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Priority Assignment Procedure in Multi-Product Disassembly

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Abstract. This paper investigates the design of a priority rule in a multi-product disassembly environment. Specifically, it is concerned with product scheduling by which the inventory control of disassembled parts can be incorporated into a priority rule to reduce part lead times. The part lead time consists of two components: flow time and supply delay. The primary focus of the paper is on the development of a disassembly priority rule that aims to reduce the supply delay. We propose a priority rule, called Minimum Distance (MD) rule, to improve the supply delay performance. Finally, we provide a comparative analysis on the performance of traditional rules and the new rule proposed in this paper via a simulation model.

Keywords: disassembly priority rule, product scheduling, inventory control, supply delay

1. INTRODUCTION

Disassembly is the process of physically separating a product into parts. Disassembly of products in their final stages of useful lives is growing into a common and worthwhile industrial practice. For example, several large companies such as IBM, Digital/Compaq, Philips, and numerous automobile makers have initiated disassembly operations to recover their used products (Das *et al.*, 2000). Accordingly, many parts in the used products could be reused if they could be disassembled efficiently.

A typical material flow in a disassembly environment is as follows. Various types of used products arriving at a disassembly system are disassembled into parts. The parts are kept as inventory to satisfy the demand of remanufacturing and leave the area of inventory when ordered from reassembly side. Lead times of disassembled parts are an important factor that we need to focus on because it can be referred to as a performance measure of coordinating the material flow between the disassembly and reassembly sides. The part lead time consists of two components: flow time in disassembly work-center and supply delay in the area of part inventory. The supply delay, which is the time a part waits for an order before leaving the part inventory, should be avoided because it increases the part lead time.

Basically, the return flow of used products is a stochastic process because it is not easy to predict when consumers dispose of their products. Due the unpredictable product return, it is very difficult for the disassembly side to control the amount of disassembled parts available for satisfying the demand of the reassembly side. On the other hand, the reassembly side can adjust the demand rate to reduce the procurement costs of disassembled parts so that the average demand rate approximates the average supply rate. Here, part service level is defined as the ratio between the demand and supply rates. Since the orders in a higher part service

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level are less frequent than in a low part service level, we can conclude that the supply delay becomes longer in proportion to the part service level.

While a significant portion of the supply delay is affected by the part service level, it is also affected by the disassembly schedule of used products that release various types and numbers of part during the disassembly. Specifically, if an inventory variance occurs due to uncontrolled product disassembly, it will result in increased supply delay especially when actual inventory levels exceed a proper level. For example, the remaining parts after they are used for satisfying an order must be in the inventory while the next order is placed.

In this paper, we are concerned with product scheduling by which the inventory control of disassembled parts can be incorporated into a priority rule to improve the part lead time performance. However, the inventory control cannot be done in an independent manner because of the distinctive disassembly sequences. This makes the disassembly scheduling of products more complex than the conventional scheduling problems. To reduce the supply delay, we develop a disassembly priority rule, which is called Minimum Distance (MD) rule, to reduce the inventory variance especially for the case where the part service level is high. This rule demonstrates that the supply delay can be maintained at a minimum level only when the inventory variance is ultimately minimized over the scheduling horizon. Finally, we provide a comparative analysis on the performance of traditional rules and the new rule proposed in this paper via a simulation model.

2. LITERATURE REVIEW

Typical disassembly characteristics result in scheduling problems that are unusual in the conventional manufacturing processes. However, the past and current research works related to scheduling have focused on shops processing assembly. Even though approaching disassembly as the reverse of assembly may be reasonable, the operational characteristics are quite different as reviewed by Brennan *et al.* (1994). In a disassembly job, for example, as disassembly operations are going on, the parts are separated from their original product sources and tend to diverge from each other. In an assembly job, however, the parts tend to converge to a single demand source (e.g., final product) as assembly operations occur. Therefore, the processing time in assembly jobs is the machining time of a part or assembling time of a subassembly. In the disassembly job of this study, however, the time required for separating all parts from a single product is considered as the processing time of the product, since our scheduling concern is not parts but used products arriving at a disassembly system. Therefore, we can conclude that the scheduling performances of the conventional dispatching rules cannot be referred to 'as is' for this type of disassembly environment.

