Operational Control Decisions in FMS under Expediting Conditions

Parames Chutima* and Chayanee Meesaplak**
Department of Industrial Engineering,
Chulalongkorn University, Bangkok 10330, Thailand
E-mail: * cparames@chula.ac.th, ** mchayanee@yahoo.com

Abstract

This paper investigates the performance of a flexible manufacturing system (FMS) under several expediting conditions by using computer simulation. The performance of several time-based as well as cost-based dispatching rules are assessed. The experiments are conducted under various factors, i.e., dispatching rules, AGV selection rules, due-date assignment rules, and expediting conditions. The performance measures consist of mean flowtime, mean tardiness, average total cost, and average machine utilization. The simulation results show that all factors affect the measures of performance at the 95% confidence level, except average machine utilization that is significantly impacted only by due-date assignment rules and expediting conditions.

Keywords: Flexible Manufacturing Systems, Scheduling, Simulation

1. Introduction

A flexible manufacturing system (FMS) is composed of a computer directed collection of CNC machines, an automated material handling system, and other supporting peripherals such as a wash station, a coordinate measuring machine, a storage rack, loading and unloading stations, linked and controlled by a central computer. Several potential benefits can be obtained by exploiting FMS for both high flexibility normally associated with job shops and high efficiency normally associated with transfer lines to produce medium-volume, medium-variety products, e.g. high machine utilization, low work-in-process inventory, and short production lead time, etc.

The major operational control decisions of FMS are composed of: (1) part entry selection, (2) alternate machine selection, (3) alternate operation sequence selection, (4) AGV (Automated Guided Vehicle) scheduling, and (5) machine scheduling. A comprehensive review and explanation about the relationships and interactions between these elements of operational control decisions can be seen in Byrne and Chutima (1994). Guidelines for designing operational control of FMS are elaborated in Chutima and Byrne (1996).

Operational control of FMS has drawn lots of attention from researchers. As a result, numerous publications have emerged. Denzier and Boe (1987) studied the performance of part entry selection rules and part routing rules against makespan. Sabuncuoglu and Hommertzheim (1992) investigated the performance of machine and AGV scheduling rules against mean flowtime criterion. These rules were tested under various experiment conditions, i.e. machine and AGV load levels, queue capacities, and AGV speeds, by using simulation. Sabuncuoglu and Hommertzheim (1995) also studied the efficiency of scheduling rules under various due-date assignment rules against mean tardiness. Furthermore, Sabuncuoglu (1998) examined the sensitivity of the rules to change in processing time distribution, various levels of breakdown rates, and types of AGV priority schemes. Tang *et al.* (1993) also studied scheduling rules in FMS against several performance measures, i.e. mean flowtime, mean tardiness, maximum tardiness, system utilization, number of machines locked, buffer size, and work in process. They established six decision points including: (1) selection of AGVs by parts, (2) selection of machines by parts on AGVs, (3) selection of parts by machines, (4) selection of machines by parts at output queues, (5) selection of parts by AGVs, and (6) selection of machines by AGVs. These decisions are related to the operations that interact among parts, machines, and AGVs.

From the recent review, Chan *et al.* (2002) reported that the most popular scheduling problem was parts dispatching, followed by machine selection and AGV scheduling. In addition, the performance measures used in FMS scheduling studies most are flowtime related measures, by tardiness or number of tardy jobs related, utilization related measures. It appeared that cost related and inventory related measures did not receive much attention from researchers. This is because inventory related measure has a close linkage with flowtime. Furthermore, a cost related measure can be the combination of several measures that have converted their original units to the same monetary units. However, in attempting to minimize cost related measures, trade-off among different composite measures can occur. This causes difficulty in justifying the performance of scheduling rules. Hoffmann and Scudder (1983) studied the performance of scheduling rules that consider both time and cost of jobs against time-oriented and cost-oriented measures. The effectiveness of composite time/cost priority scheduling rules was also evaluated against time-oriented and cost-oriented criteria in Hoffmann and Scudder (1985).

