HAL
open science

A Predictive-reactive Approach for JSP with Uncertain Processing Times

Ganggang Niu, Shudong Sun, Pascal Lafon, Lionel Roucoules

To cite this version:

Ganggang Niu, Shudong Sun, Pascal Lafon, Lionel Roucoules. A Predictive-reactive Approach for JSP with Uncertain Processing Times. IDMME - Virtual Concept 2010, Oct 2010, Bordeaux, France. 4p. hal-00951917

HAL Id: hal-00951917

https://hal.science/hal-00951917v1

Submitted on 26 Feb 2014

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Science Arts & Métiers (SAM)

is an open access repository that collects the work of Arts et Métiers ParisTech researchers and makes it freely available over the web where possible.

This is an author-deposited version published in: http://sam.ensam.eu
Handle ID: .http://hdl.handle.net/10985/7802

To cite this version :

Ganggang NIU, Shudong SUN, Pascal LAFON, Lionel ROUCOULES - A Predictive-reactive Approach for JSP with Uncertain Processing Times - 2011

Any correspondence concerning this service should be sent to the repository Administrator : archiveouverte@ensam.eu

A Predictive-reactive Approach for JSP with Uncertain Processing Times

Ganggang Niu [1], Shudong Sun [1], Pascal Lafon [2], Lionel Roucoules [3]

(1) : Institute of System Integration and Engineering Management, Northwestern Polytechnical University, Xi'an, China
Phone +86 29 88494701/ Fax +86 29 88492531
E-mail : ganggang.niu@hotmail.com; sdsun@nwpu.edu.cn

(2) : Institut Charles Delaunay - LASMIS FRE CNRS 28 48, Université de Technologie de Troyes, Troyes, France
Phone +33 03 25 71 56 55/Fax +33 03 25 71 56 75
E-mail : pascal.lafon@utt.fr

(3) : Département CIRD - LSIS UMR CNRS 61 68, Ecole Nationale Supérieure d'Arts et Métiers - CER d'Aix-en-Provence, Aix-en-Provence, France
Phone +33 04 42 93 81 40/Fax +33 06 26 58 78 64
E-mail : lionel.roucoules@ensam.eu

Abstract: JSP with discretely controllable processing times (JSP-DCPT) that are perturbed in a turbulent environment is formulated, based on which, a time-cost tradeoff based predictive-reactive scheduling approach is proposed for solving the problem. In the predictive scheduling process, on the basis of a proposed three-step decomposition approach for solving JSP-DCPT, a solution initialization algorithm is presented by incorporating a hybrid algorithm of tabu search and simulated annealing and a fast elitist non-dominated sorting genetic algorithm; in the reactive scheduling process, Pareto-optimal schedules are generated, among which every schedule that is not dominated by any initial schedule can be selected as the responding schedule so as to maintain optimality of the objective that is to minimize both the makespan and the cost. Experimental simulations demonstrate the effectiveness of the proposed approach.

Key words: Job-shop; Predictive-reactive scheduling; Time-cost tradeoff; Uncertainty

1- Introduction

Job-shops with uncertainties are provided with dynamic and complexity. Various kinds of perturbations, such as order alteration, raw materials delay, machine breakdown, processing time fluctuation, and process defects, etc., emerge during the scheduling process. Usually, perturbations cause current schedules suboptimal, non-effective, or even unfeasible. Studies on scheduling with uncertainties can be classified into three classes based on the problem formulation used: completely reactive scheduling, robust scheduling, and predictive-reactive scheduling, among which predictive-reactive scheduling is widely used **[AL1]**. Predictive-reactive scheduling is presented as a two step process. First, a predictive schedule representing the desired behavior of the shop floor over the considered time horizon is generated. Then, the schedule is modified during execution in response to unexpected disruptions. The two main questions for predictive-reactive scheduling are when to initiate a rescheduling action and what that rescheduling action should be. While in this paper, we focus primarily on the latter.

Several different scheduling approaches encountered at a specific rescheduling point have been presented. In the match-up scheduling approach (see **[AG1]** for e.g.), the objective is for the realized schedule to return to the predictive schedule within a certain time after the disruption occurring. This approach will clearly yield high-quality schedules if there is sufficient idle time in the original predictive schedules. A considerable number of researchers have viewed the rescheduling as that of selecting an appropriate action from among a suite of options in the face of different disruptions (see **[JE1]** for e.g.), which is essentially the rule-based heuristic procedure. One tool for this has been case-based reasoning (see **[O1]** for e.g.).

