

January 01, 2005

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Recommended Citation

Gupta, Surendra M. and Udomsawat, Gun, "Multi-kanban mechanism for appliance disassembly" (2005). . Paper 78.
<http://hdl.handle.net/2047/d10009838>

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Bibliographic Information

Udomsawat, G. and Gupta, S. M., "Multi-Kanban Mechanism for Appliance Disassembly", *Proceedings of the SPIE International Conference on Environmentally Conscious Manufacturing V*, Boston, Massachusetts, pp. 30-41, October 23-24, 2005.

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Multi-Kanban Mechanism for Appliance Disassembly

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ABSTRACT

The use of household appliances continues to rise every year. A significant number of End-Of-Life (EOL) appliances are generated because of the introduction of newer models that are more attractive, efficient and affordable. Others are, of course, generated when they become non-functional. Many regulations encourage recycling of EOL appliances to reduce the amount of waste sent to landfills. In addition, EOL appliances offer the appliance manufacturing and remanufacturing industries a source of less expensive raw materials and components. For this reason product recovery has become a subject of interest during the past decade. In this paper, we study the disassembly line for appliance disassembly. We discuss and incorporate some of the complications that are inherent in disassembly line including product arrival, demand arrival, inventory fluctuation and production control mechanisms. We show how to overcome such complications by implementing a multi-kanban system in the appliance disassembly line setting. The multi-kanban system (MKS) relies on dynamic routing of kanbans according to the state of the system. We investigate the multi-kanban mechanism using simulation and explore the effect of product mix on performance of the traditional push system (TPS) and MKS in terms of controlling the system's inventory while attempting to achieve a decent customer service level.

Keywords: JIT, Kanban, Disassembly.

1. INTRODUCTION

Improvements in manufacturing technology have resulted in faster and more effective way to produce products. Manufacturers can now design a manufacturing system that is flexible and can manufacture multiple products within a single system. Consumers benefit from the availability of variety of products that can be tailored to their needs at affordable prices. However, introduction of newer and more enticing products to the market leads to premature disposal of current products. This phenomenon is common for household electronics and appliances where prices and operating costs of newer products are less than the existing products. This has led an increase in waste sent to landfills. Many consumers and governments are now aware of this problem and have been demanding the manufacturers to address this issue and be more responsible. For this reason, many products are now designed to be more environmental friendly and easy to reuse, remanufacture and recycle at the end of their usage. Often, this process is not only beneficial to the environment but offers manufacturers and remanufacturers a source of less expensive raw materials and components.

Recycling household appliances is very popular in the recycling industry due to the large amount of recyclable materials and reusable components present in them. Many components in appliances could be refurbished to last longer than the products themselves. For example, electric motor from a dishwasher, washer or dryer can be rebuilt and reused several times. In order to obtain these materials and components for further reuse and recycle, manufacturer engages in a process called product and material recovery. During the process, reusable components and recyclable materials are recovered from End-Of-Life (EOL) products by disassembly and/or shredding and mining.

Disassembly of household appliances has unique characteristics. Even though different appliances have different functions and appearances, they typically share similar structure, similar materials and similar disassembly processes. However, sequencing of an EOL appliance in a disassembly process depends on the precedence relationships of components in that appliance causing difficulties because of the different products that arrive at a disassembly system.

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Others difficulties include fluctuation in demand for components and fluctuation in the supply of EOL products. These difficulties must be addressed for the disassembly system to be effective.

Disassembly line is one of the most common setup in a disassembly facility and is suitable for disassembly of products in large quantities. Disassembly line is appropriate for the disassembly of appliances because of three major characteristics, viz., similarity in the disassembly process, similarity in the targeted materials and components, and large amount of materials as well as the large size of components that may create difficulties in inventory management. Despite the advantages of using a disassembly line for appliance disassembly, the issue of production control mechanism must be addressed. Just like in an assembly line setting, there are two types of control mechanisms in a disassembly line setting as well, viz., the push system and the pull system. A push system is easy to implement but is not efficient in the disassembly environment. By its nature, it tends to generate large amounts of inventories. A pull system, in theory, creates significantly less amount of inventories. However, most production control tools that implement pull mechanisms in assembly line settings are not practical for the disassembly line settings. We will discuss these difficulties and demonstrate how the existing tools for the assembly line settings could be modified to implement them in disassembly line settings.

