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Multi-Kanban Model for Disassembly Line with Demand Fluctuation

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ABSTRACT

In recent years, the continuous growth in consumer waste and dwindling natural resources has seriously threatened the environment. Realizing this, several countries have passed regulations that force manufacturers not only to manufacture environmentally conscious products, but also to take back their used products from consumers so that the components and materials recovered from the products may be reused and/or recycled. Disassembly plays an important role in product recovery. A disassembly line is perhaps the most suitable setting for disassembly of products in large quantities. Because a disassembly line has a tendency to generate excessive inventory, employing a kanban system can reduce the inventory level and let the system run more efficiently. A disassembly line is quite different from an assembly line. For example, not only can the demand arrive at the last station, it can also arrive at any of the other stations in the system. The demand for a component on the disassembly line could fluctuate widely. In fact, there are many other complicating matters that need to be considered to implement the concept of kanbans in such an environment. In this paper, we discuss the complications that are unique to a disassembly line. We discuss the complications in utilizing the conventional production control mechanisms in a disassembly line setting. We then show how to overcome them by implementing kanbans in a disassembly line setting with demand fluctuation and introduce the concept of multi-kanban mechanism. We demonstrate its effectiveness using a simulation model. An example is presented to illustrate the concept.

Keywords: JIT, Kanban, Disassembly.

1. INTRODUCTION

Currently, environmentally conscious manufacturing (ECM) plays an important role in many companies ranging from small business to very large enterprises. The reasons are due to many crucial factors such as customers' realization of environmental deterioration, hidden value of end-of-life products and government rules and regulations. Dwindling natural resources and continuous growth in consumer waste have led manufacturers and governments to pay more attention to product designs and manufacturing processes. Product recovery is a crucial element of ECM. Utilizing disassembly can increase the product recovery rate. By allowing selective disassembly, valuable materials and components from end-of-life products could be retrieved. Disassembly also provides a way to minimize hazardous materials from entering our sensitive environment. A disassembly line is perhaps the best choice for automated disassembly of end-of-life products. A disassembly line creates situations that are very different from what one sees in assembly line environment. Thus, it requires an appropriate, albeit complicated, production control system in order to function properly.

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Some of the reasons why a production control system plays a crucial role in a disassembly line setting are due to uncertainties in demand arrival, raw material arrival, and movement of materials throughout the line. Other reasons include uncertainties in the structure and the quality of the returned products. In addition, some parts of the product may cause pollution or may be hazardous and thus may require special handling, which can also influence the utilization of the disassembly workstations. Figure 1 gives a schematic diagram of a disassembly line.

There are two types of production control systems in a typical assembly line, viz., a push system and a pull system. A push system allows production of produce the product in advance according to a predetermined plan. Materials are normally scheduled to arrive at the line according to a materials requirements plan (MRP). In this case, inventory of the system is always maximized. On the other hand, a pull system only allows production when there is a demand for the product. Thus, it keeps inventory at the lowest possible level. This advantage of the pull system makes it even more attractive for a disassembly environment, which is highly inventory impulsive. Kanbans are often used in pull system to control the inventory level. It is easy to implement kanbans in an assembly setting. However, designing a kanban mechanism for a disassembly line is challenging and has not been reported in the past. Several factors must be taken into consideration. For example, routing kanbans in a disassembly line is way more complicated than in an assembly line. There are, in fact, multiple ways to route kanbans in a disassembly line setting. In contrast, there is only one way to route kanbans in a typical assembly line setting.

In this paper, we present a methodology to implement a pull system in a disassembly line setting. We provide a numerical example to illustrate the methodology and obtain results using simulation. We compare the performance of the pull system with that of the push system.

