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New Rescheduling Methodology with Frozen Interval

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Abstract

This research presents a new rescheduling methodology that creates both efficient and stable schedule. This methodology is motivated by the fact that making changes to a schedule near the current time should be discouraged because the closer to the current time that changes have been applied, the higher the probability that the cost of making a change increases and the less stability that the system has. Instead of scheduling all unprocessed jobs every time a new condition occurs, only those scheduled beyond a specified time in the future will be rescheduled; and the new arrivals, if any, will be scheduled. The remaining jobs are untouched and are referred to as lying within the "frozen interval". The objective of this research is to study the effect of this frozen interval on the schedule performance under various environments. A genetic local search scheduler is employed to obtain a good schedule. The results indicate that using frozen interval in rescheduling provides a better and more robust schedule.

Keywords: genetic local search algorithm, frozen interval, job shop problem

1 Introduction

This research is centered on the problem of dynamic job shop scheduling when orders arrive continuously. In such environments, it is desirable to create a new schedule periodically to improve production effectiveness; however, the dynamic nature of real-world manufacturing makes the rescheduling problem in practice more complicated than theoretical approaches address. Any schedule released to the shop is immediately subject to new conditions, demands, and constraints [1]. In a sense, the schedule becomes obsolete as soon as it is created. The underlying problem is that the scheduling problem is NP-hard, but companies must create and follow schedules every day to stay in business. Hence, finding an optimal solution is impossible except for small problems or problems with special structure. This issue is significant in practice and has typically been addressed by developing algorithms that find a "good" schedule quickly.

All research on dynamic scheduling includes a myriad of assumptions and uses a number of different measures. Cost is a well understood concept everywhere and frequently found as the objective. Other research focuses on schedule efficiency. Stability, defined as the degree of deviation between the new schedule and the original schedule, however, is not often found in the literature nor does it often appear to be considered an integral measure in research. This is unfortunate because stability is incredibly important to all schedulers in industry and, in many cases, the premier constraint associated with any attempt to reschedule a shop. In this paper, cost, efficiency, and stability will be simultaneously considered because all three are important to real dynamic scheduling problems.

This basic idea behind this research is predicated on two common sense ideas related to stability: 1) stability on the shop floor is increased if jobs scheduled near the current time are not modified, and 2) repositioning jobs scheduled further in the future would have much less, if any, effect on stability. These observations were explained by Lin and Krajewski [2] and Lin et al. [3] when they suggested that changing a schedule close to the current time should be discouraged because changes made closer to the current time increase the probability that cost will be increased and the stability of the system will decrease. This research includes stability with efficiency because both are important in practice; hence, a new scheduling methodology is developed.

The new methodology partitions the current schedule into two parts. Some numbers of jobs near the current time are fixed and rescheduling is prohibited at all time in the future. This time period is defined as the "frozen interval". Jobs outside this interval are eligible for rescheduling at a future time. The length of the frozen interval is quite important. As its length is increased, more jobs are prohibited for being rescheduled and the stability is increased; however, measures of efficiency are decreased. On the other hand, a short frozen interval improves efficiency but degrades stability.

The main objectives of this research are to develop a methodology that addresses both stability and efficiency and to study the effect of system parameters on the schedule performance within various environments. These environments will involve different utilization levels and properties of the jobs like due-dates. Schedule performance is assessed with respect to both efficiency and stability with efficiency measured by makespan and tardiness and stability measured by a linear combination of the deviation between the original and revised job starting times and a penalty function associated with total deviation from the current time introduced.

2 Proposed Scheduling Methodology

The proposed methodology is based on periodic rescheduling in which a new schedule is constructed at predetermined times. Each time a new schedule is created, it consists of jobs that were previously scheduled and those that have arrived since the previous schedule was constructed. This methodology selects some of the previously scheduled jobs that were not processed and forces their starting times to remain as they were in the previous schedule to improve stability. The remaining jobs from the previous schedule that were not processed are marked as available for rescheduling to improve efficiency so their starting times in the new schedule might be different from the previous schedule if it is advantageous to do so. Finally, the newly arrived jobs must also be scheduled at the rescheduling point. Two performance attributes are used as the objective when a schedule is created: efficiency and stability.

