scenarios are considered.
  In Scenario 1, the mean arrival interval for every component demands is set to the same value, 8. The inventory levels of components C and F are, on average, below the number of component kanbans (see Table 4). The inventory level of C is below the number of kanbans because it is rare for the subassembly kanban to arrive at WS3 from a subsequent WS and further, a component kanban of C almost always arrives at the kanban post. The fluctuations of the inventory levels of component A and D are shown in Figure 5.

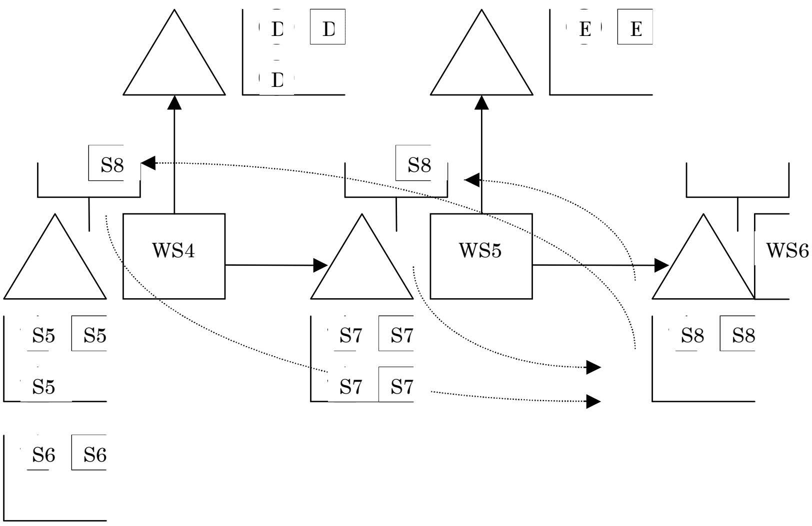

Figure 4. Movement of subassembly kanban

Table 3. Mean arrival interval of product

Product	P1	P2	P3	P4	P5	P6
Arrival interval	7	10	10	12	7	10

At WS1 where component A is disassembled, subassembly kanbans of S1 and S2 arrive from subsequent WS2 and subassembly kanbans of S3 and S4 arrive from WS3 in addition to component kanban of A. The inventory level of component A increases because of the disassembly triggered by other subassembly kanbans. Thus, the disassembly triggered by a subassembly kanban is completed at WS1 when the demands for components B and C are higher compared to the demand for component A, resulting in the increase in the inventory level of component A. In the figure 6, when one of the inventory levels is near zero, the inventory level of the other becomes high. In other words, either the inventory level of component D or the subassembly S7 disassembled at WS4 is always high. Disassembly by subassembly kanban is often done when the inventory level of component is high, and the disassembly by component kanban is similarly often done when the inventory level of subassembly is high.

In Scenario 2, the demand arrival intervals of components B, C, E and F are longer than in Scenario 1. The inventory levels of all components are below the number of kanbans (see Table 5). It is thought that subassembly kanbans arriving at WS1 from WS2 and WS3 almost disappears because there are obviously many customers for component A in comparison with the customers for components B and C. In addition, inventory levels of subassembly S1-S4 become high because of frequent disassembly by component kanbans at WS1. Similar relationships are seen at WS4-WS6.

Table 4. Numerical Results in pull system (Scenario 1)

Component buffer						Product buffer		Subassembly buffer	
	Demand arrival interval	Ave. Waiting time	Ave. Inv. level	Backorder	Backorder rate		Ave. Inv. level		Ave. Inv. level
A	8	0	236.4	0	0	P1	78974	S1	1.990
B	8	0.0809	78.56	2768	0.03938	P2	37079	S2	1.990
C	8	0.1961	1.530	6668	0.09420	P3	98154	S3	37.16
D	8	0	210.6	0	0	P4	81855	S4	36.94
E	8	0.0953	52.93	3223	0.04556	P5	17089	S5	61421
F	8	0.1914	1.531	6592	0.09323	P6	97650	S6	61420
								S7	1.980
								S8	68.75

Number of kanban at all buffers is 2.