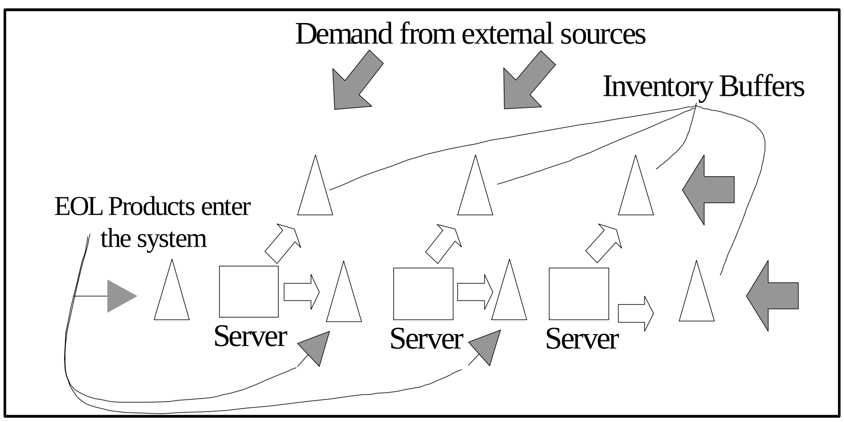

Figure 1. A Disassembly Line

2. LITERATURE REVIEW

The following is a brief review of the most relevant literature on kanban systems and disassembly.

For a basic description of kanban control mechanism, see Hopp and Spearman [10]. The authors describe the operations of kanban systems in one-card and two-cards environments. In spite of the simplicity of the kanban control mechanism, it is well known that the traditional kanban systems (TKS) fail to cope with many of the uncertainties that occur in real life situations. Gupta and Al-Turki [5], [6], [7] and Gupta *et al*. [8] propose the concept of the flexible kanban system (FKS) in various environments involving uncertainties. They demonstrated that in such environments, FKS outperforms TKS.

Several studies have recently emerged that address various aspects of disassembly. Within the area of disassembly, disassembly line has become the subject of recent interest [2], [3], [14], [16]. Korugan and Gupta [12] suggest an adaptive way of implementing kanbans to a single-stage hybrid system. A hybrid system refers to a combination of two distinct lines, viz., a production line and a disassembly line. For more information on disassembly and product recovery, see Brennan *et al*. [1], Gungor and Gupta [4], Gupta and McLean [9], Lambert [13] and Moyer and Gupta [15].

3. DISSASSEMBLY LINE

Disassembly line has unique characteristics, which makes it difficult to control when using conventional production control principles. In this section, we discuss three unique characteristics of a disassembly line, viz. arrival pattern of end-of-life (EOL) products, demand fluctuation, and inventory fluctuation. We then propose a methodology to tame these using the pull control principles.

3.1 Typical Characteristics of a Disassembly Line

Disassembly line consists of a series of workstations operating in a sequence to disassemble the end-of-life (EOL) products into subassemblies and/or components. Based on the type of EOL product, it may enter the disassembly line at any of the workstation, not just the first workstation. Similarly, depending on what is demanded, the demand could occur at any workstation, not just the last workstation. The arrival points and patterns of EOL products and demands are the two crucial differences that make a disassembly line different from an assembly line. These are also the reasons for disorderly fluctuations in the inventory levels in a disassembly line. The inventory control mechanism must therefore be carefully addressed in order to manage these fluctuations.

3.1.1. *Arrival pattern of EOL Product*

In a disassembly line, the arriving products may consist of different combinations of components from a given set of components. From a set of N components, the total number of possible combinations of components, $Q_{(N)}$ is given by

$$Q_{(N)} = 2^N - N - 1 \tag{1}$$

For example, a set of 4 components (A, B, C, D) can produce up to 11 possible product combinations (viz., AB, ABC, ABCD, ABD, AC, ACD, AD, BC, BCD, BD, CD). By adding one more component to the set, the number of possible combinations increases to 26. It is therefore clear that the number of combinations increases exponentially with the increase in the number of components. The workstation where a product enters the disassembly line depends on the combination of the components in the product. Thus for example, consider a disassembly line with three workstations. If component A is disassembled at workstation 1, component B is disassembled at workstation 2 and components C and D are disassembled at workstation 3, then 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. Furthermore, considering the same example, if an arriving product consists of components A, C, and D, it would have to enter workstation 1. However, after getting processed at station 1, it could skip workstation 2 entirely. Both these situations destabilize the disassembly line by causing an overflow of materials at one workstation while starving some other workstations leading to undesirable fluctuations of inventory in the system. It is therefore crucial to balance the line and manage the materials flow of the line.

3.1.2. *Demand Fluctuation*

The arrival pattern of demand in a disassembly line is much more complicated than in a typical assembly line. The key reason is the multilevel arrival of demand. Demand can occur at any level of the disassembly process. In most assembly lines, demand arrives only at the last workstation. In this case, even if multilevel arrival of demand were considered, its effect would be benign because the product does not go forward from there on as it is taken off the line to fulfill the demand. In a disassembly line setting, however, the arrivals of external demand at workstations other than the last one 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 it is necessary to maximize it, it becomes necessary to develop a good methodology to control the system and find a way to manage the extra inventory produced.

