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A STUDY OF SEQUENCING RULES IN A DYNAMIC PURE FLOW SHOP

دراسة لقواعد تسلسل عمليات التشغيل في ورشة انسيابية ديناميكية

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ملخص :-

يقدم هذا البحث دراسة محاكاة للتحقق من تأثير عدة قواعد استاتيكية وديناميكية لتسلسل عمليات التشغيل على اداء ورشة انسيابية ديناميكية (جميع المشغولات لها نفس التعاقب بين ماكنات الورشة) ٠ وقد تم اعتبار مستويين لمعدل تحميل (اكتظاظ) الورشة ، متوسط (٨٠٪) وعالي (٩٥٪) ٠ كما واستخدمت طريقة المحتوى التشغيلي الكلي لتحديد مواعيد تسليم المشغولات على مستويين من الاحكام ، محكم ؛ وفضفاض ٠ وتشير نتائج الدراسة على أن قاعدة تسلسل التشغيل حسب أقصر وقت للتشغيل وقاعدة تسلسل التشغيل حسب أقرب موعد للتسليم هما الافضل بين قواعد التسلسل الاخرى ٠ كما وجد أيضا أن قواعد التسلسل الاستاتيكية أكثر فعالية وكفاءة من الديناميكية لجميع الحالات التي أعتبرت للورشة ٠ وأخيرا ، بينت الدراسة بأن سياسات التشغيل ذات الاداء الافضل في الورش العامة وورش التجميع ليست بالضرورة هي الافضل للورش الانسيابية ، وأن الاختيار السليم من قبل الادارة لسياسات التشغيل يصبح أكثر فعالية في الورش الانسيابية تحت ظروف الاكتظاظ ومواعيد التسليم المحكمة ٠

ABSTRACT

This research presents a simulation study to investigate the effect of several static and dynamic sequencing rules on the performance of a dynamic pure flow shop. Two levels; medium (80%) and high (90%) of shop utilization are considered. Job due dates are set at two levels of tightness; loose and tight, using the total work content method. The results indicate that the shortest processing time rule and the earliest due date rule are superior to other rules.. Static rules are found more effective and efficient than dynamic rules for all shop conditions considered. Finally, this study shows that operating policies that perform well in job shops and assembly shops may not work well in pure flow shop environments, and management selection of the right operating policies become more effective in congested with tight due date flow shop conditions.

NOTATION

n : number of work centers in the shop.
N : number of completed jobs.
NT : number of tardy jobs.
S : set of completed jobs.
$\in$: element of.
t : time at which selection from a work center queue is to be made.
i : index over the jobs being processed in the shop.
$Z_i(t)$: the priority value of job i at the time a job from a queue is to be selected for processing.

j : index over the sequence of the work centers in the shop, $j=1,2,\ldots,n$.
J : a specific value of j, the work center the job in its queue.
P_{ij} : processing time of job i in work center j.
r_i : arrival time of job i to the shop.
d_i : due date of job i.
C_i : completion time of job i.
F_i : flow time of job i; $(F_i = C_i - r_i)$.
L_i : lateness of job i; $(L_i = C_i - d_i)$. Lateness may be negative indicating an early completion.
T_i : tardiness of job i; $(T_i = \max(0, L_i))$.
k : allowance factor (a multiplier ≥ 1).
HT : high shop load - tight due date shop condition.
HL : high shop load - loose due date shop condition.
MT : medium shop load - tight due date shop condition.
ML : medium shop load - loose due date shop condition.

INTRODUCTION

Analytical and simulation studies of job shop production systems have received considerable attention from operations research practitioners, management scientists, production and operations research analysts and mathematicians since the early 1950s. The importance of effective and efficient management policies and strategies in the area of resources allocation over time to perform tasks in production environment in today's competitive markets cannot be overlooked. The need to satisfy ccustomers demand on time with the best possible quality, and to run production plants at a high degree of efficiency and effectiveness gives rise to complex scheduling and sequencing problems in almost every production environment.

A number of books have been published on the subject of scheduling and sequencing theory and practice, e.g. Muth and Thompson [50], Conway et al [21], Baker [3], Rinnoy Kan [57], and French [27]. In addition, review articles of varying depths and breadths which survey the development of job shop scheduling theory include, Mellor [45], Lenstra et al [43], Graham et al [30], Graves [31], Frost [28], Blasewicz et al [11], Rodammer and White [58], Buxy [15], Kovalev et al [41], and White [68]. Blackstone et al [13] and Rmasesh [56] have done an excellent work classifying and organizing a voluminous body of literature on job shop scheduling. Each of the above mentioned papers provides a substantial reference for future research.

Because of the difficulties involved with analytical methods for solving complex job shop scheduling problems, computer simulations appeal to researchers by providing them with the experimental flexibility to depict real-life shop environment and the ability to manipulate different factors of the experiment in a controlled setting. Investigation of various aspects of job shop management using simulation as a tool have been documented in numerous research articles, e.g. Kanan and Gosh [40], Sawaqed [61], Noh and Herring [52], Fry et al [29], Weeks and Fryer [67], Weeks [66], Huang [37], Baker [9], Baker and Bertrand [7], Baker and Kanet [8], Baker and Dzielinski [4], Day and Hottnstien [22], Adam and Surkis [1], Ashour and Vaswani [2], Conway [18, 19], Eilon and Chowdhury [23], Elvers [24], Elvers and Taube [26], Gupta [34], Herd [35], Kanet and Hayya [39], Hottenstien [36], Miyazaki [47], Panwalker et al [53], Rochette and Sadowski [59], Smith and Seidmann [64], and Wang and Resenshine [65].

