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MULTI-KANBAN IN DISASSEMBLY LINE WITH COMPONENT-DISCRIMINATING DEMAND

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ABSTRACT

In this paper, we describe the implementation of a modified-pull system in a disassembly line setting, particularly the one with component-discriminating demand. The many complications associated with a disassembly line make it difficult for the traditional pull system to operate efficiently in this environment. These complications include: fluctuation in demand, supply and inventory, divergent flow of materials, and difficulty in selecting end-of-life products. The multi-kanban system proposed in this research utilizes enhanced routing rules and other policies to find a balance between system's efficiency and its ability to satisfy the customer's demand. A numerical example is considered for illustrating the effectiveness of the proposed system.

INTRODUCTION

One of the new challenging areas of production and operation management lies in the disassembly environment. Disassembly [1], [9], [12] [13], which is an important part of product recovery [4] is used to increase the recovery rate of components and materials from end-of-life products. Instead of shredding these products in pieces, disassembly usually involves removal of components or separation of materials. Disassembly tends to be labor intensive and offers challenges in the areas of inventory management and disassembly process planning. Because of the sheer volume of products to be disassembled, disassembly line has become the subject of recent studies [2], [3]. It perhaps is the best choice for disassembling products in large quantities. It consists of a series of workstations disassembling various components from end-of-life products. Often, disassembly line can be difficult to control because of many looming uncertainties.

In this paper, we propose a way to take advantage of the kanban mechanism [10] to control a disassembly line. We particularly look at a disassembly line where end-of-life products enter the system in various configurations. The sequences of disassembly for these products depend on their configurations. We allow customers to discriminate among various types of the same component. For example, if the customer requires a computer hard drive, there might be more than one type of hard drive available. We allow the customer to specify the type of hard drive s/he is looking for. In order to cope with such situation, we assign subassembly kanbans and component kanbans to corresponding subassemblies and components. We further break up the component kanbans into sub-levels. These sub-level component kanbans correspond to different types of components. Unlike the flexible kanban system (FKS) [5], [6], [7] and [8], here we define routing rules and product selection rules to cope with the demand and supply fluctuations. We demonstrate the efficiency of this mechanism using a simulation model. We show that in the component-discriminating demand situation, the multi-kanban mechanism has the ability to

control fluctuations in inventory levels while maintaining high customer service levels. An example is considered to illustrate the mechanism.

DISASSEMBLY LINE

Disassembly Line and Pull Mechanism

Fluctuation in demand, supply and inventory are some of the many complications encountered in a disassembly line. Unlike an assembly line, where finished products at the last workstation fulfill the demand, disassembly line fulfills the demands of various components at the workstation where they are disassembled. In a disassembly line, end-of-life products can enter at any workstation depending on their configurations. Quantity of components may vary quite widely. Because of this, the line tends to generate high inventory levels. In addition, other complications associated with the disassembly line cause more difficulties when considering a production control mechanism for a disassembly line [13].

Pull mechanism is one of the most efficient production control method utilized by small and large manufacturers. The mechanism aims to increase agility of the system by reducing inventory levels. This is achieved by performing the required task only when there is a need. A manufacturing line that employs a pull mechanism benefits from reduction in bottleneck, cycle time and inventory carrying costs. This can be crucial especially in a disassembly line where production is labor intensive and products have limited shelf lives, high carrying costs, or need large storage space. Kanban is a common device used when implementing pull mechanism in an assembly line setting. The simplicity of kanban, while providing the system's ability to control the inventory level, makes it very desirable. However, traditional kanbans have a tendency to fail when demand and supply are uncertain. Adapting the kanban to cope with uncertainties in disassembly line is challenging but can be rewarding.

Disassembly Line with Component Discriminating Demand

It is common for a disassembly line to encounter end-of-life products in different makes, models, and conditions. Different end-of-life products are needed to retrieve different types of components at different workstations of the disassembly process. There may be multiple types of demands for multiple types of components resulting from the disassembly process at a given workstation.

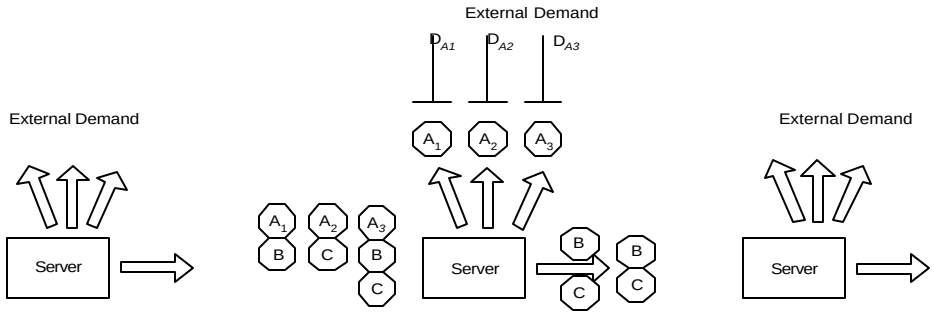

Figure 1. Disassembly Line with Component Discriminating Demand

For example, the demand for hard drives of different sizes may arrive at the workstation where these hard drives are separated from the personal computers (PCs) on a PC disassembly line. This creates discrimination of products and requires decision-making. Figure 1 shows a workstation with component discriminating demand. Note that a removal of a particular component (A_1, A_2, or A_3), results in different residuals (viz., B, C, or BC, respectively).