3.1.3. *Inventory Fluctuation*

As mentioned before, due to various disparities, a disassembly line is fraught with erratic fluctuations of inventory. Even though mechanisms such as kanban, base stock and CONWIP have been used in an assembly line setting, they have not been deployed in a disassembly line setting. This is true because these mechanisms are not suited for the disassembly environment in their current forms. This, therefore, leads to the need for developing better production control systems in order to efficiently work in a disassembly line setting.

3.2 Production Control System in Disassembly Line

In general, there are two types of control mechanisms: *push mechanism* and *pull mechanism*. The push mechanism relies on a predetermined production schedule based on the expected demand of finished products. Raw materials are pushed through the system in order to meet the future demand. On the other hand, the production in pull mechanism is triggered by the actual demand and causes a flow of materials throughout the system. These two mechanisms have been topics for debates for their superiority in system efficiency, customer service level, and ease of implementing. Conclusions from those studies are mixed. In fact, none of mechanisms dominates in all situations. The push system has advantages in terms of experience in implementing it and providing higher levels of customer service in certain production scenarios because the system tends to build up inventory. On the other hand, the pull mechanism has an advantage that it does not generate large amounts of inventory. Instead, it has a mechanism to control the inventory. However, it relies heavily on consistency of raw materials supplies and agility of the server. It only produces when and where there are needs. This is the main reason why pull mechanism is more likely to perform better than push mechanism in a disassembly line.

Kanban is one of the most commonly used pull mechanism tools available. However, once implemented in a disassembly line setting, it is fraught with numerous uncertainties. A modification of the mechanism is therefore needed to improve its performance by reducing these difficulties and allowing the system to operate at its best. In the next section, we introduce a multi-kanban mechanism that is designed for implementation in a disassembly line setting where supply and demand fluctuate extensively.

4. MULTI-KANBAN MODEL FOR DISASSEMBLY LINE WITH DEMAND FLUCTUATION

The multi-kanban mechanism proposed here employs many different kanbans that correspond to various components and subassemblies in the system. The kanbans are used mainly to control the inventory level of the system by initiating and terminating the disassembly process at workstations.

4.1 Kanban Types

There are two basic types of kanbans in the system, viz., *component kanbans* and *subassembly kanbans*. A component kanban is attached to a disassembled component that is placed in the component buffer of the workstation where it is disassembled. Similarly, a disassembly kanban is attached to a residual subassembly that is placed in the subassembly buffer of the workstation where it was separated from the component. A component placed in a component buffer can be retrieved by an external demand. When authorized, a subassembly placed in the subassembly buffer is routed for disassembly to the next workstation based on its disassembly sequence.

At the first workstation, products arrive only from outside sources. However, at any other workstation i, where $1< i \leq N$-1, there are two possible types of arrivals. The first type is a subassembly that arrives from an upstream workstation, called *internal subassembly*. There is always a subassembly kanban attached to an internal subassembly. The second type is a product (or subassembly) that arrives from outside sources, called *external subassembly*. There is no kanban attached to an external subassembly. This is also true of the products arriving from external sources to the first workstation. As long as there is an external product or subassembly available at an input buffer, the system will process it first before processing any available internal subassembly. This will avoid unnecessary pulling of an internal subassembly from an upstream workstation. Thus, the number of kanbans attached to internal subassemblies will remain constant throughout the process. Figure 2 illustrates the kanbans and materials flow in a disassembly line.

4.2 Material Types

As mentioned earlier, there are two basic types of materials in the system, viz., *components* and *subassemblies*. A component is a single item that cannot be further disassembled. It is placed in the component buffer waiting to be retrieved via a customer demand. On the other hand, a subassembly is something that can still to be disassembled.

