A SIMULATION STUDY TO INVESTIGATE THE EFFECTS OF SIMULATION BASED DUE DATES AND SYSTEM STRUCTURE COMPLEXITY ON JOB SHOP SCHEDULING

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دراسة محاكاةللتحقيق في التأثيرات الناتجة عن مواعيد التسليم المحددة بواسطة المحاكاة وتعقيد هيكل النظم على جدولة الورش

خلاصة :

هذا البحث امتداد لبحث سابق في خصائص الورش التي تنتج مشغولات مختلفة (مشغولات مكونة من قطعة واحدة وأخرى مكونة من عدة قطع) • ان تعقيد النظام من حيث هيكلة المنتج ومقياس الاداء المستخدم وقواعد تحديد مواعيد التسليم وقواعد تشغيل المشغولات من العوامل الرئيسية المعتبرة في نماذج المحاكاة المستخدمة لغايات البحث •

يقدم هذا البحث تقييما للتأثيرات الناجمة عن تحديد مواعيد التسليم بواسطة المحاكاة وزيادة عدد وتعقيد هياكل المنتجات وقواعد التشغيل لها على أداء الورش باستخدام نموذج ونتائج بحث سابق كقاعدة للدراسة •

ABSTRACT

This research is an extension of previous research on the properties of hybrid assembly job shops. The system complexity in terms of product structures, the performance measure used, the due date assignment rules, and the job dispaching rules are among the key factors considered in research simulation models. In this paper the effects of simulation based due dates, increasing the number and complexity of product structures, and dispaching rules on job shop performance are evaluated using prior research model and results as a base.

INTRODUCTION AND BACKGROUND

The general job shop is very important in manufacturing. A survey by Panwalker, Dudek and Smith [21] showed that about 57% of all manufacturing is job related. The general job shop in all its forms is the most complicated of all manufacturing systems. It is shown in French [14] that the number of possible schedules to process n jobs on m machines is $(n!)^m$. It is also shown that delaying a job that could start processing to allow another job first can minimize the maximum completion time for a fixed set of jobs to be processed on a single machine. This further increases the number of possible schedule descriptions (allowing choices for order and time of start on a machine). Adding random or dynamic demand to job shop problems seemingly further complicates the scheduling problem compared to single machine or flow shop problems. Yet, the proven effective techniques in the academic literature for schedualing a job shop in its various forms are very simple approaches which are effective across a wide variety of structures. Further, these techniques are widely implemented in industry from the small shops to the large systems. The question arises as to why the simple approach outperform more complex approaches. What is the reason for this fact: the structure of the job shope, the criteria, or has the investigation of these problems used simulation models that are too simple ?

The large research question was: does the complexity of the job shope " average out " the effects of utilizing full system information and does the interaction of the decisions on scheduling and due date setting mitigate any advantages of more complex schedualing rules ?

To partially answer these questions investigations were conducted to determine :(1) The effect of simulation based due dates on the interaction of scheduling and due date decisions .(2) The effect of increasing system complexity by increasing the number and complexity of product types.

The specific form of the job shop studied was the hybrid assembly (combines production of jobs with single components with jobs that require production of components and their assembly) job shop. This problem was chosen because of the paucity of litreature on the subject and high frequency of occurrence of this type shop.

Surveys by Blackstone, Phillips and Hogg [7] and Iskander [22] are good reviews of previous studies of different sequencing rules. The superiority of SPT in terms of $\bar{F}$, $\bar{T}$, %age tardy, and number of tardy jobs in different job settings and against a variety of rules such as LKADD (pick job with minimum work content in queues remaining on rout), SPT2 (pick job whose processing time is smallest on next two machines), time and number of operations left (NOP). Combinations of rules are demonstrated in Conway [8,9,10), Baker [6], Aggarwal [2,3], Arumugam [4], Fryer [16,17]), and Nelson [20]. EDD (pick job to process first with earliest due date) is best to minimize T_{max} in Goodwin and Goowin [18]. In hybird shops, ASMF (assembly jobs first) was best to minimize staging time (time until all components of the assembly arrive at the first assembly point) but SPT still minimized mean lateness $\bar{L}$ (see Huang [19]). Due Date Policies : TWK and NOP have outperformed rules which ignore job and job shop characteristics (see e.g. Baker and Bertrand [6] and Conway, Maxwell and Miller [11]).Weeks [32] and Eilon and Chowdhury [12] have tested estimating flow times using current queue lengths. Reiter [26], Ragatz and Mabert [24], and Elvers [13] show how using job and job shop information improve flow time estimates for the purpose of estimating due dates. These studies did not consider hybrid assembly job shops. Baker and Dzielinski [5] and Fryer [16] showed as one of their results that choice of sequencing rule and use of labor flexibility was independent of size for pure job shops.

