◆ Application Paper

On-line Scheduling Analysis for Job-Shop Type FMS

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Abstract

This paper presents a job-shop type flexible manufacturing system(FMS) scheduling problem and examines the effects of scheduling rules on the performance of FMS. Several machine and AGV scheduling rules are tested against the mean flow-time criterion. In this paper, I compare the rules under various experimental conditions by using an FMS simulation model. One of the objectives of this study is to discuss how the simulation-based scheduling problem can be operated. The other is to measure sensitivity of the rules to changes at inter arrival time, queue capacity, breakdown rates for machines and AGV, and AGV speed. Therefore, the results of simulation experiments were considered on FMS design and operating stages. A comprehensive bibliography is also presented in the paper.

1. Introduction

Due to an increasing trend towards high product varieties, small lot sizes and short lead times, manufacturing companies nowadays are forced to go through some structural changes. The concept of economies of scale has been replaced by the notion of economies of scope[1].

Flexible Manufacturing Systems(FMS's) are considered as one of the new technologies to efficiently cope with today's complex market. FMS's consisting of computer controlled machines and automated material handling devices are designed to perform a variety of operations on different parts. They provide better effectiveness, flexibility and adaptability which are lacking in traditional manufacturing systems. Successful implementation of FMS requires solution of various decision problems faced during design and operation stages of these systems. It is generally known that an improvement in manufacturing productivity depends on not only the developments of high-tech physical components, but also the effective use of these advanced hardware systems. Specifically, scheduling and control algorithms are needed to run these expensive systems efficiently. However, the scheduling and control problem of an FMS is complex and very difficult to solve[2]. An FMS is a

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highly dynamic system and its scheduling task requires additional resource considerations such as tools, fixtures, material handling equipment, and limited buffer spaces. In general, there are basically three approaches for dealing with FMS scheduling problems. First, traditionally, scheduling problems have been solved by analytical methods(i.e., mathematical programming, network theory). These often provided optimal solutions for small sized problems under simplified assumptions[3]. Second, various methods based on artificial intelligence have been developed to study the scheduling problem[4]. Third, the most commonly used method for scheduling is computer simulation[5].

Simulation modeling enabled us to model the complex manufacturing systems in detail, thereby the strategies to operate these systems efficiently can be applied in a more realistic environment. Simulation is most widely known as a design tool, but in recent years, an increasing number of researchers have been using it to develop various strategies for the operation and the control of manufacturing systems[6-7].

On-line scheduling has been a very popular research topic and is conceived as an important problem. This paper will be on simulation-based experimental studies of the job-shop type FMS scheduling problem. The problem is basically viewed as a dynamic scheduling problem and scheduling rules associated with a random FMS are analysed for the mean flowtime criterion by using a simulation model. Most earlier research was studied on various experimental conditions applying the FIFO dispatching rule to machines. I used an SPT dispatching rule which has a better result performance. I analysed the results to stochastic events such as machine and AGV breakdowns. ARENA software was run to evaluate and analyse for the simulation model.

The rest of this paper is organized as follows. First, I give scheduling rules and relevant literature. This is followed in section 3 by system considerations and the simulation model. In section 4, I present simulation results on sample problems. Finally, I conclude the paper with a summary of findings and suggestions for future research in section 5.

2. Scheduling rules and relevant literature

Scheduling rules are used to prioritize jobs for various resources(i.e., machines, material handling equipment, etc.). The terms such as decision rules, priority rules and dispatching rules are often used interchangeably with scheduling rules. They are not only used as stand-alone scheduling mechanisms, but also employed as integral parts of analytical off-line scheduling algorithms, knowledge-based scheduling systems and iterative simulation based scheduling systems.

Generally, single rule is not the best under all possible conditions(i.e., dynamic situations, changeable environments). Effectiveness of a rule depends on a number of factors such as performance criteria, system load levels, due-date tightness, etc. For that reason, there are numerous studies in the literature which investigate the performance of rules under various operating conditions. As compared to traditional job shop scheduling, there are relatively few experimental studies addressing scheduling rules in FMS environments. Moreover, the rules are mainly tested under machine-and AGV-dominated environments. One of the first