It is also noticeable in the review paper of Chan *et al.* (2002) that most researchers in the area of operational control of FMS conduct their experiments under systems without any disturbance. However, in practice disturbances are unavoidable events and normally unpredictable, such as machines or tools breakdown, orders' due-dates changing, operator absenteeism (Chutima and Fan, 1992). Disturbances normally affect the system in some way, e.g. delay shipment, switching production lines, etc. To handle disturbances, actions can be corrective or preventive or both. Of course, most companies will develop plans for preventive actions to avoid corrective actions. Some preventive countermeasures can be easily planned in-house, e.g. preventive maintenance; but others can not, e.g. orders' due-date changing. This is because customers are always considered as an external factor. Their requirements come at first priority and all companies must try by all means to maximize their satisfaction. It is revealed that an interactive scheduling mode can substantially enhance the capability of practitioners in manipulating alternate schedules to respond to disturbances effectively (Chutima and Na, 2000). Hottenstein (1970) tests the performance of three dispatching rules under expediting conditions in a job shop. It is found that SPTEX (Shortest Processing Time Expediting Rule) performs best especially when it is applied to light shop loads under mean tardiness measure.

This research is focused on evaluating the performances of FMS when the due-dates or priorities of the existing jobs are allowed to change by customers. In this case a production manager can be informed about the due-date alteration by action notices (sometimes called change notices). The jobs that need high attention will be listed in the action notices. In practice, action notices can be created when due dates of jobs are adjusted, or when there is insufficient lead time to complete the jobs. Corrective actions to respond to such changes include negotiating, releasing, rescheduling, or canceling jobs. The production manager has to consider adjusting the due-dates of orders to ensure that hot jobs (high priority jobs or jobs with modified due-dates) will not finish too early or too late but just as they are needed without interfering with the predefined completion times of the normal orders. If the customers move due-dates later, known as deferring, the production manager has to delay production until they are needed. In contrast, if the customers move due dates earlier the production manager has to rush or expedite the orders. Expediting also includes the situation when the production manager has to rush the orders because customers need them for an interval that is less than standard lead time. The approach to handle this situation in this research is by using dispatching rules. It is expected that good dispatching rules will expedite hot jobs effectively with not much negative impact on normal jobs.

2. System Configuration

In this research, the experiments to investigate the impact of dispatching jobs are conducted on an FMS consisting of 5 workstations (adapted from Liu and Duh (1992)). Workstations 2 to 5 are machining centers and workstation 1 is a storage area; that is, parts start their operations from workstation 1 and return to this workstation again when all their required operations are completed. Workstation 1 is also a staging area for available AGVs to park and wait until there is a material handling request. Figure 1 shows the layout of the hypothetical FMS used in this research. In addition, 4 AGVs with bidirectional movement are employed. The number of AGVs used in this research comes from the result of pilot runs that has average utilization of AGVs around 80%. It is expected that the effect of AGV selection rules can be seen when the average utilization of AGVs is high.

