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A STUDY OF DUE-DATE ASSIGNMENT RULES WITH CONSTRAINED TIGHTNESS IN A DYNAMIC JOB SHOP

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ABSTRACT

A manufacturing company may determine to set a specific due-date tightness level as its policy , after evaluating the expectations of the customers, the marketing strategies of the competitors and its own production capabilities. Then, an assignment rule may be selected to set the due-dates of its jobs, in conjunction with the job shop dispatching rule used and due-date tightness level desired, to minimize some performance measures. For these companies, understanding the characteristics of various due-date assignment rules with constrained tightness and selecting the rules most suitable for their situations are very important. Only very few studies have, among other things, compared the performance of various due-date assignment rules under constrained tightness. However, none of them have investigated those rules including shop status information. This may be due to the reason that the shop status of a job shop is highly dynamic and the due-date tightness of the rule that has included this information will be very difficult to control. The objective of this research is to provide a systematic study of the performance of various due-date assignment rules (including those with shop status information) with constrained tightness in a dynamic job shop.

KEYWORDS

Due-date assignment rule, dynamic job shop, scheduling, simulation, dispatching rule

INTRODUCTION

Before a job is released to the shop floor of a dynamic job shop for processing, its due-date needs to be assigned. Several methods have been used by earlier studies (Conway, 1965; Eilon and Hodgson, 1967; Weeks and Fryer, 1976; Eilon and Chowdhury, 1976; Weeks, 1979) to set the jobs' due-dates in job shops. Most of these due-date assignment rules consider some information about the characteristics of the job (e.g., total processing time, number of operations). However, due to the advances in information technologies (e.g., automated data collection, computer communications, distributed database), the current shop status information can be obtained almost instantaneously. Hence, more recent studies have considered the shop status information (e.g., number of jobs in the system when job i arrives, number of jobs in the work center queues on job i's routing when it arrives), in addition to job characteristics, in setting due-dates (Eilon and Chowdhury, 1976; Weeks, 1979; Miyazaki, 1981; Bertrand, 1983; Ragatz and Mabert, 1984; Vig and Dooley, 1993; Gee and Smith, 1993).

Most of these studies have claimed improved performance over those rules based on job characteristics only. However, the performance measures used by these studies are mainly related to the predictability of the rules (i.e., the closeness of the jobs' assigned due-dates to their actual completion dates). Although accurate prediction capabilities of the due-date assignment rules are highly desirable, forecast errors are unavoidable in a real dynamic job shop, where jobs of various types enter and leave the production system continually in a random manner. If the due-dates of the jobs are set on the basis of the predicted completion dates of a due-date assignment rule that gives unbiased flowtime forecast, without extra safety allowance, the proportion of tardy jobs may be unacceptably high (roughly 50%). Hence, instead of using the predicted completion dates, a manufacturing company may determine to set a specific due-date tightness level as its policy (e.g., average flow allowance of the jobs equals two weeks), after evaluating the expectations of the customers, the marketing strategies of the competitors and its own production capabilities. Then, an assignment rule may be selected to set the due-dates of its jobs, in conjunction with the job shop dispatching rule used and due-date tightness level desired, to minimize some performance measures (e.g., mean tardiness, proportion of jobs tardy). For these companies, understanding the characteristics of various due-date assignment rules with constrained tightness and selecting the rules most suitable for their situations are very important.

Only very few studies (Conway, 1965; Baker and Bertrand, 1981; Baker and Bertrand, 1982; Baker, 1984) have, among other things, compared the performance of various due-date assignment rules under constrained tightness. However, none of them have investigated those rules including shop status information. This may be due to the reason that the shop status of a job shop is highly dynamic and the due-date tightness of the rule that has included this information will be very difficult to control. The objective of this research is to provide a systematic study of the performance of various due-date assignment rules (including those with shop status information) with constrained tightness in a dynamic job shop.

RESEARCH METHODOLOGY

A computer simulation model, which represents a hypothetical dynamic job shop, is designed to provide the setting for this research. The simulation program is developed and validated first. Then, the performance of eight commonly studied due-date assignment rules (three of them including shop status information) are systematically evaluated with several popular job shop dispatching rules under various shop utilization rates and due-date tightness levels.

