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Multi-Kanban Mechanism for Personal Computer Disassembly

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ABSTRACT

The use of personal computers (PCs) continues to increase every year. According to a 1999 figure, 50 percent of all US households owned PCs, a figure that continues to rise every year. With continuous development of sophisticated software, PCs are becoming increasingly powerful. In addition, the price of a PC continues to steadily decline. Furthermore, the typical life of a PC in the workplace is approximately two to three years while in the home it is three to five years. As these PCs become obsolete, they are replaced and the old PCs are disposed of. It is estimated that between 14 and 20 million PCs are retired annually in the US. While 20 to 30% of the units may be resold, the others are discarded. These discards represent a significant potential source of lead for the waste stream. In some communities, waste cathode ray tubes (CRTs) represent the second largest source of lead in the waste stream after vehicular lead acid batteries. PCs are, therefore, not suitable for dumping in landfills. Besides, several components of a PC can be reused and then there are other valuable materials that can also be harvested. And with the advent of product stewardship, product recovery is the best solution for manufacturers. Disassembly line is perhaps the most suitable set up for disassembling PCs. However, planning and scheduling of disassembly on a disassembly line is complicated. In this paper, we discuss some of the complications including product arrival, demand arrival, inventory fluctuation and production control mechanisms. We then show how to overcome them by implementing a multi-kanban mechanism in the PC disassembly line setting. The multi-kanban mechanism relies on dynamic routing of kanbans according to the state of the system. We investigate the multi-kanban mechanism using simulation and demonstrate that this mechanism is superior to the traditional push system in terms of controlling the system's inventory while maintaining a decent customer service level

Keywords: JIT, Kanban, Disassembly.

1. INTRODUCTION

Recently, environmentally conscious manufacturing (ECM) has become an important issue among consumers and manufacturers. The increase in consumer waste and reduction in natural resources have threatened the environment and significantly influences the government to take step. Consequently, many products have become more environmental friendly and can be recycled at the end of their usage. Product recovery is a crucial element of ECM. Utilizing disassembly can increase product recovery rate. By allowing selective disassembly, valuable materials and components from end-of-life products could be retrieved efficiently. These materials and components can be reused in manufacturing of new or refurbished products especially in electronic industry.

Lately, disassembly of end-of-life personal computer (PC) has become subject of interests for component reseller and material recycler. Demand for PCs has increased dramatically during recent years. As the newer model become more powerful, consumers tend to discard their old PCs in favor of the newer and more affordable model. This causes PCs to have considerable shorter lifespan than other household electronics and appliances. End-of-life PCs usually contain both functional and nonfunctional components. Many reusable components can be sorted out and furnished to repair and refurbish industry. Other nonfunctional or non-reusable components commonly contain broad types of precious

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materials, such as silver, gold and platinum as well as copper and steel. These materials are highly recyclable. In fact, component and material recovery of PC is not uncommon in many environmentally concerned countries. In order to recover these components and materials efficiently, one must look into basic structure of a PC. In general, a PC consists of power supply, main board, memory, adaptors, hard drive, and media drives. These components are assembled on a steel case using screws and protected by removable steel cover. Components can be disassembled from each other using simple tools such as a screw driver. There is precedence relationship involved in disassembling a PC. Thus, each product configuration of PC has its own disassembly sequence.

Disassembly line is considered one of the best means for disassembly of end-of-life products in large quantity. It consists of series of disassembly workstations working in sequence. Products can arrive at any levels along the line. PCs can be efficiently disassembled using a disassembly line setting because of their component structure. Not only PCs share common components, but these components are also assembled together in the similar fashion, similar precedence relationship and can be basically disassembled using similar type of tools. Usually, demand for similar components does not discriminate among sub-models. This allows similar components to be disassembled at a single workstation. A series of disassembly workstation is likely to allow faster and more efficient disassembly because worker will deal with fewer amounts of materials and disassembly techniques. It also results in more manageable of demand for each type of components.

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. Some of the reasons why a production control system plays a crucial role in a PC disassembly line are due to uncertainties in demand arrival, end-of-life PCs arrival, and movement of materials throughout the line. Other reasons include uncertainties in the structure and the quality of the end-of-life PCs. In addition, some parts of the PC may cause pollution or may be very sensitive to environment 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.

