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A MODIFIED KANBAN SYSTEM FOR DISASSEMBLY

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ABSTRACT

We present a new Kanban system specifically developed for material control and scheduling in a disassembly environment. We briefly highlight the differences between the new (modified) and the traditional Kanban system. We assert that in the disassembly environment, the Kanban system is superior to the "push" system currently practiced in industry. To that end, we consider a case example and test its performance by experimenting with several different scenarios. In all instances, the Kanban system outperforms the "push" system.

INTRODUCTION

The continuous growth in consumer waste has started to threaten the environment. Recognizing this, many countries are contemplating regulations that force manufacturers to take back used products from consumers so that the components and materials retrieved from the products may be reused and/or recycled [2].

An initial step in retrieving components and materials from consumer products is disassembly. *Disassembly* is the process of systematic removal of desirable constituents from the original assembly so that there is no impairment to any useful component [1,3,5,6,9,10,11]. This research assumes complete and non-destructive disassembly.

Even though, the scheduling problems of assembly and disassembly share many characteristics (e.g., the dependent demand concept in discrete parts production systems), they also have their differences, and often the approaches to solve these two kinds of problems are very different [1]. Perhaps the most important difference is in the number of demand sources. During assembly, the parts tend to converge to a single demand source (final product) as they move on the production floor. The governing principles are constrained by this "convergence" property. Under disassembly however, as the parts start moving away from their source of origin, they tend to diverge from each other leading to the "divergence" property. In addition to the "divergence property", each component item constitutes a source of demand, and fulfilling the demand of those separate component items cannot be done in an independent manner, since many of these component items share the same procurement source [6,10,11].

In the recent past, the Just-In-Time (JIT) technique has become very popular and has even spread to small companies [4]. This philosophy evolved from a number of principles such as the elimination of waste, reduction of production cost, total quality control and recognition of employees' abilities. Some advantages of JIT include its simplicity in production scheduling, reduction of burden on operators, ease of identification of parts by the Kanbans (Kanban is a Japanese word that means "visible sign" or "card" and is used to control production) attached to the containers and substantial reduction in paper work.

We present a modified Kanban (pull) system specifically developed for disassembly systems. This type of Kanban system is much more complex than the traditional Kanban system used in production systems. For instance, unlike in a production system where the external demand occurs only at the last station, the demand in the disassembly case can also occur at any of the intermittent stations. The reason is that as a product moves on the disassembly line, various components are disassembled at every station and accumulated at that station. Therefore, there are as many demand sources as there are number of components. We consider a case example and show that the modified Kanban system is far superior to the standard push system currently practiced in industry. We compare the performance of the modified Kanban system and the push system under various conditions.

MODIFIED KANBAN SYSTEM FOR DISASSEMBLY (MKSD)

In a classical push environment, each station in the system is pushed to disassemble products at maximum capacity to fill the components' inventory buffers whether there is immediate demand for these components or not. On the other hand, in MKSD, the disassembled component inventories are kept at a minimum. They are limited by the number of the disassembly Kanbans (DKs), employed in the system. Additional products are disassembled when there is component demand.

We consider a MKSD composed of N disassembly stations (DSs) in series as shown in figure 1. Each DS has one processing machine or operator, an input buffer and two output buffers. At each station only one type of component is disassembled. The material flow is controlled via the use of disassembly withdrawal and disassembly production Kanbans. The production Kanban of a DS always circulates within that station, controlling the disassembly at that station. The withdrawal Kanban of a DS always circulates between the input buffer of that station and the partially disassembled product buffer of its preceding station.

There are two types of production Kanbans for the first *N-I* disassembly stations, viz. a disassembly production Kanban for partially disassembled unit (DPKAN) due to demand occurring at the succeeding stations and a disassembly production Kanban for the disassembled components (DPKAND) to satisfy the demand for individual

components at that station. Station N has only DPKAND to satisfy demand for the disassembled components since the product is completely disassembled at that station.

In the disassembly system there are two types of work-inprocess (WIP) (types I and II). Type I WIP is the partially disassembled product anywhere in the system and type II WIP is the disassembled component at any station's output buffer in the system.

The existence of demand at any one of the DSs triggers a pull action at the preceding DS of the MKSD. Therefore whether there is a need for the preceding DS's components or not, one more product will be disassembled, most likely causing the disassembled component buffer (DCB) of the preceding DS to exceed its capacity. On the other hand, if there is no demand for the succeeding DS's components, the partially disassembled product buffer (PDPB) for the current DS may exceed its capacity. In order to eliminate excess inventory at these buffers, MKSD disposes additional products and/or components (at some cost) when disassembly Kanban capacities are reached.

