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STUDY OF STOCHASTIC JOB SHOP DYNAMIC SCHEDULING

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Abstract:

The stochastic job shop static and dynamic scheduling has been analyzed in this paper. Based on the probability theory, an algorithm is developed to estimate the amount of scheduling-scheme. It has been pointed out that the actual amount of the scheme for process time based job shop scheduling is far less than the theoretical ones. The objective-functions of stochastic job shop scheduling have been analyzed and a multi-objective function has been developed. Considered the characteristics of stochastic and variable processing time, some scheduling rules and dynamic scheduling policies with variable criterions are proposed, which can more efficiently optimize the stochastic job shop scheduling effect than the traditional ones.

Keywords:

Job Shop; Dynamic scheduling; Schedule rules; Variable criterions

1. Introduction

Stochastic job shop scheduling is that there are *N* jobs waiting to be processed and their working- procedures in the job shop are different, and that their process times are fluctuant stochastically. Stochastic job shop scheduling can be partitioned into two types, the static scheduling and dynamic scheduling. Static scheduling is that all jobs to be processed in the plan period have already arrived and their processing sequence can be decided at the beginning of the plan period. There are two circumstances for the Stochastic job shop dynamic scheduling: (1). Jobs arrive stochastically and are instantly scheduled as they arrive; (2). The job's process time fluctuates stochastically at each machine, so the process sequences of jobs on each machine can not be predefined. Even if the sequence has been predefined, it would become invalidation due to the change of the job's actual process time. Most of the scheduling problems for job shop are the stochastic scheduling ones in real production system.

2. Review of the Scheduling Research

Stochastic job shop scheduling is a NP-complete problem. The heuristic method is the primary one in traditional scheduling. Priority rules and their application in job shop scheduling problem have been yet widely researched by the scholars in the world. In the past decades, the scheduling research has achieved a great progress. The research has developed from single objective scheduling to multi-objective scheduling [1,2], from static and decided scheduling to dynamic and stochastic scheduling [3-5], frome single phase and single method scheduling to muliti-phase and synthetical method scheduling. Monfared(2005)has proposed a four-stage method to deal with the scheduling problem for a complicated production system. From a low stage to a high one, the method can improve the scheduling effect and deal with the complicated, stochastic and real time scheduling. Shnits(2004) has developed a two- stage scheduling system. In the first stage, the system decides the scheduling criterion and the priority rule to get the initial scheduling scheme. In the second stage, the system uses a simulation method to compare and validate the scheduling scheme, to get the optimization scheduling scheme. Multi-Agent theory is one of the research focuses on production scheduling and control. Iwamura(2005) and Cowling(2004) have developed a scheduling and control model for the complicated production system based on Multi-Agent theory. In their model, each of the agent has itself scheduling rule and objective. According to the production condition and some agreements among the agents, the system does the real time scheduling and control and realizes the holistic objective. Conventional researches on production scheduling and control are almost job oriented. Hans-Peter(1999) has investigated the problem for a long time and collected a great deal of data. Based on the statistics and analyses, he has developed a load oriented production scheduling and control model.

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3. Analysis of Stochastic Job Shop Scheduling

Scheduling is to sequence the jobs waiting to be processed according to some objectives and criterions. The job's process sequences in manufacture system affect directly the productivity, machine utilization, work-in-process, rate of delivery on time, etc. Jobs reaching stochastically the discrete manufacturing system are generally as follows:

(1)Different jobs arrive solely. The reaching time is stochastic and submits to a Poisson distributing.

(2) Some different jobs arrive synchronously. The reaching time is stochastic and submits to the Poisson distributing.

Scheduling conditions：

(1) Just one job can be processed at the same time for machine M_j; (j=1,2⋯,m);

(2) Just one machine can processe the job j_i at the same time; j_i (i=1,2…,n).

3.1. Stochastic Job Shop static Scheduling

There are two reaching manner and the method of static scheduling as follows:

(1)Deferent jobs stochastically arrive alone. One can schedule the new reached jobs by a certain interval (such as hour/day/week). The new reaching job doesn't change the sequence of former jobs.

(2) Several deferent jobs arrive synchronously and stochastically. One can schedule the new reaching jobs as they arrive. The new reaching jobs don't change the sequence of former jobs.

The static scheduling method is simple, but the adaptability is poor as the production condition changes, such as urgent jobs inserting, client altering their order and equipment malfunctioning etc. the actual result is often different from the scheme.