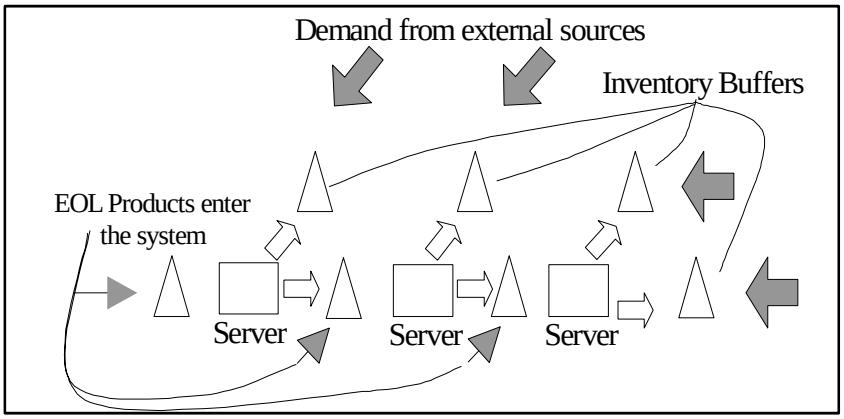

Figure 1. A Disassembly Line

Push system and pull system are two types of production control systems in a typical assembly line. A push system allows production of produce the product in advance according to a predetermined plan. Materials arrive the line according to a predetermined schedule, called materials requirements plan (MRP). In this case, the mechanism always maximizes inventory. On the other hand, a pull system only allows production when there is a demand for the product. Thus, inventory is kept down at the lowest possible level. This advantage of the pull system makes it even more attractive for a PC disassembly, which is highly inventory impulsive and component should not to be stored. This is because the disassembly process is labor intensive and PC components are easily obsolete. There are many tools to help implementing pull system. Kanbans is among the easiest tools to implement yet powerful enough to control the inventory level efficiently. 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 Kanban pull system in a PC 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.

2. LITERATURE REVIEW

Hopp and Spearman [13] describe the basic description of kanban control mechanism and its operations in one-card and two-card environments. Kanban control mechanism is well known in the simplicity. However, the traditional kanban systems (TKS) fail to cope with many of the uncertainties that occur in real life situations. Gupta and Al-Turki [8], [9], [10] and Gupta *et al*. [11] 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. Gungor and Gupta [7] provide a comprehensive survey of issues in environmentally conscious manufacturing and product recovery. Within the area of disassembly, disassembly line has become the subject of recent interest [5], [6], [19], [22]. Korugan and Gupta [16] 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*. [2], Gupta and McLean [12], Lambert [18] and Moyer and Gupta [20].

Many researches address end-of-life strategies, disassembly sequencing, and recycling plan of personal computer and electronics disassembly. Lambert [17] suggest the optimal disassembly sequence in electronics disassembly using linear programming. Das *et al*. [3] report on the use of WebVDM tool to analyze a personal disassembly from disassembly perspective. Boon *et al.* [1] investigate the factors that most influence the profitability of end-of-life processing of PCs. For more information on electronics disassembly and recycling, see Jung and Bartel [14], Ellis [4], and Sodhi and Reimer [21].

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.

3.3 Disassembly Line for Personal Computer Disassembly

As mentioned earlier, the majority of components from end-of-life PC are reusable or recyclable, especially steel cover, adaptors, memory, hard drive, media drive, power supply, main board, and steel case. Components that are functional can be supplied to second hand market, used in refurbished products, or used in PC repair. Other components that are outdating easily or not functional can be supplied to recycling industry. Printed circuit board (PCB), transformer, steel cover and case, are composed of recyclable steel, copper and other precious materials such as silver, gold and platinum. Obviously, demands for these components are highly uncertainty and varied component by component. It results in fluctuation in inventory level of the disassembly system. This is very crucial because, by nature of PC industry, many components can be obsolete within short period. Also, disassembly is a labor intensive process. Thus, components should not be stocked for future demand. This is when a pull-type system comes into the picture.

Disassembly of PCs in large quantity can be facilitated by employing a disassembly line. Each workstation removes one type of component at a time. The disassembly process starts by removing the cover, adaptors, memory, hard drive, media drive, power supply, main board and case. The disassembly sequence for a completed PC is shown in Figure 2. The advantage of disassembly line is that it helps operator to deal with variation in different demand for different components. It also allows employing of pull-type mechanism in order to cope with inventory fluctuation. However, a mechanism such as kanban needs to be adapted to multiple-product and multiple-demand environment. In the next section, we propose a Multi-kanban model for disassembly line. The Multi-Kanban Mechanism proposed here employs many different types of 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