This methodology uses two important intervals: the scheduling interval and the frozen interval (see figure 1). The scheduling interval is the time interval between two successive schedules and determines how often a new shop-floor schedule is generated. A point in time when a new schedule is generated is called a rescheduling point. All unprocessed jobs from the previous schedule plus jobs that have arrived since the previous schedule was constructed are scheduled. The frozen interval is the time interval that includes the start times of jobs that cannot be rescheduled [1]. On an intuitive level, it is clear that the scheduling interval length and the frozen interval length affect the efficiency and stability of the system. Figure 1 suggests stability is improved by making the frozen interval length longer than scheduling interval length because some numbers of jobs near the current time are fixed and rescheduling is prohibited at all time in the future. On the other hand, increased efficiency will result from a frozen interval length as small as possible.

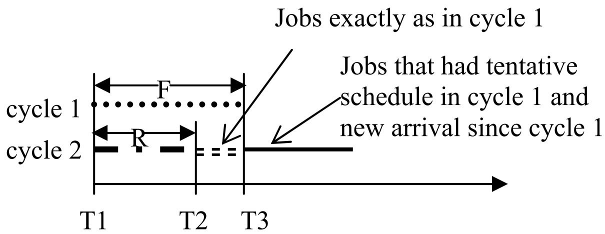

Figure 1: Frozen interval and scheduling interval

To quantify these relationships, the environmental factors like utilization and tightness of due-date are considered. Utilization is defined as the ratio of the average arrival rate to the average service rate and determines the congestion of the system. High utilization level will, on average, introduce more jobs into the system than can be processed; therefore, there will routinely be jobs left unprocessed outside the frozen interval. Tightness of due-date indicates the urgency of a job to be processed and can also have a dramatic impact. For example, jobs with closer due-dates are more urgent and likely to be inserted in the middle of the schedule instead of at the end resulting in lower stability even though the efficiency may be increased.

3 Scheduling Model

A schedule is generated using the scheduling heuristic that addresses both efficiency and stability simultaneously as suggested by Masuchun and Ferrell [4]. Since the environment in which scheduling actually takes place contains a large degree of uncertainty, questions regarding the proposed methodology to study the significance of the frozen interval are framed in the form of hypothesis tests. To answer these questions, a simulation approach as suggested by Masuchun and Ferrell [4] is employed that replicates this environment over a finite set of conditions.

4 Proposed Scheduling Methodology

To study the impact of the scheduling interval length and the frozen interval length on the schedule performance (efficiency and stability) under various utilization levels and tightness of due-dates, fifteen hypotheses tests are constructed. The details of all fifteen hypotheses tests are given in table 1.

5 Experiment Design

To test the hypotheses, a full factorial design has been selected with each factor at three levels as indicated in table 2.

Hence, 81 experiments are conducted with each replicated 10 times for a total of 810 simulation runs.

Table 1: Test hypotheses #1 - # 15

Test	Statistical Hypotheses	
#1	H_0: sch = 0;	H_a: sch ≠ 0
#2	H_0: ratio = 0;	H_a: ratio ≠ 0
#3	H_0: sch*ratio = 0;	H_a: sch*ratio ≠ 0
#4	H_0: util = 0;	H_a: util ≠ 0
#5	H_0: dd = 0;	H_a: dd ≠ 0
#6	H_0: util*dd = 0;	H_a: util*dd ≠ 0
#7	H_0: sch*util = 0;	H_a: sch*util ≠ 0
#8	H_0: sch*dd = 0;	H_a: sch*dd ≠ 0
#9	H_0: ratio*util = 0;	H_a: ratio*util ≠ 0
#10	H_0: ratio*dd = 0;	H_a: ratio*dd ≠ 0
#11	H_0: sch*ratio*util = 0;	H_a: sch*ratio*util ≠ 0
#12	H_0: sch*ratio*dd = 0;	H_a: sch*ratio*dd ≠ 0
#13	H_0: sch*util*dd = 0;	H_a: sch*util*dd ≠ 0
#14	H_0: ratio*util*dd = 0;	H_a: ratio*util*dd ≠ 0
#15	H_0: sch*ratio*util*dd = 0;	H_a: sch*ratio*util*dd ≠ 0