3.2. Stochastic Job Shop dynamic Scheduling

(1) As a new job arrives, one decides afresh all the jobs sequence according to certain priority rules. This method will make the sequence of former jobs in the system changed and the jobs complete time is uncertain.

(2) As jobs process time at the machine fluctuates stochastically, the jobs complete time is uncertain and the time of jobs reaching each machine can't be predefined. In this condition real time scheduling for each machine is needed. Viz. as the machine has finished a job, one chooses immediately next one of the jobs to process according to certain priority rules.

Although it is difficult to predict the jobs complete time for the dynamic scheduling, the scheme may be expediently adjusted as the production condition changes. So the adaptability of the dynamic scheduling is better。

4. Study of the number of sequences for Stochastic Job Shop Scheduling

4.1. Analyses of the number of sequences for Stochastic Job Shop Static Scheduling

By traditional theory analyses，the possible number of sequences for job shop scheduling is equal to $(\boldsymbol{n}!)^{\boldsymbol{m}}$ (n = number of the jobs； m = number of the machines). As the n and m is biggish，the number of sequences is too many for one to find the optimal **one**, even use a computer to do that. Fortunately the actual possible number of sequences is far less than the academic one. This can be proved by the following analyses.

Supposing the numbers of the machines in the manufacture system is *m,* and the number of jobs waiting to be processed at the machine M_j at the same time is n, the possible number of sequences for these jobs at the machine M_j is equal to n**!**. Because each job has different working-procedures，the event that n jobs waiting for machine M_j to be processed at the same time occur with certain probability. The number of sequences of n jobs for machine M_j and the entire manufacturing system are analyzed as follows:

The probability of job j_i waiting for machine M_j to be processed at a certain time is:

$$P_j(J_{i,j}) = t_{i,j}/T_i \tag{1}$$

The probability that R jobs waiting for machine M_j to be processed at a certain time is:

$$P_j(R) = \prod_{i=1}^{R}(t_{i,j}/T_i) \tag{2}$$

The number of sequences for R jobs waiting for machine M_j to be processed is equal to R! (R=1,2 …,n);

The expectation of the number of sequences for n jobs waiting for machine M_j to be processed is as follows:

$$E_j(n,m_j)=\sum_{R=1}^{n}C_n^R R!\prod_{i=1}^{R}\left(\frac{t_{i,j}}{T_i}\right)$$
$$=\sum_{R=1}^{n}\frac{n!}{R!(n-R)!}R!\prod_{i=1}^{R}\left(\frac{t_{i,j}}{T_i}\right) \quad (3)$$
$$=\sum_{R=1}^{n}\frac{n!}{(n-R)!}\prod_{i=1}^{R}\left(\frac{t_{i,j}}{T_i}\right)$$

$t_{i,j}$ = the process time for job J_i at machine M_j;

T_i= the total process time for job J_i in the manufacturing system;

In order to predigest the analysis, supposing the process time for the jobs in different machines is approximately equal, viz. $t_{i,j}/T_i \approx 1/m$, the expectation of the number of sequences for n jobs waiting for machine M_j to be processed can be predigested as follows:

$$E_j(n,m_j)\approx\sum_{R=1}^{n}\frac{n!}{(n-R)!}(1/m)^R \quad (4)$$

The expectation of the number of sequences for static scheduling and n jobs and m machines is as follows:

$$E_T(n,m)\approx\left[\sum_{R=1}^{n}\frac{n!}{(n-R)!}\left(1/m\right)^R\right]^m \quad (5)$$

For example, let n=8, m=6, the expectation of the number of sequences at machine M_j can be got:

$$E_j(n,m)\approx\sum_{R=1}^{8}\frac{8!}{(8-R)!}(1/6)^R = 7.2$$

The expectation of the number of sequences for the manufacturing system can be got:

$$E_T(n,m) \approx (7.2)^6 = 1.4\times10^5$$

The number of sequences got by tradition analysis method is as follows:

$$(n!)^m = (8!)^6 = 4.3\times10^{27}$$

It is obvious that actual number of sequences is far less than the one got by tradition analysis method.

4.2. Study of the number of sequences for Job Shop Dynamic Scheduling

The stochastic job shop scheduling is that jobs reach stochastically and discretely each machine of the manufacturing system. For predigesting, supposing the jobs' arriving submits to Poisson distributing and regarding the manufacturing system as the queue system $M/M/1/\infty$, the expectation of job numbers waiting in the system is:

$$\bar{n}=E(n)=\frac{\lambda}{\mu-\lambda} \quad (6)$$

λ = the mean of jobs reached in per unit time;

μ = the mean of completed jobs in per unit time.