Huang [19] modeled a hybrid assembly job shop to test SPT and ASMF rules along with a combination of these rules. SPT minimized mean lateness and ASMF minimized mean staging time.

Adam, Bertrand, and Surkis [1] tested rules that were directed toward assembly jobs. Their rules tried to coordinate movement through the system by selecting components to process whose other components in the same assembly had moved forward.

Russell and Taylor [27] look at an assembly shop (all items involve assembly). They investigated labor assignment rules, sequencing rules and due date assignment rules. Since this shop has only assembly jobs, SPT was not one of the sequencing rules tested .

Experimental Model: Huang's model [19] was chosen as the basis for extending research into hybrid assembly job shops and into the structural reasons for the effectiveness of simple scheduling rules. This model was a hypothetical job shop consisting of nine machine centers. Three machine centers have two identical machines in each, while only one nachine is available in each of the other six machine centers . A set of three predetermined product structures was used to assign a job strcture to each arriving job. One of these product strctures is an assembly structure, while the other two structures contain only series operations with a different number of operations in each. Nine operations are included in the assembly structure, while the series structures have five and six operations in each. Figure 1 shows these job structures. Huang used 20,30, and 40 percent assembly jobs as basic situations with 20 replications for each factor combination. Huang used 400 jobs as the length of warm up without any statistical justification. We used schruben's test [31] to determine warm up when multiple criteria are being analzed. This test indicated a proper warm up of 1000 jobs. At this level of warm up nine replications duplicated the relative results given by Huang [19]. The proportions of each product structure type in the job sets considered are diplayed in Table 1. Time between job arrivals was randomly generated fromn an exponential distribution. The parameters of operation time distribution were determined so that the machine centers had reached a utilization of more than 95% . Table 2 displays these parameters.

Huang used Q-GERT simulation language in his study, while we recoded this model using SLAM II simulation language. Figure 2 shows the SLAM network employed in this research.

All statistical tests except Schruben's test were run automatically on the SAS computational system [23] . Huang did not look at the interaction of due dates and scheduling rules. The effect of simulation based due dates has not been tested to our knowledge. A due-date can be set by simulation by inputting current system status (current queue at each machine), generating arrivals and observing the average flow time. Ravindran [25] showed that simulstion of this type take from 1.50 minutes to 5 to 7 times longer to do the simulation. The flow time data for a class of jobs can then be evaluated to set a due date for an entering job. The above listed run times show that this a feasible option for many companies.

All machine centers are fully manned and no labor movment is assumed. In Huang's research, due dates were determined as a multiple of the sum of processing times for each series job and a multiple of the longest path for assembly jobs.

I. THE EFFECT OF SIMULATION BASED DUE DATES

The intent of this experiment is to investigate the effect of using simulation based due date assignment procedures on the performance of sequencing rules in terms of due date related performance measures such as EDD. This experiment is referred to as Experiment 1. A two-factor factorial design was considered.

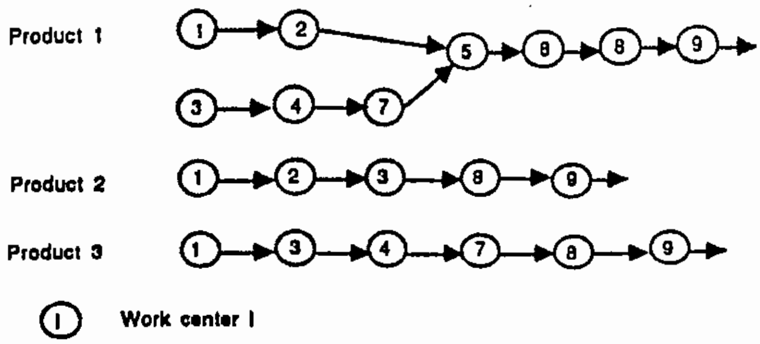

Figure 1: Basic model product structures.