The problems of disassembly scheduling can be categorized based on the scopes of concerned object (i.e., product level or part level) and scheduling stage (i.e., planning level or execution level). Guide's research group investigated the part release mechanism in a recovery system that disassembles heavy machines such as engines and ships. Guide (1997) and Guide *et al.* (1997) examined the variants of the traditional dispatching rules with respect to part scheduling. They concluded that the simplest first-in, first-out method is a suitable method for their part release mechanisms of the heavy machines. No methods for disassembly scheduling have been reported for high-volume recoverable operations for goods such as consumer electronics (Guide *et al.*, 1999). There is a need to develop the scheduling methods that address the requirements of high-volume disassembly operations.

Gupta and Taleb (1994) presented a scheduling algorithm that reverses the MRP procedure for disassembly of a single product. In their next study, the algorithm is extended to two companion algorithms, the core algorithm and allocation algorithm (Taleb and Gupta, 1997). The core algorithm determines the amount of used products required to be disassembled over the planning horizon, and the allocation algorithm determines when and what products should be disassembled for each period, considering the disassembly time and order interval. Unfortunately, Taleb and Gupta ignored the characteristics of the disassembly environment, including dynamical product arrival, disassembly operation, and order interval. This makes the implementation of their algorithms difficult in the execution stage of disassembly scheduling.

3. DISASSEMBLY ENVIRONMENT

Figure 1 illustrates a schematic diagram of the disassembly environment. Various types of used products arrive at the collecting area. In the sorting area, the products are classified into families of products based on part commonality. Each family of products is transferred to a disassembly shop where disassembly, cleaning, and refurbishing operations are carried out. The disassembled parts are kept at the disassembly shops and sent to the reassembly area when demanded. Any un-reused parts will be recycled or disposed of.

As illustrated in Figure 2, we consider a disassembly shop that is composed of two subsystems. The first subsystem is a work-center that is assumed to have a machine continuously available for disassembly. The products arriving at the work-center make a queue if the machine is disassembling other products. During the disassembly of a certain product, various types and

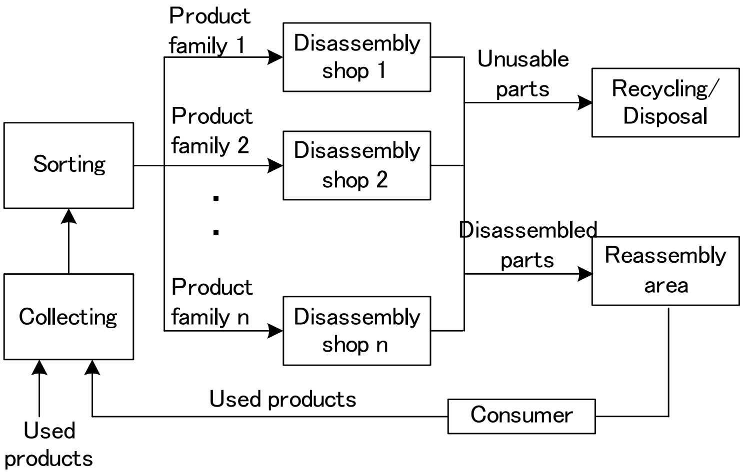


Figure 1. Schematic diagram of disassembly environment

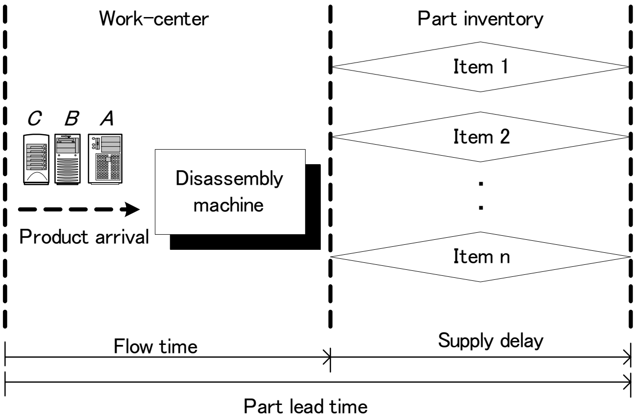


Figure 2. Disassembly shop

numbers of parts are released according to a disassembly sequence of the product. The disassembly sequence can be referred to as the optimum sequence of the product (Johnson and Wang, 1995; Lambert, 1999; Min *et al.*, 2003; Penev and de Ron, 1996; Pnueli and Zussman, 1997). The second subsystem is planned delay points of disassembled parts, which we call part inventories. Part inventories are stages where the parts disassembled from used products are allowed to accumulate and leave the inventory area when ordered from reassembly side.

