

Evaluation of Value and Time Based Priority Rules in a Push System

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Abstract

This paper presents the results of a scheduling research carried out in a push system of manufacturing. In this study three newly developed priority rules that are based on the value and time ratios have been evaluated. For purposes of comparison three conventional priority rules SPT, FIFO and EDD were used. The rules were evaluated on the following criteria: flow time, work-in-process inventory (WIPI) in monetary terms and in number of jobs, number of tardy jobs, and tardiness. A hypothetical model using GPSS was developed. The results were then revalidated using a real world push system. Appropriate statistical tests were used to analyze the results. The results show that SPT rule dominates on all performance measures except WIPI in monetary terms. The newly developed priority rule, the ratio of the total value added to the current processing time (TV/CPT) is the best performer under the performance measure WIPI in monetary terms.

Keywords: *job shop, priority rules, criteria of performance, work-in-process inventory, flow time*

1 Introduction

This study was carried out in a single resource constrained system. There has been considerable research both of analytical and experimental nature into steady state characteristics of queuing networks with single resource constrained systems. The job shop problem is too large and complex to be handled by analytical techniques. Hence researchers attacked the problem with computer simulation.

There have been two prominent avenues of research associated with computer simulation investigations of single resource limited network of waiting lines. One has been concerned with research of abstract models with the intent of developing a general theory of such systems. The other has been associated with

operational studies designed to solve specific real problem.

It appears from review of literature [1-21,23,24,26-27] that most of the early work considered time based priority rules. The criteria used for evaluating the performance of the priority rules were also mostly time based measures such as flow time, lateness, and tardiness. In later works time and cost based rules were extensively investigated and cost or profit measures were used for evaluating the performance of the rules. The effect of due date tightness was investigated in recent works more than in early works. The following conclusions emerge from the literature review:

1. No priority rule is superior to the others for all performance measures.
2. SPT rule results in minimum WIPI in terms of number of jobs, low mean lateness, maximum machine utilization, and minimum mean flow time.
3. Cost or profit based rules perform better under cost or profit oriented performance measures.
4. The arrival rate distribution does not have significant influence on the relative performance of the priority rule.
5. The size of the shop does not appear to have significant influence on the performance of the dispatching rules.
6. The relative performance of the priority rules appear to be affected by due date tightness.
7. It appears that priority rules based on the ratio between the value of the job and either processing time or time remaining to completion or time remaining to job's due date have not yet been completely evaluated.

The last conclusion prompted the current research to develop and investigate the performance of some rules based on the above ratios.

2 The Hypothetical Job Shop

In this study a representative job shop similar to those reported in the past studies [6,7,14,20,19,23,24] was constructed. This job shop was used to serve as an

experimental vehicle for the evaluation of the newly developed rules. The hypothetical shop consists of six machine centers with one machine each. Jobs arrive continuously during the simulation. The interarrival times were generated using an exponential distribution. The mean of the distribution was chosen such that 25%, 45%, and 60% of the jobs were completed late under FIFO rule. Upon arrival each job is assigned a due date calculated by using the total work content method as in reference [6] as follows:

$$d_j = r_j + k p_j \dots (1)$$

Where

d_j = due date for job j

r_j = arrival time of job j

k = allowance factor

p_j = total processing time of job j

The allowance factor k is determined from past research [6,7] as 3 for tight and 5 for moderately tight due dates respectively. A job is subsequently routed through the machine centers in the shop based on a randomly generated processing sequence. No two consecutive operations require the same machine. Setup and processing times are assumed to be exponentially distributed. Queue disciplines at all machine centers are the same and varies with the particular priority rule under which the simulation is conducted. The material cost is assumed to be uniformly distributed between 3 to 15 Libyan Dinars (LD) and the overhead cost is assumed to be proportional to the job's total processing time. The cost of machining is directly proportional to processing time at a particular machine center [22].

3 Simulation Model

In order to achieve a reasonable blend of structure and details, the following assumptions were made:

1. There are six machine centers with one machine each
2. The jobs arrive at the shop dynamically and the interarrival times are times are exponentially distributed.
3. Upon arrival at the shop the number of operations and the machining sequence are determined at random for each job.
4. The processing times are generated from exponential distribution with mean processing times different from one machine to another, and the job due date is calculated.
5. Setup times are sequence independent and are exponentially distributed.
6. An operation will not begin until its preceding operations are completed.