simulation studies that tested the performance of scheduling rules for an AGV-based material handling system was performed by Egbelu and Tanchoco[8].
In this study, several AGV scheduling rules were developed and their performances measured via a simulation model. Acree and Smith[9] tested different cart selection and tool allocation rules. Montazeri and Van Wassenhove[10] examined several machine scheduling rules and found that these rules have a larger impact on system performance. Tang et al.[11] identify six decision rules for FMS scheduling involving operations among parts, machine, and AGV. Sabuncuoglu and Hommertzheim[12-14] study machine and AGV scheduling rules against various performance measures for a random type FMS. Manivennan[15] designs a knowledge-based on-line simulation system to control a manufacturing shop floor. Pelagagge and Cardarelli[16] show application to real time scheduling for effective job-group loading at a dedicated manufacturing system.
Tunali[17] presents the results of comparative simulation studies on flexible and prefixed routing of parts in a job-shop type FMS, which is subjected to unexpected machine breakdown. Sabuncuoglu[2] examines the effects of scheduling rules on the performance of FMS. He compares the rules under various experimental conditions by using an FMS simulation model.

3. System considerations and the simulation model

3.1 System considerations

Table 1 shows machine and AGV scheduling rules[2].

Table 1. Machine and AGV scheduling rules.

Symbol	Description
(1) Machine scheduling rules	
SPT	Shortest processing time
SPT.TOT	Smallest value of operation time multiplied by total operation time
SPT/TOT	Smallest value of operation time divided by total operation time
LPT.TOT	Largest value of operation time multiplied by total operation time
LPT/TOT	Largest value of operation time divided by total operation time
LWKR	Least amount of work remaining
MWKR	Most amount of work remaining
FOPNR	Fewest number of operations remaining
MOPNR	Most number of operations remaining
FCFS	First come first served
FAFS	First arrived first served
(2) AGV scheduling rules	
FCFS	First come first served
LOQS	Largest output queue size
LQS	Largest queue size
STD	Shortest travel distance
FOPNR	Fewest operations remaining
LWKR	Least work remaining

Figure 1 shows the layout of the hypothetical FMS studied in this paper. The schematic diagram of FMS assumed for the development of the simulation model is given in Figure 1.

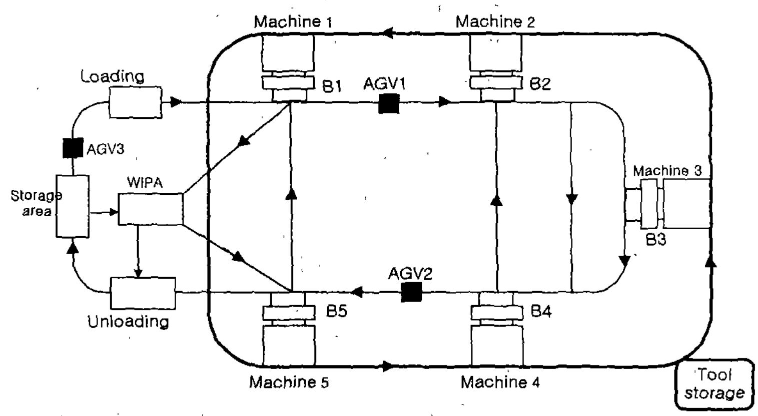

Figure 1. Schematic diagram of the FMS considered

As it is seen in the figure, the system consists of five machines, which are multi-purpose horizontal or vertical machining centers. A buffer with capacity of N is installed in front of each machine. The parts are introduced into the system through a loading station. A work-in-process area(WIPA) serves to store the parts when the machine input buffers reach full capacity. Transportation of the parts within the system is handled by three AGVs. The AGVs travel undirectionally along predefined paths and they can transfer only one part at a time. Also a staging area is included in the model to prevent the idle AGVs from blocking the movement of other active vehicles. The cutting tools are stored in the tool storage and they are delivered to the requesting machines via carts. The completed parts leave the system through an unloading station.

3.2 Scheduling problem

The objective of this study is investigated on a simulation-based experimental environment for the job-shop type FMS scheduling problem. FMS scheduling problems necessitate a two-level hierarchical decision-making process: (1) assignment; (2) sequencing. To select a machine to perform the required operation takes place in the first level. In machine selection decisions, this study utilizes a heuristic algorithm, which intends to balance the load on machines and also to minimize the traveling time from one machine to another. It proceeds as follows:

1. Determined the set of alternative machines $\{M_1, M_2, \cdots, M_k\}$ to process operation j of part i.
2. compare $\Delta k = T_k - T_{ijk}$ for each machine where

   T_k : earliest time that machine k can start processing the required operation.