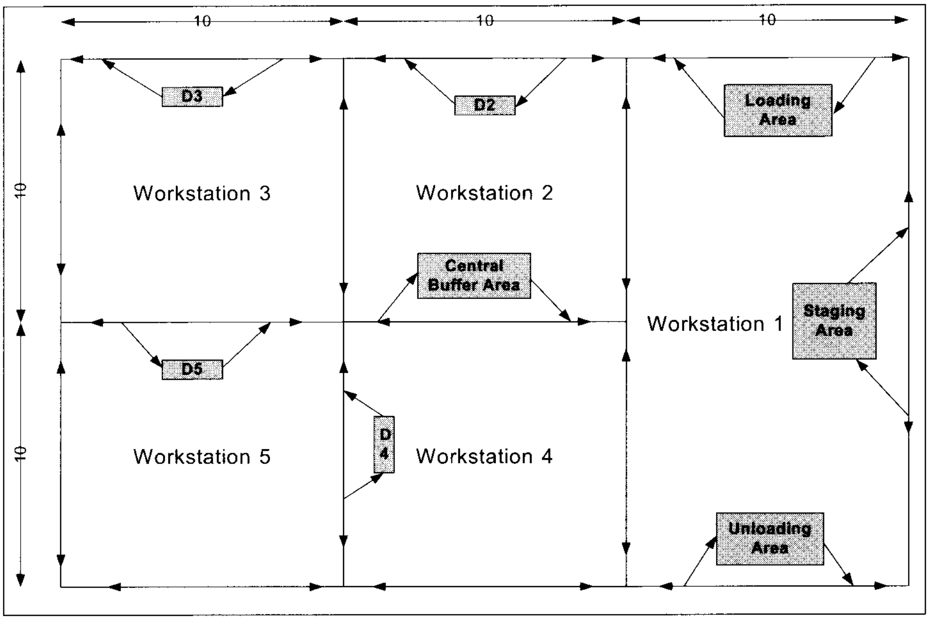

Figure 1: *System Layout*

Three types of products are manufactured in FMS. Table 1 illustrates the routing sequences and processing times for each product. The processing times in "time units" are normally distributed with standard deviations of 10% of their corresponding means. It is assumed that the processing time of jobs at workstation 1 is zero (loading and unloading time is not significant comparing to the processing time). Furthermore, five priority levels can be assigned to each customer's order, i.e. 1, 2, 3, 4, and 5 with equal proportion (20% each) respectively. High priority orders are indicated by high numbers.

Table 1: *Characteristics of Products*

Product Type	Sequence	Processing Time
A	1,2,3,4,1	0,11,21,7,0
B	1,3,5,4,1	0,15,15,23,0
C	1,4,3,2,5,1	0,10,6,18,17,0

The sizes of incoming and outgoing queues of each workstation are limited to accommodate only 5 parts. Since the queues are capacitated, workstation blocking and locking can sometimes happen. A central buffer area is used to handle this problem.

3. Experimental Design

In this paper, the performance of an FMS is investigated under various expediting conditions by using computer simulations. The measures of performance consist of mean flowtime, mean tardiness, average total cost (holding cost + cost of tardiness x weight (or priority level) of each order), and average machine utilization. Not only are time-based dispatching rules examined but also dispatching rules that prioritize orders based on cost-based criteria are included, i.e. cost of tardiness. Several factors are investigated including dispatching rules, AGV selection rules, due-date assignment rules, and expediting conditions. The details are as follows:

Dispatching Rules:

1. FIFO: First In First Out
2. SPT: Shortest Processing Time
3. WSPT: Weighted Shortest Processing Time
4. EDD: Earliest Due Date
5. TEC: Total Expected Cost; If the job is late, TEC = Cost of Tardiness x Weight; If the job is early, TEC = Earliness.

AGV Selection Rules:

1. SDS: Shortest Distance to Station
2. CYC: Cyclic Priority
3. RAN: Random Priority

Due-Date Assignment Rules:

1. TWK: Total Work
2. NOP: Number of Operations
3. CON: Constant
4. RAN: Random

The parameter (k) that makes the number of tardy jobs approximately 20% of the normal condition is assigned for each due-date assignment rule (Table 2). These numbers are set to provide opportunities for orders to be late.

Table 2: *Parameter k for Each Due-date Assignment Rule*

Symbol	Description	Parameter, k
TWK	Proportional to the total work (or processing time)	14
NOP	Proportional to the total number of operations	210
CON	Constant lead time for all jobs	720
RAN	Random	-

Expediting Conditions:

1. Normal (no expedited job)
2. The number of jobs is expedited = 10%. The due-date of the expedited job is shortened = 10 %.
3. The number of jobs is expedited = 10%. The due-date of the expedited job is shortened = 20 %.
4. The number of jobs is expedited = 20%. The due-date of the expedited job is shortened = 10 %.
5. The number of jobs is expedited = 20%. The due-date of the expedited job is shortened = 20 %.