7. Once an operation is started on a machine, it is not interrupted.
8. Each machine can process only one operation at a time.
9. No reject or rework occur at any machine.
10. The value added to a job consists of four components:
 - i. the material cost is uniformly distributed between 3 and 15 dinars
 - ii. setup cost is proportional to setup time
 - iii. machining cost is proportional to machining time
 - iv. overhead cost is directly proportional to total work content of the job.
11. Machines are continuously available for production.
12. Handling times are included in the processing times.
13. Upon completion the job leaves the shop immediately.

The above assumptions were also made in most of the past studies.

The computer program was written in GPSS. The program consists of three segments, each developed in a modular form and integrated into one program. The first segment depicts the generation of jobs, the number of operations to be performed, sequence of operations, setup and processing times, due date, value added, priority level of jobs, and WIPI statistics. The second segment collects the necessary statistics and the third segment forces the model to terminate after 7500 jobs have been processed. The model was implemented using GPSS package available with Siemens main frame BS 2000 at the Arab Gulf Oil company in Benghazi.

3.1 Starting Conditions and Sample Size

In most of the simulation studies the model starts under idle empty conditions and the statistics for analysis will be collected after the system reaches a steady state. Shannon [25] summarized the suggestions of several researchers to overcome this problem. One of the suggestions is use of long computer runs so that data from transient period become insignificant relative to the data from the steady state condition. The above suggestion is used in this study.

Sample size determines the length of the computer run. In most of the past studies the sample size varied from 1000 to 10000 jobs [7,20,24,27]. In this study a sample size of 7500 jobs was used as it is sufficiently

large enough. The steady state conditions were reached approximately after 280 jobs.

3.2 Priority Rules

The hypothetical job shop was used to evaluate the three newly developed rules along with three others conventional rules for comparison purposes. The newly developed rules are as follows:

1. The ratio of the Total Value Added to Time Remaining to Completion rule (TV/TRC) – highest priority is given to a job with the largest value of the ratio TV/TRC.
2. The ratio of the Current Value Added to Time Remaining to Completion rule (CV/TRC)- top priority is given to the job with highest value of the ratio CR/TRC.
3. The ratio of the Total Value Added to the Current Processing Time (TV/CPT) – the job with the highest value of the ratio TV/CPT is given highest priority.

The value added to the job at each operation is determined using the following equation:

$$\text{Value added} = \text{machining cost} + \text{setup cost} + \text{material cost} + \text{overhead cost}$$

The three conventional rules selected for comparison purposes based on their performance in the past studies [7,17,20,23,24] are as follows:

1. The Shortest Processing Time rule (SPT) – highest priority is given to a job with lowest processing time
2. The Earliest Due Date (EDD) – highest priority is given to a job with earliest due date
3. The First In First Out rule (FIFO) – the job that arrived first will get the highest priority.

3.3 Criteria of Performance

In order to determine the relative performance of the six priority rules the following five criteria were used:

1. Flow Time: It is defined as the amount of time a job spends in the system
2. Work-In-Process Inventory (WIPI) in monetary terms: It is defined as the monetary (dinar) value of all jobs in the shop at any given time.
3. WIPI in terms of number of jobs (WIPI-NJS): It is defined as the total number of jobs in the system at any given point in time
4. Number of Tardy Jobs (NTJ): It is defined as the total number of jobs for which the completion time exceeded their due date.

5. Tardiness: It is defined as the amount of time by which the completion time exceeded the due date.

The above five measures satisfy the two important criteria used in industries to evaluate the performance of their production systems. They are delivery performance and work-in-process inventory.

3.4 Experimental Design

The purpose of this research is to compare the performance of six priority rules on the five performance measures. The performance of the rules are compared at three different load levels. The three load levels are chosen such that 25%, 45%, and 60% of the jobs were completed late under FIFO rule respectively. This method was used in a past study [23]. These load levels are obtained by adjusting the mean time between arrival while maintaining the mean shop service rate constant. The effect of due date tightness on the relative performance of the rules is also investigated. The following two due date tightness were considered: (1) tight due dates (2) moderately tight due dates.