To that end, we propose a multi-kanban mechanism for the appliance disassembly environment. The mechanism is designed in such a way its implementation helps reduce the inventory build up in the system that is commonly found in a disassembly line with push system implementation. The mechanism is able to ensure a smooth operation of the disassembly line where multiple types of appliances arrive for processing. 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

Gungor and Gupta [7] provide a comprehensive survey of issues in environmentally conscious manufacturing and product recovery. Within the area of product recovery, many researches address disassembly and its significant domains such as disassembly sequencing [18], disassembly line [6], disassembly line balancing [5], and disassembly line scheduling [20]. For more information on disassembly and product recovery, see Brennan *et al.* [2], Gupta and McLean [12], and Moyer and Gupta [21]. A recent book by Lambert and Gupta [19] is also helpful in understanding the area of disassembly and disassembly modeling.

In a typical assembly environment, Hopp and Spearman [13] describe the kanban control mechanism in one-card and two-card environments. 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 demonstrate that in such environments, FKS outperforms TKS. 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.

In the area of electronics and appliance disassembly, Lambert [17] suggests the optimal disassembly sequence in electronics disassembly. Udomsawat *et al.* [25] propose an application of pull control mechanism for a personal computer disassembly. More information on electronics disassembly and recycling can be found from Boon *et al.* [1], Das *et al.* [3], Ellis [4], Jung and Bartel [14] and Sodhi and Reimer [22].

3. APPLIANCE DISSASSEMBLY

In the past, recyclers opted not to disassemble components from EOL appliances due to lack of disassembly strategies and technology. Appliances were usually sent to shredder in order to process for material content. With the availability of new tools and better understanding of the disassembly process, recyclers have started to realize the hidden value of reusing components to refurbish, repair and remanufacture products. However, without proper planning, disassembled components have a danger of being overabundant. Since disassembly is an expensive process, such situation is undesirable. Typical household appliances that can be disassembled for components and materials are refrigerators, washers, dryers, and conventional and microwave ovens. These appliances contain reusable components such as electric motors, control circuits and thermostatic switches. They also contain many recyclable materials such as steel and aluminum and copper (see Table 1).

Table 1. Appliances and their Contents

Appliance	Recyclable Materials and Reusable Components						
	Metal frame	Aluminum component	Copper piping	Electric motor	Compressor	Circuit board	Solenoid/thermal valve
Microwave Oven	X	X	-	X	-	X	-
Washer/Dryer	X	X	-	X	-	X	X
Refrigerator	X	X	X	X	X	-	-
Electric/Gas Range	X	-	X	-	-	X	X
Dishwasher	X	-	X	X	-	X	X
Water heater	X	X	X	-	X	-	X
Vacuum Cleaner	-	-	-	X	-	-	-

Because these appliances share similar materials and components, they can be disassembled together in the same disassembly facility. These appliances also require similar disassembly process and disassembly tools. A disassembly facility can benefit from disassembling multiple types of appliances in two ways. First, this reduces the uncertainty in supply of materials and components. The facility has a better chance of having a continuous supply of EOL products. Second, the variety of components and material retrieved from the EOL appliances is much broader. This helps increase customer satisfaction. However, the facility must be flexible enough to accommodate the ensuing variety of products that would enter the system. More notably, it needs a very efficient production control system to deal with disassembly of multiple products, components and materials.

Because most appliances are large in size, a disassembly line is best suited for the job especially when also dealing with a large number of appliances. Figure 1 depicts an example of a disassembly line setting for multiple appliances disassembly line. In this paper, a pull system is implemented using kanban to make the line operate efficiently.