A review of published articles reveals a lack in investigation studies of the dynamic pure flow shop. The major distinction between a flow shop and a job shop lies in the flow pattern of jobs between shop machines or/and work centers. A job shop consists of a set of machines/workcenters through which each job has its own individual flow pattern, or specific route which must be adhered to. In the flow shop, on the other hand, each job has an identical flow pattern, i.e. all jobs have the same routing.

Among the reported results on the job shop, Ashour and Vaswani [2] concluded that the shortest processing time (SPT) sequencing rule was superior to other rules in reducing job lateness and flow time. Baker and Dzielinski [4] and Weeks [66] showed similar results. Conway [19] observed that the first in system first processed (FISF) rule was the best in reducing flow time variance, while the shortest processing time rule worked best in reducing mean flow time. It was also shown that the percentage of tardy jobs (jobs with positive latenss) was highest for the FISF rule and smallest for the SPT rule, when due dates were established exogenously. Additionally, sequencing rules based on due dates performed worse than those based on the shortest processing time in terms of proportion of tardy jobs.

Blackstone et al [13] pointed out that the need for scheduling dispatching rules arises from the fact that no dispatching rule has been demonstrated to be optimal for a job shop environment. Montazer and Van Wassenhove [48] concluded in their study that no single scheduling rule is the best on all performance measures considered and it is up to the user to select the rule according to the performance measure prevailing in the particular situation.

Elvers [24] investigated the performance of ten dispatching rules over five variations of the total work content based due date rules, and noted that the shortest processing time rule exhibited the best performance when due dates were assigned six times total processing time or less. Due date based rules produced more late jobs than the shortest processing time rule. Eilon and Chowdhury [23] found that the percentage of late jobs was higher for the first in system first served rule than for the shortest processing time rule. Elvers and Taube [26] indicated that at shop loading below 91.6% the shortest processing time rule is outperformed by other rules, while the shortest processing time rule outperformed other rules in terms of mean flow time in more heavily loaded shops. Quite contrary to other results, Weeks [66] observed the due date based rules performed better than the shortest processing time rule in terms of meeting due dates. In general high utilization, tight due dates, and due date independent of processing times favor the shortest processing time rule [19, 23, 24]. Rochette and Sadowski [59] observed in their simulation experiment that sequencing jobs with smallest value of product of imminent operation time by total processing first served (SOT*TOT) outperformed the shortest processing time (SPT) rule in terms of mean flow time and mean tardiness.

Several heuristics to minimize make-span (completion time of all jobs) have been developed in a static flow shop settings. Park et al [54] conducted a simulation study to evaluate the performance of sixteen static flow shop scheduling heuristics. They concluded that the number of jobs available in the shop has significant impact on the performance-effectiveness of heuristics investigated. Although these heuristics are capable of optimizing mean flow time, computational complexities pose sever restrictions on their applications in practice. Furthermore, these algorithms are applicable to static flow shop environments which require that all jobs be available at time zero. As such, in a dynamic flow shop where jobs arrive on a continuous and random pattern, these heuristics may not be effective in dynamic flow shop environments.

Muth [49] simulated a two-stage production process (a flow shop of two machines) and one sequencing rule, Johnson's rule [27]. He mentioned that it is not known to what extent the results generalize to several stages. Barrett and Barman [10] studied the application of combined scheduling rules in dynamic flow shop consisting of two work centers. They found that the shortest processing time rule applied in both centers is better than the application of the earliest due date rule in terms of mean flow time and mean tardiness, while the earliest due date rule applied in both centers performed better in terms of mean lateness. They recommended that futher research is needed to investigate the inclusion of more dynamic dispatching rules in a dynamic flow shop with more than two work centers, and the use of tight and loose due dates to find out how these factors would affect the flow shop performance under variations in shop loading levels.

The purpose of this research is to investigate the performance of static and dynamic scheduling rules in a dynamic pure flow shop environment under different shop loading conditions, job due date tightness in an attempt to explore whether scheduling rules performance in a flow shop environment differs from that in a job shop environment as reported in job shop scheduling literature.

SIMULATION METHODOLOGY

In this research, the operation of a hypothetical dynamic pure flow shop is simulated under various sequencing rules, due date tightness and shop loading. The flow shop simulated consists of four work centers, with one machine in each center. The selection of the shop size was made in the light of previous research. Muth [49], Barrett and barman [10], each simulated a flow shop of two machines. Huang et al [38] and Gupta et al [33] simulated four-machine production systems. Additionally, Baker and Dzielinski [4] and Nanot [51] tested scheduling rules in shops of various sizes and found that the size of the shop does not affec the relative performance of rules. Buffa [14] concluded that since the shop size has never appeared as a major variable, it becomes possible to experiment with relatively small shops and generalize the resulting conclusions. The following sections describe the experimental design, the shop simulation model and the experimental conditions.

Experimental Design

The objective of this study is to assess the impact of static and dynamic sequencing rules on the performance of a hypothetical dynamic pure flow shop under different shop conditions in terms of shop loading (shop utilization) level and job due date tightness in an attempt to explore whether such an impact would have the same significance in flow shop environment as in job shop environment.