In this study, we do not consider individual customer order. Therefore, the order release interval is normally distributed and the batch size is constant. The due-date of orders is fixed at zero because of the unpredictability of product return and the use of new parts. This is also based on the assumption that the time to procure new parts is shorter than the disassembly time. But it can be easily extended to be more realistic cases.

In Figure 2, the lead time of a part is the sum of the time that its parent product arrives at the work-center queue and the time that the part leaves the inventory. The flow time of a part is the sum of the time required for the part to wait for the machine at the work-center queue and the time required for the part to be released from its parent product. Here, the release time of a part is the sum of total disassembly time of its preceding parts and the disassembly time of the part. In case of product type *A* of Figure 3, the release time of part *c* is 50 minutes because the total disassembly time of its preceding parts (i.e., parts *a*, *f*, *h* and *d*) is 40 minutes and the disassembly time of the part is 10 minutes.

Product type	Part release sequence and release time
A	a(2,10) → f(3,20) → h(4,30) → d(5,40) → c(3,50)*
B	b(8,30) → c(7,60) → f(6,75) → g(6,90) → e(6,110) → a(5,120)
C	a(3,5) → h(6,20) → b(2,25) → g(4,45) → e(4,55) → f(1,60) → d(5,80)

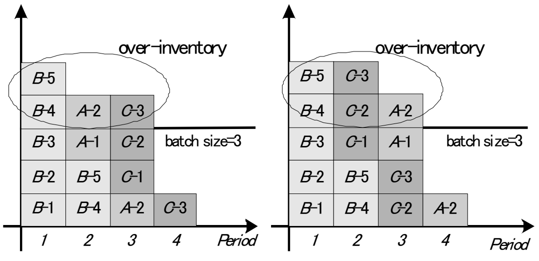
c(3,50)*: part type (number of parts, release time in minute)

Figure 3. Example of job structure

4. SCHEDULING OBJECTIVE OF PRODUCT DISASSEMLY

In this section we will focus on understanding the disassembly scheduling of products and its impact on the supply delay performance. A major reason of the supply delay is the variance of part inventories, especially over-inventory. Therefore, our scheduling objective is to improve the supply delay performance by reducing the inventory variance as much as possible. For an illustration, let us refer to Figure 4. The figure represents two different disassembly schedules with respect to products *A*, *B,* and *C*: schedules *B* → *A* → *C* and *B* → *C* → *A*.

For an illustration, we consider a single type of part. Each type of product has a different number of parts; i.e., product *A*, *B*, and *C* have part *a* 2, 5, and 3, respectively. We now examine the impact of each disassembly schedule on the performance of the supply delay. We assume that product disassembly times and order intervals are equal to unit time period. At the beginning of each period, the parts included in a product type are released, while at the end of each period a batch of parts leaves the inventory to meet the demand. Here, the mean value of the supply delay can be calculated as: (the sum of supply delay)/(the number of parts). Note that the mean supply delay of schedule *B* → *A* → *C* is less than that of schedule *B* → *C* → *A*. It also means that the supply delay depends on the disassembly schedule of products. As a result, a priority assignment procedure has to be judged on how well it succeeds in reducing the supply delay.



Schedule *B*-> *A*-> *C*
Mean supply delay: (14/10=1.4)

Schedule *B*-> *C*-> *A*
Mean supply delay: (15/10=1.5)

Figure 4. Comparison of two disassembly schedules

5. DEVELOPMENT OF PROPOSED RULE

Notations

i	: index for product type $(i = 1, 2, \ldots, I)$
j	: index for part type $(j = 1, 2, \ldots, J)$
k	: index for disassembly decision $(k = 1, 2, \ldots, K)$
n	: number of products
t	: index for time
$t_{[k]}$	: the time that k^{th} decision is made
$PI^{j}_{t_{[k]}}$	: inventory level of part type j at $t_{[k]}$
Dt_i	: the time required for product type i to be : completely disassembled
$\overline{Dt_j}$	: mean interval time of disassembly of part type j
$\overline{Lt_j}$	: mean interval time of orders for part type j
$MD^{i}_{t_{[k]}}$	: MD value of products type i at $t_{[k]}$
Q_{ij}	: number of part type j in product type i
u_j	: proper inventory level for part type j
λ_j	: batch size of orders for part type j
$i^{*}_{t_{[k]}}$	: the product that is selected at $t_{[k]}$
$S^{i}_{t_{[k]}}$	: set of products of type i available at $t_{[k]}$
$n^{i}_{t_{[k]}}$	: set of products of type i newly arrived at $t_{[k]}$
d_1, d_2	: differences between actual and ideal inventory levels
$R_{t_{[k]}}$	: binary variable representing operation state of machine at $t_{[k]}$

$$\begin{cases} = 1 & \text{If machine is busy} \\ = 0 & \text{If machine is idle} \end{cases}$$

