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A simulation analysis of part launching and order collection decisions for a flexible manufacturing system

Yi-Chi Wang[a,*], Toly Chen[a], Hsiangtsai Chiang[b], Hui-Chen Pan[a]

[a] Department of Industrial Engineering and Systems Management, Feng Chia University, No. 100, Wenhwa Rd., Seatwen, Taichung 40724, Taiwan

[b] Department of Accounting, Feng Chia University, No. 100, Wenhwa Rd., Seatwen, Taichung 40724, Taiwan

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ABSTRACT

In a dynamic flexible manufacturing system (FMS) environment jobs arrive randomly, and in most of the existing studies the due date for a single part is set individually. However, when the due date is set for an order that consists of multiple parts, some completed parts may have to wait for the rest of the order to be completed. This paper studied the scheduling problem in the FMS in which orders require the completion of different parts in various quantities. The orders arrive randomly and continuously, and all have predetermined due dates. Two scheduling decisions were considered in this study: launching parts into the system for production, and determining the order sequence for collecting the completed parts. A new part-launching rule, named the Tardiness Estimating Method (TEM) was proposed. A discrete-event simulation model of the FMS was developed and used as a test-bed for experiments under various system conditions. The proposed part launch rule was capable of providing good performance regarding minimum mean tardiness and maximum service level, but provided only a moderate flow time when compared with the other five rules commonly used in the literature. In addition, three order collection rules were tested in the experiments. Collecting parts for the order with the earliest due date (EDD) was found better than the other rules for tardiness related measures.

1. Introduction

Given the increased level of global competition, the common challenge is that every modern manufacturing enterprise must be capable of making customized high-quality products with small lot sizes and short lead times in order to survive in today's competitive market. A flexible manufacturing system (FMS) is a computerized and highly automated production system that is designed to produce a mid-volume and a mid-variety of products at a high level of efficiency. This type of production system combines the efficiency of a mass production line with the flexibility of a job shop and is the best fit for modern manufacturing enterprises to boost their productivity and competitiveness [1]. Since the successful implementation of the first flexible manufacturing system (FMS) in the 1960s, an abundance of FMS issues have been studied. A FMS usually consists of a set of computer numerically controlled machines (CNCs) linked with an automated material handling system. One of the characteristics distinguishing the FMS from other manufacturing systems is that the FMS provides routing

* Corresponding author. Fax: +886 4 24510240.
E-mail addresses: wangyc@fcu.edu.tw, wang_yichi@yahoo.com.tw (Y.-C. Wang).

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flexibility because of the capability of modern CNC machines, essentially allowing the design of alternative process plans for a job. This flexibility and level of automation make the FMS an extremely complex, large-scale modern production system.

A large amount of research has been conducted to solve problems such as loading, scheduling, automated guided vehicle (AGV) dispatching, or cutting tools management in FMSs. Most of the existing literature treats a job as a single order when released into the FMS, and each job in the shop normally represents a single type of part. The problem investigated in this study is that an order may require to complete different parts, each part in different quantities. Contrary to launching a part with a production due date, this problem involves two decisions as follows:

(1) Part launch: this refers to the selection of the parts to be loaded onto a pallet with at the loading/unloading end of the FMS for subsequent processing in the system.
(2) Order collection: since there may be many different parts that must be completed in the output buffer of FMS, they must be collected to form a completed order for shipment. This decision refers to deciding the order of collecting the completed parts and the subsequent shipment.

The purpose of this paper is to provide a simulation analysis by examining the above two decisions when operating a dynamic FMS. A discrete-event simulation model for a make-to-order FMS was developed and used as a test-bed for experiments under various system conditions. The remainder of this paper is organized as follows. Section 2 reviews the literature on scheduling as well as FMS control issues. Section 3 details the FMS simulation model used in the present research. Section 4 describes the order collection rules and the part launch rules as well as the experimental conditions in this study. Section 5 discusses the simulation results. Finally, in Section 6 conclusions are drawn and directions for future research are provided.

2. Literature review

A large amount of literature has been devoted on the examination of the effects of the planning and scheduling strategies of the FMS, both from an operational and a control point of view. To implement a FMS, the following issues must be taken into consideration [2]:

- Sequencing of the parts to be loaded into the system.
- Part routing.
- Sequence the parts waiting in each machine to be processed.
- Sequence those parts that require transportation.
- Allocate material handling devices to fulfill the transportation requirements of the parts.

These five issues can be further classified into eight scheduling problems. Table 1 provides a summary of the literature focusing on these eight problems. It is obvious that the top three are part launching (B), part routing (F), and part sequencing in the machine buffer (C).