Since measures of both the schedule performance that must be maintained and the disruption caused by rescheduling are needed to be taken into account, which automatically leads to the formulation of the rescheduling problem as a multi-objective scheduling problem, a naturally adopted approach is the multi-objective optimization approach, which is to generate Pareto-optimal schedules. **[TU1]** considered a static rescheduling problem in which a number of new jobs must be inserted into an existing schedule so as to minimize the total completion time of the new jobs without causing existing jobs to miss their deadlines. **[AA1]** investigated the problem of rescheduling identical parallel machines with disruptions and provide heuristic algorithms to minimize the number of rescheduled jobs subject to optimizing the total completion time of all jobs in the system.

In real-life job-shops, the operation processing time could be controllable by allocating resources, such as additional

money, overtime, energy, fuel, catalysts, subcontracting, or additional manpower, to the operation. Therefore the operation processing time can have a finite number of possible durations **[SS1]**. JSP with discretely controllable processing times (JSP-DCPT) is a generalization of JSP, to which operation processing times can be reduced by allocating additional resource that is limited and discretely divisible. In this paper, the discretely controllable processing time is taken into account, and a time-cost tradeoff based predictive-reactive scheduling approach is investigated in order to deal with the processing time uncertainty in job-shops.

The remainder of this paper is organized as follows: Section 2 gives the formulation of JSP-DCPT with processing time perturbations. In Section 3, a time-cost tradeoff based predictive-reactive scheduling approach is proposed for solving the problem. Experimental simulations are implemented in Section 4. Finally in Section 5, conclusions are presented.

2- Formulation

A feasible solution of JSP-DCPT is specified by a JSP schedule that indicates job sequences on each machine and a mode selection vector that ascertains the mode selection for processing each operation. In order to formulate JSP-DCPT with processing time perturbations, notations used in this paper are given as follows:

σ	the JSP schedule;
δ	the mode selection vector for all operations;
$T(\sigma,\delta)$	the makespan of the JSP-DCPT solution specified by σ and δ;
$C(\delta)$	the cost of the JSP-DCPT solution specified by δ;
n	the job number;
m	the machine number;
J_i	job i;
M_j	machine j;
O_{ij}	the operation of job J_i that is processed on machine M_j;
s_{ij}	the time when operation O_{ij} starts being processed;
x_{ij}	the selected mode for processing O_{ij};
l_{ij}	the total number of different modes for processing O_{ij};
$\mu_{ij,1}$	the nominal processing time for processing O_{ij} in the normal mode;
$\mu_{ij,l_{ij}}$	the nominal processing time for processing O_{ij} in the most crash mode;
ε	the uncertain degree of the processing times;
$t_{ij}(x_{ij},\varepsilon)$	the actual time elapsed for processing O_{ij} in mode x_{ij} with uncertain degree ε;
$c_{ij}(x_{ij})$	the cost spent for processing O_{ij} in mode x_{ij}.

The uncertain degree of processing time is defined by its variety range, for example, if μ_{ij} is the nominal processing time of the operation O_{ij}, then the actual processing time can by expressed by $\mu_{ij} \in \left[\mu_{ij} - \varepsilon\mu_{ij}, \mu_{ij} + \varepsilon\mu_{ij}\right]$, where $\varepsilon \in [0,1]$. The objective is to minimize both the time and the cost criterion, that is to minimize the bicriteria $T(\sigma,\delta)$ and $C(\delta)$. By extending the standard three-field notation $\alpha \mid \beta \mid \gamma$ introduced by **[LG1]**, the problem can be represented as $J_m \mid DCPT \mid (T(\sigma,\delta), C(\delta))$, where J_m indicates the job-shop context; $DCPT$ is the abbreviation of discretely controllable processing times; $(T(\sigma,\delta), C(\delta))$ is the objective to minimize. JSP-DCPT with processing time perturbations is formulated as follows:

$$\min(\max(s_{ij} + t_{ij}(x_{ij},\varepsilon)), \sum c_{ij}(x_{ij})) \tag{1}$$

$s.t.$

$$\begin{aligned} & s_{ij} \ge s_{ik} + t_{ik}(x_{ik},\varepsilon), \\ & \text{for all } i = 1,\ldots n;\ j,k = 1,\ldots m; \text{and } j \ne k \end{aligned} \tag{2}$$

$$\begin{aligned} & s_{ij} \ge s_{hj} + t_{hj}(x_{hj},\varepsilon), \\ & \text{for all } i,h = 1,\ldots n;\ j = 1,\ldots m; \text{and } i \ne h \end{aligned} \tag{3}$$

$$\begin{aligned} & t_{ij}(x_{ij},\varepsilon) \in \left[\mu_{ij,x_{ij}} - \varepsilon\mu_{ij,x_{ij}}, \mu_{ij,x_{ij}} + \varepsilon\mu_{ij,x_{ij}}\right], \\ & \text{for all } i = 1,\ldots n;\ j = 1,\ldots m; \\ & x_{ij} = 1,2,\ldots l_{ij},\ \varepsilon \in [0,1], \\ & \text{and } \mu_{ij,1} > \mu_{ij,2} > \cdots > \mu_{ij,l_{ij}} \ge 0 \end{aligned} \tag{4}$$

Equation (1) indicates that the objective is to minimize both the makespan (that is $\max(s_{ij} + t_{ij}(x_{ij},\varepsilon))$) and the cost (that is $\sum c_{ij}(x_{ij})$) for JSP-DCPT; Equation (2) guarantees operation precedence constraints between machine M_j and M_k for job J_i, i.e., O_{ij} succeeds its job predecessor O_{ik}; Equation (3) guarantees un-overlapping constraints among operations on M_j, i.e., O_{ij} succeeds its machine predecessor O_{hj} on M_j. Equation (4) ensures the actual time elapsed for processing O_{ij} (i.e., $t_{ij}(x_{ij},\varepsilon)$) can only be a value from a variety range that is determined by the nominal value $\mu_{ij,x_{ij}}$ and the uncertain degree ε.

3- Approach

3.1 Predictive scheduling

The fact that a feasible solution of JSP-DCPT is specified by a JSP schedule and a mode selection vector inspires a decomposition approach for solving JSP-DCPT. JSP-DCPT, which is denoted by P, can be solved by using a three-step decomposition approach.

Firstly, all JSP schedules are obtained by solving the corresponding JSP (denoted by PI) that is transformed from the JSP-DCPT problem by setting all operations in the most crash mode. Secondly, for each JSP schedule σ_i that determines the job sequences on each machine, the optimal mode selection vectors are derived by solving the corresponding discrete time-cost tradeoff problem (denoted by $PII(\sigma_i)$). At last, by searching for dominant JSP-DCPT solutions among all solutions that are derived by composing the two parts, i.e., the JSP schedule σ_i and the

corresponding optimal mode selection vectors, the optimal JSP-DCPT solutions can be found.

The time-cost phase plane is introduced to describe tradeoffs of $PII(\sigma_i)$. Point $P_j(c_j,t_j)$ corresponds to tradeoff s_j of $PII(\sigma_i)$.

Definition 1. Point dominance

Given two points $P_1(c_1,t_1)$ and $P_2(c_2,t_2)$, if either $c_1 < c_2$, $t_1 \le t_2$ or $c_1 \le c_2$, $t_1 < t_2$ is satisfied, then P_1 strictly dominates P_2, written as $P_1 \succ P_2$.

Let A denote the collection of all JSP schedules that are obtained by solving the corresponding JSP problem PI. $A = \{\sigma_i \mid i = 1,2,...,u,...,v\}$, v is the size of collection A. t_{σ_i} is the makespan for $PII(\sigma_i)$ at the tradeoff where all operations are set in the most crash mode.

On the basis of the proposed three-step decomposition approach for solving JSP-DCPT, a solution initialization algorithm for predictive scheduling is presented by incorporating a hybrid algorithm of tabu search and simulated annealing (TSSA, see **[ZL2]**) and a fast elitist non-dominated sorting genetic algorithm (NSGA-II, see **[DA1]**), so as to effectively and efficiently solve the two kinds of sub problems (i.e., JSPs and the discrete time-cost tradeoff problems) decomposed from JSP-DCPT.