5.1 Minimum Distance (MD) rule

In this section, we present the design of the priority assignment procedure. Figure 5 illustrates a typical inventory scenario. Suppose that at time $t_{[k]}$ a product is completely disassembled. $PI^{j}_{t_{[k]}}$ indicates the inventory level at the time. Before determining the next product to disassemble, we confirm whether or not there are products available for further disassembly. Let $i^{*}_{t_{[k]}}$ be the product selected for the next disassembly at time $t_{[k]}$. While disassembling the product $i^{*}_{t_{[k]}}$, inventory $PI^{j}_{t_{[k]}}$ decreases to satisfy the orders until the parts of amount Q_{ij} are newly released. The inventory decreases until when all parts of the product is disassembled. The complete disassembly of the product makes an amount $(Dt_i / \overline{Lt_j})\lambda_j$ of parts leave the inventory. Therefore, $\{PI^{j}_{t_{[k]}} - (Dt_i / Lt_j)\lambda_j + Q_{ij}\}$ is equal to $PI^{j}_{t_{[k+1]}}$, which is the inventory level at time $t_{[k+1]}$.

The vertical distances d_1 and d_2 are referred to as the inventory variance between the resulting inventory level and line u_j. The line u_j can be considered as a proper inventory level that minimizes the supply delay if actual inventory levels ultimately achieve the line. (The detailed estimation of u_j is presented later in this section.) If the inventory variance becomes larger, the supply delay

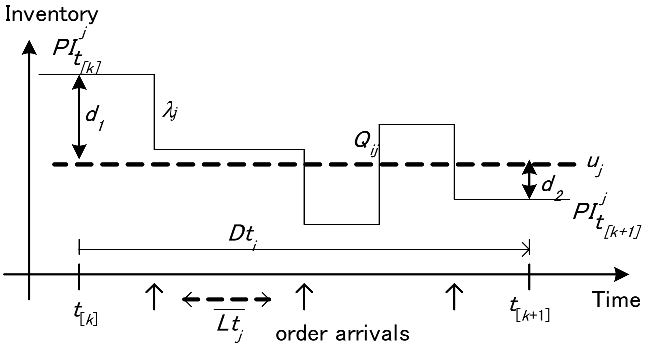


Figure 5. Typical inventory scenario resulted from the disassembly of a product

increases in proportion to the waiting time of parts in the inventory. The supply delay can be maintained at a minimum level only when the inventory variance is ultimately minimized over the scheduling horizon. However, the inventory control cannot be done in an independent manner because each type of product releases different type and number of part during the disassembly. To minimize the inventory variance, it is necessary to control each part inventory toward to its proper inventory level. For example, in Figure 5, the vertical distance d_2 is the inventory difference between the predicted inventory level $\{PI^j_{t_{[k]}} - (Dti/\overline{Ltj})\lambda_j + Q_{ij}\}$ and the proper inventory level u_j. Therefore, the inventory variance can be minimized by selecting a product type that minimizes the sum of the vertical distances for all part inventories. The Minimum Distance (MD) rule is given as Eq.(1).

$$MD^i_{t_{[k]}} = \sqrt{\sum_{j=1}^{J}\left(PI^j_{t_{[k]}} - \frac{Dti}{\overline{Ltj}} \times \lambda_j + Q_{ij} - u_j\right)^2} \qquad (1)$$