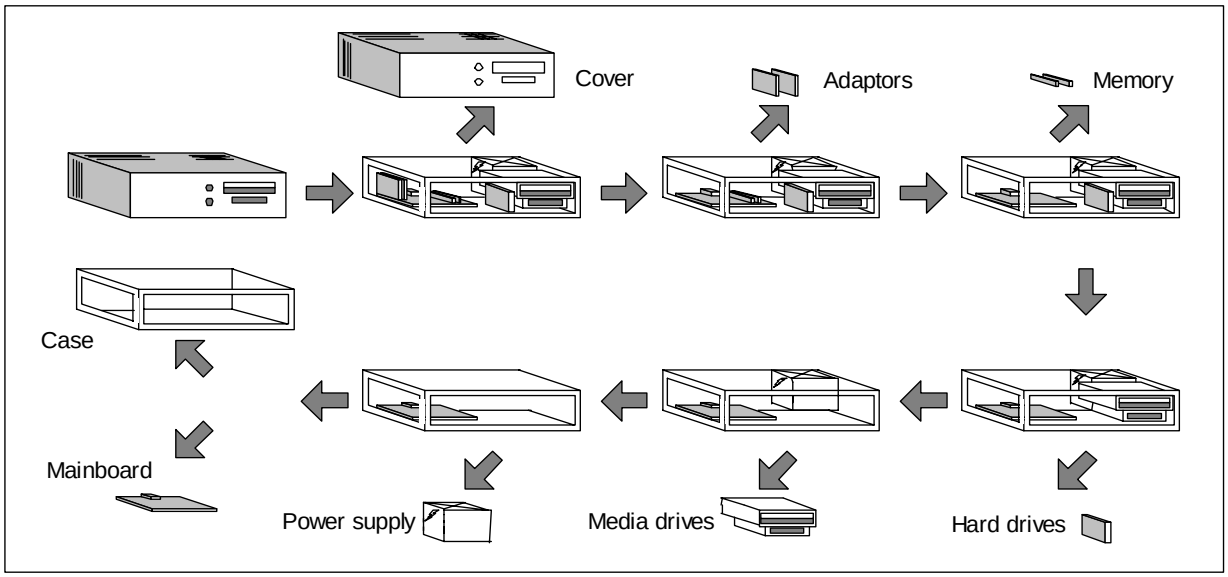

Figure 2. Disassembly of Personal Computer

4. MULTI-KANBAN MODEL FOR DISASSEMBLY LINE

4.1 Material Types

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

4.2 Kanban Types

Corresponding to material 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 3 illustrates the kanbans and materials flow in a disassembly line.

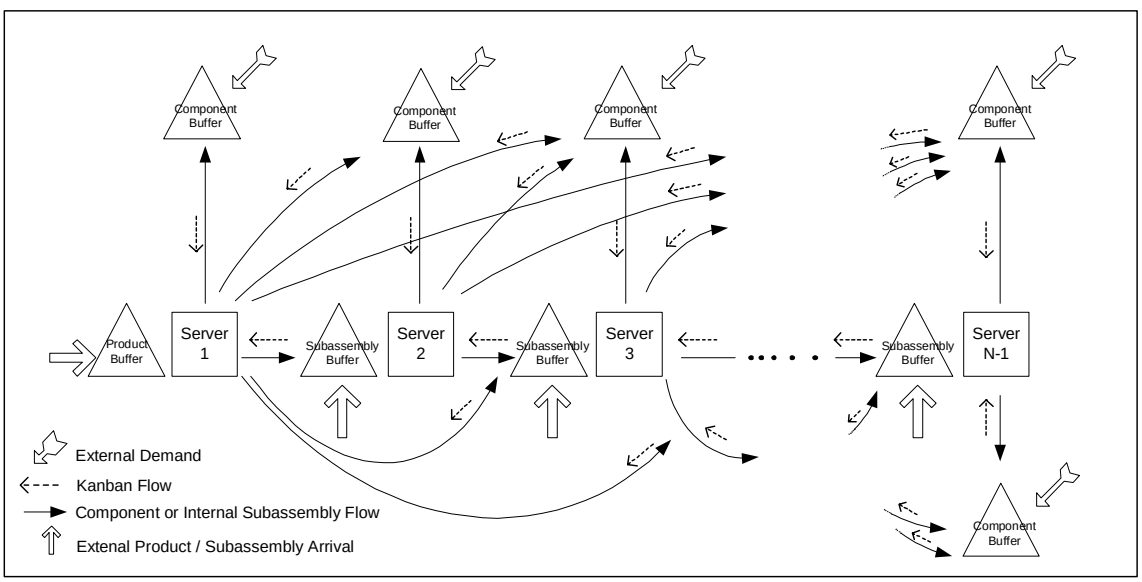

Figure 3. Kanbans and Materials Flows in a Disassembly Line

4.3 Kanban Routing Mechanism

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 $1 \leq i \leq (j-1)$, 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.