Job set	Product structure		
	1	2	3
1	0.20	0.40	0.40
2	0.30	0.35	0.35
3	0.40	0.30	0.30

Table 1: Basic model product-mix.

Work center	Mean	Work center	Mean
1	1.5	6	2.5
2	2.5	7	1.5
3	2.0	8	0.7
4	1.0	9	1.0
5	2.0		

Table 2: Basic model operation time parameters.

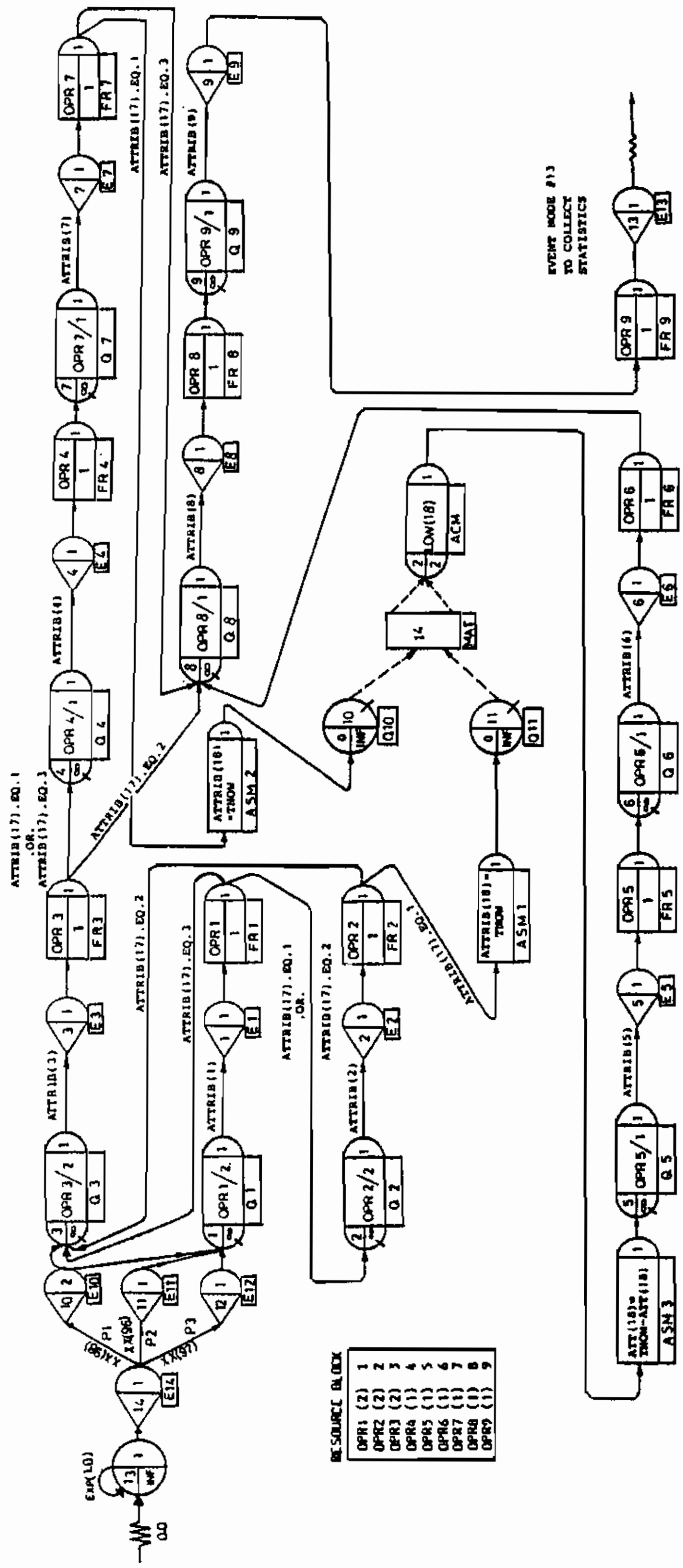

Figure 2. SLAM network for the basic model.

The first factor represented the sequencing rules employed in job shop operation, and the second factor represented the due date assignment procedure used to assign job due dates. Three levels for the first factor representing three sequencing rules, and five levels for the second factor representing five due dates assignment procedure were considered. The basic simulation model, with a warm up period of 1000 jobs and nine runs per factor combination, each for 10,000 completed jobs were used to generate data. A job stream consisting of 40% assembly jobs was generated in each run. This level of assembly jobs was chosen since the level of assembly jobs was not an experimental factor and this level made the model furthest from a pure job shop.