1- Shop loading

Most studies of sequencing rules in job shops for which results have been published are based on a single predetermined level of shop utilization. Carrol's work [16] and that of Baker and Dzielinski [4] were based on a utilization level of 80%. A utilization level of 90% was used in [23] and [67]. A heavily loaded shop at 97% was used by Elvers [24, 25]. Two different shop loading levels of 72% and 94% were used in [36]. Conway [18, 19] examined shop performance at three utilization levels of 88.4%, 90.4% and 91.9%. An average shop loading of 90% was used in [40]. Rochette and Sadowski [59] used 80% and 95% shop loads.

In this study two shop loads are considered. A high shop load of 95% and a medium shop load of 80%. The mean interarrival time of jobs to the shop was the mechanism for adjusting shop loading [12]. Jobs arrive according to a negative exponential distribution with mean interarrival times of 1.15, 1.37 time units (hours) for high and medium shop loading respectively. Common random number streams were utilized as a variance reduction mechanism, with processing times being generated without using common random number streams to ensure independence [1], [46]. The normal distribytion was used to generate operation processing times. Elvers [25] concluded that the distribution with respect to shape and range of the arrival rate for incoming jobs is not a significant variable in evaluating the relative effectiveness of sequencing rules. Furthermore, the normal distribution was used to generate operation processing times in [12], [33], [40] and [62].

2- Due date tightness

Job due dates were assigned using the total work content (TWK) method. In this method due dates are set internally by the scheduler as each job arrives to the shop on the basis of job characteristics. This method is most extensively used in job shop research to assign due dates. Baker [5] confirmed that not only does due date allowance affect the performance of sequencing rules, but the total work content method to establish due dates is usually the best approach. According to Baker and Bertrand [6], Cheng and Gupta [17], this method can be stated as follows:

$$d_i = r_i + k * \sum_{j=1}^{n} P_{ij}$$

The factor k reflects the level of due date tightness. It was concluded in [8] that no emperical research has been done to reveal the actual values of k for different industries. Benton [12] used a multiplier of 5 in his study to set job due dates. Amultiplier of 3 was used in [10], while multipliers of 2 and 7 were used in [60] and [26] respectively. Goodwin and Goodwin [32] used two levels of due date tightness by changing the value of the multiplier k from 3 to 7 to represent a tight and loose allowance respectively.

In this study two due date allowance factors (multipliers) of 2.7 and 7 were used to generate tight due dates (40% of jobs are tardy when using the shortest processing time sequencing rule under 95% shop load) and loose due dates (10% tardy) respectively. These proportions were used by Baker [5].

3- Sequencing rules

Seven sequencing rules are considered in this study. These rules included a representitive sample of commonly used sequencing rules in job shop research, and are presented in Table 1. Sequencing rules 1, 2, 3 and 6 are static rules, while sequencing rules 4, 5, and 7 are dynamic rules. Static rules do not change in terms of their priority value. On the other hand, the priority value of a dynamic rule changes over time. The simple static rules FISF, SPT and DDATE have been tested extensively in job shop research. The FISF rule ignores processing time requirements. Instead, it accelerates jobs to completion that have been in the system the longest. The SPT rule concentrates on processing as many jobs throuh a work center as possible. The DDATE rule considers acceleration of jobs by including job arrival time in its calculations. These three rules have been tested in [32], [44], [61], and [63]. The SPT rule performed the best of the three static rules as reported by

Maxwell [44] and Siegel [63]. However, Goodwin and Goodwin [32] found that the DDATE rule was the best performer when compared with the SPT rule. Rochette and Sadowski [59] found that the SPR rule performs better than the SPT rule in terms of mean flow time and mean tardiness at a shop load of 95%. They also concluded that the DDATE rule is a poor performer in most cases compared with the SPT rule in terms of job tardiness, but it performed better than the DSLK rule in terms of mean flow time and mean tardiness for all cases considered.

No.	Symbol	Definition of priority value $Z_i(t)$=	Description
1	FISF	r_i	First in system first served.
2	SPT	P_{ij}	Shortest processing time first.
3	DDATE	$r_i + K_i * \sum_{j=1}^{n} P_{ij}$	Earliest due date first.
4	DSLK	$d_i - t - \sum_{j=J}^{n} P_{ij}$	Minimum dynamic slack first.
5	CR	$\frac{d_i - t}{\sum_{j=J}^{n} P_{ij}}$	Minimum critical ratio first.
6	SPR	$P_{iJ} * \sum_{j=1}^{n} P_{ij}$	Minimum value of product of imminent processing time by total processing time first.
7	DPR	$\frac{P_{iJ} * \sum_{j=1}^{n} P_{ij}}{\sum_{j=J}^{n} P_{ij}}$	Minimum value of SPR divided by total remaining processsing time first.

All sequencing rules are processed low value of $Z_i(t)$ first.

Table 1: Sequencing rules considered.

Conway [19] showed that DSLK is better than the DDATE for minimizing job mean lateness. Blackstone et al [13] commented that Critical Ratio rule is in fairly common use throughout industry and there seem to be an appearant need for comparison of the performance of this rule with other rules. Because of the promising findings of Rochette and Sadowski [59] regarding the SPR (SOT*TOT as referred to in their study) a new dynamic version of the SPR rule, the DPR rule, was introduced in this study with the conjecture that it may provide good performance, since it accelerates jobs having more remaining processing time, and thus reducing job stagnancy between work centers.