The above problem can be handled as a multifactor experimental design. Thus a 6x3x2 factorial experimental design is used. That is six priority rules, three load levels and two due date tightness.

4 Results and Discussions of Hypothetical Model

The job shop was simulated according to the factorial experimental design. At the end of the each run the statistics for each of the performance measures were collected. The results are presented in the Tables 1 to 5. To compare the relative performance of the priority rules, analysis of variance (ANOVA) and multiple range test were applied.

4.1 Flow Time

The mean flow time (MFT) and standard deviation of flow time (SDFT) were used to compare the relative performance of the priority rules under different shop conditions. Table 1 presents the results of simulation for MFT and SDFT under three different load levels and moderate due date tightness for each priority rule. The due date tightness appeared not to have any effect on the relative performance of the rules. Therefore, the tight due date results were not used in the analysis.

Table 1. Simulation output of mean and standard deviation of flow time under three load levels.

Performance Measure

Priority rule	Mean						Standard Deviation					
	L1	R	L2	R	L3	R	L1	R	L2	R	L3	R
1. FIFO	2339	5	3150	6	3789	6	1448	5	1954	1	2957	2
2. SPT	1619	1	1905	1	2178	1	1381	1	2056	2	2941	1
3. EDD	2021	3	2604	3	3266	3	1842	4	2563	4	3618	4
4. TV/TRC	2164	4	2953	4	3514	4	2108	5	3779	6	5154	6
5. CV/TRC	2373	6	3127	5	3784	5	2140	6	3007	5	4390	5
6. TV/CPT	1696	2	2014	2	2347	2	1392	2	2090	3	3070	3

Note L = load level; R = performance rank

Mean Flow Time

As reported in the past studies the performance of the SPT rule dominated all other rules under all the load levels. The performance of the TV/CPT rule is very close to that of SPT rule. The results of multiple range analysis test show that the difference in performance between SPT and TV/CPT rules is insignificant at 95% confidence level and the performance difference between any one of the above two rules and each of the remaining rules is significant. The results of analysis of variance show that there is significant difference between MFT values due to load level and due to rule at 95% confidence level.

Standard Deviation of Flow Time (SDFT)

From Table 1 it can be seen that SPT, TV/CPT and FIFO rules dominate all other rules. The analysis of variance revealed that there is significant difference between SDFT values under different load levels and rules at 95% confidence level. The results of multiple range analysis test showed that different load levels produced significantly different values of SDFT.

4.2 Work-in-Process Inventory in Monetary Terms

The results of simulation output are presented in Table 2. Since the due date tightness did not have significant influence on WIPI, the moderate due date tightness was selected for analysis. It is clear from the results that that rules based on value and time ratios TV/CPT and TV/TRC dominate. The results of analysis of variance revealed that there is significant difference in the value of WIPI under different load levels. The results of multiple range test show that there is no significant difference in performance between the best performers TV/CPT and TV/TRC rules. The performance of the other rules were significantly

different from the best performers. The results also revealed that different load levels produced significantly different values of WIPI.

Table 2. Simulation output of mean and standard deviation of WIPI in monetary terms under three load levels

Priority rule	Performance Measure											
	Mean						Standard Deviation					
	L1	R	L2	R	L3	R	L1	R	L2	R	L3	R
1. FIFO	32739	5	43173	5	53533	5	17738	5	26092	5	36159	5
2. SPT	26105	3	39444	4	40221	3	12804	4	16309	3	20093	3
3. EDD	27102	4	34092	3	42074	4	10769	3	16481	4	23175	4
4. TV/TRC	24720	2	30602	2	36429	2	9565	1	13483	2	17244	2
5. CV/TRC	35735	6	46191	6	57551	6	19363	6	28516	6	37926	6
6. TV/CPT	24502	1	29804	1	34767	1	10671	2	13157	1	15900	1

Note L = load level; R = performance rank

With respect to standard deviation of WIPI, the multiple range test revealed that there is no significant difference in the value of standard deviation between any of the following rules TV/CPT, TV/TRC, SPT, and EDD.

4.3 WIPI Measured by Number of Jobs in System

The results of simulation are presented in Table 3.