Three due date related performance measures were considered:
(1) Job mean lateness.
(2) Job mean tardiness.
(3) Percentage of tardy jobs.

The sequencing rules which were used in job shop operation are:
(1) Shortest processing time rule (SPT).
(2) Mixed sequencing rule (MIXED). The rules uses the assembly first rule (ASMF) with (SPT) as a tie-breaker.
(3) Earliest due date rule (EDD).

The due date assignment rules that were used to assign job due dates consisted of five rules. Two rules were based on multiples of job total processing times. Two multipliers 3 and 7 were used to represent tight and loose due dates asreported in Huang [19], Goodwin and Goodwin [18], Weeks [23], and Elvers [13]. The other three rules were based on job mean flow times estimated by simulation. Job mean flow times and their standard deviation for jobs of product structure 1, 2, and 3 were collected separately from a pilot investigation, under each of the SPT, EDD, and ASMF rules.

These estimated mean flow times and their standard deviations are presented in Table 3, and were used in computing job flow time allowance under each sequencing rule. Five due date assignment procedures were used in this experiment:
(1) Assign a due date for a job as the sum of its arrival time and three times its total processing time (DD1).
(2) Assign a due date for a job as the sum of its arrival time and the mean flow time estimated for its product structure given the sequencing rule used (DD2).
(3) Assign a due date for a job as the sum of its arrival time and the mean and one standard deviation of the flow time estimated for its product structure given the sequencing rule used (DD3).
(4) Assign a due date for a job as the sum of its arrival time and the mean and two standard deviation of the flow time estimated for its product structure given the sequencing rule used (DD4).
(5) Assign a due date for a job as the sum of its arrival time and seven times its total processing time (DD5).

Table 4 presents the flow time allowences used under each sequencing rule for DD2, DD3, and DD4 due date assignment procedures for jobs with product structures 1, 2 , and 3.

Experimental Results: Table 5 displays the means of the observed values in terms of job mean lateness, job mean tardiness, and

Sequencing rules	Product 1		Product 2		Product 3	
	mean	standard deviation	mean	standard deviation	mean	standard deviation
SPT	51.04	6.55	25.94	5.20	33.61	4.70
MIXED	38.32	4.13	39.95	7.43	63.31	11.70
EDD	155.60	37.84	81.41	34.73	114.90	36.93

Table 3. Exp.1: Mean and standard deviation of estimated flow time.

Sequencing rules	Product 1			Product 2			Product 3		
	DD2	DD3	DD4	DD2	DD3	DD4	DD2	DD3	DD4
SPT	51	58	64	26	32	36	34	39	44
MIXED	38	43	47	39	47	55	63	76	88
EDD	156	185	224	82	117	153	115	152	189

Table 4. Exp.1: Flow time allowance.

Sequencing rules	Due date procedure				
	DD1	DD2	DD3	DD4	DD5
Mean lateness					
SPT	10.30	-0.11	-6.21	-11.31	-26.90
MIXED	17.77	-0.48	-8.03	-15.56	-19.54
EDD	92.61	2.47	-31.12	-68.14	47.21
Mean tardiness					
SPT	15.54	14.85	13.82	13.11	9.27
MIXED	22.62	17.42	15.95	14.77	13.51
EDD	92.74	22.65	11.38	4.87	51.41
Percentage of tardy jobs					
SPT	34.41	18.95	14.93	12.73	6.21
MIXED	48.60	21.65	17.24	14.08	14.88
EDD	97.81	43.76	25.35	11.55	77.04

Table 5. Exp.1: Mean observed values of performance measures.

percentage of tardy jobs. A two-way ANOVA procedure was conducted on the collected data and the results showed a significant level of 0.0001 for all main effects and their interactions for all performance measures considered. To further investigate the significance of all sequencing rules within each due date procedure, one-way ANOVA and Tukey's range test procedures were performed.

Considering the mean values for the mean lateness performance measure, the results make sense as the measure is approximately zero for DD2 which sets the due date as the expected flow time. There would be about as many late as early. As the due dates get looser, EDD will get many jobs very early relative to the loose due date, and mean lateness will average high negative as in the value for DD4 under EDD dispatching. As would be expected, choosing a constant multiplier of work content won't perform well (be loose) for some enviroments because loosness or tightness depends on the particular production enviroment.