Subassembly is composed of at least two components. Both types of materials can be further distinguished as regular or overflow items. Regular items are what customers or downstream workstations demand. In order to fulfill the demand, a server must disassemble the demanded component or subassembly. The residual item from this disassembly process that does not fulfill any request is called overflow item. Because the disassembly process is initiated by a single kanban, the overflow item will not have a kanban attached to it. However, the overflow item is routed in the same way as the regular item. The only difference between them is that the overflow item is given priority of being retrieved after it arrives at its buffer. It should be noted that, as long as there is an overflow item in the buffer, its demand would not initiate any further disassembly process. This will help the system eliminate any extra inventory first that is caused due to unbalanced demands.

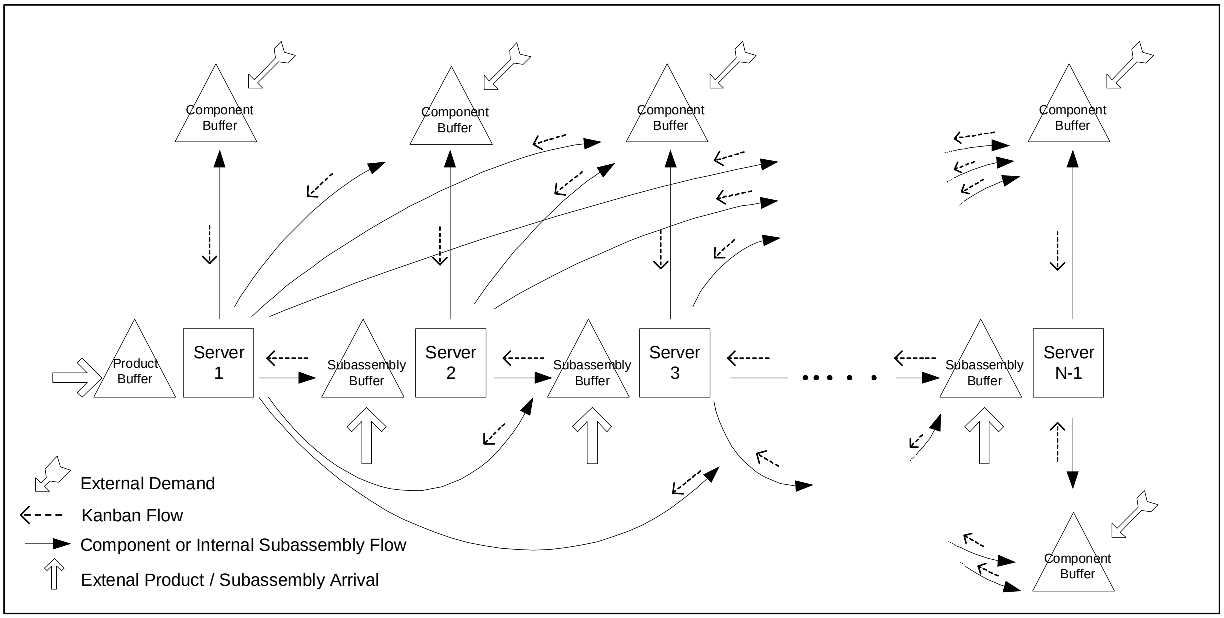

Figure 2. **Kanbans and Materials Flows in a Disassembly Line**

4.3 Kanban Routing Mechanism

Figure 3 illustrates how the kanban mechanism works. Consider workstation j, where $1 \leq j \leq N$-1. When a demand for component j arrives at the component buffer of workstation j, one unit of component j is retrieved and the component kanban j attached to it is routed to the most desirable workstation. The procedure for determining the most desirable workstation to route component kanban j is given below. (Note that this procedure is not applicable to component kanbans N-1 and N. In both cases the kanbans are routed to the input buffer of the last workstation).

A component kanban originating from workstation j will be routed to a workstation i, where $1 \leq i < j$, or workstation j depending on the availability and the desirability of the subassembly that contains component j. Routing component kanban j to workstation i, where $1 \leq i \leq (j\text{-}1)$, will result in an immediate separation of component j from component i. Thus, the only subassembly located at the input buffer of workstation i that would be useful is a subassembly that contains only components i and j. If this type of subassembly exists in the input buffer of workstation i, then workstation i is qualified. Similarly, if there is at least one subassembly in the input buffer of workstation j, then workstation j is qualified.