4. Results and Analysis

There are several methods for solving operational control of FMS including: (1) mathematical programming, (2) multi-criteria decision making, (3) heuristics, (4) control theory, (5) artificial intelligence, and (6) simulation (Basnet and Mize, 1994). Since this research is focused on the operational issues of FMS and the system is also complicated by the interactions among parts, machines, queue, and AGV, a simulation technique seems to be the most appropriate one. As a result, a discrete event simulation model of the FMS is written by using ARENA.

Because this system is a non-terminating system, there is no event that causes the system to return to a fixed initial condition. As a result, no natural basis for selecting either the starting conditions or the length of the run exists. In non-terminating systems, the steady-state behavior of the system is of interest (Pegden *et al.*, 1995). Thus, the transient phase is eliminated by discarding the observations recorded during the transient phase of the simulation. The truncated point is selected from a plot of the simulation response over time. As a result, a pilot experiment with 150,000 minutes is conducted. From the Moving Average graph (Cumulative), the truncated point is 20,000 minutes and the number of observations per batch are 9,420. Having setup all tactical issues of simulation, the experiments are conducted under different expediting conditions. The results of ANOVA are shown in Table 3.

***Table 3:** Analysis of Variance*

Factors	F-Ratio (no measurement unit)			
	Flow time	**Tardiness**	**Total Cost**	**Machine Utilization**
RULE	2040.53*	26000.00*	5120.50*	1.43
AGV	17.40*	9.39*	3.06*	2.65
DUE	9.04*	1145.67*	130.24*	3.75*
CON	33.70*	120000.00*	19000.00*	25.88*
RULE x AGV	12.41*	3.11*	2.56*	2.91*
RULE x DUE	3.34*	104.38*	18.64*	2.44*
RULE x CON	8.47*	3854.73*	765.59*	1.64
AGV x DUE	0.46	0.47	2.06	3.34*
AGV x CON	0.03	1.87	1.76	0.22
DUE x CON	0.72	14.74*	4.12*	0.66
RULE x AGV x DUE	1.48	1.72*	1.20	0.97
RULE x AGV x CON	0.73	1.51*	1.88*	0.93
RULE x DUE x CON	0.41	14.37*	4.08*	0.35
AGV x DUE x CON	0.03	1.02	1.91*	0.57
RULE x AGV x DUE x CON	0.10	1.02	1.95*	0.31

*Note 1: RULE = Dispatching Rules, AGV = AGV Selection Rules, DUE = Due-Date Assignment Rules, CON = Expediting Conditions, and * = factors that are significant at 95%*

Note 2: The reason that F-ratio is used here rather than p-value is because most of the main effects and interactions that show significace have p-value = 0.000 which cannot show the discrimination among them.

4.1 Performance of FMS with respect to mean flowtime:

For mean flowtime (Table 3 and Figure 2), all main factors including dispatching rules, AGV selection rules, due-date assignment rules, and expediting conditions are significant at the 95% confidence level. Moreover, Duncan's multiple range tests indicate that SPT is the best dispatching rule, followed by WSPT, EDD, TEC, and FIFO. In addition, EDD, TEC, and FIFO are the group of dispatching rules that is worst for mean flowtime performance and they are not statistically different. The reason that SPT demonstrates best performance is that it prioritizes jobs according to their processing times. As a result, the jobs with small processing times have chances to complete first.