4- Performance measures

Four performance measures were used to evaluate the results. These are: mean job flow time, mean lateness, mean tardiness and percentage of tardy jobs. Table 2 gives the mathematical formulation of each of these performance measures. The mean flow time, lateness, tardiness and percentage of tardy jobs performance measures are most often used for studying sequencing rules in job shops [13], [73], [63], [67]. The mean flow time is as a measure of the work in process and the mean tardiness as a measure of process's ability to meet its due date. These performance measurs are of primary importance due to the volatility of fashion industry as well as market competition at the retail level [26].

Performance measure	Definition	Description
1. Mean flow time	$\sum_{i \in S} F_i / N$	Mean flow time of completed jobs.
2. Mean lateness	$\sum_{i \in S} T_i / N$	Mean lateness of completed jobs.
3. Mean tardiness	$\sum_{i \in S} T_i / N$	Mean tardiness of tardy jobs.
4. Percentage of tardy jobs	100*NT / N	%age of jobs completed tardy.

Table 2: Performance measures considered.

Neither mean tardiness nor mean lateness measures actual production cost. These noncost measures of performance were chosen because of the highly variable cost structure encountered in industry.

Simulation Model

The operation of the flow shop was modeled in the SLAM II simulation language [55], using the PC version on a 386-25 Mz with math-coprocessor personal computer. The work centers were modeled in network form; the assignment of processing times, due dates and the calculations of sequencing rule priority values ($Z_i(t)$) were maintained in a discrete-event subroutine. Figure 1 shows the SLAM II network model for the simulated shop. Model verification was performed using pilot runs with a trace of the simulation to observe the flow pattern of entities through the system; logical patterns were observed in the trace. Moreover, extensive debugging and thorough revisions of model network and discrete-event subroutine were conducted.

Experimental Conditions

The simulation experiment of this study cosists of three main factors: A, B, and C. Factor A represents the sequencing rule variable at seven levels. Factor B repesents the due date tightness variable at two levels. Finally, Factor C represents the shop load (shop utilization) variable at two levels. A composite of the experimental variables and their various levels is given in Table 3. The simulation experiment is a 7X2X2 complete factorial design.

Law and Kelton [42] suggested that at least three runs of the simulation should be made to assess the variability of the output analysis. Four and five simulation runs were used by Noh and Herring [52], and Rochette and Sadowski [59] respectively. In this study, six simulation runs, with deffering random number seeds, were made for each of the twenty-eight factor combinations. But the data for the last five runs were used in the analysis to reduce the initial biase and any transition effects. Each run was simulated for 12000 time units (hours) with a warm-up period of 5000 time units (hours) used in order to eliminate the transient effect of system start-up. Statistics on the performance measures considered were collected after the warm-up period in each run. The steady state was identified using a test run of the simulation model under the SPT rule, tight due dates, high shop load conditions, and considering job flow time as the performance measure. Results from the