We use the similar analysis method in 3.1. The probability of R jobs among the $\bar{n}$ jobs waiting for machine M_j to be processed in the same time is:

$$P_j(R)=C_{\bar{n}}^R\left(t_{i,j}/T_i\right)^R \quad (7)$$

The expectation of the number of sequences at the machine M_j can be expressed as follows:

$$E_j=\sum_{R=1}^{\bar{n}}\frac{\bar{n}!}{(\bar{n}-R)!}\left(t_{i,j}/T_i\right)^R \quad (8)$$

Suppose the number of machines in the manufacturing is m, the expectation of the number of sequences for $\bar{n}$ jobs and m machines can be expressed as follows:

$$E_T=\prod_{j=1}^{m}\sum_{R=1}^{\bar{n}}\frac{\bar{n}!}{(\bar{n}-R)!}\left(t_{i,j}/T_j\right)^R \quad (9)$$

Suppose the process time of the jobs in each machine is approximately equal, viz. $t_{i,j}/T_i \approx 1/m$, the E_T can be expressed as follows:

$$E_T\approx\left[\sum_{R=1}^{\bar{n}}\frac{\bar{n}!}{(\bar{n}-R)!}\left(1/m\right)^R\right]^m \quad (10)$$

For example, let λ=0.7, u=0.6, m = 6; the mean of jobs waiting in the system can be got as follows:

$$\bar{n}=\frac{\lambda}{u-\lambda}=\frac{0.6}{0.7-0.6}=6$$

The expectation of the number of sequences is as follows:

$$E_T\approx\left[\sum_{R=1}^{6}\frac{6!}{(6-R)!}\left(\frac{1}{6}\right)^R\right]^6\approx 456$$

By the traditional analysis method, the number of sequences is as follows:

$$(\bar{n}!)^m=(6!)^6=1.4\times10^{17}$$

It is obvious that whether static or dynamic scheduling, the actual number of sequences is far less than the academic one $(\bar{n}!)^m$.

5. Studies of Objective and Strategy for Stochastic Job Shop Scheduling

5.1. Objective function of Stochastic Job Shop Scheduling

For the multi-variety and small batch production system, it is important to satisfy the various demands of consumers, improve on the productivity and reduce the cost synchronously. In order to compare the different scheme decided by the multi-criteria method, we convert different criteria into expense criteria. Suppose the scheduling criteria includes: f_d = defer delivery expense, f_z = work-in-process holding cost, $f_\triangle$=the machines stoppage expense, the objective-function of synthesis multi-criteria scheduling can be expressed as follows:

$$F_\alpha = f_d + f_z + f_\Delta = \sum_{i=1}^{n} \alpha_i D_i + \sum_{i=1}^{n} \beta_i F_i + \sum_{j=1}^{m} \delta_j T_{\Delta j} \quad (11)$$

α_i = the expense of per unit lateness time for job J_i

D_i = the lateness time of job J_i;

$=max\{0, F_i - d_i\}$;

β_i =the holding cost of per unit time for job J_i;

F_i = the flow time of job J_i (from begin waiting to be finished);

δ_i = the expense of per unit time stoppage for machine M_j;

$T_{\Delta j}$ = stoppage time of machine M_j.

$T_{\Delta j} = max\{F_{i,j}\} - \sum_{i=1}^{n} t_{i,j}$.

5.2. Analysis of Stochastic job shop dynamic scheduling

There are many priority rules/criteria that can be used to schedule for the job shop. These rules/criteria can be divided into three types: (1) the process time based rules: such as shortest process time rule (SPT), shortest remain process time rule(SRPT), longest process time rule(LPT) and so on; (2) the due-date based rules: such as earliest due-date rule(EDD), critical ratio rule(CR), shortest laxity time/(remain) operation rule(SL/OP); (3) other common rules: such as first-come-first-serve rule (FCFS). With different scheduling rules/criteria, one can get the different scheme and effect. For example with the SPT rules, one can get shortest mean flow time and least mean work-in-process holding, but it may result in some lateness. With the due-date based rules, one can get lesser lateness. However, the job's flow time may become longer. It is obvious that each scheduling rule has itself some virtue and demerit. Using a synthesis scheduling rule/criteria can improve the scheduling effect.