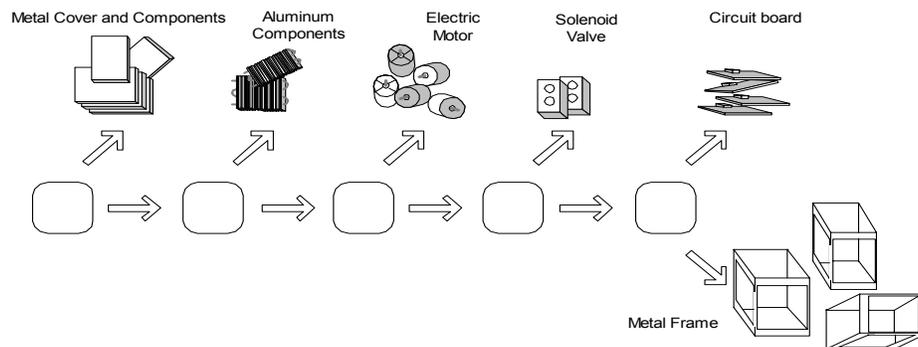


Figure 1. Appliance Disassembly

4. DISSASSEMBLY LINE

A disassembly line is composed of a series of workstation working in a sequence. The series of workstations in the disassembly line disassemble the EOL products into subassemblies and/or components. EOL products may enter the disassembly line at any workstation depending on their types. Similarly, depending on what is demanded, the demand may occur at any workstation. Arrival points, configuration of EOL products and variety of demanded items are what make a disassembly line difficult to manage. These also lead to substantial fluctuations in inventory in a disassembly line. In this section, we highlight some of the crucial issues in using a disassembly line for appliance disassembly. We then propose a methodology to overcome these using the pull control principle.

4.1 Mixed and Arrival Pattern of EOL Appliances

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

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

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. Fortunately, not all combinations exist in reality. Unlike an EOL personal computer, where its components are modular and usually come in various combinations, household appliances commonly arrive in fewer combinations. This is because they are rarely modified by consumers. Nevertheless, the workstation where an appliance enters the disassembly line still depends on the type and 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. 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. Furthermore, appliances with different precedence relationship must be processed through workstations in different sequences. These three 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.

4.2 Demand Fluctuation and Inventory Management

Among many unique characteristics of a disassembly line, the multilevel arrival of demand is one of the major reasons that makes the disassembly line much more complicated compared to a typical assembly line. Demand can occur at any station of the disassembly line. In most assembly lines, demand arrives only at the last workstation. However, in that 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.

4.3 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.

5. MULTI-KANBAN MODEL FOR DISASSEMBLY LINE WITH MULTIPLE PRECEDENCE RELATIONSHIPS

The multi-kanban model proposed here is an expanded version of the original multi-kanban model [24]. Many key elements of the model remain unchanged. However, as shown in the Figure 2, difference in precedence relationships of components in different products causes variation in disassembly sequences. Thus, the kanban routing mechanism is modified so that it can be deployed on a disassembly line where multiple types of products with different precedence relationships are presented. The first common type is the product that its precedence relationship of components follows the sequencing of disassembly process. This type of product is disassembled and travels in downstream direction only. The second type of product is more complicated because its precedence relationship of components does not follow the sequencing of disassembly process. Hence, it can travel in both upstream and down stream direction depending on which component is to be disassembled next.

5.1 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.

5.2 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.

5.3 Kanban Routing Mechanisms

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).