* sch = scheduling interval length
ratio = ratio of the scheduling interval length to the frozen interval length
util = utilization
dd = tightness of due-date

Table2: Experimental Design Factors

Factor	Levels
Scheduling interval length	60, 100, 300
Ratio of frozen interval length to scheduling interval length	1:1, 2:1, 3:1
Utilization	70%, 80%, 90%
Tightness of due date	6, 10, 14

6 Data Analysis

The Analysis of Variance (ANOVA) is conducted for all parameters and interactions to determine the significant treatment effects. The model to be fit is shown as follows.

$$\begin{aligned} Y_{ijkl} &= \mu + sch_i + ratio_j + util_k + dd_l \\ &+ sch_i * ratio_j + sch_i * util_k + sch_i * dd_l \\ &+ ratio_j * util_k + ratio_j * dd_l + util_k * dd_l \\ &+ sch_i * ratio_j * util_k + sch_i * ratio_j * dd_l \\ &+ sch_i * util_k * dd_l + ratio_j * util_k * dd_l \\ &+ sch_i * ratio_j * util_k * dd_l \end{aligned}$$

7 Results

The general observation of the average results from ten simulation runs is performed first. The results are further investigated to determine robustness of each combination. Sets of hypotheses are then constructed followed by an Analysis of Variance (ANOVA) to test the hypotheses. To further analyze the outcome of the ANOVA results, the Student-Newman-Keuls (SNK) test is performed to simultaneously investigate all combinations of these four parameters. Schedules were determined using an algorithm based on genetic algorithms. Since genetic algorithms require the fitness function to be maximized, the well known conversion, Min z = Max –z, was utilized. As such, numerical results reported in this section should be interpreted as the more negative a value, the better.

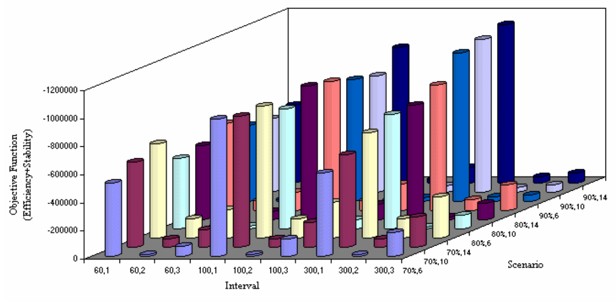

Figure 1: Means from 10 simulation replications

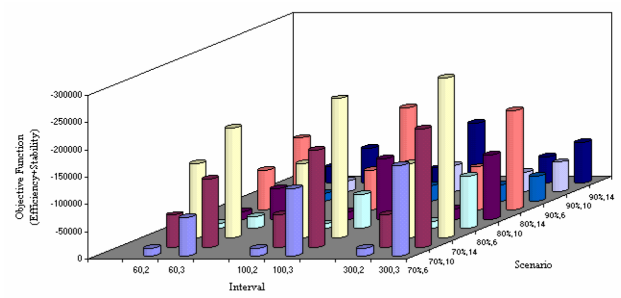

Figure 2: Means from 10 simulation replications (ratio is either 2 or 3)

From figure 1, combinations with Intervals (60,1), (100, 1), and (300, 1), which implies a periodic rescheduling strategy, perform poorly compared to the others with higher ratios (i.e., Intervals (60, 2), (100, 2), (300, 2), (60, 3), (100, 3), and (300, 3)). To investigate the results more closely, the combinations with the ratio of 1 (i.e., Intervals (60,1), (100, 1), and (300, 1)) are eliminated. The remaining combinations are displayed in figure 2. This figure shows that, on average, the combinations with Intervals (60, 2), (100, 2), and (300, 2) generate better schedule than those with Intervals (60, 3), (100, 3), and (300, 3). However, any real conclusion from this general observation cannot be made without further statistical analysis.