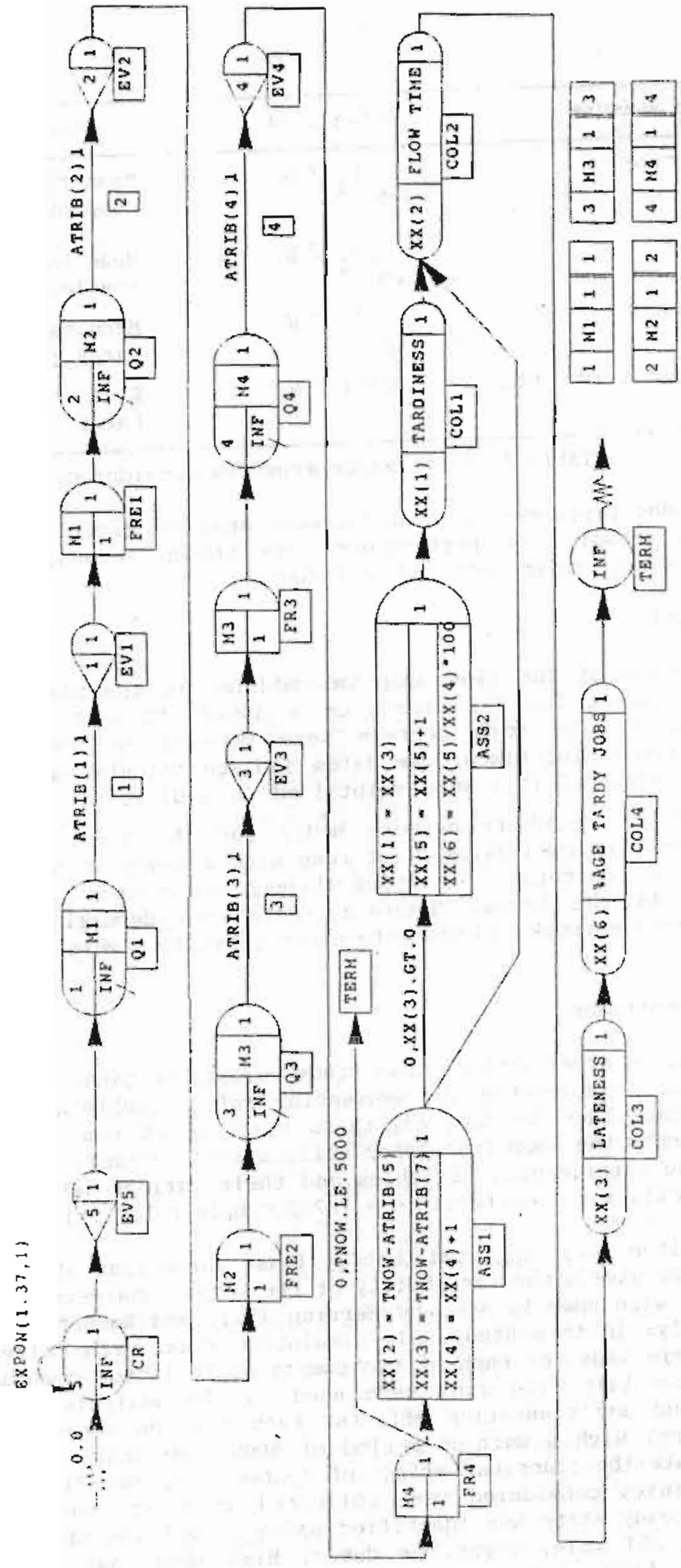

Figure 1: Flow shop SLAM II network model.

simulation experiment were analyzed using analysis-of-variance (ANOVA) procedure and graphs to identify significant differences in experimental factors and their interactions.

Experimental factor	Description and Levels
A	Sequencing rules
	FISF, SPT, DDATE, DSLK, CR, SPR, DPR
B	Due date tightness
	T : Tight (k=2.3), L : Loose (k=7)
C	Shop load (utilization)
	H : High (95%), M : Medium (80%)

Table 3: Experimental factors and their levels: a 7X2X2 complete factorial design.

EXPERIMENTAL RESULTS

ANOVA test results for the experimental factors are shown in Table 4. Tables 5, 6, 7, and 8 show the observed mean values of the performance measures considered. Furthermore, the interactions between shop conditions, in terms of shop load-due date tightness, and the sequencing rules are plotted in Figures 2, 3, 4, and 5.

Source	A	B	C	AXB	AXC	BXC	AXBXC
Degrees of freedom	6	1	1	6	6	1	6
Mean flow time:							
F value	33.512	.215	2546.017	.604	23.594	.198	.288
Sig. level	** .000	.643	** .000	.727	** .000	.657	.942
Mean tardiness:							
F value	80.615	82.825	477.082	34.205	30.503	34.513	14.942
Sig. level	** .000	** .000	** .000	** .000	** .000	** .000	** .000
Mean lateness:							
F value	33.363	3369.190	2512.049	.597	23.453	.177	.281
Sig. level	** .000	** .000	** .000	.732	** .000	.675	.945
Percentage tardy jobs:							
F value	167.608	2388.030	2909.933	29.079	77.826	201.628	2.279
Sig. level	** .000	** .000	** .000	** .000	** .000	** .000	.041

** : highly significant.

Table 4: ANOVA test results.

The ANOVA results show that sequencing rules have significant impact on all performance measures considered. The due date tightness factor has no significance in terms of mean flow time, while it is highly significant in terms of the orther performance measures. Factor C which represents the shop load variable has shown significant impact on all performance measures considered. The most significant effect among factors interactions on shop performance is the effect of the interaction between the sequencing rule and the shop load factors. In terms of mean flow time the SPT and the SPR outperformed other rules under all experimental conditions. This superior performance is more significant at high shop load as shown in Figure 2. The

PPERFORMANCE MEASURE: MEAN FLOW TIME									
SHOP LOAD	DUE DATE	RUN NO.	FISF	SPT	DDATE	DSLK	CR	SPR	DPR
HIGH (95%)	TIGHT	1	29.90	23.60	29.20	36.90	27.00	23.30	34.10
		2	28.10	22.60	27.90	36.30	25.30	22.70	37.00
		3	25.20	20.30	25.00	33.30	23.80	20.20	30.20
		4	22.70	18.20	22.30	27.90	21.10	17.80	26.30
		5	27.10	21.10	27.10	35.30	24.90	21.00	34.90
	MEAN		26.60	21.16	26.30	33.94	24.42	21.00	32.50
	VARIANCE		7.64	4.38	2.71	13.26	4.76	4.76	18.07
	LOOSE	1	29.50	23.60	28.70	36.20	30.00	23.30	34.10
		2	28.10	22.60	27.70	35.80	28.70	22.70	37.00
		3	25.20	20.30	24.70	32.60	26.60	20.20	30.20
		4	22.70	18.20	22.10	27.40	24.00	17.80	26.30
		5	27.10	21.10	26.80	35.50	28.10	21.00	34.90
	MEAN		26.52	21.16	26.00	33.50	27.48	21.00	32.50
	VARIANCE		7.01	4.38	6.93	13.65	5.28	4.76	18.07
MEDIUM (80%)	TIGHT	1	9.05	8.40	8.96	9.55	9.13	8.35	9.24
		2	8.61	8.07	8.54	9.20	8.75	8.02	8.96
		3	9.14	8.51	9.11	9.65	9.29	8.42	9.40
		4	9.25	8.60	9.27	10.10	9.40	8.55	9.82
		5	8.94	8.31	8.85	9.66	9.12	8.23	9.38
	MEAN		8.99	8.38	8.95	9.63	9.13	8.31	9.36
	VARIANCE		0.06	0.04	0.08	0.10	0.06	0.04	0.09
	LOOSE	1	9.05	8.40	8.71	9.36	9.56	8.35	9.24
		2	8.61	8.07	8.38	8.94	9.20	8.02	8.96
		3	9.14	8.51	8.82	9.43	9.75	8.42	9.40
		4	9.25	8.60	9.01	9.85	9.99	8.55	9.82
		5	8.94	8.31	8.74	9.44	9.63	8.25	9.38
	MEAN		8.99	8.38	8.73	9.40	9.62	8.31	9.36
	VARIANCE		0.06	0.04	0.05	0.10	0.08	0.04	0.09

Table 5: Observed values of mean flow time.