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 $j < k \leq (N-1)$, 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. Figure 4. shows a concept of the Multi-Kanban Mechanism.

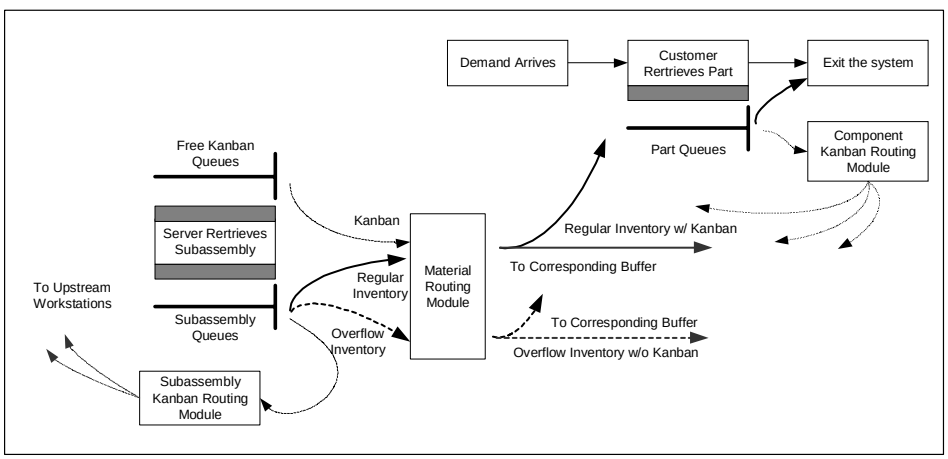

Figure 4. The Multi-Kanban Mechanism

4.4 Selection of Products

Because we allow multiple combinations of products, the worker may have several options when selecting the product for disassembly. If the authorization of disassembly is initiated by the subassembly kanban (j_x), which can occur only at workstation *i*, where $1 \leq i < j$, the workers will have no option but to select the subassembly that results in immediate separation of subassembly (j_x), viz., subassembly (ij_x). If the authorization of disassembly is initiated by component kanban *j* at workstation *i*, where $1 \leq i < j$, the worker will have to remove subassembly *(ij)* from the product buffer with no other options because the only subassembly that results in immediate separation of component *j* is the subassembly *(ij)*. However, if the component kanban *j* arrives at workstation *j*, there are multiple options because every subassembly located in the product buffer contains component *j* and always results in immediate separation of component *j*. In this case, we determine whether or not the residual that is created by the disassembly will result in overflow of inventory. We choose the subassembly (j_x) where *x* is the most desirable residual ranking based on the request of subassembly kanban *x*

at workstation j (existing kanban x at the workstation j) or current inventory level of subassembly (component) x, respectively.

4.5 Determining the Kanban Level

The kanban level plays an important role in the multi-kanban mechanism as it maintains a proper flow of components and subassemblies at a desired level throughout the system. It can be determined by considering product arrival rate, demand arrival rate and disassembly time. The number of kanbans for both the *component kanban*, k_i and the *subassembly kanban*, k_j^* can be computed, at any point in the disassembly line, using the following general expressions:

$$k_i = \max(1, R_i / F_i) \tag{2}$$

$$k_j^* = \max(1, R_j^* / F_j^*) \tag{3}$$

where R_i is the *request rate* of component i, F_i is the *furnish rate* of component i, R_j^* is the *request rate* of subassembly j, and of F_j^* is the *furnish rate* subassembly j. These request rates and furnish rates can be calculated as follows:

$$R_i = d_i \text{ , for } 1 \le i \le N \tag{4}$$

$$F_i = \sum_{w=1}^{i} s_{(i,w)} \text{ , for } 1 \le i \le N \tag{5}$$

$$R_j^* = s_i \text{ , } i \text{ is the next component to be disassembled in the sequence} \tag{6}$$

$$F_j^* = a_j^* + \sum_{w=1}^{m-1} s_{(i,w)} \text{ , } i \text{ is the latest component disassembled in the sequence} \tag{7}$$