7.1 Results

In general, excellent overall performance may be defined as good performance by considering a number of key measures in a number of different environments. Therefore, knowing which Intervals are robust may be more valuable than knowing which Interval is best in each particular situation. To determine robustness, a Scenario that has the best average performance score is identified as well as all those are within 10% of the best and 20% of the best. The results are given in table 3. The pair of number in the first column labeled Interval represents the length of scheduling interval followed by the ratio of frozen interval length to scheduling interval length.

The results show that the best performance (highlighted cell in table 3) is always with the ratio of 2 (Intervals (60, 2) and (100, 2)) meaning that schedule is robust when using the ratio of 2 in the with the scheduling interval lengths of 60 and 100.

Table 3: Interval robustness

Interval	Scenario								
	70%, 6	80%, 6	90%, 6	70%, 10	80%, 10	90%, 10	70%, 14	80%, 14	90%, 14
60,1									
60,2	***	**	**	***	**	**	***	**	**
60,3	**	**	**	**	**	**	**	**	**
100,1									
100,2	**	***	***	**	***	***	**	***	***
100,3	**	**	**	*	**	**	*	*	**
300,1									
300,2	**	**	**	**	**	**	**	**	**
300,3	*	**	**	*	**	**	*	**	**

* = within 20% of the best, ** = within 10% of the best, *** = the best

7.2 Analysis of Variance (ANOVA)

A full factorial experiment with 10 replications in each cell is used to study the effect of frozen interval and scheduling interval on the schedule performance under various environments. The resulting data is analyzed using the Generalized Linear Models procedure of SAS (Version 8). The experimental conclusions related to all statistical hypotheses posed in table 1 are shown in table 4. This table identifies each null hypothesis, the corresponding F value, and its p-value. In this study, the null hypothesis is rejected in favor of the alternative if the p-value is less than 0.05. From table 4, one hypothesis, hypothesis 8, has the p-values greater than 0.05; therefore, all factors except this one are considered significant. The further analysis of how these factors affect the schedule performance will be examined at the highest-level interaction that is considered important. From table 4, the highest-level interaction that is considered important is the four-way interaction. Therefore, the focus will be on the four-way interaction.

7.3 SNK Test

Using the SNK test on the means, each combination is compared to determine if there are any settings that are significantly different at a specified level of significance. Assuming $\alpha = 0.05$, the results from SNK tests show that all combinations with the ratio of 1, Intervals (60, 1), (100, 1), and (300, 1), are at the bottom of the table and none of these combinations shares the same SNK grouping letter as any one of other combinations with the higher ratios (2 and 3), Intervals (60, 2), (100, 2), (300, 2), (60, 3), (100, 3), and (300, 3). This means that using a frozen interval length that is equal to the scheduling interval length generates the worst schedule because all unprocessed jobs previously scheduled near the current time are rescheduled. This degrades the stability. The performance of schedule will be significantly and positively improved if the ratio is higher; therefore, from this point, the attention is turned to the interpretation of those combinations with Intervals (60, 2), (100, 2), (300, 2), (60, 3), (100, 3), and (300, 3).

Table 4: ANOVA Results

Hypothesis	F Value	p-value
Test 1: H_0: sch = 0	1059.72	<.0001
Test 2: H_0: ratio = 0	32435.9	<.0001
Test 3: H_0: sch*ratio = 0	679.69	<.0001
Test 4: H_0: util = 0	45.26	<.0001
Test 5: H_0: dd = 0	339.59	<.0001
Test 6: H_0: util*dd = 0	19.51	<.0001
Test 7: H_0: sch*util = 0	124.14	<.0001
Test 8: H_0: sch*dd = 0	0.78	0.5378
Test 9: H_0: ratio*util = 0	222.8	<.0001
Test 10: H_0: ratio*dd = 0	3.52	0.0074
Test 11: H_0: sch*ratio*util = 0	157.07	<.0001
Test 12: H_0: sch*ratio*dd = 0	3.52	0.0005
Test 13: H_0: sch*util*dd = 0	4.21	<.0001
Test 14: H_0: ratio*util*dd = 0	7.61	<.0001
Test 15: H_0: sch*ratio*util*dd = 0	5.39	<.0001