For estimating u_j, there are four factors that significantly influence the actual levels of part inventory: part number, part release interval time, order batch size, and order interval time. The factors related to the order are beyond control, but the number of parts to be released from used products can be controlled by the MD rule proposed in this paper. Hence, three deterministic factors are used here for estimating u_j: mean interval time of disassembly ($\overline{Dtj}$), mean order interval time ($\overline{Ltj}$), and order batch size (λ_j). If, for instance, $\overline{Dtj}$ is equal to $\overline{Ltj}$, u_j becomes λ_j, because the amount of λ_j is sufficient to meet the orders arriving in interval $\overline{Ltj}$. In case of a larger $\overline{Dtj}$ than $\overline{Ltj}$, however, a larger u_j than λ_j is necessary to meet the demand because more than one order arrives during $\overline{Dtj}$. The required inventory level becomes higher in proportion to the ratio of ($\overline{Dtj}$ / $\overline{Ltj}$)λ_j. Even though $\overline{Dtj}$ is smaller than $\overline{Ltj}$, however, u_j should be equal to λ_j. This is because the orders of batch size λ_j may not be satisfied due to the lower inventory u_j. Accordingly, the three cases can be represented as:

$$u_j = \begin{cases} (\overline{Dtj}/\overline{Ltj})\lambda_j & (\text{if } \overline{Dtj} > \overline{Ltj}) \\ \lambda_j & (\text{if } \overline{Dtj} \le \overline{Ltj}) \end{cases} \qquad (2)$$

In Eq.(2), $\overline{Dtj}$ denotes the mean value of part release time for each part type. It differs according to the disassembly pattern of two successive products. With respect to three product types *A*, *B*, and *C*, we can categorize the disassembly patterns to be of nine types: *A*→*A*, *A*→*B*, *A*→*C*, *B*→*A*, *B*→*B*, *B*→*C*, *C*→*A*, *C*→*B*, and *C*→*C*. As an example of estimating $\overline{Dtj}$, we consider the case of part type *a* in Figure 3. Two parts of type *a* are released within 10 minutes after the disassembly of product type *A* is started. Since we need an additional 40 minutes to disassemble the remainder of parts *f*, *h*, *d*, and *c*, a total of 50 minutes is required for disassembling the product type completely. For products of type *B*, on the other hand, the release time of part *a* is 120 minutes. Accordingly, in the case of disassembly pattern *A*→*B*, the release interval of part type *a* ($\overline{Dta}$) becomes 160 minutes (40+120=160). This means that each disassembly pattern results in different release intervals for each part type. If a certain product type does not contain specific part types, the complete disassembly time of the product type is summed for estimating $\overline{Dtj}$ of the part type.

Generally, the return rates of used products are different. This implies that each disassembly pattern may not be equally featured over the scheduling horizon. The appearance probability of each disassembly pattern can be calculated by multiplying individual return rates of two product types considered in the disassembly pattern. For a given part type *j*, $\overline{Dtj}$ can be calculated as Σ (appearance probability × disassembly interval time) / (total number of disassembly patterns). Appendix B shows an example for estimating $\overline{Dtj}$ with respect to *Job structure 1*.

5.2 Algorithm

Based on the MD rule, we present an algorithm that consists of four steps. Step 1 identifies the set of used products available for disassembly. Step 2 checks the availability of products and disassembly machine, and then selects a product to disassemble. After finishing the disassembly of the selected product, Step 3 updates the set of available products for each product type by considering whether or not there are newly arrived products. Step 4 implies that the machine has to wait for a certain product to arrive if no products are available.