2.1. Fixed part routing

In some studies, the part routes were determined in the FMS planning phase. In these studies the focus was on scheduling problems other than the dynamic part routing problem. For example, Sabuncuoglu and Hommertzheim [7] examined the effects of the dispatching rules used for prioritizing the jobs waiting for processing in the machine queue, and the rules to dispatch an automated guided vehicle (AGV) under various experimental conditions. They found that the smallest modified operation due-date (MOD) was the best rule for sequencing the jobs in the machine queue, and that the largest queue size (LQS) was the preferred rule for the dispatching an AGV for various due-date criteria. For different criteria, like minimizing the mean flow time, these researchers indicated that the shortest processing time (SPT) combined with any AGV rule tended to be suitable [8]. Among the AGV rules examined, LQS and STD (shortest travel distance) in combination with any machine rule proved to be the best rules. These authors also investigated the performance of the rules under various approaches of setting the internal due dates in a FMS [9]. They found that the 'flow-allowance is proportional to the total work' (TWK) rule outperformed other due-date setting rules by minimizing the mean tardiness for most of the conditions tested. Sabuncuoglu [11] extended their earlier work to measure the sensitivity of the machine and the AGV scheduling rules to the processing time distributions, loading levels, and machine and AGV breakdowns. The results of their study showed that the performance of scheduling rules is affected by the variances of the distribution of the operating time, the different system loading levels, as well as the machine downtime percentage.

Sabuncuoglu and Lahmar [16] compared two operation grouping policies: aggregation and disaggregation. In the aggregation case, all the operations required for making a part are performed at a single machine. The machine does not release a part until all the operations required are completed. Disaggregation is the process of assigning the operations required on a part to various machines. In short, aggregation is the case of a single-stage multi-machine FMS [26], while disaggregation is the case of a normal FMS. Their study concluded that although FMS managers may advocate the aggregation approach in order to reduce the number of setups, the aggregation approach is not always advantageous in a variety of FMS environments. They also concluded that the disaggregation approach is only suitable for FMSs composed of non-identical machines, and especially under heavy loading conditions.

Table 1
Summary of the literature related to FMS scheduling.

Literature (sorted by year)	A	B	C	D	E	F	G	H
Denzler et al. [3]		x						
Denzler and Boe [4]		x						
Slomp et al. [5]			x			x	x	x
Ro and Kim [6]				x		x		x
Sabuncuoglu and Hommertzheim [7]			x	x				
Sabuncuoglu and Hommertzheim [8]			x	x				
Sabuncuoglu and Hommertzheim [9]			x	x				
Maheshwari and Khator [2]		x	x	x		x		
Caprihan and Wadhwa [10]		x				x		
Sabuncuoglu [11]			x	x				
Chen et al. [12]		x		x				
Chan [13]						x		
Sabuncuoglu and Karabuk [14]	x							
Chan [15]		x	x			x		
Sabuncuoglu and Lahmar [16]						x		
ElMekkawy and ElMaraghy [17]	x	x	x			x		
Sabuncuoglu and kizilisik [18]	x	x	x			x		
Chan et al. [19]	x	x	x					
Chen and Chen [20]	x	x	x		x	x		
Chan and Chan [21]		x	x		x			
Chutima and Meesaplak [22]		x	x		x			
Caprihan and Wadhwa [23]			x			x		
Chan et al. [24]			x			x		
Chan et al. [25]			x			x		
Kumar and Sridharan [26]			x					
Ali and Wadhwa [27]		x						

Notes:
Dynamic re-scheduling issue.
Part launching in the system.
Part sequencing in the input buffer of the machine.
AVG dispatching.
Tool management.
Part routing (machine selection).
Operator management.
AGV routing.

2.2. Dynamic part routing

Contrary to the studies above, other studies considered that part routes are dynamically determined once the parts are released into the system. When considering flexible part routing for a FMS, it is necessary to understand the impact of the various levels of routing flexibility on the performance. One common but important conclusion has been made in several studies [10,15,24,25,27]: increasing routing flexibility at the cost of increasing the processing time, is not always beneficial for the performance of a FMS. Choi and Malstrom [28] evaluated the performance of traditional scheduling rules by simulating an FMS system that was constructed based on the data of an actual FMS. The rules evaluated consisted of seven job-dispatching rules and four machine-selection rules, creating a total of 28 combinations. Each combination was evaluated by six performance criteria. The simulation results indicated that the rule that resulted in the least work in queue (WINQ) in terms of processing time was the best machine selection rule. Ro and Kim [6] proposed three machine selection heuristics (ARD, ARP, and ARPD). The ARD rule selects the machine that requires the shortest total time for travel time, queuing time, and processing time combined. The use of the ARP rule requires that routes be determined by a linear programing (LP) model with the objective of minimizing the makespan. Implementation of the ARP rule requires that the LP model must be solved whenever a new job arrives or when a machine breaks down. The ARPD rule is a combination of the ARD and ARP rules. Initially, the routes are determined by solving the LP model, but if the primary machine (from the LP solution) is busy, then a machine is selected based on the ARD rule. Ro and Kim compared their three heuristics with two other heuristics (NAR and WINQ). The NAR rule selects the route with the least total processing time (no alternate routes are permitted). Their simulation results determined that the ARD rule provided the best results in four performance measures (makespan, mean flow time, mean tardiness, and maximum tardiness) but not for system utilization. They also found that the ARD, APRD, and WINQ rules were significantly better than the ARP and NAR rules in every performance measure. Chan [13] continued a research project similar to the work of Ro and Kim [6]. He studied the effects of three routing rules (DAR, PAR, and NAR): DAR, a dynamic alternative routing rule which is basically similar to ARD. PAR is the planned alternative routing rule which is similar to ARP, and NAR is the rule without any alternative routes. In his study, Chan also examined the influence of adopting the universal loading station and dedicated loading stations. His simulation results indicated that the FMS with a dedicated loading station outperformed the FMS with universal stations in all aspects. Subramaniam et al.