Define C [(sch, ratio), (util, dd)] as a combination that has the Interval (sch, ratio) and Scenario (util, dd), and $R_{2,3}$ {sch, (util, dd)} as a pair of combinations that have the ratios of 2 and 3 with similar scheduling interval length sch and Scenario (util, dd). For example, C [(60, 1), (90%, 10)] is a combination that has Interval (60, 1) and Scenario (90%, 10); and, $R_{2,3}$ {60, (80%, 6)} is the set consisting of {[(60, 2), (80%, 6)], [(60, 3), (80%, 6)]}. When considering each $R_{2,3}$ {sch, (util, dd)}, it is always true for every group tested that either the combinations with the ratio of 2 and 3 belong to the same group or the combination with the ratio of 2 belong to a better group (higher row in the table). For example, considering $R_{2,3}$ {60, (80%, 6)}, C [(60, 2), (80%, 6)] (third combination) appears before C [(60, 3), (80%, 6)] (sixteenth combination); however, they are not significantly different because they have the same SNK grouping letter of A. Another example that each individual in a set does not belong to the same group is $R_{2,3}$ {100, (70%, 10)}. That is, C [(100, 2), (70%, 10)] (twenty-eighth combination) appears before C [(100, 3), (70%, 10)] (forty-eighth combination); and, they belong to different groups. C [(100, 2), (70%, 10)] belongs to group A, B, C, D, E, or F while C [(100, 3), (70%, 10)] belongs to group I, J, K, or L.

Tables 5 and 6 summarize every $R_{2,3}$ {sch, (util, dd)} that its members belong to the same group and different group, respectively. Each row will be highlighted only if all the rest of the combinations with the similar Scenario (util, dd) also exist in the same table. For example, from table 5, all combinations with Scenario (90%, 6) (first row from the top through the third) are in this table meaning that at each level of scheduling interval length with the utilization of 90% and the tightness of due date of 6, the schedule performance is not significantly different when using the different ratio (2 or 3). Moreover, the results show that, with this scenario, the scheduling interval length does not significantly impact the performance because all combinations have the same SNK Grouping letter of A. The similar results are also true when the Scenario is (90%, 10) (fourth row from the top through the sixth). That is, with the utilization of 90% and the tightness of due date of 10 (SNK Grouping letter of A or B), not only is the performance not significantly different when using different ratio (2 or 3), it is also not significantly different when using different scheduling interval length because schedule would be very busy and no many slots that long enough to insert any jobs within it. Therefore, using different scheduling interval lengths or different ratios would not provide significantly different performance.

Table 5: $R_{2,3}$ {sch, (util, dd)} similar SNK grouping letter

$R_{2,3}$ {sch, (util, dd)}	SNK Grouping
$R_{2,3}$ {60, (90%, 6)}	A, B
$R_{2,3}$ {100, (90%, 6)}	A
$R_{2,3}$ {300, (90%, 6)}	A, B, C
$R_{2,3}$ {60, (90%, 10)}	A, B
$R_{2,3}$ {100, (90%, 10)}	A, B
$R_{2,3}$ {300, (90%, 10)}	A, B, C
$R_{2,3}$ {60, (70%, 6)}	A, B
$R_{2,3}$ {60, (80%, 6)}	A
$R_{2,3}$ {100, (80%, 6)}	A
$R_{2,3}$ {60, (80%, 10)}	A, B
$R_{2,3}$ {60, (90%, 14)}	A, B, C
$R_{2,3}$ {300, (90%, 14)}	B, C