Algorithm

```
Step 1      : $k = 1$.
            : For each $i$, identify set $S^{i}_{t_{[k]}}$.
Step 2      : If $\cup^{I}_{i=1} S^{i}_{t_{[k]}} \neq \{\phi\}$ and $R_{t_{[k]}} = 0$, go to step 2.1.
            : Otherwise, go to Step 4.
  step 2.1  : $i = 1$.
  step 2.2  : While $i \leq I$, repeat this step.
            : If $S^{i}_{t_{[k]}} \neq \{\phi\}$, calculate $MD^{i}_{t_{[k]}}$.
            : $i = i + 1$.
  step 2.3  : Select $i^{*}_{t_{[k]}}$ among $S^{i}_{t_{[k]}}$ that has the minimum
              value of $MD^{i}_{t_{[k]}}$.
            : Load $i^{*}_{t_{[k]}}$ on disassembly machine and start
              disassembly.
            : $S^{i}_{t_{[k]}} = S^{i}_{t_{[k]}} - \{i^{i}_{t_{[k]}}\}$.
            : Wait for the machine to finish the disassembly.
            : If the machine is idle, go to the next step.
Step 3      : For each $i$, $S^{i}_{t_{[k+1]}} = S^{i}_{t_{[k]}} + n^{i}_{t_{[k]}}$.
            : $k = k + 1$.
            : Go to Step 2.
Step 4      : Wait for a newly arriving product.
            : If a product has arrived, for each $i$ update
              $S^{i}_{t_{[k]}}$ by identifying the new product.
            : Go to step 2.1.
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6. SIMULATION STUDY

A disassembly system, subject to uncertain product arrivals and operation times, is considered dynamic in nature (Guide, 1997; Bras and McIntosh, 1999). To cover this dynamic nature, a simulation model is developed in ARENA simulation language (Law and Kelton, 2000). In the model, three types of products that are denoted by capital letters *A*, *B*, and *C* are disassembled. The type of arriving product is determined from a pre-specified input probability: $A = 0.2$, $B = 0.3$ and $C = 0.5$. A total of eight different types of parts that are referred to with lowercase letters *a*, *b*,…, *g* and *h* are released through the pre-determined release sequence for each product type. Therefore, the disassembly shop simulated in this study is designed to have eight different types of disassembly machine to disassemble each part. Meanwhile, Holthaus and Rajendran (1997) demonstrated their job-shop simulation with only six machines, claiming it was adequate to represent the complex structure of a job shop.

6.1 Experimental Design

The important factors of this simulation study are service levels of parts, job structures, and priority rules. Three levels of the part service are simulated in the experiment: 85% and 95% for all part types. From the assumption that consumption rates of parts are not equal, we also consider different part service levels: 95% for parts *a* and *b*; 75% for parts *c*, *d*, *e* and *f*; and 55% for parts *g* and *h*. Three levels of job structures are examined. For each job structure, a different part composition, part release sequence, and release time are pre-determined, as shown in Appendix A. No priority rules for product disassembly scheduling have been reported in the existing literature. To show the effectiveness of the proposed MD rule, we examine the scheduling strategies of first-in, first-out (FIFO) and shortest processing time (SPT). The processing time of a product is measured based on the time required for separating all parts from the product.