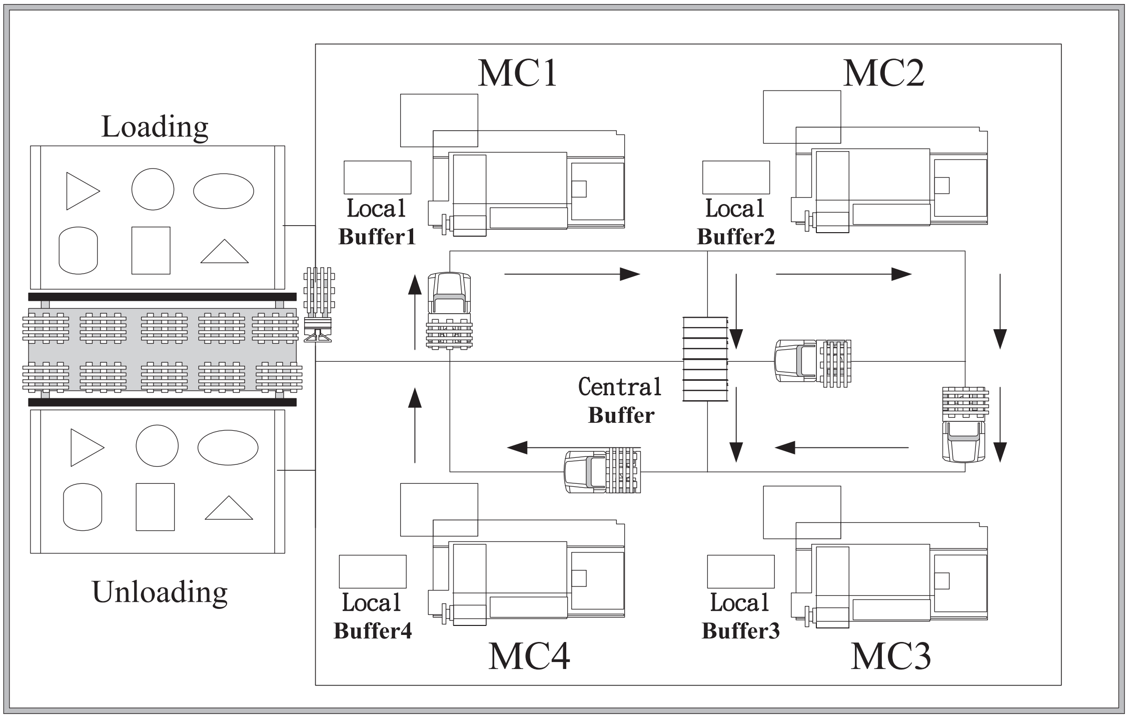

Fig. 1. Layout of the FMS in this study.

[29] proposed three route selection rules: LAC, LAP, and LACP. LAC selects the machine with the lowest average processing cost for each operation in the machine queue. For LAP the machine selection is based on the lowest average processing time for each operation in the machine queue. LCAP awards the highest priority to the machine that has the lowest aggregate cost and processing time. They found that the LAC and LAP rules perform best for the mean cost and the mean tardiness performance measures, respectively, while the performance of the LACP rule was between that of the LAC and LAP rules.

Sridharan and Subash Babu [30] conducted a simulation study to examine the effectiveness of part launching, part routing, and part sequencing for taking AGV in the situation of a failure-prone FMS. Kumar and Sridharan [26] presented another simulation study in which they investigated the effect of scheduling rules on part launching and tool request selection decisions in a FMS. They concluded that the part launching rule is significant for all the performance measures, while the tool request selection rule tends not to be significant for any of the performance measures. Joseph and Sridharan [31] also investigated the effect of dynamic due-date assignment models, routing flexibility levels, sequencing flexibility levels, and part sequencing rules on the performance of a FMS. Their statistical analysis of the simulation results revealed significant interactions among all factors considered for the performance measures.

In general, most researchers treated an order as a job to produce a part within the flow of a FMS. The only exception was the study of [30]. Although they considered a situation in which an order required making several parts, they were only of one type. In the real world however, it is not uncommon for a customer to place an order that requires different types of parts in various quantities. An order for making different part types will require that some completed parts will have to wait for the rest of the order to be finished before the order can be shipped to the customer. This complicates the scheduling and control problem of the FMS. From the reviewed literature it is evident that this problem has not yet been resolved. Therefore, the present paper will focus on part launching and order sequencing of collecting the finished parts in an attempt to solve the above mentioned problem using a discrete-event simulation model.