Table 6: $R_{2,3}$ {sch, (util, dd)}: different SNK grouping letter

$R_{2,3}$ {sch, (util, dd)}	SNK Grouping When Ratio = 2	SNK Grouping When Ratio = 3
$R_{2,3}$ {60, (70%, 10)}	A, B, C, D, E	F, G, H
$R_{2,3}$ {100, (70%, 10)}	A, B, C, D, E	I, J, K, L
$R_{2,3}$ {300, (70%, 10)}	A, B, C, D, E	L
$R_{2,3}$ {60, (80%, 14)}	B, C, D, E, F	G, H, I
$R_{2,3}$ {100, (80%, 14)}	B, C, D, E, F	K, L
$R_{2,3}$ {300, (80%, 14)}	C, D, E, F	J, K, L
$R_{2,3}$ {60, (70%, 14)}	G, H, I, J	K, L
$R_{2,3}$ {100, (70%, 14)}	G, H, I, J	M
$R_{2,3}$ {300, (70%, 14)}	G, H, I, J	N
$R_{2,3}$ {300, (80%, 6)}	A, B	D, E, F, G
$R_{2,3}$ {100, (80%, 10)}	A, B	E, F, G
$R_{2,3}$ {100, (70%, 6)}	A, B	F, G, H
$R_{2,3}$ {300, (70%, 6)}	A, B	H, I, J, K
$R_{2,3}$ {300, (80%, 10)}	A, B, C	F, G, H
$R_{2,3}$ {100, (90%, 14)}	A, B, C	E, F, G

From table 6, all combinations with Scenario (70%, 10) (first row from the top through the third) are in this table meaning that at any levels of scheduling interval length with the utilization of 70% and the tightness of due date of 10, using the ratio of 2 generates significantly better schedule performance than using the ratio 3. The results also show that the scheduling interval length significantly impact the schedule performance because all combinations do not have the same SNK Grouping letter. The similar results are also true when the Scenarios are (80%, 14) (fourth row from the top through the sixth) and (70%, 14) (seventh row from the top through the ninth). That is, with the utilization of 70% or 80% and the tightness of due date of 14, using the ratio of 2 generates significantly better performance than using the ratio 3. Moreover, the performance is significantly different when using different scheduling interval length because all combinations do not have the similar SNK Grouping letter.

Notice from both tables 5 and 6 that all combinations with utilization of 90% except one pair, which is $R_{2,3}$ {100, (90%, 14)}, are in table 5 whereas all combinations with utilization of 70% except one pair, which is $R_{2,3}$ {60, (70%, 6)}, are in table 6. That is, at high utilization of 90%, the ratio of frozen interval length to scheduling interval length does not significantly impact the performance while, at low utilization of 70%, it is preferable to use the ratio of 2 instead of 3. This is because at low utilization of 70%, the schedule may have a slot available between each job. This slot may be long enough so that some new jobs can be inserted and scheduled within it in order to improve the efficiency with little disturbing the current schedule. Therefore, when the utilization is low, using the ratio of 2 would be preferable because it increases the chance to insert jobs into the available slots than using the ratio of 3. On the contrary, at high utilization level of 90%, schedule would be very busy and no many slots that long enough to insert any jobs within it. To generate a new schedule means to disturb the current schedule that leads to poor stability; therefore, the new schedule may not be much different from the current schedule or it may not give significant advantage. Hence, when utilization is high, using ratio of 2 or 3 would not produce much significant difference.

8 Conclusion

This paper presents a new rescheduling method to obtain a schedule that is both efficient and stable. "Frozen interval" has been introduced to freeze some jobs from being rescheduled. The objective of this interval is to increase the number of jobs whose schedule will not change while decreasing the number of jobs that their schedules can be altered. Results from simulation and statistical analysis prove that using frozen interval in scheduling problem can significantly improve the performance of the schedule. From the experiment, using the frozen interval length equal 2 times the scheduling interval length can produce the robust schedule with a set of scheduling interval lengths investigated. In conclusion, using frozen interval can produce more stable, efficiency, and robust schedule.

9 References

[1] Li, Y.C.E., Shaw, W.H., Jr., and Martin-Vega, L.A., Flow-time performance of modified scheduling heuristics in a dynamic scheduling environment, *Computers & Industrial Engineering*, Vol 3, No 1-2, pp 213-216 (1996).

[2] Lin, N.P. and Krajewski, L., Scheduling in uncertain environments, *Decision Sciences*, Vol 23, pp 839-861 (1992).

[3] Lin, N.P., L. Krajewski, G.K. Leong, and W.C. Benton, The effects of environmental factors on the design of master production scheduling systems, *Journal of Operations Management*, Vol 11, pp 367-384 (1994).

[4] Masuchun, R. and Ferrell, W.G., "Dynamic rescheduling with stability", *The Proceedings of the 5th Asian Control Conference, Melbourne 20 - 23 July 2004*, pp 1886-1894 (2004).