Where d_i is the demand arrival rate of component i, $s_{(i,w)}$ is the disassembly rate of component i at workstation w, s_j is the disassembly rate of subassembly j, a_j^* is the arrival rate of subassembly j (from external source), m is the current workstation index, N is the maximum number of component, and N-1 is the maximum number of workstation. For the case of *component kanban*, which is requested only from a single source, request rate is equal to the customer demand arrival rate. However, because the component kanban arrives from several sources in the system, the furnish rate is the summation of arrival rates from all possible sources. For the case of *subassembly kanban*, the furnish rate is influenced by both the disassembly rate and the external subassembly arrival rate. Thus, we take all external and internal arrival rates of subassemblies at the buffer into account. Similarly, the two requesting sources, viz., the demand for target component and the demand for residual subassembly affect the request rate. The number of kanbans is determined at the beginning of the disassembly process. It is clear that demand, supplies, disassembly time, and product structure, all affect the computation of the number of kanbans.

5. LINE DESCRIPTION AND ASSUMPTIONS

We consider a PC disassembly line with 6 workstations. End-of-life PCs arrive the line in various configurations. The input location for end-of-life PCs depends on its configuration. The input location for a PC is the most upstream workstation that disassembles the first component, according to precedence relationship, from that PC. Only one type of component is disassembled at a given workstation except the last workstation where motherboard and case are separated.

It takes different amount of time to disassemble different components. At each workstation, there are two types of output buffers, viz., component buffer and subassembly buffer. The component 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 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, a PC 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. If there is no component available at the component buffer, the demand waits there in the form of a backorder.

In studying the example model using simulation, the following assumptions were made:

(a) Customer backorder is allowed.
(b) External demand is for component only and can arrive at any workstation.
(c) Components must be disassembled according to their precedence relationships one type at a time until the last component in disassembly sequence is disassembled.
(d) Products and subassemblies can arrive at any workstation along the line depending on its configuration.

6. NUMERICAL EXAMPLE

A numerical example of a PC disassembly line with 6 workstations is used to illustrate the application of the multi-kanban concept. In this case, we disregard the steel cover in order to reduce the size the model. There are seven target components, viz. memory, adaptor card, media drive, hard drive, motherboard, power supply, and case. We use an online survey to investigate common configuration of discarded PCs. Six most common product configurations are shown in Table 1. From this data, disassembly is performed on a disassembly line consisting of six workstations. Component A, representing memory module is disassembled at workstation 1. B, representing adaptor card, is disassembled at workstation 2. Component C, representing media drive, is disassembled at workstation 3. Component D, representing hard drive, is disassembled at workstation 4. Component E, representing motherboard, is disassembled at workstation 5. Finally, component F, representing power supply, is disassembled from component G, representing steel case, at workstation 6. Table 1 also provides mean arrival rates for products, mean disassembly times for components, mean demand arrival rates for components, which are all exponentially distributed, and kanban level, which calculated using formula proposed in this paper. Table 2 presents the data for all seven subassemblies results from both disassembly process and external arrival.

We used ARENA® software [15] 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 subassembly kanban EFG (as explained in the Kanban Routing Mechanism subsection) in order to reduce the inventory built up caused by disparity in demands among components. We also utilize product selection method (as explained in the Selection of Products subsection) for the first three workstations. In these experiments, statistics on the following two performance measures were collected: system's ability to fulfill demand and average inventory level.

It is clear from Figure 5 and Figure 6 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 EFG could be routed to either workstation 2 or workstation 3 or workstation 4. 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 54% while fulfilling customers' demands using only 2 kanbans or less in the system

Table 1. Product Details

	Component	Demand arrival rate	Products (external arrival)						Disassembly time	Kanban level
			1	2	3	4	5	6		
A	Memory	15	X	X	-	-	-	-	2	1
B	Adaptors	15	X	X	X	X	-	-	3	1
C	Media drives	15	X	X	X	-	X	-	5	2
D	Hard drive	10	X	-	-	-	-	-	3	1
E	Mother board	20	X	X	X	X	X	X	3	1
F	Power supply	20	X	X	X	X	X	X	3	1
G	Case	20	X	X	X	X	X	X	3	1
Arrival Rate			10	5	2	1	1	1		