Table 6 illustrates the interaction effect. Note that ranking is the same for DD1 and DD5, which illustrates that DD5 is not necessarily loose as reported in previous research. The table makes clear that the dispatching rule and due date rule should be chosen as a set to achieve the particular performance measure goal.

Similar significant results were found for the sequencing rules considered in terms of mean tardiness and percentage of tardy jobs. The only exception is that DD3 generates similar values for mean tardiness statistic and DD4 generates similar values for percentage of tardy jobs no matter what sequencing rules was applied. It is also worth noting that different performance measures were differently affected by the due date rules used. Figure 3, 4, and 5 show the interaction effects of the sequencing rules and the due date assignment rules on the performance measures considered. A control strategy is defined as a combination of due date assignment rule and a sequencing rule. Fifteen control strategies were formulated as follows:

Due date rule	1			2			3			4			5		
Sequencing rule	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Control Strategy	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Tukey's Range Test Results			Due Date Rule
1st	2nd	3rd	
SPT	MIXED	EDD	DD5
MIXED	SPT	EDD	DD2
EDD	MIXED	SPT	DD3, DD4
SPT	MIXED	EDD	DD1

Table 6. Exp.1: Analysis of interaction effect for mean lateness. Rules that are not significantly different are in underlined group (α>.05).

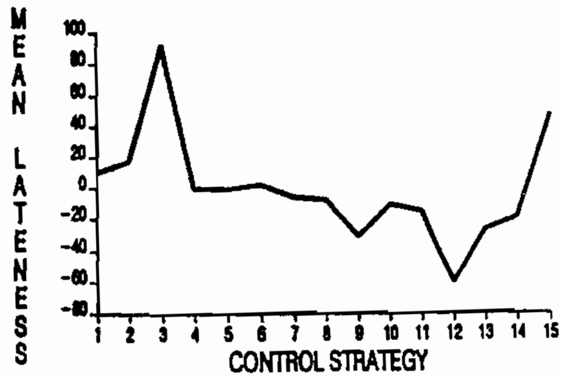

Figure 3. Exp.1: Mean lateness as a function of control strategy.

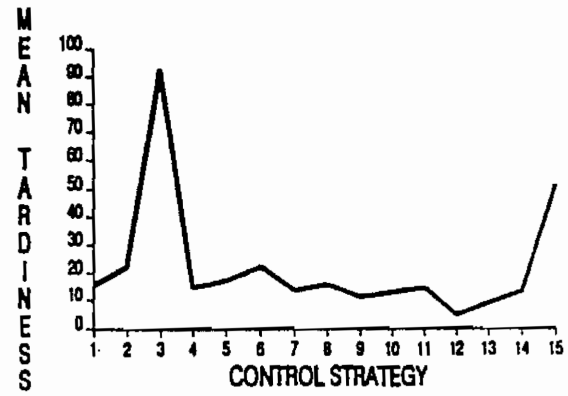

Figure 4. Exp.1: Mean tardiness as a function of control strategy.

Figure 5. Exp.1: Percentage tardy jobs as a function of control strategy.

II.THE EFFECTS OF SYSTEM COMPLEXITY AND SINGLE MACHINE SEQUENCING RULES

Although many systems are like Huang's model in that the ending operations are the same (inspection and packaing, for example) the advent of CNC equipment has reduced final inspection and packing and became a warehouse function in many cases. We observed that ending operations varied in most cases. Thus, a class of problems observed have alternate exits and more varied product structure. To represent this class, products were added to Huang's product set as shown in Figure 3 which are representative of structures we observed. The number of machines (machine centers) remains the same. The shop is loaded as before to the 95% utilization for one center as in Huang's study. Russell and Taylor [27] used 84% maximum loading for an assembly shop (this is a hybrid assembly shop). Manegers interviewed confirmed that at about 85% maximum shop utilization, the impact of decision rules start to make a difference. Ninety-five percent was chosen to match Huang's study.