T_{ijk} : earliest time that operation j of part i will be ready to be processed by machine k

3. Determine the set of machines C, $\{M_1, M_2, \cdots, M_k, m \leq k\}$ for which $\Delta k \leq 0$ and the set of machines D for which $\Delta k > 0$
4. if $m \geq 1$, rank the machines in the set C according to T_{ijk} parameters(i.e., lowest value first). Otherwise, go to Step 7.
5. Assign the operation to the machine with highest rank within the set C if its buffer content is less than N, and update its buffer status and go to Step 11, or go to Step 6.
6. Remove the currently evaluated machine from the set C. If the set C is empty, go to Step 8; if not, go to Step 5.
7. Rank the machines in the set D according to T_k parameter(i.e., lowest value first)
8. Assign the operation to the machine with the highest rank within the set D if its buffer content is less than N and update its buffer status and go to Step 11. Otherwise, go to Step 9.
9. Remove the currently evaluated machine from the set D. If the set D is empty, go to Step 10; if not, go to Step 8.
10. Assign the operation to the machine with highest rank in the set D and send the part to the work-in-process-area(WIPA).
11. Send the part to the selected machine.

The sequencing decisions, which take place in the second level, concern assigning priorities to each part waiting for the services of the limited resource(i.e., machines, AGVs). In this study, the priority assignment of parts for machining are based on a first-in-first-out(FIFO) and a shortest-processing -time(SPT)scheduling rules.
The parts waiting for an AGV are based on a shortest-travel-distance(STD) and largest-queue-size(LQS)scheduling rules.

3.3 Simulation model and assumptions

The following assumptions are made to develop the simulation model of the FMS layout given :

1. The system is capable of processing various part-types and each part is associated with a probability of arrival
2. Parts arrive at the system with inter-arrival times being exponentially distributed.
3. The system consists of a loading station, five multi-purpose machines, a staging area, a work-in-process area and an unloading station.
4. Each machine has an ample capacity to store the required cutting tools. Therefore, the tool availability is not considered in developing the model.
5. Each machine has a limited buffer storage(i.e., 5 jobs)
6. Part transportation is handled by three AGVs, which have automatic loading/ unloading capability.
7. Machining times, AGV loading and unloading times are taken to be deterministic. Machine set-up times are included in machining times.

8. Each part-type has a process plan, which includes information about the operations needing to be processed in sequence.
9. The approach of flexible routing of a part process plan is adopted in processing the parts. The machine selection decisions are made in real time by utilizing the current system status information.
10. Machine 1 and 3 breakdowns, occurring randomly, with both time for failure and repair times are exponentially distributed

4. Simulation results on sample problems

I will give a processing route for the simulation. Figure 2 shows the logic for the scheduling problem.

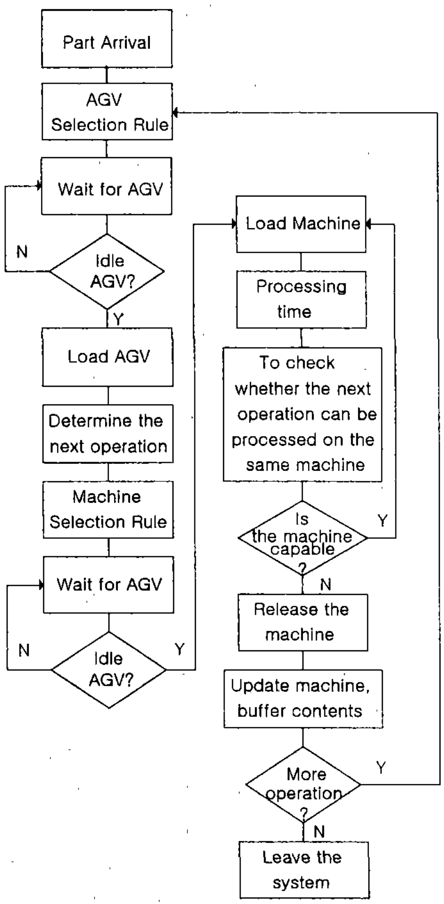

Figure 2. The flow chart for the scheduling problem.