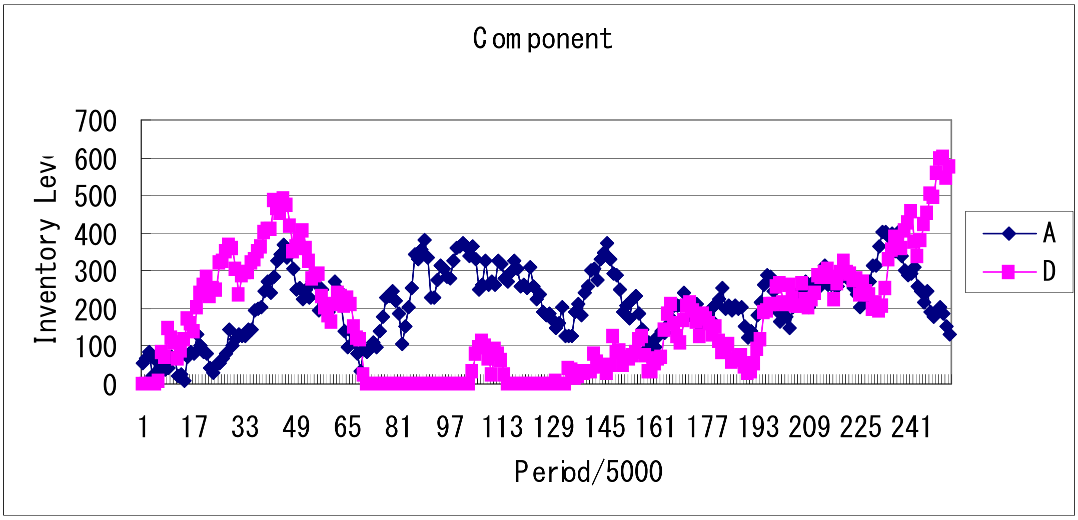

Figure 5. Inventory level of A and D (Scenario 1)

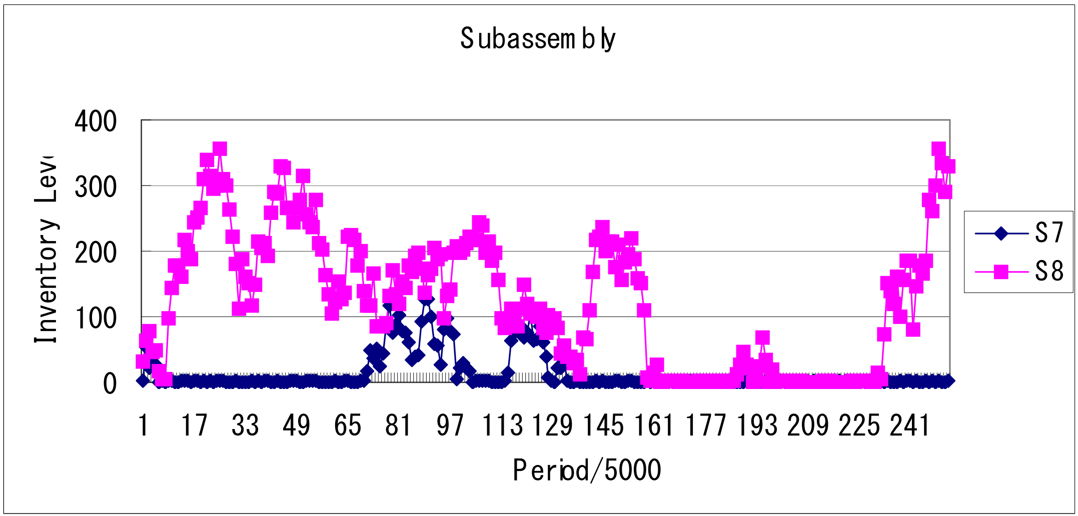

Figure 6. Inventory level of S7 and S8 (Scenario 1)

Table 5. Numerical Results in pull system (Scenario 2)

Component buffer						Product buffer		Subassembly buffer	
	Demand arrival interval	Ave. Waiting time	Ave. Inv. level	Backorder	Backorder rate		Ave. Inv. level		Ave. Inv. level
A	8	0.19393	1.532	6600	0.09343	P1	84183	S1	6111
B	10	0.09450	1.646	3053	0.05434	P2	44189	S2	6111
C	10	0.10430	1.644	3290	0.05846	P3	93061	S3	6117
D	8	0.19336	1.529	6749	0.09532	P4	74864	S4	6117
E	10	0.09683	1.644	3127	0.05539	P5	29094	S5	49113
F	10	0.11044	1.641	3488	0.06159	P6	85642	S6	49113
								S7	12459
								S8	12470

Number of Kanban at all buffers is 2.

6. Conclusions

In this paper, we proposed the disassembly line model of EOL products based on an actual EOL vehicular disassembly factory. It is controlled by the pull system using MKS with two types of kanbans. We investigated the fluctuations in components and subassemblies inventories, average customers' waiting times and backorder rates using simulation. Numerical results showed some properties of the disassembly line using two types of kanbans. These results demonstrated the effectiveness of utilizing the multi-kanban mechanism in a disassembly line. In the future works, we plan to implement this methodology into different types of disassembly lines and compare among the systems using various scenarios.

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