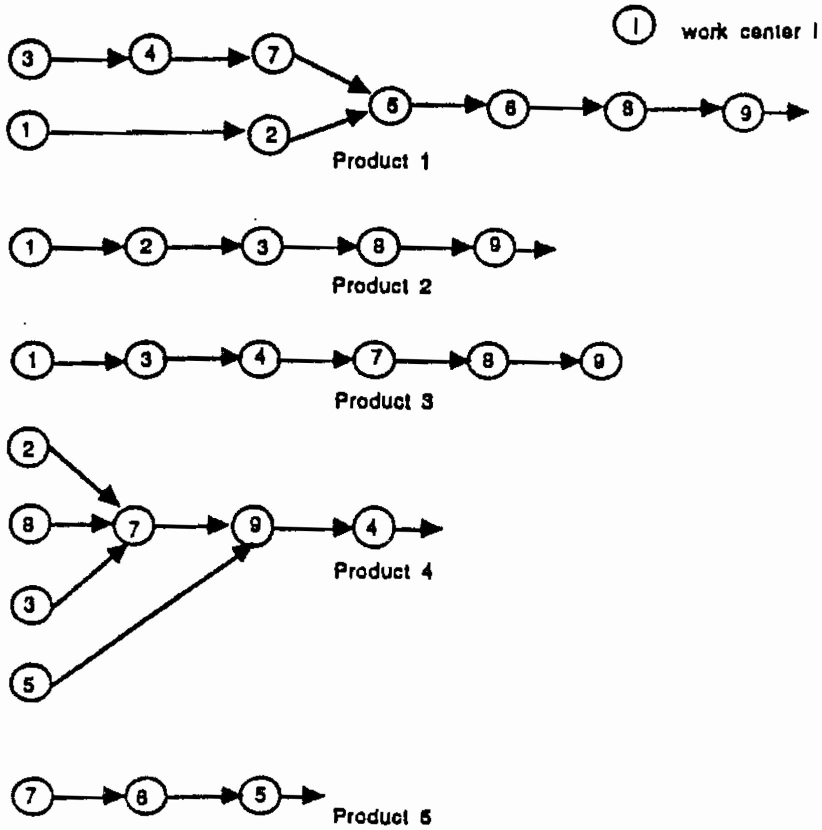

Figure 3. Exp.2: Extended basic model product structures.

Our research hypothesis was that increasing the coplexity of the research model by increasing the number and comlexity of product types would not change the optimal policies from the single machine rules to one that looked at more comprehensive system information. The utilization level is such that choice of sequencing rule would make an impact. As utilization decreases, the impact of sequencing rule choice decreases.

This experiment is referred to as Experiment 2. A two-factor factorial design was considered. The first factor represented the sequencing rules employed in the job shop operation, and the second factor represented the product-mix in the job streams considered. The product-mix was represented by the the percentage of assembly jobs in the job streams generated. Seven sequencing rules and three job streams were considered as levels of the first and second factor, respectively. The sequencing rules which were considered are:

(1) First in system first served rule (FISF).
(2) First come first served rule (FCFS).
(3) Shortest processing time rule (SPT).
(4) Earliest due date rule (EDD).
(5) Assembly first rule (ASMF).
(6) Look ahead rule (LKAHD). This rule considers the sum of work content waiting in all queues on the remaining routing of a job. The job with the minimum sum of work content is processed first.
(7) Two-machine shortest processing time rule (SPT2). If a job is waitting in work center i queue and its next operation is in work center j, then its two-machine processing time is the sum of its processing times in both work centers i and j. The job with the shortest two-machine processing time is processed first.

The shortest processing time rule was considered as a tie breaker for all sequencing rules.The first six sequencing rules were taken from Huang's [19] study for the purpose of comparisons. FIFS, FCFS, SPT, EDD, and ASMF rules were considered as single machine sequencing rules. The SPT and EDD rules are well known optimal single machine sequencing rules in terms of mean flow time and maximum tardiness, respectively. The LKAHD rule and the SPT2 rule were added because they combine more than one machine in their functions, and it was our conjecture that these rules may perform better than the other rules since they include more information in their function. Conway [8,9] has tested two look ahead oriented rules: Minimum number of jobs in next queue and minimum amount of work content in next queue. He found that these rules are inferior to the SPT rule in terms of mean flow time, mean lateness, shop utilization and work in process.

The three job sets considered consisted of 20%,30%, and 40% assembly jobs, and are denoted by P20%, P30%, and P40%, respectively.These product-mix levels are the same as those used in Huang's [19] study. Six performance measures were considered:

(1) Job mean flow time.
(2) Job mean lateness.
(3) Job mean tardiness.
(4) Job mean staging time.
(5) Percentage of tardy jobs.
(6) Maximum tardiness.