An exponential distribution is used to cover the largely distributed product arrival time. It is considered that the disassembly times and order arrivals are normally distributed, respectively. The shop utilization is ranged between 80-90% because of the highly distributed product arrival times. For each simulation set, we fix the number of replications at 20. The independence of replications is accomplished using different random numbers for each replication. The run length is fixed at 205,000 simulation run time for every replication, and the statistical counters are cleared after 5,000 simulation run time.

6.2 Discussion of Results

For each experiment set, the performance measures of flow time, supply delay, and part lead time were investigated. The numerical results are presented in terms of mean and standard deviation values. The standard deviation values of a performance measure indicate the performance stability of a priority rule. The statistical analysis of the experimental results with three-factorial ANOVA and Duncan's multiple range test (Montgomery, 1991) were conducted using the significance level of 1%. Before the statistical tests were conducted, the output results were examined to ensure equality of variances and normality.

Table 1 summarizes the results of the experimental analysis. With respect to the performance of mean supply delay, the ANOVA analysis shows the statistical differences between the MD rule and the traditional rules

Table 1. Results of the simulation study

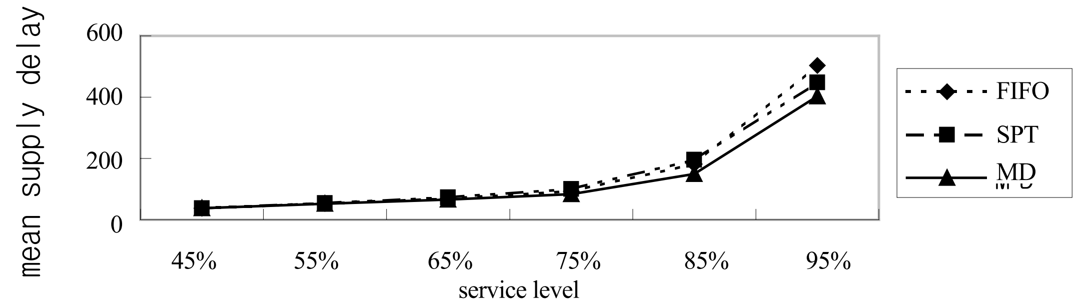
Service level	Job structure	Priority rule	Flow Time		Supply Delay		Part Lead Time	
			mean	sd	Mean	sd	mean	sd
85%	1	FIFO	541.76	149.57	181.77	21.10	723.43	157.57
		SPT	489.90	191.27	195.45	21.34	685.25	204.20
		MD	482.15	114.39	149.65	10.67	631.97	117.95
	2	FIFO	615.63	340.80	138.05	17.15	753.63	344.84
		SPT	637.17	174.29	149.53	15.14	786.65	183.17
		MD	602.63	183.17	121.41	7.84	725.84	187.98
	3	FIFO	542.98	136.51	200.62	46.96	755.86	149.13
		SPT	680.75	256.97	241.76	35.80	920.65	288.99
		MD	521.54	119.42	171.59	10.43	693.19	124.69
95%	1	FIFO	681.61	257.37	503.62	136.40	1185.13	384.68
		SPT	614.49	345.16	448.07	158.24	1061.93	288.99
		MD	562.54	154.44	402.90	102.95	965.09	124.69
	2	FIFO	629.21	156.93	413.74	157.09	1042.76	297.78
		SPT	702.79	174.67	385.85	85.26	1087.38	235.94
		MD	613.18	182.70	307.22	58.21	920.27	226.20
	3	FIFO	552.63	156.68	501.98	128.44	1058.84	281.14
		SPT	578.48	183.02	529.25	111.74	1106.87	276.10
		MD	510.45	101.02	409.52	82.89	919.76	171.87
95% (*a*, *b*) 75% (*c*~*f*) 55% (*g*, *h*)	1	FIFO	635.27	299.00	211.87	49.05	847.74	183.48
		SPT	623.55	183.48	233.43	42.22	856.73	218.41
		MD	549.06	119.31	168.50	21.68	717.36	132.49
	2	FIFO	616.27	141.83	216.36	62.72	831.95	190.83
		SPT	689.29	211.49	219.07	36.80	907.91	234.93
		MD	549.06	83.88	168.77	28.51	745.79	101.61
	3	FIFO	614.99	225.84	272.15	42.83	886.36	253.05
		SPT	581.22	125.31	283.80	42.46	865.14	153.83
		MD	508.23	95.06	221.25	23.78	729.29	103.80