Table 3. Simulation output of mean and standard deviation of flow time under three load levels.

Priority rule	Performance Measure											
	Mean						Standard Deviation					
	L1	R	L2	R	L3	R	L1	R	L2	R	L3	R
1. FIFO	12.8	5	18.2	5	23.7	5	8.7	5	12.8	5	18.0	6
2. SPT	7.1	1	10.2	1	12.9	1	4.9	1	6.4	1	7.9	1
3. EDD	10.4	3	14.8	4	19.9	4	5.8	3	9.1	4	12.8	4
4. TV/TRC	10.9	4	14.6	3	18.7	3	6.2	4	8.6	3	11.5	3
5. CV/TRC	13.0	6	22.3	6	33.7	6	8.8	6	13.1	6	17.5	6
6. TV/CPT	8.0	2	11.1	2	14.4	2	5.0	2	6.7	2	8.6	2

Note L = load level; R = performance rank

Since the due date tightness did not have significant influence on WIPI, the moderate due date tightness data was selected for the analysis. SPT rule appears to dominate all rules under all load levels as in the past studies. The results of multiple range analysis test

show that there is no significant difference in performance between SPT and TV/CPT rules at 95% confidence level. The above test also revealed that different load levels produced different values of WIPI. The results of analysis of variance show that there is significant difference between WIPI values due to load level and due to rule at 95% confidence level. With regard to standard deviation, the SPT rule produced the minimum value under all load levels. The analysis of variance revealed that there is significant difference in the value of standard deviation due to load and rules. The results of multiple range analysis test show that there is no significant difference in standard deviation value between SPT and TV/CPT rules. The same test also revealed that different load levels produced significantly different standard deviation.

4.4 Number of Tardy Jobs

The number of tardy jobs depends on how tight the due dates are. Tighter the due date larger will be the tardy jobs, looser the due dates smaller the tardy jobs. Hence the performance were investigated under two due date tightness level. The tightness of due date was controlled by the multiplier k. For moderate due dates k is assigned the value 5 and for tight due dates the value 3 according to past studies [7]. The results are presented in Table 4.

Table 4. Simulation output of number of tardy jobs under three load levels and two due date tightness.

Priority rule	Performance Measure											
	k = 5						k = 3					
	L1	R	L2	R	L3	R	L1	R	L2	R	L3	R
1. FIFO	1862	6	3129	6	4164	6	4399	6	5678	6	6326	6
2. SPT	336	1	575	1	750	1	1767	1	2291	1	2724	1
3. EDD	554	2	1328	3	1978	3	2977	4	4100	4	4682	4
4. TV/TRC	963	4	1521	4	2001	4	2803	3	3603	3	4152	3
5. CV/TRC	1779	5	2506	5	3118	5	3636	5	4498	5	5043	5
6. TV/CPT	636	3	960	2	1215	2	2133	2	2700	2	3203	2

Note L = load level; R = performance rank

The SPT rule was the best performer under all load levels and due date tightness. This result is in accordance with past studies [6,23,24,26]. The results of multiple range analysis test show that there is no significant difference in performance between SPT and TV/CPT rules. The same test also revealed that different load levels and different due date tightness produced significantly different number of tardy jobs.

The analysis of variance test showed that there is significant difference between NTJ values due to load level, due to rule, and due to due date tightness expected. It can be seen from the results of the simulation that tighter due dates resulted in larger number of tardy jobs.

4.5 Tardiness

Since tardiness is directly affected by tightness of due dates the model was simulated under two levels of tightness of due dates(k = 3 and k = 5). The results of simulation are presented in Table 5.

Table 5. Simulation output of mean and standard deviation of tardiness under three load levels and two due date tightness.