This causes rapid turnaround time for jobs on average. Among the AGV selection rules, SDS and CYC show best performance. Due-date assignment methods also have significant impact on mean flowtime. It is found that low mean flow times are obtained from TWK, NOP, and CON. However, they are not significantly different. In addition, when parts are expedited, their flow times are less than the case where they are in normal conditions because when job due-dates are shortened, rules such as EDD or TEC can expedite jobs more effectively. Table 3 also indicates that interactions between some factors are significant, i.e. dispatching rules and AGV selection rules, dispatching rules and due-date assignment rules, and dispatching rules and expediting conditions. In addition, the interaction between dispatching rules and AGV selection rules is most significant (F-ratio = 12.41). It is noticeable that dispatching rules are the common factor of the interactions that are significant. As a result, high attention should be paid in selecting suitable dispatching rules to use with the other factors. The results from the experiments show that SPT performs consistently best while joining with the other factors.

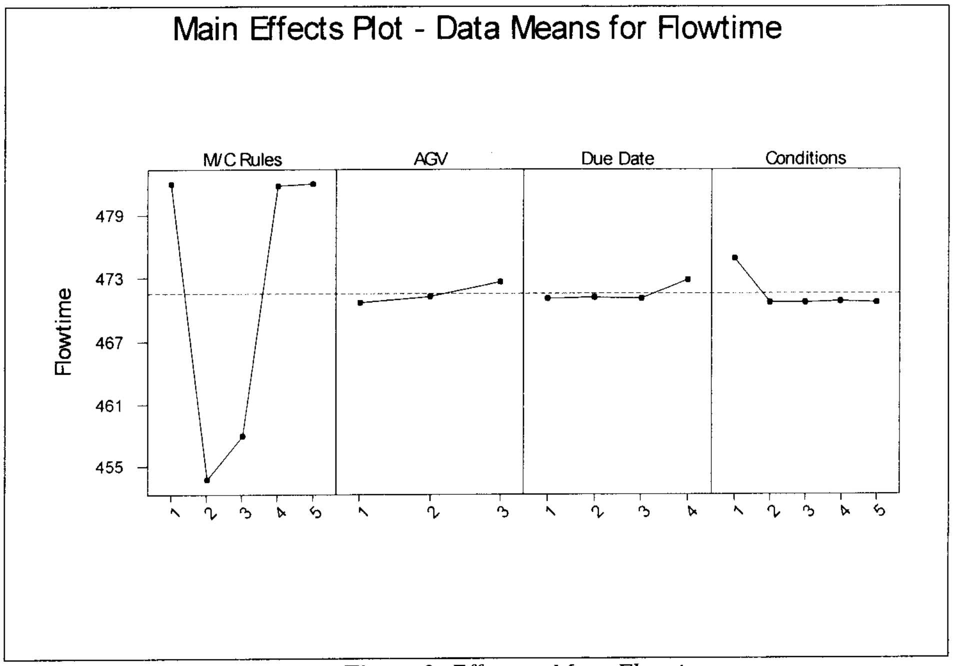

Figure 2: *Effect on Mean Flowtime*

4.2 Performance of FMS with respect to mean tardiness

The performance of FMS regarding mean tardiness is shown in Table 3 and Figure 3. It is indicated that every main factor has significant impact on mean tardiness. Expediting conditions have most impact to mean tardiness (F-ratio = 120000), followed by dispatching rules. For dispatching rules, TEC provides least tardiness, followed by WSPT, SPT, EDD, and FIFO. The tardiness performance of TEC is best because it gives high priority to the tardy jobs. Hence more tardy jobs can be expedited out of the system. Besides, SDS and CYC perform significantly better than RAN for the AGV selection rules. For due-date assignment rules, NOP is the best. In addition, normal (non-expediting) conditions give lowest tardiness. Increasing in mean tardiness is obvious as more expedited jobs and more shortened due-dates are circulated in the FMS. Two-factor interactions that show significant impact are the same as those of flowtime measures plus the interaction between due-date assignment rules and expediting conditions. However, for mean tardiness, the interaction between dispatching rules and expediting conditions exhibits most significance (F-ratio = 3854.73). It is noticeable that TEC is least sensitive to the changes in expediting conditions.