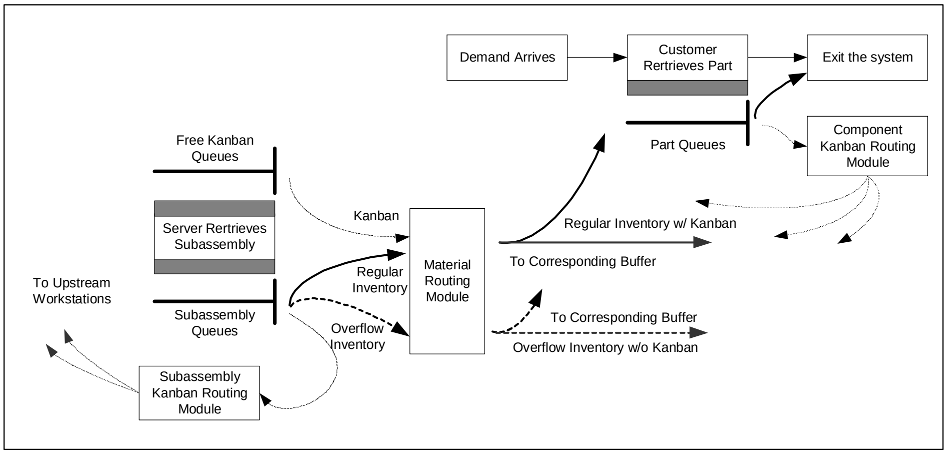

Figure 3. The Multi-Kanban Mechanism

Next, we need to select the most desirable workstation to route component kanban *j* to, among the qualified ones, such that, if chosen, will cause the least amount of extra inventory in the system. Choosing workstation *i* will increase the inventory level of component *i* by an additional unit. Thus, the best workstation *i* is the one that is most starving for its component. By checking the backorder level for demand *i*, we could determine the most starving workstation. If there is a tie, select the most downstream workstation. Choosing workstation *j* will create a residual subassembly that will be further disassembled at downstream workstations. If workstation *j* is chosen, then a proper subassembly must be chosen to disassemble. For example, if a backorder exists at the component buffer of workstation *k*, where $j < k \leq (N\text{-}1)$, then, if available, we might try to disassemble a subassembly that contains only components *i* and *k*. If more than one workstation qualify as starving workstations, then the one that is most starving among them is chosen. If there is a tie, then the most downstream workstation is selected.

We can now compare the starving levels of workstations *i* and *j*. If the highest starving level of workstation *i* is greater than or equal to the starving level of workstation *j* then we will route the component kanban *j* to workstation *i*, otherwise, we will route it to workstation *j*. Note that whenever an external subassembly is available, it will always be chosen first. Internal subassemblies will only be used when no external subassembly of the desired kind is available. Subassembly kanbans are routed in a fashion similar to component kanbans.

5. LINE DESCRIPTION AND ASSUMPTIONS

We consider a disassembly line with *N*-1 workstations. The inputs to the line are products (raw materials) with structures that are composed of various combinations of up to *N* unique components from a list of *N* unique components. Any combination of components is possible. The input location for an arriving product depends on its configuration. The input location for a product is the most upstream workstation that is used to disassemble a component from that product. Only one type of component is disassembled at a given workstation except at the last workstation where component *N*-1 and component *N* are separated.

We assume that each component takes the same amount of time to disassemble. At each workstation, there are two types of output buffers, viz., component buffer and subassembly buffer. The componennt disassembled at a workstation, s_i, is placed in the *component buffer*, B_i. The rest of the subassembly is routed to the *subassembly buffer*, B'_i. The subassembly buffer becomes the input buffer for the subsequent workstation to further disassemble the subassembly according to its disassembly sequence.

There are multiple sources of demands. A demand can occur at any workstation. The demand at a given workstation is always for the component that is disassembled at that workstation. Regardless of the configuration, products must be disassembled in a predefined sequence from the first component to the last component. When a particular component is demanded, it is retrieved from the output component buffer, B_i, of the workstation where it is disassembled. We allow only single-unit retreival at a time. If there is no component available at the component buffer, the demand waits there in the form of a backorder.

6. NUMERICAL EXAMPLE

We employ a numerical example to illustrate the application of the multi-kanban concept. Consider three different products (ABCDE, ABC, and AC) made up of various combinations of components from a set of five possible components, viz., A, B, C, D, and E, that have to be disassembled to fulfill the demands of each of the components. Disassembly is performed on a disassembly line consisting of four workstations. Component A is disassembled at workstation 1, component B is disassembled at workstation 2, component C is disassembled at workstation 3, and components D and E are disassembled at workstation 4. Figure 4 shows the movement of subassemblies and components throughout the system. Table 1 provides the products' mean arrival rates, the mean disassembly times for components and the mean demand arrival rates for components, which are all exponentially distributed, except for the demand rate for component C, which is a constant.