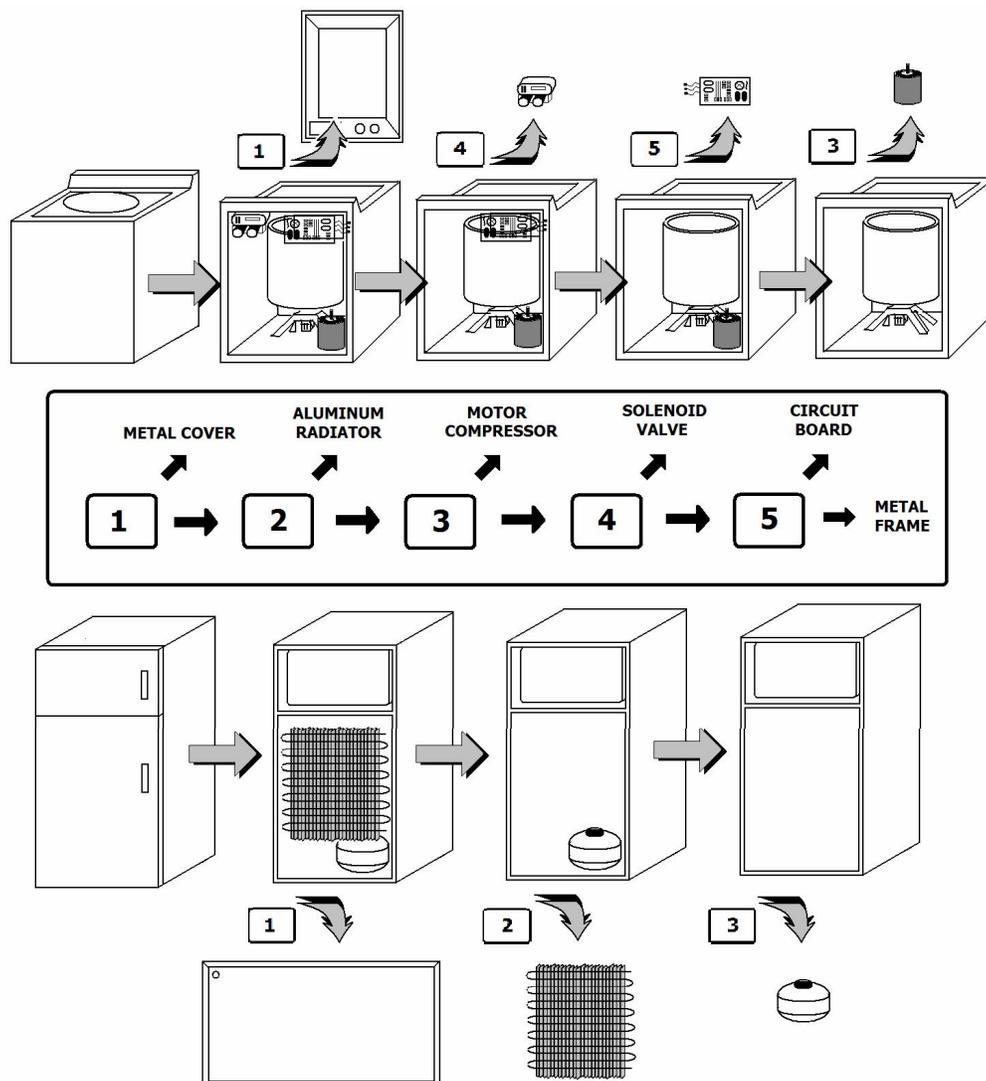


Figure 2. Effect of Different Precedence Relationship on Disassembly Sequence

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 workstations 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.

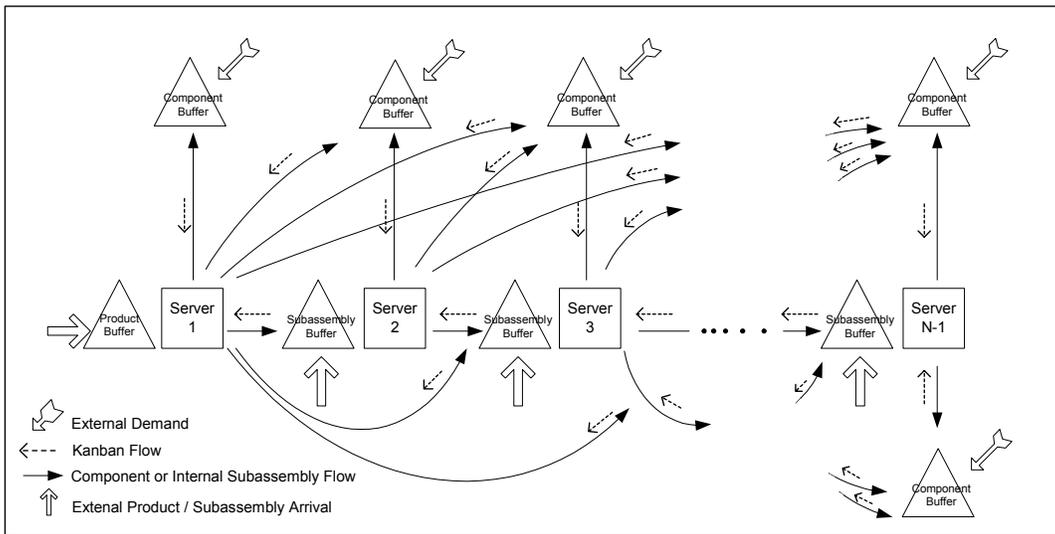


Figure 3. Kanbans and Materials Flows in a Disassembly Line

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.