(p-value < 0.01). Even though improvement in the part lead time performance of the MD rule is obscured by the large variance of the flow time component, the part lead times resulting from the use of the proposed rule are still more effective than the traditional rules if we compare the relative change in the mean part lead time.

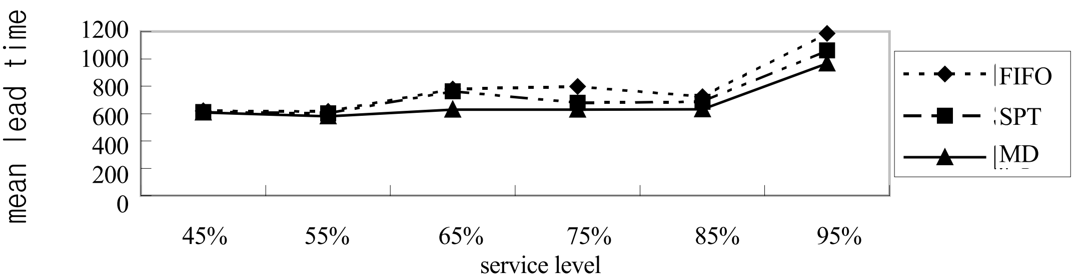
Figure 6-(a) and (b) illustrate the change of the mean supply delay and part lead time with respect to the part service level. From the figures, we can conclude that our rule is useful especially in the case where the supply delay is high. Figure 7-(a) and (b) represent the sample out of real inventory variance with respect to the priority rules (service level 95% and *Job structure 1*). The figures also show that our MD rule is more useful than other rules in reducing the inventory variance.

7. CONCLUSIONS

This paper studied product scheduling in the design of a priority assignment rule for shops disassembling multi products. We focused on the supply delay as the major performance measure. In an attempt to improve the performance of the supply delay, we proposed the Minimum Distance (MD) rule that aims to control part inventories toward to a proper level. A comparative analysis on the performance of the traditional rules and the MD rule is provided via a simulation model. The new rule shows a significant improvement over the traditional rules with respect to the mean supply delay. The proposed rule may become more useful when used in combination with rules that are effective for the flow time component. Further research will be focused on that issue.

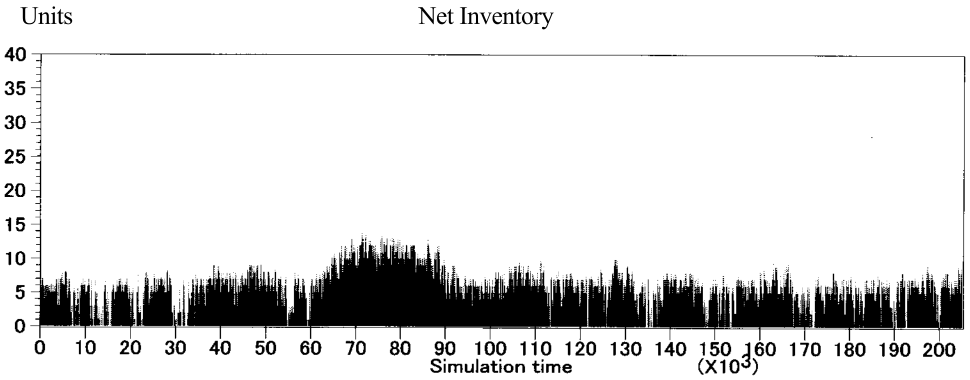


(a) Mean supply delay

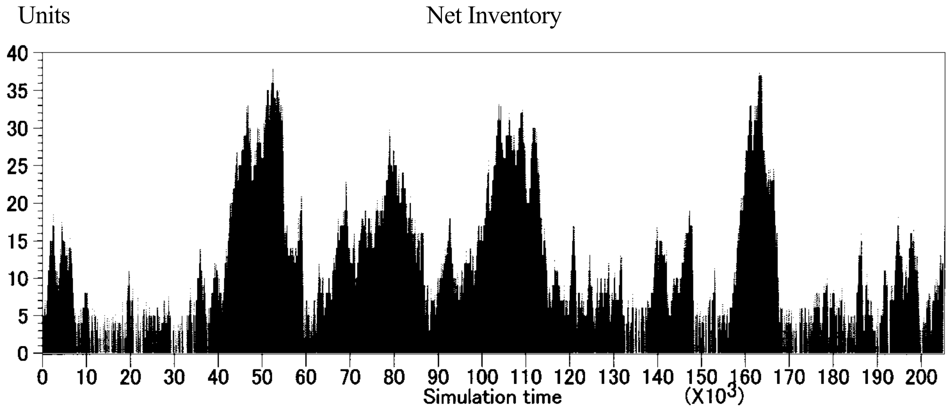


(b) Mean part lead time

Figure 6. Performance with respect to part service level



(a) Example of the MD rule



(b) Example of the traditional rules

Figure 7. Sample output of inventory variance

APPENDIX

A. Table of Job structures

Job	Product type	Part release sequence and release time
1	A	a(2,10)→f(3,20)→h(4,30)→d(5,40)→c(3,50)*
	B	b(8,30)→c(7,60)→f(6,75)→g(6,90)→e(6,110)→a(5,120)
	C	a(3,5)→h(6,20)→b(2,25)→g(4,45)→e(4,55)→f(1,60)→d(5,80)
2	A	a(8,20)→c(5,35)→b(7,50)→e(2,60)→d(7,80)→h(4,90)→f(7,110)→g(3,120)
	B	b(3,10)→c(2,15)→g(3,25)→h(4,35)→e(5,50)
	C	e(3,10)→h(2,15)→a(2,25)→f(3,40)→g(4,50)→d(3,65)→c(3,80)
3	A	c(2,10)→h(6,30)→b(6,50)→f(1,55)→e(6,75)→g(2,80)
	B	a(5,20)→g(3,30)→b(4,40)→h(4,50)→c(8,70)→f(8,100)→d(7,120)
	C	d(3,10)→a(5,30)→g(4,40)→e(4,50)

c(3,50)*: part type (number of parts, release time in minute)

B. Table of $\overline{Dtj}$ (*Job structure 1*)

Disassembly pattern	Proba-bility	Part type							
		a	b	c	d	e	f	g	h
A→A	(0.04)	50	100	100	50	100	50	100	50
A→B	(0.06)	160	80	60	130	160	105	140	140
A→C	(0.10)	45	75	80	90	105	90	95	40
B→A	(0.06)	130	140	110	160	60	65	80	150
B→B	(0.09)	120	120	120	240	120	120	120	240
B→C	(0.15)	5	115	110	200	65	105	75	140
C→A	(0.10)	85	105	130	40	75	40	85	90
C→B	(0.15)	195	85	140	120	135	95	125	180
C→C	(0.25)	80	80	160	80	80	80	80	80
$\overline{Dtj}$	∑(1.00)	93.20	96.00	123.50	122.00	96.00	86.00	96.00	122.00

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