PERFORMANCE MEASURE: MEAN TARDINESS									
SHOP LOAD	DUE DATE	RUN NO.	FISF	SPT	DDATE	DSLK	CR	SPR	DPR
HIGH (95%)	TIGHT	1	20.70	37.00	20.50	28.70	18.00	39.70	32.30
		2	20.80	39.40	20.50	30.00	17.50	43.70	37.10
		3	16.90	30.70	16.60	26.10	15.20	33.80	28.80
		4	14.60	26.70	14.30	20.30	12.70	29.00	24.10
		5	19.50	33.20	19.50	28.70	16.90	36.30	36.00
	MEAN		18.50	33.42	18.28	26.76	16.06	36.50	31.76
	VARIANCE		7.23	25.47	7.50	15.04	4.64	31.42	28.75
	LOOSE	1	11.40	97.70	10.30	21.90	9.37	106.00	61.20
		2	21.30	127.00	21.50	27.30	16.20	136.00	78.90
		3	9.30	76.60	8.40	21.50	7.53	78.20	53.40
		4	7.70	72.80	7.57	17.20	6.29	76.50	47.80
		5	12.60	88.00	12.20	25.50	10.30	92.20	73.30
	MEAN		12.46	92.42	11.99	22.68	9.94	97.78	62.92
	VARIANCE		28.14	469.60	31.44	15.33	14.69	598.92	171.33
MEDIUM (80%)	TIGHT	1	4.26	8.66	4.14	6.59	4.04	9.40	7.78
		2	3.63	8.29	3.63	5.75	3.53	9.03	7.03
		3	4.01	8.73	4.09	6.18	4.05	9.13	7.71
		4	4.17	8.88	4.19	7.00	3.99	9.56	8.72
		5	3.73	8.82	3.75	6.15	3.71	9.07	7.74
	MEAN		3.96	8.67	3.96	6.33	3.86	9.24	7.79
	VARIANCE		0.07	0.05	0.06	0.23	0.05	0.05	0.36
	LOOSE	1	2.17	21.00	0.00	11.20	1.94	19.20	14.20
		2	2.37	21.60	0.68	9.32	1.83	26.30	13.60
		3	3.01	19.10	0.82	9.86	1.87	20.60	13.40
		4	1.24	25.80	0.00	12.50	1.91	22.50	19.50
		5	0.81	17.80	0.00	7.62	1.55	17.80	13.90
	MEAN		1.92	21.26	0.30	10.10	1.82	21.28	14.92
	VARIANCE		0.73	9.77	0.17	3.44	0.03	10.90	6.65

Table 6: Observed values of mean tardiness.

PERFORMANCE MEASURE: MEAN LATENESS

SHOP LOAD	DUE DATE	RUN NO.	FISF	SPT	DDATE	DSLK	CR	SPR	DPR
HIGH (95%)	T	1	19.40	13.50	19.10	26.80	16.90	13.20	25.90
	I	2	18.00	12.50	17.80	26.20	15.20	12.60	26.90
	G	3	15.10	10.10	14.80	23.20	13.70	10.00	20.10
	H	4	12.50	8.08	12.20	17.80	10.90	7.68	16.10
	T	5	17.00	10.90	17.00	25.20	14.80	10.80	24.80
	MEAN		16.40	11.06	16.18	23.84	14.30	10.85	22.36
	VARIANCE		7.21	4.46	7.39	13.26	4.93	4.83	18.31
	L	1	-1.24	-7.21	-2.03	5.39	-0.77	-7.46	3.27
	O	2	-2.64	-8.18	-3.09	4.99	-2.13	-8.05	6.22
	O	3	-5.59	-10.60	-6.12	1.84	-4.22	-10.70	-0.63
	S	4	-8.14	-12.60	-8.66	-3.44	-6.79	-13.00	-4.53
	E	5	-3.67	-9.74	-4.04	4.67	-2.70	-9.84	4.07
	MEAN		-4.26	-9.67	-4.79	2.69	-3.32	-9.81	1.67
	VARIANCE		7.23	4.43	6.95	13.70	5.27	4.89	18.20
MEDIUM (80%)	T	1	-1.02	-1.68	-1.11	-0.53	-0.95	-1.73	-0.83
	I	2	-1.47	-2.02	-1.55	-0.88	-1.34	-2.07	-1.12
	G	3	-0.95	-1.57	-0.97	-0.45	-0.80	-1.66	-0.69
	H	4	-0.57	-1.50	-0.83	0.00	-0.71	-1.55	-0.28
	T	5	-1.21	-1.84	-1.26	-0.49	-1.03	-1.92	-0.78
	MEAN		-1.05	-1.72	-1.14	-0.47	-0.96	-1.78	-0.74
	VARIANCE		0.11	0.04	0.08	0.09	0.05	0.04	0.09
	L	1	-21.60	-22.30	-22.00	-21.30	-21.10	-22.30	-21.40
	O	2	-22.10	-22.60	-22.30	-21.80	-21.50	-22.70	-21.70
	O	3	-21.60	-22.20	-21.90	-21.30	-20.90	-22.30	-21.30
	S	4	-21.50	-22.10	-21.70	-20.90	-20.80	-22.20	-20.90
	E	5	-21.90	-22.60	-22.10	-21.40	-21.30	-22.70	-21.50
	MEAN		-21.74	-22.36	-22.00	-21.34	-21.12	-22.44	-21.36
	VARIANCE		0.06	0.05	0.05	0.10	0.08	0.06	0.08

Table 7: Observed values of mean lateness.