For a product whose precedence relationships do not coincide with the disassembly sequence of the line, we may need to route the kanban to one of downstream workstations (workstation k , where $j < k \leq (N-1)$) depending on whether it meets the above described criteria or not. We select the best destination using the same criteria as for the regular products that are routed in only the downstream direction. In other words, there are more choices to select from when allowing mixed products with multiple precedence relationships into the system. However, the selection criteria remain the same regardless of kanban routing direction.

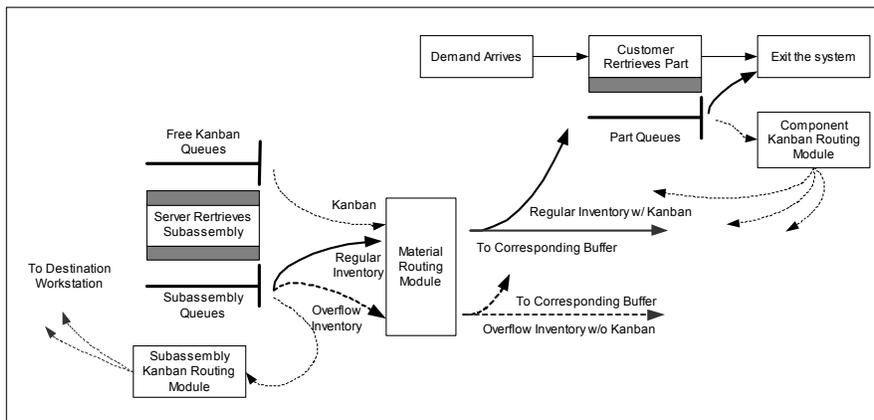


Figure 4. The Multi-Kanban Mechanism

5.4 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.

5.5 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:

$$k_i = \max(1, R_i / F_i) \quad (2)$$

$$k_j^* = \max(1, R_j^* / F_j^*) \quad (3)$$

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:

$$R_i = d_i, \text{ for } 1 \leq i \leq N \quad (4)$$

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

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

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

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.

6. LINE DESCRIPTION AND ASSUMPTIONS

We consider an appliance disassembly line with 5 workstations. EOL appliances, viz. washer, dryer and refrigerator, arrive at the line in two different precedence relationships configurations. The input location for EOL appliances depends on its configuration. The input location for an appliance is the most upstream workstation that disassembles the first

component, according to its precedence relationships. Only one type of component is disassembled at a given workstation except when there are only two components left in the product. 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 corresponding to the next component to be disassembled. 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, an appliance 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 the disassembly sequence is disassembled.
- (d) Appliance may enter the line at any workstation along the line depending on its configuration.

7. NUMERICAL EXAMPLE

A numerical example of an appliance disassembly line with 5 workstations is used to illustrate the application of the multi-kanban concept. Three products, viz. washers, dryers, and refrigerators arrive at the line with two different precedence relationships. There are six target components, viz. metal cover, aluminum and steel radiator or heat exchanger unit, motor or compressor, solenoid valve, circuit control board, and frame. Five workstations of the disassembly line are positioned in an oval shape. The line employs a one-way conveyor as a material handling system. When a subassembly or component needs to travel upstream, it actually goes pass the downstream workstations before arriving at the destination. However, we do not consider the effect from material traveling time and loading time in the experimentation. Arrival data for appliances is shown in Table 2. Disassembly is performed on a disassembly line consisting of five workstations. Component A, representing metal cover is disassembled at workstation 1. B, representing radiator or heat exchanger unit, is disassembled at workstation 2. Component C, representing motor or compressor, is disassembled at workstation 3. Component D, representing solenoid valve, is disassembled at workstation 4. Component E, representing control board, is disassembled from component F, representing frame, at workstation 5. Table 3 provides mean disassembly times for components, mean demand arrival rates for components, which are all exponentially distributed. The demands for metal parts are expressed in units of product instead of weight in order to facilitate the calculation and the assignment of kanbans.