MULTI-KANBAN MODEL

Material and Kanban 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. On the other hand, a subassembly is something that can still be disassembled. Subassembly is composed of at least two components. Because the disassembly process is initiated by a single kanban, the residual or overflow item will not have a kanban attached to it. The overflow item is given priority of being retrieved after it arrives at its buffer. This helps the system eliminate this extra inventory first which is the result of unbalanced demand. Analogous 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. A component kanban can be further distinguished by the particular component it represents. These sublevel component kanbans are located at the same workstation where the components are disassembled. A subassembly kanban is attached to a residual subassembly that is placed in the subassembly buffer of the workstation where a component was separated from it. 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.

Kanban Routing Mechanism

Consider workstation j, $1 \pounds j \pounds N$-1, where N is the maximum number of components, N-1 is the maximum number of workstations and sublevel kanban is k, k=1, 2, .. Q, where Q is the maximum number of sublevel components. When a demand for the kth sublevel of component j (j_k) arrives at the component buffer of workstation j, one unit of component j_k is retrieved and the component kanban j_k attached to it is routed to the most desirable workstation.

The procedure for determining the most desirable workstation to route component kanban j_k is as follows. (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 $1 \pounds i < j$, or workstation j depending on the availability and the desirability of the subassembly that contains component j_k. Routing component kanban j_k to workstation i, where $1 \pounds i \pounds (j\text{-}1)$, will result in an immediate separation of component j_k from component i_r, $r=1,2,$ .. Q, given that there exist product $j_k i_r$ at workstation 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_r and j_k. 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_k 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_r by an additional unit. Thus, the best workstation i is the one that is most starving for its component i_r. By checking the backorder level for demand of i_r, we could determine the most starving workstation. If there is a tie, select the most downstream workstation. If there is a tie inside workstation i, select the one with most available subassembly $j_k i_r$. 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 l, where $j < l$ £ (N-1), then, if available, we might try to disassemble a subassembly that contains only components l_r and j_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. If there is a tie inside a workstation, we break it the same way as a tie inside upstream workstation.

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.

Determine 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:

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

$$k_j^* = \max(1, R_j^* / F_j^*) \tag{2}$$

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 F_j^* is the *furnish rate* of subassembly j. These request rates and furnish rates can be calculated as follows:

$$R_i = d_i \text{ , for } 1 £ i £ N \tag{3}$$

$$F_i = \sum_{w=1}^{i} s_{(i,w)} \text{ , for } 1 £ i £ N \tag{4}$$

$$R_j^* = s_i \text{ , } i \text{ is the next component to be disassembled in the sequence} \tag{5}$$

$$F_j^* = a_j^* + \sum_{w=1}^{m-1} s_{(i,w)} \text{ , } i \text{ is the last component disassembled in the sequence} \tag{6}$$

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 components, and $N-1$ is the maximum number of workstations.

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.

NUMERICAL EXAMPLE

The numerical example we used to evaluate the multi-kanban system consists of a four-workstation disassembly line. End-of-life products consist of at most five different components, viz., A, B, C, D and E. In this study, only products ABCDE, ADC, BCDE, BCE, and CDE are disassembled in sequence. There are two sub-components of B (B_1 and B_2) and two sub-components of C (C_1, C_2 and C_3). The sub-components of B are disassembled at workstation 2 and the sub-components of C are disassembled at workstation 3. Demands for components and sub-components arrive according to Poison distributions. All service times are exponentially distributed and are the same for all sub-components in a workstation. Using ARENA® simulation software [11], we performed 30 runs of 40 production-hour week with warm-up period of 10 hours. In the two scenarios, viz., pull-system using multi-kanban and push system, we collect statistics of system's inventory and number of demand satisfied. Results are shown in Table 1. It is clear that the multi-kanban model, utilizing routing rules mentioned in the last section, provides comparable number of satisfied demands despite the fact that the system carries a much lower inventory level. The multi-kanban system proposed here minimizes the amount of extra inventory caused by residuals from disassembling a discriminated component.

Table 1. Results

	Average Inventory (units)			**Satisfied Demand (units)**		
	Push	Multi-Kanban	% Change	Push	Multi-Kanban	% Change
A	28	5	-82.1	172	169	-1.7
B_1	62	6	-90.3	65	66	+1.5
B_2	60	5	-91.7	61	64	+4.9
C_1	64	6	-90.6	102	106	+3.9
C_2	62	6	-90.3	109	104	-4.6
D	30	5	-83.3	38	41	+7.9
E	27	4	-85.2	37	40	+8.1

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