Due dates were set by using multipliers of work content for serial jobs or work content of longest path for assembly jobs as in Huang [19]. These multipliers were set by pilot runs so that each product would have a percentage of tardy jobs between 25%, and 30%. In this experiment, level of assembly jobs was an experimental factor. Simulation developed due-date were not a part of Huang's study and we wanted to compare results since we use Huang's basic model.

Experimental Results: A two-way ANOVA procedure was conducted on the abserved data, and showed that the main effects and their interactions are highly significant at a level of 0.00001. Table 7 presernts the means of each cell in terms of the performance measures considered. This indicates the different behaviors of sequencing ruls for different product-mix levels. To further investigate the significance of sequencing rules within each level of the product-mix factor, one-way ANOVA and Tukey's range procedures were conducted on the first factor for each level of the second factor. Table 8 displays these results. the one-way ANOVA test showed a significance of 0.0001 for the sequencing rule factor within each level of the product-mix factor for all performance measures.

The statistical tests conducted on the performance of the sequencing rules showed that: (1) the shortest processing time rule is the best choice in terms of mean flow time, mean lateness, mean tardiness, and percentage of tardy jobs, (2) the ASMF rule is the best choice in terms of mean stging time, and (3) the earliest due date rule is the best choice in terms of maximum tardiness just as Huang's study and our validation runs of his model showed. Thus, increased system complexity did not change the results. Even though non-single machine sequencing rules suggested here were, in some cases, grouped in the same class with the ranked rule, none of them has been ranked first under any condition.

It is evident that optimal single machine sequencing rules were ranked first in all conditions even in a complex system. This leads to the cojecture that single machine sequencing rules suffice for job shop systems relative to the measure the single machine rule was developed for.

Sequencing rules	Product-mix			Product-mix		
	P20%	P30%	P40%	P20%	P30%	P40%
	Mean flow time			Mean lateness		
FIFS	149.22	234.76	342.08	126.22	211.03	317.61
FCFS	161.18	255.75	377.17	138.17	232.04	252.72
SPT	27.22	31.77	34.76	4.75	8.99	11.69
EDD	145.62	229.73	336.32	122.61	206.00	311.84
ASMF	32.43	45.17	53.81	9.83	21.76	28.29
LKAHD	38.32	52.33	68.39	15.77	29.25	44.72
SPT2	31.78	36.00	39.32	9.37	13.24	16.17

Table 7. Exp.2: Mean observed values of performance measures.

Sequencing rules	Product-mix			Product-mux		
	P20%	P30%	P40%	P20%	P30%	P40%
	Mean tardiness			Mean staging time		
PIFS	129.45	213.59	319.79	172.92	238.70	285.27
PCPS	141.02	234.55	354.83	184.08	267.98	339.87
SPT	11.89	15.69	18.09	142.98	169.01	162.45
EDD	129.02	208.56	314.16	176.43	242.40	288.62
ASMF	17.18	28.90	35.16	100.31	125.47	149.72
LKAHD	22.81	35.93	51.23	234.37	237.41	217.67
SPT2	16.39	19.85	22.27	142.75	148.85	174.70
	Percentage of tardy jobs			Maximum tardiness		
FIFS	76.71	78.72	81.00	379.87	644.88	932.54
FCFS	75.18	77.72	80.97	440.21	741.19	1102.56
SPT	25.35	27.12	28.23	1199.37	1349.39	1468.46
EDD	73.51	75.65	77.49	366.79	629.53	914.65
ASMF	32.26	33.20	34.35	1185.16	1363.21	1660.81
LKAHD	35.19	37.74	38.55	1280.69	1338.65	1622.72
SPT2	26.41	28.15	30.78	1295.61	1567.31	1562.94

Table 7. Exp.2: continued.

Performance Measure	20%	30%	40%
F	SPT, SPT2 ASMF	SPT, SPT2, ASMF	SPT, SPT2, ASMF
L	same	same	same
T	same	same	same
%T	same	same	same
ST	AFMF	ASMF	ASMF, SPT, SPT2
T_{max}	EDD, FISF, FCFS	EDD, FISF, FCFS	EDD, FISF, FCFS

Table 8. Exp.2: Analysis of the interaction of product-mix and sequencing rule in an environment where number and complexity of job types is increased. Underlining indicates rules which are statistically indistinguishable in terms of effect on performance measure. Rules are listed in rank order 1st, 2nd, and 3rd (α>.o5).

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