4.1 Simulation conditions.

This section explains a set of experiments conducted to investigate various conditions which affect the performance criteria(i.e., mean flow time) in scheduling a job-shop type

FMS which is subject to unexpected machine breakdown. Experiments conducted consist of nine scenarios. Three sets of part-types(i.e., job arrival pattern is modeled by a Poisson distribution with a mean inter-arrival time of 7,8,9 min) are used to set up each scenario. The input to the simulation model consists of part-types to be produced(i.e., process plans associated with each part-type, probability of arrival), machine(i.e., number of machines, functionality of each machine, buffer capacities, mean time to machine failure and mean repair times), material handling devices(i.e., number of AGVs, their speed) and the system configuration(i.e., AGV path, distance between each system resource etc.). To relate the performance of FMS strictly to the routing policies employed, the AGV loading/unloading and machining times are assumed to be deterministic. Part types(1,2,3), number of operations and probability of arrivals are expressed in Table 2:

Table 2. Part process associated with flexible routing

Part type	Number of operations	Probability of arrival	1	2	3	4	5	6
1	4	0.4	E(8)	C(9)	I(7)	F(10)★		
2	5	0.3	B(7)	C(8)	A(10)	D(6)	G(8)	
3	6	0.3	D(7)	H(10)	A(9)	E(8)	B(7)	F(9)

★ The number in parentheses are processing time(min)

Each machine's functionality with respect to these operations is expressed with following F_{kn} matrix;

Table 3. Operation available matrix for machine functionality

$F_{kn}=$

k \ n	A	B	C	D	E	F	G	H	I
1	1	1	0	0	1	0	1	1	0
2	0	0	1	1	1	1	1	0	0
3	1	1	0	1	0	1	0	0	1
4	0	1	1	1	0	0	0	1	1
5	0	0	0	1	1	1	1	1	0

k : Machine No. n : Operation type.

With regard to the functionality of machine 1, this matrix states that the machine 1 is capable of performing operations A, B, E, G and H. This machine functionality matrix and the process plans associated with each part type (i.e., see Table 2) are given as input to the machine selection rule introduced earlier. I proposed FIFO and SPT for machines and LQS and STD for AGVs which are better scheduling rules found the past research[2].

4.2 No breakdown machine

This is normally and continuously operating machine and AGV.

4.2.1 The performance of the machine and AGV scheduling rules combination.

Table 4 shows experimental results when FIFO and SPT were applied to machines, and LQS and STD to AGV. The best results are SPT and LQS scheduling rules for machine and AGV.

Table 4. Machine and AGV scheduling rule combination

inter arrival time \ scheduling rule / part type		FIFOLQS	FIFOSTD	SPTLQS	SPTSTD
7	Type 1	144.16	145.57	124.98	130.84
	Type 2	147.87	151.82	141.02	144.72
	Type 3	227.14	233.55	211.14	220.69
8	Type 1	133.06	134.66	123.47	122.24
	Type 2	136.57	140.87	133.28	135.16
	Type 3	221.32	228.74	205.82	213.32
9	Type 1	127.83	130.76	121.08	125.71
	Type 2	133.91	135.34	127.45	128.33
	Type 3	215.74	224.67	199.18	210.83

4.2.2 The effect of queue capacity on the relative performance of the scheduling rules.

I examined the effect of different queue capacities on the relative performance of scheduling rules. The mean flowtime performance of three machine and AGV scheduling rules combinations at varying queue capacities are shown in Table 5.

Table 5. Queue capacity on scheduling rule

queue capacity \ scheduling rule / part type		FIFOLQS	FIFOSTD	SPTLQS	SPTSTD
Queue 2	Type 1	175.05	178.81	138.95	139.69
	Type 2	179.92	180.23	166.03	169.41
	Type 3	253.8	254.02	234.41	244.27
Queue 3	Type 1	156.27	158.55	128.14	130.32
	Type 2	159.44	161.24	151.35	148.6
	Type 3	231.57	233.54	212.94	224.38
Queue 4	Type 1	143.35	146.37	124.25	131.47
	Type 2	148.21	151.22	143.35	144.27
	Type 3	228.25	234.68	210.15	221.67
Queue 5	Type 1	144.16	145.57	124.98	130.84
	Type 2	147.87	151.82	141.02	144.72
	Type 3	227.14	233.55	211.14	220.69
Queue 6	Type 1	146.57	146.24	125.16	130.84
	Type 2	149.16	152.14	142.87	144.72
	Type 3	230.27	235.57	205.04	220.69
Queue 7	Type 1	146.57	146.24	125.16	130.84
	Type 2	149.16	152.14	142.87	145.14
	Type 3	230.27	235.57	205.04	220.71

On the machine scheduling rules, SPT rule provided a flowtime improvement over FIFO rule. On the AGV scheduling rules tested, LQS minimized slightly the mean flowtime over STD. However, their relative performances changed as queue capacity was varied. The SPT machine rule and the LQS AGV rule combination brought good results at all queue capacity levels.