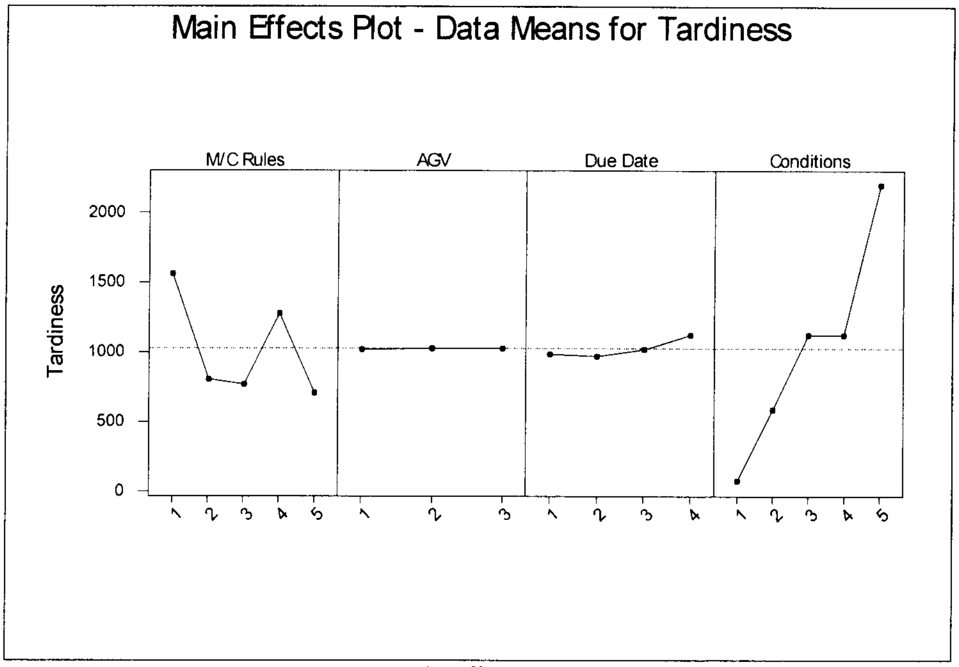

Figure 3: *Effect on Mean Tardiness*

4.3 Performance of FMS with respect to average total cost

The total cost in this research is the holding cost plus tardiness cost multiplied by weight of each order. Table 3 shows that all factors have significant effect on average total cost. Similar to mean tardiness, expediting conditions have most impact (F-ratio = 19000). This is because both measures use the value of tardiness in their objective functions. It is found that WSPT is the best dispatching rules, followed by TEC, and SPT (Figure 4). However, these dispatching rule do not perform significantly different. Since this performance measure penalizes both early and tardy jobs, it is not surprising that TEC is also included in those rules that demonstrate best performance. The reason is that TEC gives priority to jobs based on their chances to be early or tardy. Like flowtime and tardiness measures, SDS and CYC are the best AGV selection rules. Furthermore, TWK and NOP are the best rules that provide lowest total cost. It is also exhibited that average total cost is higher when more jobs are expedited and more due-dates of orders are shortened. Two-factor interactions that have significant impact on average total cost are the same as in the case of mean tardiness. The dispatching rules that show consistent performance with respect to average total cost include WSPT, TEC, and SPT.