3. Simulation model

The problem considered in the present study is related to the dynamic environment of a FMS which is configured as shown in Fig. 1. In this study the FMS is comprised of four different CNC machines each with one local input buffer that can manufacture six different types of parts. To fabricate each type of part requires four to six operations. Each machine is capable of performing several different operations. Some operations can be performed by an alternative machine. The best level of routing flexibility found by Chan [15] is 2. This means that an operation can be performed by either one of two different machines. In this study, this level of routing flexibility is used for all operations when producing the six different types of parts. The routing strategy used for selecting one or the other machine to perform the operation is ARD policy, which has been proven to be a good part-routing strategy [6,21].

Table 2
Process plan for part types/processing times and required fixtures (unit: minutes).

Part type	Operation	Machine				Fixture type
		1	2	3	4	
A	1	7	3	–	–	3
	2	–	11	–	1	3
	3	–	6	6	–	1
	4	1	–	–	7	2
B	1	5	–	10	–	1
	2	–	–	9	2	2
	3	–	8	–	4	2
	4	8	–	7	–	3
	5	5	–	–	9	2
	6	–	–	7	11	1
C	1	6	–	8	–	1
	2	–	–	4	7	2
	3	8	–	–	4	3
	4	6	10	–	–	1
	5	–	9	–	7	2
D	1	–	–	7	8	3
	2	9	8	–	–	1
	3	–	1	3	–	2
	4	10	–	9	–	2
	5	–	7	–	8	1
E	1	3	–	5	–	1
	2	–	1	–	10	3
	3	10	–	–	8	1
	4	–	2	7	–	2
	5	4	6	–	–	2
	6	–	–	7	2	1
F	1	2	–	6	–	3
	2	7	–	–	5	3
	3	–	4	2	–	1
	4	–	–	5	11	2

Chan and Chan [21] conducted a comprehensive survey on scheduling issues of the FMS. They found that most of researchers focused on only a few decision points. Modeling a complex FMS with multiple decisions points may be difficult, but it is necessary to make the model as close as possible to reality. They also pointed out that some authors considered only time-processing-based rules and ignored due-date based rules. From the summary they provided, it is evident that only a scant few authors consider more than one scheduling problem like part dispatching problems, machine selection problems, and AGV scheduling problems simultaneously in their simulation models. Raj et al. [1] reviewed some implementation issues of the FMS and pointed out that there is a wide gap between research on the FMS and the actual implementation of a FMS. They addressed the importance of including the issues of AGV dispatching, the machining tools and equipment management. Thus, in our simulation model, the AGV transportation time, the pallets and the dedicated fixtures for the parts are all taken into consideration.

When a particular operation of a part is completed by a machine, that part will then be sent to the central buffer and stays there until it is transported to another machine for its next operation. If a fixture replacement is necessary, the part will be sent to the loading area and re-enter the system after the proper fixture for the next operation is successfully installed. All transportation is handled by four AGVs. The transportation times are calculated based on the distance between the facilities involved (shown in Table 2) and the AGV's travelling speed. When a part requires transportation, only the AGVs that are free at that time are taken into consideration. If there is more than one AGV free at the same time, then the request will be sent to the AGV closest to where the part is. This is the STD rule which is suggested from the study of Sabuncuoglu and Hommertzheim [8]. Each AGV may receive several requests from parts. It may be worth trying various AGV dispatching rules like MOD, LQS, et cetera. Since AGV dispatching is not our focus in this study, FCFS (first come first served) is employed in the transportation request selection for an AGV.

In this study the simulated FMS is developed on the following assumptions:

- Each machine can carry out only one operation at a time.
- A part in the loading area is available for launching into the system when a pallet and a proper fixture are available.
- Operation preemption is not allowed.
- Processing times for each operation are deterministic. All the processing times are presented in Table 3.
- The part may revisit the same machine before completing all its manufacturing steps.
- Machines may break down. The mean time between failures is set at 34,200 min and the mean time for repairing the broken machine is set at 18 min.

Table 3
Distances between the facilities (unit: meter).

To/From	L/UL	MC1	MC2	MC3	MC4	WIP
L/UL	–	12.15	18	36	41.85	24.3
MC1	41.85	–	5.85	23.85	29.7	12.15
MC2	36	41.85	–	18	23.85	21.15
MC3	18	30.15	36	–	5.85	12.15
MC4	12.15	24.3	30.15	48.15	–	21.15
WIP	9	21.15	27	12.15	21.15	–

Table 4
Notation used in this study.