Algorithm 1. Solution initialization for predictive scheduling

Step1: For JSP-DCPT, set each operation in the most crash mode and solve the corresponding JSP problem PI by using TSSA. A collection $A = \{\sigma_i \mid i = 1,2,...,v\}$ satisfying $t_{\sigma_1} < t_{\sigma_2} < ... < t_{\sigma_v}$ is derived.

Step2: Set integer $i = 0$; and set collection $B = \varnothing$.

Step3: Do:

Step3.1: $i = i + 1$.

Step3.2: Solve discrete time-cost tradeoff sub-problem $PII(\sigma_i)$ by using NSGA-II. All dominant tradeoffs derived from solving $PII(\sigma_i)$ are then added to collection B.

Step3.3: Sort B in a descending order by using the point dominance defined in *definition 1*.

Step3.4: Truncate all non-dominant tradeoffs in collection B.

Until $i = v$.

Step4: Return B, which is a collection of all Pareto-optimal solutions of JSP-DCPT.

3.2 Predictive-reactive scheduling

A time-cost tradeoff based predictive-reactive scheduling approach for dealing with processing time perturbations in job-shops is presented as follows:

Procedure 1. Predictive-reactive scheduling

Step1: Predictive scheduling: apply *algorithm 1* to get the initial Pareto-optimal solution collection (denoted by C_1) for JSP-DCPT scheduling.

Step2: Ascertain one solution from the initial solutions, and implement the solution.

Step3: When perturbations occur, decide whether to respond to perturbations or not.

Step4: In the case when perturbations are responded, execute reactive scheduling:

Step4.1: Ascertain all operations waiting to be processed.

Step4.2: Apply *algorithm 1* to generate the new Pareto-optimal solution collection (denoted by C_2) for JSP-DCPT scheduling.

Step4.3: Seek in C_2 solutions that are not dominated by any solution in C_1; all sought solutions consist collection C_3.

Step4.4: if $|C_3| > 0$, then return C_3; else, go to Step5.

Step5: Procedure terminates.

Any solution in the returned collection C_3 can be selected as the new schedule that could keep the optimality of objectives in the face of processing time perturbations.

In order to illustrate the proposed predictive-reactive scheduling approach, an illustrative case is given as follows:

Let s_1, s_2, s_3, and s_4 denote the initial Pareto-optimal JSP-DCPT tradeoffs. On a time-cost phase plane as shown in Fig.2, points P_1, P_2, P_3, and P_4 correspond to s_1, s_2, s_3 and s_4, respectively. In addition, it is assumed that the tradeoff selected and applied to the process control is s_3. After processing time perturbations occur, the new Pareto-optimal JSP-DCPT tradeoffs are s_1', s_2', s_3' and s_4', which is separately denoted by P_1', P_2', P_3', and P_4' on the time-cost phase plane as shown in Figure 1.

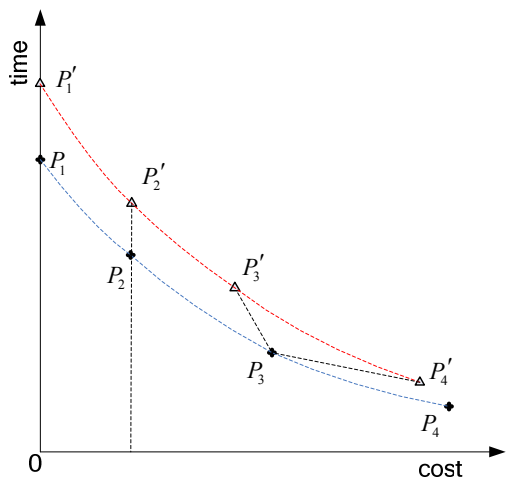

Figure 1: Illustrative figure to demonstrate the predictive-reactive scheduling approach.

In Figure 1, $P_1 \succ P_1'$ and $P_2 \succ P_2'$, hence P_1, P_2, P_3', P_3, P_4' and P_4 are on the same Pareto frontier. As a result, in the case when perturbations occur, tradeoff s_3' or s_4' can be selected as the new tradeoff that is to be implemented in order to maintain optimality of the objective that is to minimize both the makespan and the cost.