PERFORMANCE MEASURE: PERCENTAGE OF TARDY JOBS

SHOP LOAD	DUE DATE	RUN NO.	FISF	SPT	DDATE	DSLK	CR	SPR	DPR
HIGH (95%)	T	1	95.10	39.80	94.50	93.60	95.10	36.80	73.90
	I	2	88.60	35.30	89.30	90.70	88.90	32.30	71.20
	G	3	92.70	40.0	92.40	90.70	93.20	37.00	72.70
	H	4	91.00	38.90	90.70	92.50	91.40	34.70	72.50
	T	5	83.00	35.30	82.50	81.10	85.30	31.60	62.30
	MEAN		90.08	37.36	89.88	89.72	90.78	34.48	70.52
	VARIANCE		21.31	5.63	20.79	24.75	14.62	6.21	22.03
	L	1	48.60	10.90	52.40	46.60	53.50	9.79	24.10
	O	2	31.00	8.45	37.60	46.40	36.00	8.14	23.00
	O	3	34.60	12.10	36.90	47.80	45.00	11.50	26.10
	S	4	28.80	9.92	25.50	38.60	36.40	9.14	23.50
	E	5	32.40	8.17	34.30	34.40	37.60	7.74	19.60
	MEAN		35.08	9.91	37.34	42.76	41.70	9.26	23.26
	VARIANCE		61.57	2.73	94.12	35.15	56.88	2.22	5.57
MEDIUM (80%)	T	1	25.60	14.20	23.90	25.70	30.30	12.60	20.90
	I	2	30.60	15.10	30.00	33.10	36.50	13.30	25.80
	G	3	29.40	15.30	28.20	30.00	34.40	14.20	23.50
	H	4	34.90	17.70	37.10	35.10	40.10	15.80	27.20
	T	5	25.40	12.80	24.30	27.00	30.50	11.60	22.10
	MEAN		29.18	15.05	28.70	30.18	34.36	13.50	23.90
	VARIANCE		15.47	3.22	28.72	15.73	17.22	2.56	6.72
	L	1	0.22	1.17	0.00	1.23	1.31	1.18	1.6
	O	2	0.27	1.50	0.03	1.34	1.25	1.12	2.74
	O	3	0.41	0.95	0.01	0.78	1.11	1.04	1.83
	S	4	0.22	1.98	0.00	2.65	2.12	1.78	2.94
	E	5	0.07	1.20	0.00	1.03	0.65	1.22	1.67
	MEAN		0.24	1.36	0.01	1.41	1.29	1.27	2.16
	VARIANCE		0.02	0.16	0.001	0.53	0.28	0.09	0.40

Table 8: Observed values of percentage of tardy jobs.

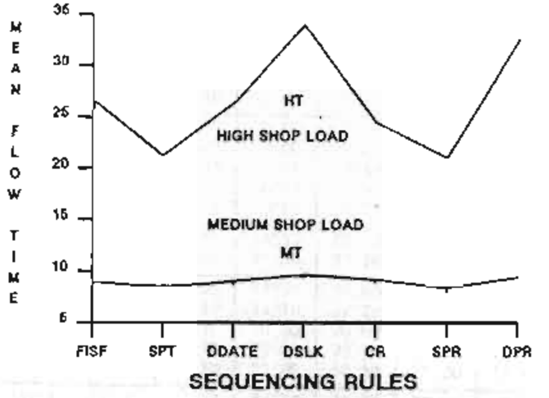

Figure 2: Mean flow time as a function of sequencing rule for shop comditions MT, and HT.

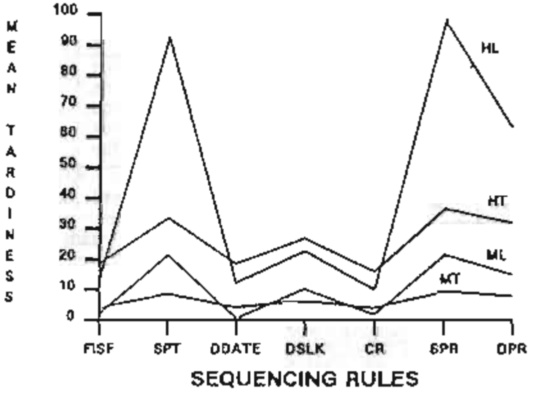

Figure 3: Mean tardiness as a function of sequencing rule for shop conditions MT, ML, HT, HL.

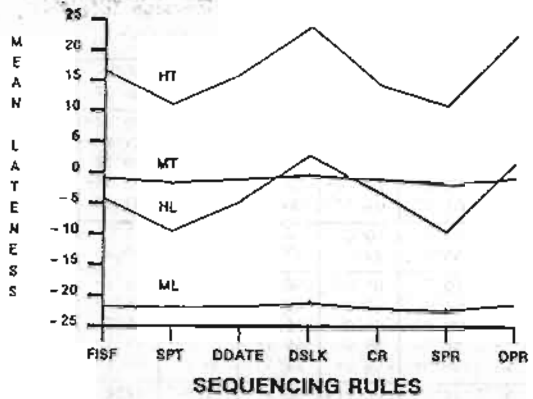

Figure 4: Mean lateness as a function of sequencing rule for shop conditions MT, ML, HT, HL.