SCT	Simulation Clock Time.
P_k	The estimated processing time per piece for operation *k*. This value is determined by averaging two of the processing times performed by two different machines.
$ETPT_i$	The estimated total processing time for order *i*. This is computed by summing all the estimated processing times for the required operations.
IC_j	Inter-completion time of the last two completed parts (for part type *j*).
IQ_j	The quantity of part type *j* that has been launched for production.
Q_j	The required quantity of part type *j*.
ETM_j	The estimated total processing time for all the remaining quantity of part type *j*.
ET_j	The estimated tardiness for part type *j*.
D	Due date for a certain order.

- All pallets are general-purpose pallets. The capacity of each pallet is one part and the total number of pallets is limited to fifteen.
- Dedicated fixtures are used for each operation (i.e. an operation can only be performed using a dedicated fixture). The number of each fixture type is limited to ten.
- Parts may return to the input buffer of the system if changing to a proper fixture is required.
- A part must leave the system and vacate its pallet and the fixture when all their operations are finished.
- Local buffer capacity for each machine is limited and is set at 5.
- No collisions occur along the AGV path.
- There is no scrap produced by the machines.
- Once the order is placed, no cancelation is allowed.

4. Operational and control strategies in the FMS

The most difficult part of the present problem is that each order requires making different parts in various quantities. Making a part requires the completion of a series of operations. In the FMS model, each operation can be performed with one of two machines and the system is capable of making 6 different types of parts. Once several orders have arrived it is time for the production launch. Logically, the decision in which order the production will be launched should be determined before sequencing the part for launching into the system. However, the manufacturing lead time for the different parts varies based on processing time, resource (machines/AGVs) availability, equipment (pallet/fixture) usage, and levels of part congestion in the system. This also makes it difficult to control the production of different part types in different quantities. In that case, the sequence for part launching is based on the output of the FMS. In other words, we first determine the order for the complete part collection. With this information we then decide which part type should be launched for production.

4.1. Order collection rules

As mentioned above, the first decision that must be made is determining for which order to collect the completed parts. The notations used in this paper are presented in Table 4. The three scheduling rules employed in the present study are described as follows.

- Early Due Date (EDD): Collect the completed parts for the order with the earliest due date.
- Critical Ratio (CR): The critical ratio (CR_i) for order *i* is defined as follows:

$$CR_i = (D_i - SCT)/ETPT_i \tag{1}$$

With this rule, the highest priority is given to the order with the smallest CR value.

- Minimum Slack Time (MST): The remaining slack in order *i*, defined as ($D_i - ETPT_i - SCT$), is computed. The order with the minimum remaining slack time will be selected for completed part collection.

With any of these three order collection rules, order pre-emption is allowable in this study. In other words, the operators may be forced to change the order they use for collecting the completed parts. When this happens, those parts that have been collected will be used for the new order.

4.2. Part launching rules

A part launch rule is used to select the next part type for a production launch in the FMS. The proposed part launch rule as well as the other 5 rules commonly used in the literature is described as follows:

- TEM (Tardiness Estimation Method): The proposed part launch rule is designed to estimate tardiness (ET_j) for each part type and to choose the part type with the largest estimated tardiness value for the production launch. The value of ET_j is computed as follows.

$$ET_j = (SCT + ETM_j) - D \tag{2}$$

$$\text{Where } ETM_j = (Q_j - IQ_j) \times IC_j \tag{3}$$

- LRPQ (Largest Remaining Production Quantity): The part type with the largest remaining production work is assigned the highest priority for the next production launch.
- LRPQ/TPQ (Largest Ratio of Remaining Production Quantity over Total Production Quantity): The part type with the largest remaining production quantity over the total production quantity is assigned the highest priority for the next production cycle.
- LTRW (Longest Total Remaining Production Work): The part type with the largest remaining production work is assigned the highest priority for the next production cycle. Production work refers to the total processing time for making the quantity of parts ordered.
- LRUW/TRPQ (Smallest Ratio of Unit Production Work over Total Remaining Production Quantity): The part type with the smallest ratio of the unit production work divided by the remaining production quantity.
- RANDOM: Randomly select one of six types of parts.

4.3. Performance measures

Four performance measures are used for evaluation as follows:

- Mean tardiness: Tardiness is the positive difference between the completion time of an order and its due date.
- Maximum tardiness: This measure is important because customers may tolerate a small amount of tardiness but may be very upset for larger ones.
- Service rate: The ratio of the number of no-tardy orders to the total number of orders completed.
- Mean flow time: The average time orders spend in the FMS; from launching the first part for production to the last part being completed.