Due-date Assignment Rules

The due-date assignment rules selected for this study are as follows: Constant Flow (CON): $d_i = r_i + k$; Equal Slack (SLK): $d_i = r_i + P_i + k$; Number of Operations (NOP): $d_i = r_i + kN_i$; Processing Plus Waiting (PPW): $d_i = r_i + P_i + kN_i$; Total Work (TWK): $d_i = r_i + kP_i$; Jobs in System (JIS): $d_i = r_i + P_i + kJIS_i$; Jobs in Queue (JIQ): $d_i = r_i + P_i + kJIQ_i$; Work in Queue (WIQ): $d_i = r_i + P_i + kWIQ_i$; where r_i, P_i, N_i, d_i, JIS_i, JIQ_i, and WIQ_i denote the arrival time, the total processing time, the number of operations, the due-date, number of jobs in the system when the job arrives, number of jobs in the work center queues on the job's routing when it arrives, and total work in the work center queues on the job's routing when it arrives, of job i respectively; and the value of k is related to the level of due-date tightness desired.

Dispatching Rules

The job shop dispatching rules tested in this research are: (1) first-come first-serve (FCFS): select the job with the earliest arrival time at the work center; (2) shortest processing time (SPT): select the job with the shortest imminent processing time; (3) least slack time (LST): select the job with the least value of dynamic slack time; (4) earliest due date (EDD): select the job with the earliest due-date; (5) earliest operation due-date (ODD): select the job with the earliest operation due-date, which is set by the total work (TWK) operation due-date rule (Baker 1984); and (6) modified operation due-date (MOD): select the job with the earliest modified operation due-date, which is determined based on the original operation due-date or its early finish time, whichever is larger (Baker and Kanet 1983).

Simulation Model

The simulated job shop used in this study consists of 10 unique work centers. Jobs arrive continually with interarrival times generated from a negative exponential distribution, which has a mean value chosen to create a certain expected shop utilization rate. Each job has 2 to 8 operations (drawn from a uniform distribution with a mean of 5) with pure job shop routing (i.e., when a job leaves a work center, it is equally likely to go to each of the other work centers). Work center processing times are drawn from a negative exponential distribution with a mean of 10. The processing times and the job arrival times are rounded to the nearest integer. Other assumptions made in this system are: the resources are available continuously; pre-emption of a job is not allowed; set-up times are included in the processing times; transportation times are excluded; and processing times of the jobs are known after their arrivals at the shop.

Shop Utilization Rates

The expected shop utilization rate can be determined by: $\rho = \lambda\mu_p\mu_g/m$, where ρ is the expected shop utilization rate, λ is the mean job arrival rate (= 1/mean job arrival time), μ_p is the mean processing time per operation (= 10.0), μ_g is the mean number of operations per job (= 5), and m is the number of work centers in the shop (= 10). The expected shop utilization rates considered in this study are 0.9, 0.7 and 0.5 (that is, the mean values of job interarrival times are 5.56, 7.14, and 10.00 respectively).

Due-date Tightness

For each shop utilization rate, three different flow allowances (= d_i-r_i) are chosen to represent tight, moderate, and loose due-date tightness levels. The proportions of tardy jobs with respect to these three due-date tightness levels are 50%, 25% and 10% respectively, based on preliminary studies using FCFS dispatching rule and CON due-date assignment rule. The flow allowances are 400, 600, and 800 for 0.9 shop utilization rate; 150, 225, and 300 for 0.7 shop utilization rate; 90, 135, and 180 for 0.5 shop utilization rate.

In order to make fair comparisons among different due-date assignment rules, the average flow allowance assigned to the jobs should be tightly controlled such that it is close to the targeted due-date tightness level in every case. In this research, the first-order exponential smoothing technique is used to dynamically estimate the values of shop status and job characteristics.