4.3 The analysis of scheduling rules under machine and AGV breakdown

In the previous section, machines and AGVs were assumed to be available continuously. However, manufacturing systems are subject to various interruptions such as machine failures, AGV breakdowns, tool failure, etc.. In this section, scheduling rules are tested under the possibility of machine and AGV breakdown.

4.3.1 The results of under machine breakdown.

Machine and AGV rules combinations were tested under various levels of machine down time percentages. The results of the simulation experiments are summarized in Table 6.

Table 6. Machine breakdown

down time \ part type \ scheduling rule		FIFOLQS	FIFOSTD	SPTLQS	SPTSTD
1%	Type 1	145.69	147.0921	124.99	131.1
	Type 2	148.26	151.92	142.03	144.78
	Type 3	228.88	234.15	211.17	221.48
2%	Type 1	147.15	152.29	125.49	131.24
	Type 2	152.85	156.84	143.36	147.98
	Type 3	231.85	234.86	214.25	224.18
3%	Type 1	149.16	154.07	128.58	134.83
	Type 2	155.96	157.03	144.93	148.75
	Type 3	233.94	235.28	225.58	225.67
5%	Type 1	155.1	164.84	130.34	136.94
	Type 2	158.88	160.62	146.38	149.58
	Type 3	236.84	239.02	228.76	231.76
7%	Type 1	159.03	168.89	132.86	137.3
	Type 2	162.01	164.37	147.97	152.6
	Type 3	240.09	246.31	231.16	234.13
10%	Type 1	162.18	173.48	136.72	138.69
	Type 2	164.58	168.52	148.23	158.77
	Type 3	242.29	250.06	233.13	236.73

Under the machine breakdown(Table 6), SPT was the best machine scheduling rule. The AGV rules tested, LQS performed better than STD.

4.3.2 The results of under AGV breakdown.

Machine and AGV rules combinations were tested under various levels of AGV down-time percentages. The results of the simulation experiments are summarized in Table 7.

Table 7. AGV breakdown

down time \ part type \ scheduling rule		FIFOLQS	FIFOSTD	SPTLQS	SPTSTD
1%	Type 1	146.13	147.53	125.01	131.17
	Type 2	148.71	152.12	142.44	144.7
	Type 3	229.57	234.86	211.51	222.15
2%	Type 1	147.59	152.75	125.87	131.64
	Type 2	153.31	157.34	143.79	148.43
	Type 3	232.55	235.54	214.9	224.86
3%	Type 1	149.61	157.54	128.97	135.24
	Type 2	156.43	157.5	145.37	149.2
	Type 3	234.65	235.99	226.26	226.35
5%	Type 1	155.57	165.34	130.73	137.35
	Type 2	159.36	161.13	146.82	150.03
	Type 3	237.55	239.74	229.45	232.46
7%	Type 1	159.54	169.4	133.26	137.71
	Type 2	162.5	164.87	148.42	153.06
	Type 3	240.81	247.05	231.86	234.84
10%	Type 1	162.67	174.94	137.13	139.11
	Type 2	165.08	169.03	148.68	159.25
	Type 3	243.62	250.81	233.83	237.44

Under the AGV breakdown(Table 7), SPT was the best machine scheduling rule. The AGV rules tested, LQS performed better than STD.

4.3.3 The results of under machine and AGV breakdown.

Machine and AGV rules combinations were tested under various levels of machine and AGV down time percentages. The results of the simulation experiments are summarized in Table 8.

Table 8. Machine and AGV breakdown

down time \ part type \ scheduling rule		FIFOLQS	FIFOSTD	SPTLQS	SPTSTD
1%	Type 1	146.57	147.98	125.16	131.57
	Type 2	149.16	152.14	142.87	145.14
	Type 3	230.27	235.57	212.15	222.82
2%	Type 1	148.04	153.21	126.25	132.04
	Type 2	153.78	157.82	144.23	148.88
	Type 3	233.25	236.25	215.55	225.54
3%	Type 1	150.07	158.02	129.36	135.65
	Type 2	156.91	157.98	145.81	149.65
	Type 3	235.36	236.71	226.95	227.04
5%	Type 1	156.04	165.84	131.13	137.77
	Type 2	159.84	161.62	147.27	150.487
	Type 3	238.27	240.47	230.15	233.16
7%	Type 1	160.03	169.91	133.67	138.13
	Type 2	162.99	165.37	148.87	153.53
	Type 3	241.54	247.8	232.56	235.55
10%	Type 1	163.16	174.53	137.55	139.53
	Type 2	165.58	169.54	149.13	159.73
	Type 3	244.36	251.57	234.54	238.16

Under the machine and AGV breakdown(Table 8), SPT was the best machine scheduling rule and LQS performed better than STD in AGV scheduling rule.