5. Experimental results

The simulation model was developed using the discrete-event simulation technique. It was programed in C++ language and was implemented on a personal computer. The elements in the FMS such as machines, orders, parts, and AGVs, are all developed using objects. With such modulized elements (objects), this simulation model can easily be extended to as many stages (machining processes) and many elements in the stage of the FMS as needed. This simulation model logically mimics the interactions within the elements of the FMS and can be used to see how the output performance measures are affected by exercising numerically the model for the inputs. The model was verified and validated by the techniques recommended by Law and Kelton [32]. The model may also be constructed with the multi-agent distributed modeling technique [33]. A horizon of 10,000 order completions was determined to be an appropriate run length under all conditions to guarantee that the system had reached a steady state. After these 10,000 orders were completed as a system warm-up, 5000 additional orders were processed for computing the performance measures. In this study, two phases of simulation analysis were conducted. In Phase I, we adopted EDD as the only rule for completed parts collection, and compared the six part launching rules described earlier under four different system conditions. These four system conditions were set by varying the mean inter-arrival time of the orders in the system and the tightness of the due date. The time between the orders arriving in the system follows an exponential distribution, with a mean of 800 min representing a heavy loading condition and 900 min a light loading condition. The due date of the order was determined based on the following equation:

Due date = Arrival time + Allowance factor $(K) \times$ Estimated total processing time

The allowance factor was drawn from the uniform distribution between 0.65 and 1.45, $U(0.65, 1.45)$, for orders with tight due dates and between 1.65 and 2.45, $U(1.65, 2.45)$, for orders with loose due dates. The settings are shown in Table 5.

Figs. 2–5 show the simulation results for the mean tardiness, maximum tardiness, service rate, and mean flow time measures, respectively. Randomly selecting a part type for the production launch proved to be a bad idea for the three due date related measures compared with the other five rules. It however did give a shorter mean flow time because of the

Table 5
Experiments in Phase I are conducted under the following conditions.

System conditions	Order arrivals	Due date tightness (K)
1	Exp(800)	*U*(0.65, 1.45)
2	Exp(900)	*U*(0.65, 1.45)
3	Exp(800)	*U*(1.65, 2.45)
4	Exp(900)	*U*(1.65, 2.45)

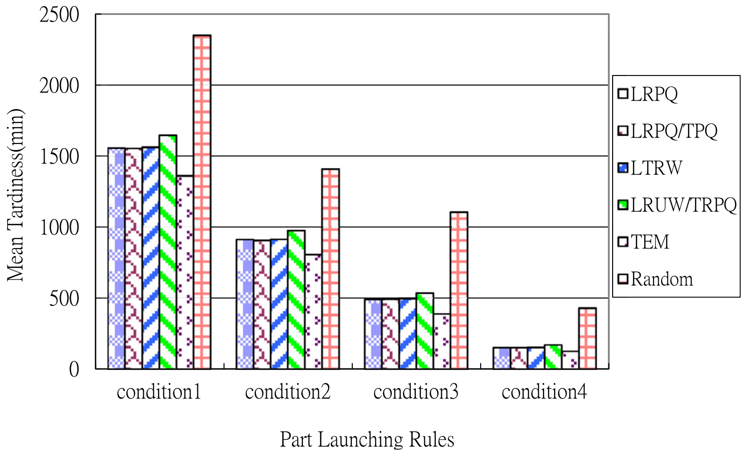

Fig. 2. Mean tardiness measure for part launching rules.

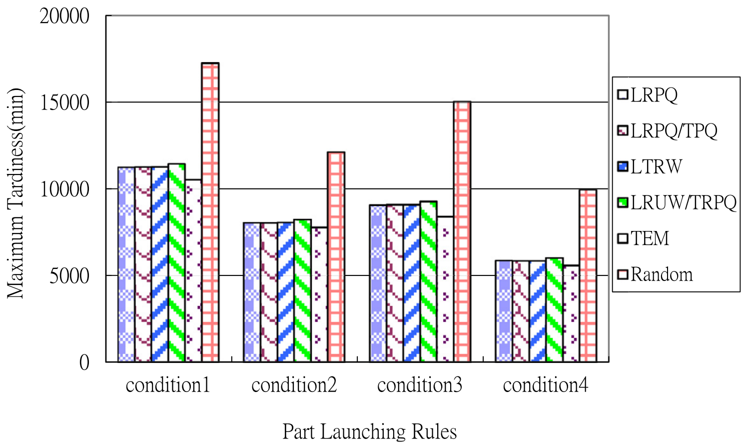

Fig. 3. Maximum tardiness measure for part launching rules.

balanced production launch for different part types. In addition to RANDOM, LRUV/TRPQ provided poor performance for almost all the measures among these five rules. LRPQ, LRPQ/TPQ, and LTRW provided a similar performance for the due-date related measures. Among these three rules LRPQ/TRQ performed slightly better for the measure of mean flow time. It was evident that the proposed rule (TEM) outperformed all other rules for every measure because both the details for production progress and the due date of an order were considered.

In Phase II of the simulation experiments we used TEM, the best part launch rule found in Phase I, and combined it with each of the three order collection rules, EDD, CR, and SMT for further investigation under the heaviest system loading condition (condition 1). Figs. 6–8 show the results of the three rules on mean tardiness, maximum tardiness, and service rate, respectively. EDD outperformed the other two rules for mean tardiness measure. For maximum tardiness measure, CR tended to result in some orders with a very large tardiness value because the possibility of changing the collection order is much higher than for the other rules. However, under the heaviest system loading condition (the service rate was close to 20%), CR provided a slightly better performance than the other two rules for the service rate measure. It should be noted that frequent interrupting and changing the collection orders may result in a slightly better service rate but will also result in some orders that are extremely tardy.