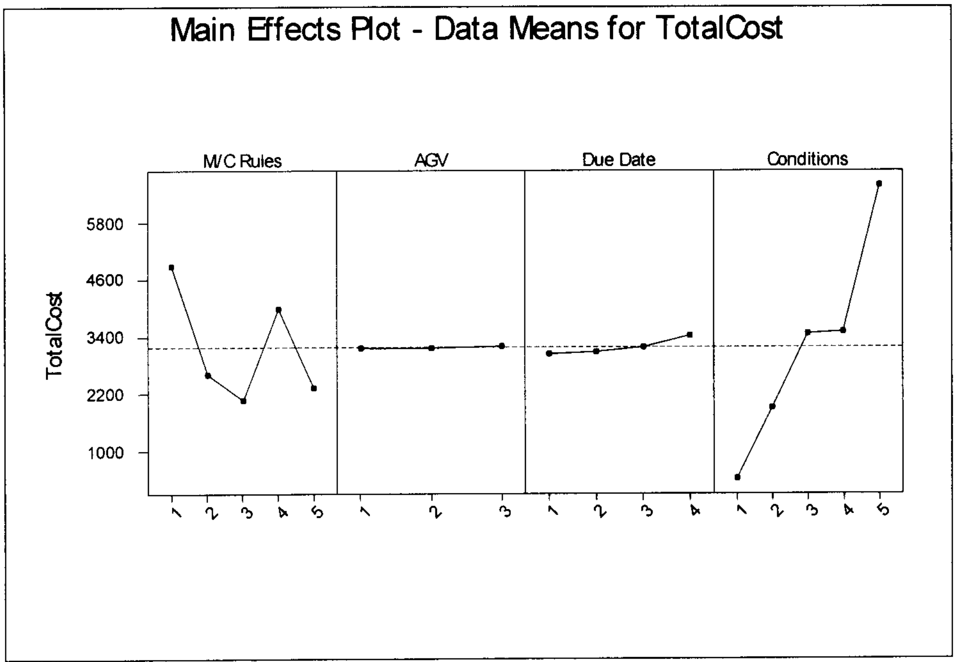

Figure 4: Effect on Average Total Cost

4.4 Performance of FMS with respect to average machine utilization

From Table 3, only two main effects are significant at 95% significant level, i.e. due-date assignment rules and expediting conditions. It is noticeable that expediting conditions have the most impact on average machine utilization (F-ratio = 25.88). It is also found that there is no significant difference in terms of average machine utilization among several expediting conditions (Figure 5). This is logical since expediting conditions in this research mean due-date shortening for some expedited jobs, and no additional job being added into the system. However, job expedition increases average machine utilization a little compared to the one without expedition (i.e. normal condition). This implies that if a dispatcher takes a closer look at jobs in the system, average machine utilization can be improved. Two-factor interactions that are significant are dispatching rules and AGV selection rules, dispatching rules and due-date assignment rules, and AGV selection rules and due-date assignment rules. Although they are not substantial in terms of value (i.e. F-ratio), the interaction between AGV selection rules and due-date assignment rules shows most significance (F-ratio = 3.34).

4.5 Interaction between dispatching rules and expediting conditions

From Table 3, it is worth mentioning about the interaction between dispatching rules and expediting conditions for tardiness performance since it is significant with very high F-ratio (3854.73). From Figure 6, it can be seen that TEC and WSPT are least sensitive to an increase in the levels of expediting conditions; whereas FIFO is the most sensitive. This is demonstrated by sharp increasing slopes of FIFO when the levels of expediting conditions are increased. As a result, TEC and WSPT have less impact to customer satisfaction when customers are allowed to change their shipment dates.