Table 2. Subassembly Details

	Component	Subassembly							Disassembly time
		1	2	3	4	5	6	7	
A	Memory	-	-	-	-	-	-	-	2
B	Adaptors	X	X	-	-	-	-	-	3
C	Media drives	X	X	X	X	-	-	-	5
D	Hard drive	X	-	X	-	X	-	-	3
E	Mother board	X	X	X	X	X	X	-	3
F	Power supply	X	X	X	X	X	X	X	3
G	Case	X	X	X	X	X	X	X	3
Source station's disassembly time		2	2	3	3	5	3, 5, 3	3	
External arrival rate (a_j)		-	2	-	1	-	1	-	
Subassembly Kanban Level		1	1	1	1	2	1	1	

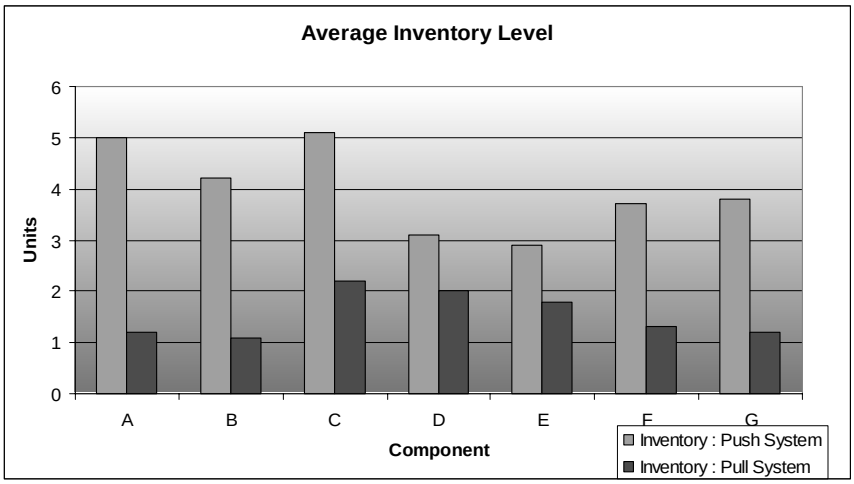

Figure 5. The Average Inventory Level

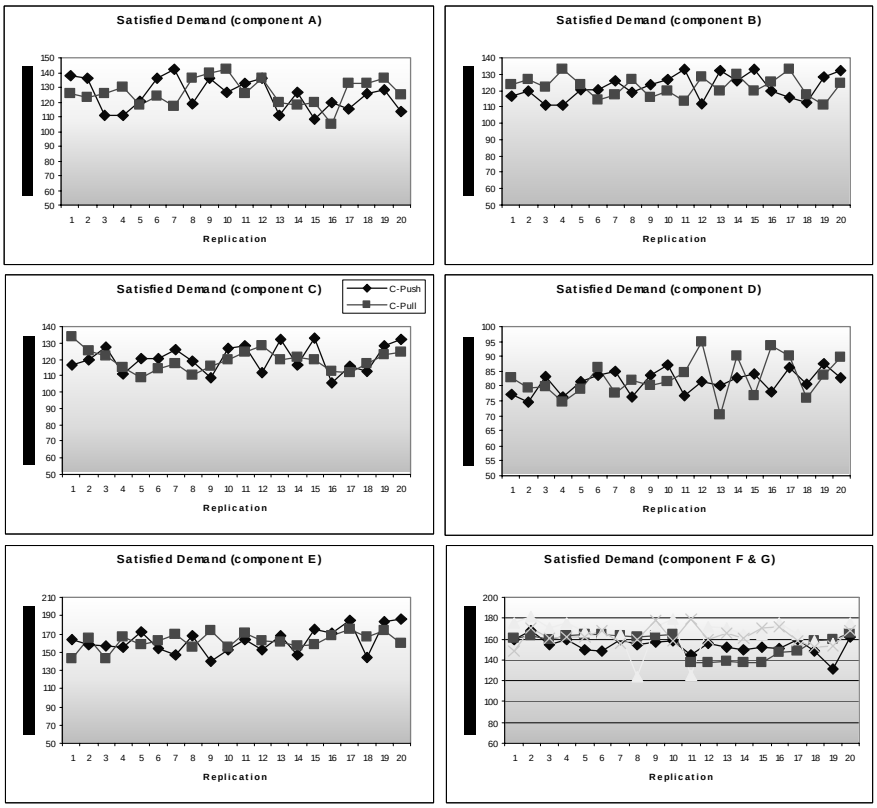

Figure 6. Number of Satisfied Demand for Multi-Kanban System and Push System

7. CONCLUSIONS

This paper demonstrated that a pull system could be adapted to perform well for PC disassembly, despite serious complications in a disassembly line. 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

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