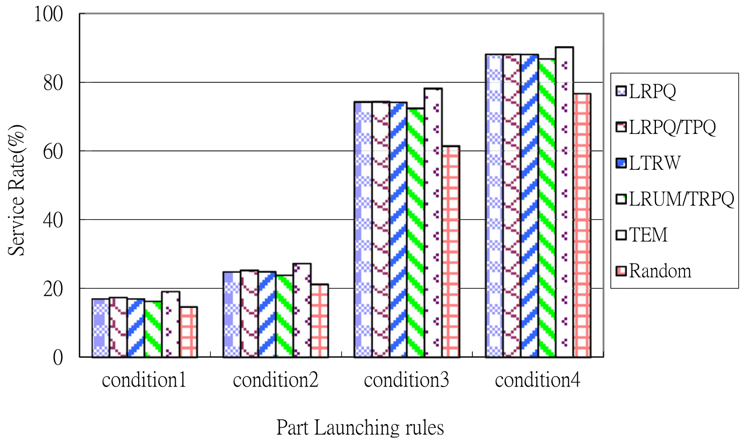

Fig. 4. Service rate measure for part launching rules.

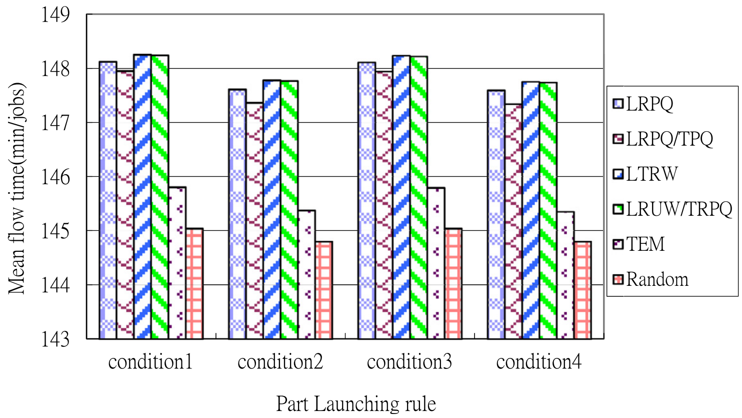

Fig. 5. Mean flow time measure for part launching rules.

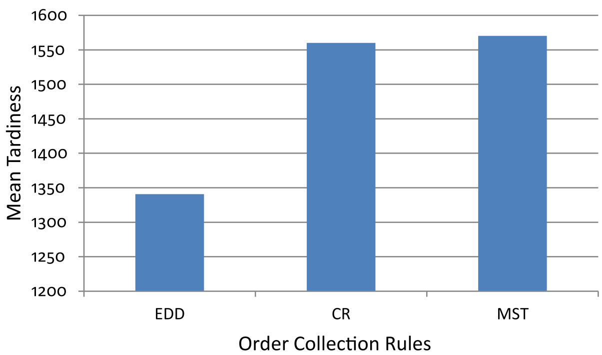

Fig. 6. Mean tardiness measure for order collection rules.

In this study, we allow order pre-emption when collecting the completed parts. For instance, With EDD as the order collection rule, it takes time to collect the whole parts for a certain order. Within the collection period, it is likely that the collecting order is pre-empted by the other order with earlier due date. In such a case, all the parts that have been collected for the previous order will then be transformed for this pre-emptive order. Since order pre-emption may be a problem when the previous order that has just been pre-empted was almost done only short of a few parts, it is reasonable not to allow pre-emption in such a case. We thus consider using a threshold value to manage if the collecting order should be pre-empted. This threshold value represents the completion percentage of the collecting order. For instances, if the threshold value is set 0.6 meaning that the collecting order can be pre-empted only when the completion percentage is less than 60%. Therefore the lower the threshold value is, the lower the possibility for order pre-emption will be. Shortly, this threshold

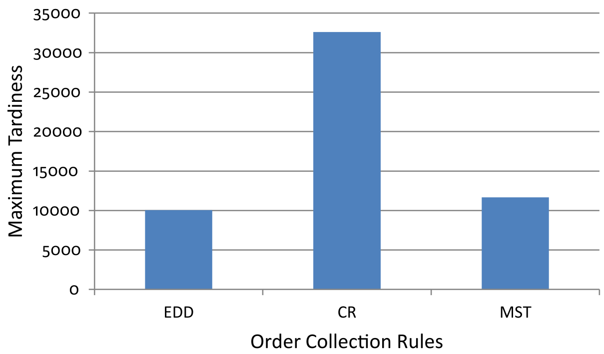

Fig. 7. Maximum tardiness measure for order collection rules.