Experimental Conditions

A three-factor full factorial design is utilized in this experiment to systematically study the performance of various due-date assignment rules with constrained tightness for each shop utilization rate. The first factor is the due-date assignment rules that has eight levels (CON, SLK, NOP, PPW, TWK, JIS, JIQ, WIQ); the second factor is the dispatching rule that has six levels (FCFS, SPT, LST, EDD, ODD, MOD); and the third factor is the targeted due-date tightness level that has three levels (400, 600, and 800 for 0.9 shop utilization rate; 150, 225, and 300 for 0.7 shop utilization rate; 90, 135, and 180 for 0.5 shop utilization rate).

On the basis of the system parameters described in the "Simulation Model" section, 5 job files are generated for each of those three shop utilization rates. Every job file has 5,000 jobs. Then, for each shop utilization rate, the same 5 job files are scheduled for each treatment(there are 144 (=8*6*3) treatments, each with a specific combination of due-date assignment rule, dispatching rule, and due-date tightness level). For each simulation run (there are 2160 (=5*3*144) runs), after the completion of the first 1,000 jobs, the related statistics of the next 3,000 jobs are recorded, and the performance measures of mean tardiness (MT), and proportion of jobs tardy (PT) are then calculated.

RESULTS

For the MT performance measure, due-date assignment rules CON, SLK, NOP, and JIS are dominated by the PPW rule with very few exceptions, while the JIQ and WIQ rules are always very close. However, the comparisons between PPW, TWK, and JIQ seem to indicate that no single due-date assignment rule is consistently better than the others. Among these three rules, the JIQ rule performs at or close to the best when the due-date tightness levels are tight or moderate and/or when the shop utilization rate is high; except when the SPT dispatching rule is utilized to sequence the jobs. Also, the performance of the TWK rule seems to be greatly affected by the dispatching rule used. Specifically, when the SPT dispatching rule is used, the TWK rule performs very well. Especially when the shop utilization rate is high (=0.9), the TWK rule out performs the other due-date rules by very significant margin. On the other hand, when the FCFS rule is used, the TWK rule always performs very poorly.

For the PT performance measure, due-date assignment rules CON, SLK, NOP, and JIS are dominated by the PPW rule again with very few exceptions, and the JIQ and WIQ rules are always very close. Similarly, the comparisons between PPW, TWK, and JIQ seem to indicate that no single due-date assignment rule is consistently better than the others. Among these three rules, the PPW rule performs the best when the shop utilization rate is low (=0.5), while the JIQ rule performs the best with few exceptions when the shop utilization rate is high (=0.9). Again, when the SPT dispatching rule is used under high shop utilization rate, the TWK due-date rule is clearly better than the other due-date rules.

CONCLUSIONS

The objective of this research is to provide a systematic study of the performance of various due-date assignment rules (including those with shop status information) with constrained tightness in a dynamic job shop. Among those eight due-date assignment rules studied in this research, CON, SLK, NOP, and JIS are dominated by the PPW rule almost in all cases, while the JIQ and WIQ rules are always very close, for both MT and PT performance measures. Further comparisons between PPW, TWK, and JIQ seem to indicate that no single due-date assignment rule is consistently better than the others. Also, the performance of a due-date assignment rule is highly dependent on the dispatching rule used to sequence the jobs; the due-date tightness level desired; and the utilization rate of the shop. Specifically, for shops with high levels of utilization rates, if the SPT dispatching rule is used, then TWK may be the best rule for due-date assignment; if other dispatching rules are used, then JIQ is the better choice. However, for shops with low levels of utilization rates, PPW is the best due-date rule for the PT performance measure; while JIQ is the best rule for the MT performance measure, when non-SPT dispatching rule is used and the due-date tightness levels are tight or moderate.

The findings of this study can help the production managers of the dynamic job shops, that set specific due-date tightness levels as their policies, to improve their due-date related performance. On the basis of their current shop utilization level and strategies for dispatching rule and due-date tightness level, they can select the due-date assignment rule that is the best for them. Then they can apply the technique described in this research to control their due-date tightness level better as well as to improve their due-date related performance measures. Moreover, if they want to conduct their own investigation on other due-date assignment rules and dispatching rules, they can follow the procedures similar to those described in this study.

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