NOTATION

We use the following notation in this paper:

- d_i : Disposal cost per unit for component type I (I=1,...,k).
- dc_n : Disassembly processing cost per unit at disassembly station n (n=1,...,N).
- dr : Disposal cost per unit of whole or partially disassembled product.
- h_j : Holding cost per unit of type *j* WIP per period (*j* = I or II).
- k: Number of different components in the product.
- N: The total number of disassembly stations in the system.
- Nci: Number of components disassembled of component type i (i=1,..., k).
- Nd_i : Number of disposed components of component type *i* (*i*=1,..., *k*).
- np_i: Number of components per product of component type i (i=1,...,k).
- Nr : Number of whole or partially disassembled products disposed.
- p_i : Sale price for a disassembled component type i (i=1,...,k).
- S_i : Shortage cost for component type *i* per period (*i*=1,..., *k*).
- TR : Total Revenue

THE TOTAL REVENUE FUNCTION

There are six distinct terms in the total revenue function:

- Profit from the sale of components.
- Cost of disposing components.
- Cost of components' shortage.
- Cost of disassembly processing.
- Cost of holding WIP inventory.
- Cost of disposing whole or partially disassembled products.

The total revenue function can be written as follows:



(Note that in the above function, we have assumed that N=k).



CASE EXAMPLE

We present a case example of the system of the type shown in Figure 1, to demonstrate the advantages of MKSD over the push system. Simulation was used to study the performances of the MKSD and the push system of the case example. Simulation models using the PC version of Arena 2.0 [7] were developed to study the performance of the two systems. Performance of the two systems were compared with each other using such performance criteria as disposals, shortages, type I and II WIP levels, and total revenues generated. The push system is designed with exactly the same system parameters as the MKSD except for the Kanbans (since there are no Kanbans for the push system).

Following is the relevant data for the case example:

- **k**: 4
- N: 4
- d_i : \$0.20, \$0.30, \$0.40, and \$0.50 per unit for component type *i* (*i*=1,..., *k*).
- dc_n : \$1.50 per unit at disassembly station n (n=1,...,N).
- dr : \$4.00 per unit of whole or partially disassembled product.
- h ; : \$1.40/unit-period for type I WIP and \$0.14/unit-period for type II WIP
- np;: 4 type 1 components, 3 type 2 components, 2 type 3 components and 1 type 4 component.
- *p*_{*i*} : \$4.00, \$6.00, \$8.00, \$10.00 per unit for component types 1, 2, 3 and 4
- S_i : \$0.30, \$0.40, \$0.50, \$0.60 per unit-period for component types 1, 2, 3, and 4 respectively.
- Products arrive according to Poisson distribution with a mean of 0.5/ min.
- Processing times at every station are independently and triangularly distributed with a minimum time
 of 2 minutes, average time of 4 minutes and a maximum time of 6 minutes.
- The disassembled component buffers at stations 1, 2, 3, and 4 are set to 8, 6, 4 and 2.
- It takes 1.0 minute to transfer a withdrawal Kanban from a station to its preceding station.
- The warehouse capacity is set to 100 units.
- First-come-First-serve queue discipline is observed.

EXPERIMENTATION AND RESULTS

The experiments were divided into two groups; group 1 (with relatively high demand for the components) and group 2 (with relatively low demand for the components).

Group 1. For this group of experiments we assumed that the demand rates for the components were distributed according to Poisson distribution with the means of 1.00, 0.50, 0.33 and 0.25 per minute for component types 1, 2, 3 and 4 respectively. We conducted six different experiments consisting of three scenarios of the MKSD and three scenarios of the push system. In the MKSD scenarios the number of Kanbans were set to 1, 2 and 3 for scenarios 1, 2 and 3 respectively. In the push system scenarios we used

input buffer capacities of 8, 11 and 14 units/station for scenarios 4, 5, and 6 respectively to equate the number of their buffers to that of the MKSD scenarios. In Table 1, we use MKSD-*x* and P-*y* to represent the six scenarios, where *x* (x = 1, 2, 3) represents the number of Kanbans in the MKSD and *y* (y = 8, 11, 14) represents the input buffer capacities in the push system.