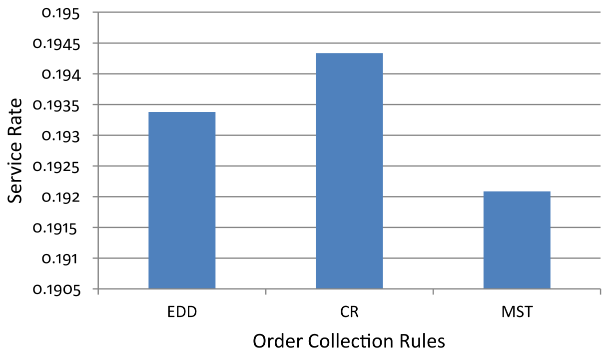

Fig. 8. Service rate measure for order collection rules.

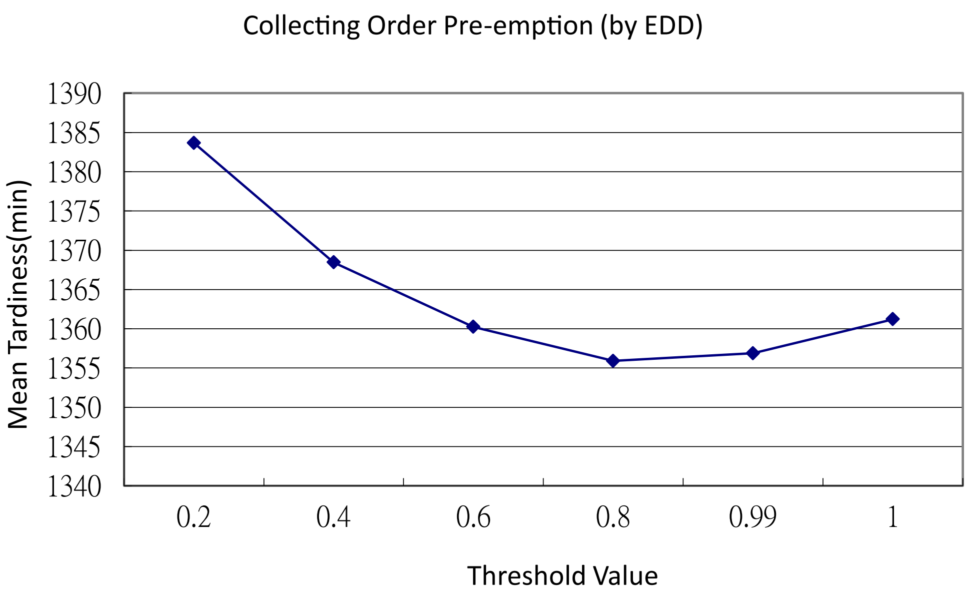

Fig. 9. Mean tardiness measure of using various threshold values to manage order preemption.

value determines how much likely order pre-emption may occur. In order to evaluate how this threshold value may affect those performance measures. We test the system only under the system condition 1. Under this condition, the due date allowance factor is determined according to *U*(0.65, 1.45). Such high variations for the due date allowance factor will cause more order pre-emption if the threshold value is also set high. Figs. 9 and 10 show how different levels of the threshold value for managing order pre-emption affect the performance measures on mean tardiness and service level, respectively. In Fig. 9, it is evident that setting the threshold value 0.8 offers the best performance on mean tardiness measure. While, In Fig. 10, the lower the threshold value is, the higher the service level can be reached.

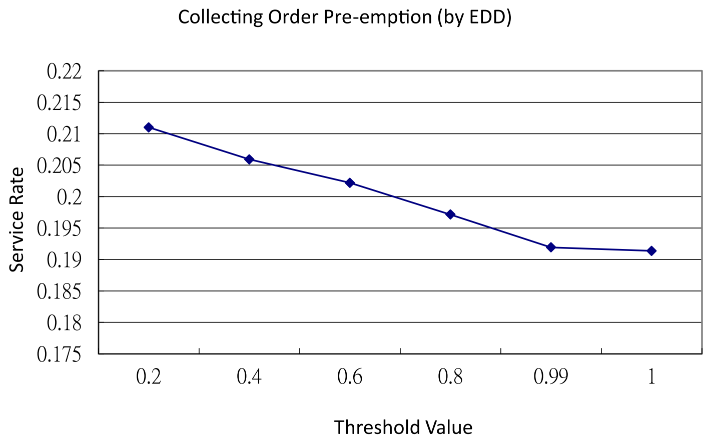

Fig. 10. Service level measure of using various threshold values to manage order preemption.

6. Conclusions

This paper presented a simulation study that was conducted to analyze the part launch and order collection decisions in the FMS. All the decisions were examined in the two phases of the experiments. The part launch rules considered for experimentation included LRPQ, LQPQ/TPQ, LTRW, LRUW/TRPW, and the proposed TEM in addition to the RANDOM rule. The simulation results in Phase I of the experiments revealed that the proposed TEM rule outperformed the other rules in all the performance measures. Three order collection rules, EDD, CR, and MST were tested under a heavy loading system condition. EDD outperformed the others for almost all the measures. The significance of frequently changing the order (pre-emption) of the part collection was addressed in the simulation analysis in Phase II of the experiments.

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