We used ARENA® software [11] to simulate the model. We ran two sets of experiments representing the push system and the multi-kanban system. For each experiment, we collected the data over a two-day period. In the push system, all arriving products are processed continuously in the order of their arrival. The demand is fulfilled as soon as the components are available. In the multi-kanban pull control system, we utilize smart-routing for kanban C (as explained in the Kanban Routing Mechanism subsection) in order to reduce the inventory built up caused by disparity in demands among components A, B, C, D and E. In these experiments, statistics on the following two performance measures were collected (see Table 2): system's ability to fulfill demand and average inventory level.

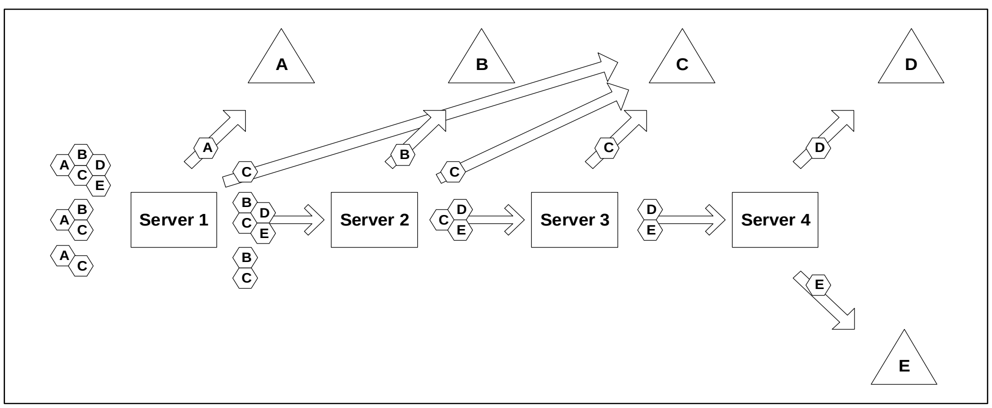

Figure 4. Material Movement in the Disassembly Line

Table 1. Mean Disassembly Times and Mean Arrival Rates

Product / Component	Mean Disassembly Time (minutes)	Product / Demand Mean Arrival Rate (units/hour)
ABCDE	-	3
ABC	-	3
AC	-	3
A	8	5
B	8	2
C	8	3*
D	8	1
E	8	1

* Constant value

Table 2. Performance Measurements of Push and Multi-Kanban Pull Control System

	Fulfilled Demand (unit)			Average Inventory (units)		
	Push	Multi-Kanban	% Change	Push	Multi-Kanban	% Change
A	237	239	+ 0.8%	39	4	- 89.7%
B	90	94	+ 4.44%	81	5	- 93.8%
C	145	145	-	85	39	- 54.1%
D	52	54	+ 3.8%	45	5	- 88.9%
E	55	53	- 3.6%	36	8	- 77.8%

It is clear from Table 2 that the multi-kanban mechanism significantly reduces average inventory while maintaining the components' demands fulfillment rates. In the push environment, the system builds up inventory in order to fulfill customers' demands. A fluctuation in demands is coped well by the large amount of inventory. On the other hand, the multi-kanban mechanism deals with fluctuation among demands by routing the kanbans to the most suitable workstation. In the example considered here, kanban C could be routed to either workstation 1 or workstation 2 or workstation 3. By examining the number of parts being requested in real time, the system selected the appropriate destination for the kanban. For the example considered, the system was able to reduce the inventory level by an average of 80% while fulfilling customers' demands using only 5 kanbans in the system.

7. CONCLUSIONS

Despite serious complications in a disassembly line, this paper demonstrated that a pull system could be adapted to perform well in the disassembly setting. With the help of an example, it was shown that the proposed multi-kanban mechanism could be implemented effectively. The multi-kanban mechanism allows the system to meet the customers' demands and stabilizes the fluctuations in the system's inventory levels. To achieve this, the mechanism relies on real time adjustment of kanban routing.

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