In Table 1 we summarize the results of the experiments conducted in group 1. The Welch procedure [8] was used to confirm the existence of steady state. In all cases, the steady state was reached well before the 100 days of warm-up period used in all the experiments. The statistics were collected for the next 50 days. The results show that the MKSD is superior to the push system in terms of total revenue, amount of disposals and WIP levels.

Group 2. For this group of experiments also we assumed that the demand rates were distributed according to Poisson distribution but with means of 0.2500, 0.1250, 0.0833 and 0.0625 per minute for component types 1, 2, 3 and 4 respectively. We conducted two different experiments representing one scenario of the MKSD and one scenario of the push system (Table 2). In the MKSD scenario the number of Kanbans was set to 2 and in the push system scenario the buffer capacity of 8 was used (Note that these scenarios were chosen because they were the best performing scenarios in group 1 for MKSD and the push system respectively).

	MKSD-1	MKSD-2	MKSD-3	P-8	P-11	P-14
	Scenario-1	Scenario-2	Scenario-3	Scenario-4	Scenario-5	Scenario-6
Product disposal	1137	830	749	5924	6043	6024
Component-1 Disposal	0	33	0	71	140	119
Component-2 Disposal	1659	2170	2431	5960	5994	6198
Component-3 Disposal	557	893	1007	3940	4049	4015
Component-4 Disposal	0	0	0	0	6	5
Component-1 Shortage	0	0	206	75	0	24
Component-2 Shortage	0	0	0	0	0	0
Component-3 Shortage	0	0	0	0	0	0
Component-4 Shortage	1735	1533	1462	54	0	8
Type I WIP Average	128.16	40.98	40.74	113	116	119
Type II WIP Average	5.39	5.77	5.83	8	8.18	8.13
Total Revenue	\$239,450.0	\$241,652.0	\$241,540.0	\$228,964.0	\$228,465.0	\$227,629.0

From the results of this case, we can see that MKSD performs a lot better than the push system (Table 2). The disposal rates between the two systems are drastically different and the total revenue for MKSD is much higher than the push system. MKSD scenario exhibits positive revenue whereas the push system experiences a loss due to high disposal rates and excessive production cost. In terms of shortages in the system, MKSD experiences a shortage of 475 units for component 4 over a 50-day period. Even if this residual demand for component 4 were to be satisfied using new components, the MKSD would outperform the push system by avoiding other high costs associated with the push system.

SENSITIVITY ANALYSIS

In Table 3 we present the results of some additional experiments where the values of disposal, holding and shortage costs were changed (one at a time) while the values

of all other parameters were kept at the same level as in the group 2 experiments. As is clear from Table 3, in all cases, MKSD-2 continues to outperform P-8. Note also that MKSD-2 is relatively insensitive to changes in the disposal, holding and shortage costs. However, when the shortage costs are low, the P-8 shows positive revenue albeit quite a bit less than its MKSD-2 counterpart.

CONCLUSIONS

We showed that the Modified Kanban System for Disassembly is better than the push system. In order to make disassembly more desirable for the industry, a minimum cost and minimum waste production system should be selected. The case example included in the paper revealed that even when the demand rate is high, the MKSD outperforms the push system. However, for companies where the demand rate is low, the benefits of the MKSD are very significant.

Table 2. MKSD and Push Systems Comparison at Low Demand Rates

	MKSD-2	P-8
Product disposal	10952	6011
Component-1 Disposal	1316	18102
Component-2 Disposal	164	15073
Component-3 Disposal	41	10039
Component-4 Disposal	0	4520
Component-1 Shortage	0	0
Component-2 Shortage	0	0
Component-3 Shortage	0	0
Component-4 Shortage	475	0
Type I WIP Average	139	113
Type II WIP Average	13	19
Total Revenue	\$16,409.00	-\$1394.74

 Table 3. Sensitivity Analysis for MKSD-2 and P-8 Systems at Low Demand Rates

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 Delta
 Total Revenue MKSD-2
 Total Revenue P-8

 organ Constant
 \$\$1,202,00
 \$\$1,202,50

1 al anicter 5	Dena	Total Revenue MIRBD-2	Total Revenue 1-0
Disposal Costs	-\$0.05	\$17,032.00	\$1,292.50
Disposal Costs	-\$0.10	\$17,656.00	\$3,980.00
Holding Costs	-\$0.05	\$16,416.00	-\$1388.00
Shortage Costs	+\$0.05	\$16,385.00	-\$1394.74

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