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 kanbans in both upstream and downstream directions (as explained in the Kanban Routing Mechanism subsection) in order to reduce the inventory build up caused by the disparity in demands among the components. We also utilize product selection method (as explained in the Selection of Products subsection). In these experiments, statistics on the following two performance measures were collected: system's ability to fulfill demand and average inventory level (see Figures 5 and 6).

Table 2. Appliance Arrival Data

Appliance	Disassembly Sequence	Mean Arrival Rate (units/hour)
Washer	1, 2, 3, 4, 5	2
Dryer	1, 2, 3, 5	2
Refrigerator	3, 2, 1, 5	2

Table 3. Component Data

Component Type	Mean Demand Arrival Rate (units/hour)	Mean Disassembly Time (minutes)
A	6	8
B	4	12
C	6	8
D	2	4
E	4	4
F	6	4

It is clear from Figures 5 and 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. For the example considered, the system was able to reduce the inventory level by an average of 33% while fulfilling customers' demands comparable to the push system.

8. CONCLUSIONS

Despite serious complications in a disassembly line, this paper demonstrated that a pull system could be adapted to perform well for appliance disassembly. 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 routing adjustment of kanban.

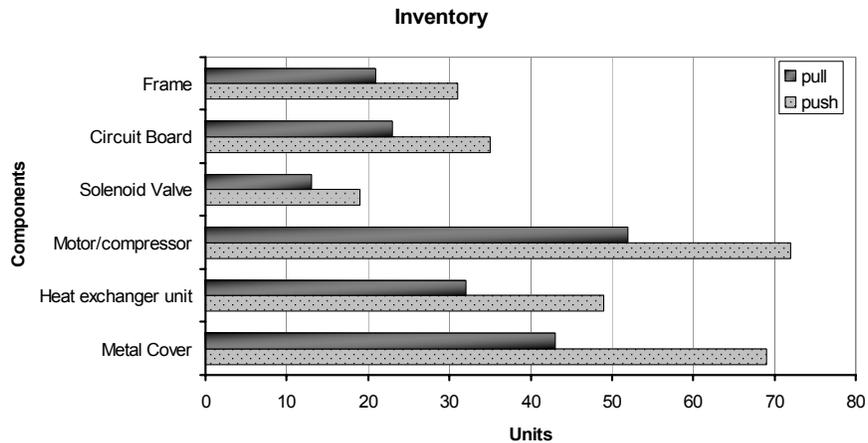


Figure 5. The Average Inventory Level

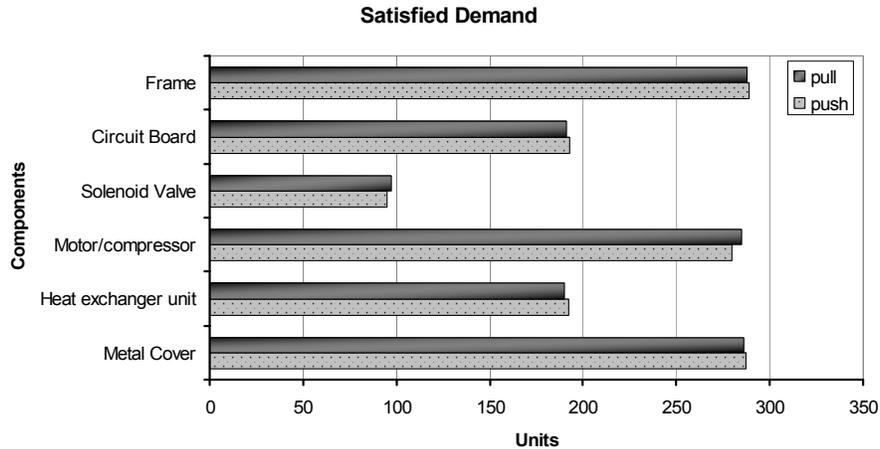


Figure 6. Number of Satisfied Demand for Multi-Kanban System and Push System

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