5.2.1. Strategy of Stochastic job shop dynamic scheduling

Because the jobs arrive stochastically and the process time is stochastic, to forecast the jobs finish time at each machine is difficult. If the static scheduling method be used for stochastic process time based job shop scheduling, the scheme will become nullification in a short time. This paper proposes a tactic of dynamic, real time and alterable rule/criterion scheduling to improve the dynamic scheduling result, that is whenever a machine finishes a job, according to the conditions of the machine and the jobs, one can decide a priority rule to choose the next job to be processed for the machine. To implement the dynamic scheduling tactic, the real time information of the manufacture system and the job's manufacture process should be got in time.

5.2.2. Scheduling Strategy for Stochastic Job Shop with an invariable Criterion

Whenever there are more than one job waiting to be processed at a machine, these jobs should be sequenced with certain priority rule. The invariable criterion strategy is that one schedules the jobs always according to an invariable criterion. There are two approaches to use the scheduling criterion:

- The nesting means. First one uses the chief criterion to sequence the jobs. If more than one job's values of criterion are equal, one uses the subordination criterion to sequence these jobs, and so on. When the importance of several criterions is approximate, the scheduling effect of this approach will be poor.
- The integrative multi-criterion means. That is to use the integrative multi-criterion to determine the jobs' sequence. The value of the integrative multi-criterion for Job J_i to be processed at machine M_j is as follows:

$$R_{i,j} = \sum_{r=1}^{p} w_k f_{i,j,k} \quad (12)$$

w_k = the weight of criterion k;

p =the number of criterion used for scheduling;

$f_{i,j,k}$ = the value of criterion k of job J_i at machine M_j.

5.2.3. Strategy of Stochastic Job Shop Scheduling with the Alterable Criterion

The Strategy of stochastic job shop scheduling with variable criterion is that as the circumstances of the manufacture system and job's urgent degrees change, one can dynamically change the priority rules/criterions and sequence the jobs.

Let: π_j = the set of jobs waiting to be processed at machine M_j;

S_i = the relaxation time of job J_i to the due-date;

$S_i = T_{di} - T_{si}$; $T_{di} = d_i - r_0$;

$T_{si} = \sum_{i=1}^{m} t_i - \sum_{i=1}^{j-1} t_i$;

r_0 = the current time;

$t_{i,j-1}$ = the process time of job J_i at M_{j-1}

M_{j-1} = the machine processing job J_i just before the M_j;

T_{di} = the time from now to due-date of job J_i;

T_{si} = the leavings process time of job J_i;

$t_{i,j}$ = the process time of job J_i at machine M_j;

n_j = the number of jobs waiting for M_j to be processed.

For the stochastic process time based job shop scheduling and n_j jobs waiting to be processed at machine M_j, this paper proposes an alterable rule/criterion method to schedule these jobs according to these jobs conditions as follows:

- $S_i \le \sum_{i=1}^{n_j} t_{i,j}$, if these jobs according with condition (1) are last processed at machine M_j, it will result in the lateness. In order to make delivery on time and reduce the lateness penalty, these jobs should be scheduled according to S_i by sort ascending. If the unit lateness time penalty for the jobs is different, these jobs should be sequenced according to their weight value of the lateness penalty C_{di} by sort descending.

$$C_{di} = \alpha_i \left(\sum_{i=1}^{n_j} t_{i,j} - S_i\right) \tag{13}$$

α_i =the penalty of per unit lateness time for J_i.

- $S_i > \sum_{i=1}^{n_j} t_{i,j}$, Whatever process sequence it is, these jobs will not be postponed at machine M_j. These jobs sequences should be decided according to their remaining working-procedure time $T_{s,i}$ by sort ascending. If the unit work-in-process holding cost of the jobs is different, these jobs should be sequenced according to C_{Fi} by sort descending.

$$C_{Fi} = \beta_i \left(\sum_{e=1, e\ne i}^{n_j} t_{e,j}\right) \tag{14}$$

β_i =the holding cost of per unit flow time for job J_i.

A simulation has been executed and the result has indicated that the adaptability of dynamic and alterable rule/criterion scheduling strategy is better. Under the circumstance that process time fluctuates stochastically, combining the real time and dynamic scheduling method with the alterable criterion strategy, one can obtain a better scheduling effect.

6. Conclusion

The multi-variety, small batch and make-to-order production system scheduling is a stochastic job shop scheduling problem, whether the static or dynamic scheduling, the actual number of sequences is far less than the one got by tradition academic analyses. When the jobs' process time fluctuates stochastically, using a static scheduling strategy will soon result in the invalidation of the scheme. It is obvious that the static scheduling strategy cannot adapt to the diverse circumstance for manufacturing system. The dynamic and alterable rule/criterion strategy and the real time scheduling method proposed in this paper can effectively improve the scheduling effect.

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