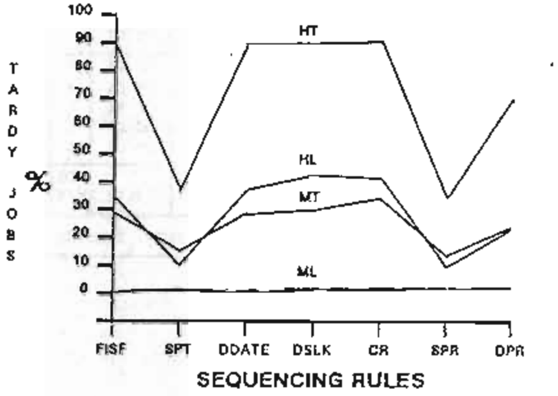

Figure 5: Percentage of tardy jobs as a function of sequencing rule for all shop conditions.

shortest processing time rule performed better than all other rules in reducing flow time variance under all conditions except one. The variance of flow time was reduced by the DDATE rule under high shop load and tight due dates condition. The lower the variance of flow time, the more is the predictability in job completion times. It can be noted that the SPT and processing time related rules are superior in reducing job mean flow time in a dynamic pure flow shop. Moreover, static sequencing rules are more effective than dynamic sequencing rules.

Regarding the mean tardiness performance measure, both the shop load and due date tightness factors affect the performance of sequencing rules significantly. This effect becomes more evident at high shop load-tight due date (HT) condition. The CR rule minimizes the mean and variance of tardiness, especially in highly loaded flow shop. Although yht difference in in performance between CR and DDATE rules is not as much as that among other rules, DDATE rule performed best for a medium shop load-loose due date (ML) shop condition. Due date related sequencing rules outperformed other rules under all shop conditions in terms of mean job tardiness as shown in Table 6 and Figure 3.

Considering the mean lateness performance measure, the SPT and SPR rules outperformed other rules, including rules which are based on job due dates. The difference in sequencing rule performance becomes more significant in a more congested flow shop. Again, dynamic sequencing rules have shown no improvement over static sequencing rules considered as shown in Table 7 and Figure 4.

The percentage tardy jobs and the variance of percentage tardy jobs are reduced by the SPR and SPT rules. As can be seen from Table 8 and Figure 5, the difference in the performance between SPR and SPT rules in not highly significant, but their performance significantly differs from those of other rules considered, including the dynamic rules, under the MT, HL, and HT shop conditions. When shop utilization becomes lower and due dates are looser, i.e. under ML shop condition, the difference between sequencing rules performance becomes less significant, and thus any rule, especially simple rules, would suffice, even though the DDATE rule showed good performance over other rules. It is also evident that due date related rules (DDATE, DSLK, and CR) become less and less effective as due date tightness and shop load increase.

The experimental results showed that the shortest processing time rule is the best among all other rules in terms of mean flow time, mean lateness, and percentage of tardy jobs under all shop conditions. The earliest due date DDATE rule could be considered as the best performer in terms of mean tardiness under all shop conditions. It is also appearant that the inclusion of flow shop status in sequencing rule structure did not improve the performance of sequencing rules. Therefore, dynamic rules DSLK , CR, and DPR have not shown superiority over static rules in terms of all performance measures considered under all flow shop conditions dealt with. Although they outperformed some other rules in certain circumstances.

CONCLUSIONS

This research has presented an experimental analysis of a dynamic pure flow shop production system, using simulation, to test the performance of various sequencing rules under various conditions of job due date tightness and shop utilization. Seven sequencing rules, two due date tightness levels, and two levels of shop load were experimented. Results indicate significant differences in performance measures considered; mean flow time, mean tardiness, mean lateness, and percentage of tardy jobs under differing shop load levels and due date tightness. The resuls show that managing a flow shop is not necessarily the same as managing a job shop in terms of operating policies. In general, the following conclusions could be derived from the results of this experimental research:

1- The shortest precessing time sequencing rule is superior to other rules, especially in a highly congested flow shop environment. Since this rule does not require complex computations, it is highly recommended to be used by shop management when mean flow time, mean lateness, and percentage of tardy jobs are of management concern in a dynamic pure flow shop environment.

2- Dynamic sequencing rules that take into consideration the shop status are not necessarily better than static rules, as reported in previous job shop research, when applied in a dynamic pure flow shops. This may be attributed to the fact that all jobs, by the nature of flow shops, have the same routing, thus each job has to pass through the same flow shop bottleneck machines/work centers, which is not the case in job shop environments.

3- The earliest due date DDATE rule and critical ratio CR rule may only have impact on mean tardiness, but not on mean flow time as reported in previous job shop research, when employed in a flow shop environment. It is more efficiently to use DDATE rule rather than CR rule since DDATE rule requires less computation than CR rule.

4- The selection of the right sequencing rules to be employed becomes more important to management as the flow shop becomes more congested and job due dates become tighter. It is advisable to flow shop management to employ simple static sequencing rules rather than complex dynamic rules. In addition, sequencing rules that work effectively in job shop, assembly shop, and flexible manufacturing system environments may not be appropriate for flow shop envirnments.

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