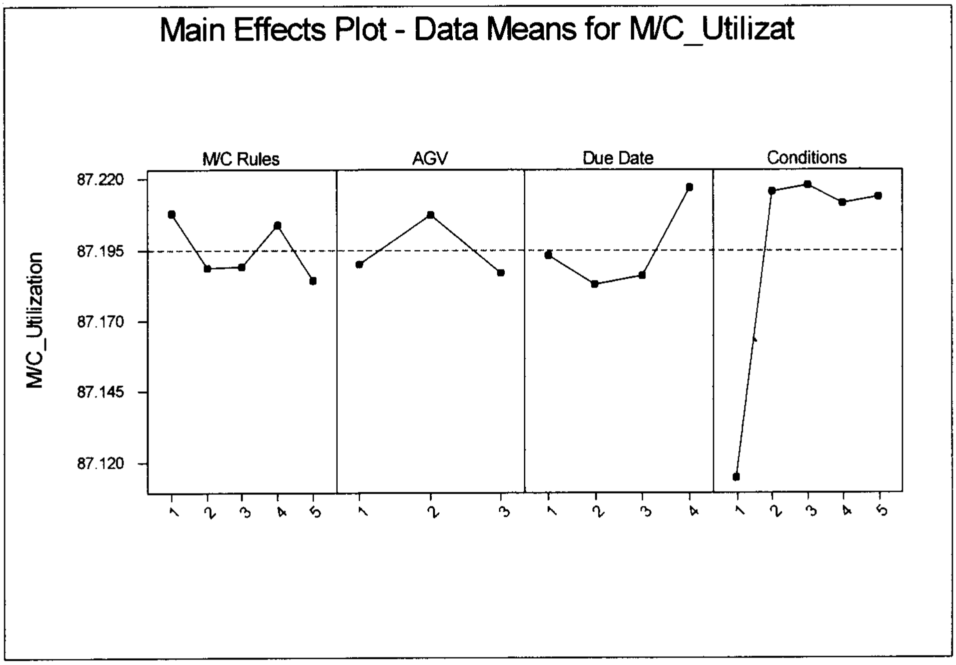

Figure 5: Effect on Average Machine Utilization

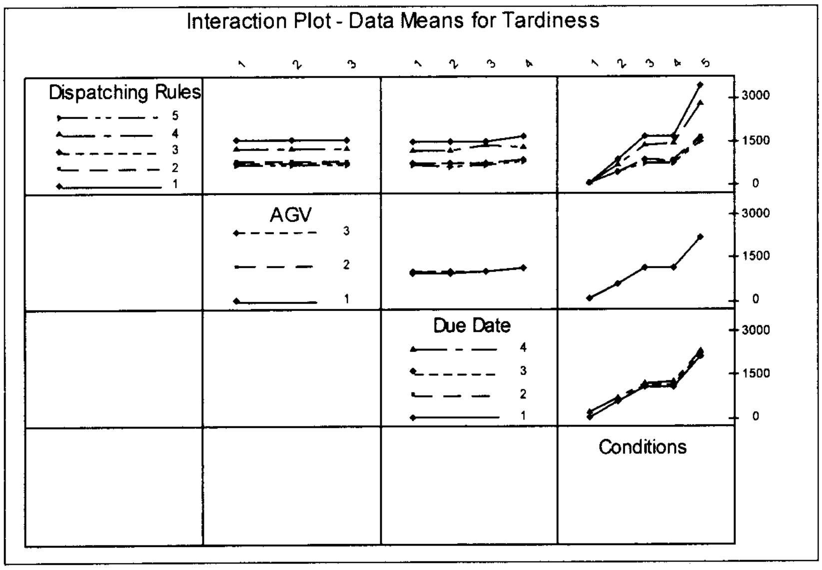

Figure 6: Interaction Effect for Mean Tardiness

5. Conclusion

In practice high priority jobs are regularly released to the shop floor. This can be caused by external factors such as an order's due-date shortening or as a result of inefficient operations management, i.e. noticing a late job in the system. This research finds that expediting has a significant impact on all major measures used in real life, i.e. mean flowtime, mean tardiness, average total cost, and average machine utilization. However, proper operational control decisions can alleviate this problem. For example, the results of the research show that dispatching rules, AGV selection rules, and due-date assignment rules can be the way out for this problem when performance measures are mean flowtime, mean tardiness, and average total cost. However, only due-date assignment rules can be used to increase average machine utilization in cases where order expediting is allowed. It is found that SPT, TEC, and WSPT are the best dispatching rules for mean flowtime, mean tardiness, and average total cost. Similarly, SDS and CYC provide the best performance for every measure except average machine utilization. TWK and NOP are the due-date assignment rules that perform consistently acceptable for all measures.

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