Priority rule	Performance Measure at k = 5											
	Mean						Standard Deviation					
	L1	R	L2	R	L3	R	L1	R	L2	R	L3	R
1. FIFO	1061	1	1531	1	2112	1	1061	1	1564	1	2164	1
2. SPT	1745	4	2515	4	2463	2	2430	3	3869	5	5967	5
3. EDD	1598	3	2229	2	3148	4	2547	4	2945	2	4270	2
4. TV/TRC	1994	5	3491	6	4624	6	2591	5	5070	6	7253	6
5. CV/TRC	1998	6	2714	5	3604	5	2675	6	3683	3	5467	3
6. TV/CPT	1564	2	2264	3	3027	3	2233	2	3698	4	5640	4
Priority rule	Performance Measure at k = 3											
	Mean						Standard Deviation					
	L1	R	L2	R	L3	R	L1	R	L2	R	L3	R
1. FIFO	1378	3	2118	3	2965	3	1161	1	1660	1	2660	1
2. SPT	1291	2	2002	2	2966	4	2585	5	3481	6	4686	5
3. EDD	1219	1	1938	1	2690	1	1725	3	2733	2	3714	2
4. TV/TRC	1574	5	2631	5	3142	5	2253	4	3193	4	4338	4
5. CV/TRC	1931	6	2647	6	3830	6	2853	6	3270	5	4815	6
6. TV/CPT	1466	4	2483	4	2866	2	1705	2	2782	3	4026	3

Note L = load level; R = performance rank

The following discussions apply to moderate due dates: the FIFO rule resulted in minimum mean tardiness as well minimum standard deviation of tardiness under all load levels. The analysis of variance test show that there is significant difference between mean tardiness values due to load level, due to rule, and due to due date tightness. The multiple range analysis test revealed that there is significant difference in the performance between the best performer FIFO and each of the remaining rules. The

same test also shows that different load levels produced significantly different mean tardiness.

The following discussions apply to tight due dates: The EDD rule dominates all other rules under all load levels. With regard to standard deviation FIFO rule resulted in the minimum value under all the three load levels. The performance difference between the EDD rule and each of the other rules is significant. The multiple range test revealed that difference in mean tardiness value due to due date tightness is significant at 95% confidence level.

5 Case Study

A case study was conducted in order to revalidate the results obtained from the hypothetical model. Central Maintenance Workshop in Benghazi caters the needs of the spare parts of most of the industries located in and around Benghazi. This workshop employs job production method and push system to manufacture different spare parts. This workshop was found to be more suitable to revalidate the results of the hypothetical model.

5.1 Description of the Push System

The actual job shop manufactures spare parts against orders. Orders for spare parts are received at random intervals. The technical department prepares the manufacturing drawings, estimates processing and setup times, determines the materials required, specifies the sequence of operations and due date. Then the job is released to the shop. In the shop floor the jobs are processed according to the sequence of operation using FIFO rule.

5.2 Input Data Analysis

The data required for the simulation model were collected from the past data. The interarrival time distributions and arrival rate of orders were determined from the past data. The data for the processing and setup times for different jobs on various machines were collected from the records. The sequence of operation for different types of spares were obtained. The cost of labor per hour, machining cost, overhead cost, and cost of materials were collected from cost accounting department.

The data collected with respect to interarrival time, setup and processing times were analyzed to determine whether the data fits any standard statistical distribution. Goodness of fit tests were used to test the distributional assumptions.

5.3 Simulation Results of the Case Study

A model similar to the one used in the hypothetical study was developed and it was run as per the experimental design discussed earlier. The same run length of 7500 jobs was used. All the performance criteria used in the hypothetical model were considered to evaluate the performance of the six priority rules. The simulation model was validated using t-test. The simulation output were analyzed using ANOVA and multiple range analysis test.

The results of the case study appears to be in accordance with the results of the hypothetical model.

6 Conclusions

The SPT rule resulted in minimum mean flow time, minimum mean WIPI in terms of number of jobs in the system, and minimum number of tardy jobs. The load level did not affect the performance of the SPT rule. Rules based on total value added TV/CPT and TV/TRC performed better than the other rules with respect to WIPI in monetary terms. The TV/CPT rule which resulted in minimum mean WIPI in monetary terms will be exactly equal to the SPT rule if the total value added to all the jobs are the same. FIFO rule produced the minimum value of standard deviation of tardiness. In most of the cases there was insignificant difference in performance between SPT and TV/CPT rules.

Further work can be done to explore the performance of composite rules developed by combining different rules. Another area where this type of work can be conducted is using different rules at different machines. In this study only the effect of two system parameters, the load level and the due date tightness were studied. As further work, the effect of varying the other parameters of the system such as delays, labor efficiency, reject and rework, machine breakdown, etc. may be studied.

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