4.3.4 The results of under machine and AGV breakdown, and various queue capacities.

The effect of machine and AGV breakdown and queue capacity using SPT/LQS scheduling rule capacity was tested under various levels of down percentages and queues. The results of the simulation experiment are summarized in Figure 3.

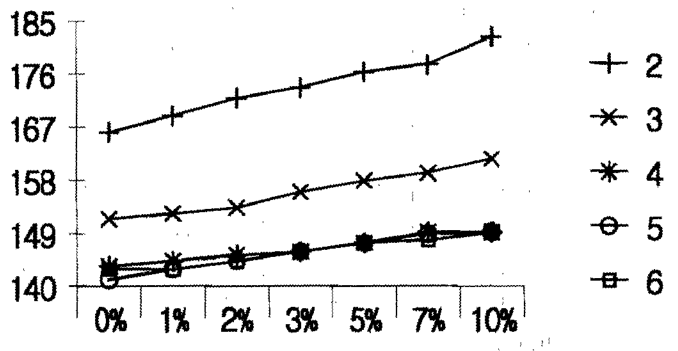

Figure 3. Machine and AGV breakdown, and queue capacity

Under the machine and AGV breakdown and queue capacity using SPT/LQS scheduling rule, 5 queue capacities is good value.

4.3.5 The results of machine and AGV utilization, interval of arrival time and AGV speed.

I tested different scheduling rules under various levels and conditions. The results of simulation experiment were SPT for machine and LQS for AGV to the best scheduling rules. Using SPT and LQS scheduling rules, machine and AGV utilization, interval of arrival time and AGV speed were tested under various levels and conditions.
The results of the simulation experiments are summarized in Table 9.

Table 9. Machine and AGV utilization, inter arrival time and AGV Speed

Conditions	Case 1	Case 2	Case 3	Case 4
Machine Utilization(%)	75	75	55	55
AGV utilization(%)	82	55	81	55
inter-arrival time	17	17	21	21
AGV Speed(m/h)	20	30	10	20
Type 1 SPTLQS	65.859	63.862	96.463	56.178
Type 2 SPTLQS	84.987	83.779	135.35	124.86
Type 3 SPTLQS	117.15	112.9	168.75	161.74

Cases 1,2 are superior to cases 3,4 in the relative performance of mean flowtime. The factor of machine utilization and inter-arrival time effect mean flowtime. Comparing case 1 to case 2, AGV speed effects mean flowtime on the same machine utilization and inter arrival time. Low machine utilization and inter-arrival time bring bad performance. Considering inter-arrival time under Table 4, the largest impact on the result of mean flow time is machine utilization. If machine utilization and inter-arrival time are the same value and condition, AGV speed has more effect than AGV utilization.

5. Conclusion

This paper presents a simulation model of a job-shop type FMS developed to investigate how the performance of scheduling decisions(i.e., mean job flow time) is affected by the use of scheduling rules, or utilization and various conditions in case of a machine breakdown situation. The performance of FMS can be improved considerably by using appropriate scheduling rules. The experiment results are as follows:

(1) In most cases at breakdown or nonbreakdown machines, SPT is the best scheduling rule for machine. LQS is slightly better than STD scheduling rules for AGV.
(2) The performance of the rules deteriorated as the down time percentage increased. The results also indicate that the effect of machine failure on the system performance is more than the AGV failure.
(3) As the queue capacities are increased, the system flow times shorten. It dos not shorten mean flowtime when queue capacities are over 5. Therefore, 5 queue capacities are adequate to this system.
(4) AGV speed effects more than AGV utilization.
(5) The machine utilization and AGV speed effect more mean-flow time. Considering table 9, case 1 and 2 are superior to case 3 and case 4. The machine utilization and scheduling rules can significantly affect the system performance.

The results presented in this paper are valid under the experimental conditions described earlier. Hence, there is a need for further research to develop new rules and continue testing the existing ones under different FMS configurations and experimental conditions.

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