4- Simulation study

To simplify a JSP-DCPT instance for simulation, it is assumed that each operation can only be processed in two

modes, namely the normal mode (in such case, $x_{ij} = 1$) and the most crash mode (in such case, $x_{ij} = 2$). For operation O_{ij}, the nominal operation processing time in the normal mode (denoted by $\mu_{ij,1}$) is twice as much as that in the most crash mode (denoted by $\mu_{ij,2}$). In addition, the compression cost is assumed to be equal to the time shortened. $c_{ij,1}$ and $c_{ij,2}$ are the compression costs for O_{ij} in the normal mode and in the most crash mode, respectively. The processing data for the JSP-DCPT instance is given in Table 1.

Table 1: The data for the illustrative JSP-DCPT

Job	*Machine*, ($\mu_{ij,1}$, $\mu_{ij,2}$), ($c_{ij,1}$, $c_{ij,2}$)		
J1	*M1*,(6,3),(0,3)	*M2*,(4,2),(0,2)	*M3*,(10,5),(0,5)
J2	*M1*,(6,3),(0,3)	*M3*,(10,5),(0,5)	*M2*,(2,1),(0,1)
J3	*M2*,(4,2),(0,2)	*M1*,(10,5),(0,5)	*M3*,(6,3),(0,3)

In addition, the actual processing time of an operation with perturbations varies randomly in a given range. According to Equation (4) in Section 2, the actual processing time of O_{ij} processed in the normal and the most crash mode is expressed by $t_{ij}(1,\varepsilon)$ and $t_{ij}(2,\varepsilon)$, respectively. $t_{ij}(1,\varepsilon) \in \left[\mu_{ij,1} - \varepsilon\mu_{ij,1}, \mu_{ij,1} + \varepsilon\mu_{ij,1}\right]$, and $t_{ij}(2,\varepsilon) \in \left[\mu_{ij,2} - \varepsilon\mu_{ij,2}, \mu_{ij,2} + \varepsilon\mu_{ij,2}\right]$, where $\varepsilon \in [0,1]$.

To verify the effectiveness of the proposed predictive-reactive scheduling approach under various uncertainty degrees, 10 groups of simulations are implemented, and for each group ε is set to be a different value from 10% to 100%. Each group includes 50 simulations, during which processing time perturbations occur. The computational results for the 50 simulations of each of the 10 groups are given in Table 2.

Table 2: Computational results for the simulation

ε	n_1	n_2		
		Average	Best	Worst
10%	10	2.8	3	1
20%	11	4.6	5	2
30%	13	3.8	4	2
40%	12	3.9	4	3
50%	15	5.7	6	3
60%	16	4.8	5	2
70%	17	3.9	4	2
80%	16	4.6	5	3
90%	18	5.7	6	4
100%	18	4.8	5	2

Notes : ε is the uncertainty degree ; n_1 is the number of initial Pareto-optimal tradeoffs; n_2 is the number of tradeoffs that can be implemented in order to maintain the optimality of the objective that is to minimize both the makespan and the cost.

5- Conclusion

JSP-DCPT with processing time perturbations is formulated. The time-cost tradeoff based predictive-reactive scheduling approach is proposed for solving the problem. Simulations for the illustrative JSP-DCPT case demonstrate the effectiveness of the proposed approach, which hence could be an approach of potentiality for dealing with other kinds of uncertainties in job-shops.

6- Acknowledgments

The paper is supported by the Asia-Link project funded by the European Commission (CN/ASIA-LINK/024 (109093)), the National Natural Science Foundation of China (50705076, 50705077), and the National Hi-Tech R&D Program of China (2007AA04Z187).

7- References

[AA1] Alag z, O. and Azizolu, M. Rescheduling of identical parallel machines under machine eligibility constraints. European Journal of Operational Research 2003; 149; 523-532.

[AG1] Akturk, M. and Gorgulu, E. Match-up scheduling under a machine breakdown. European Journal of Operational Research 1999; 112; 81-97.

[AL1] Aytug, H., Lawley, M. A., et al. Executing production schedules in the face of uncertainties: A review and some future directions. European Journal of Operational Research 2005; 161; 86-110.

[DA1] Deb, K., Agrawal, S., et al. A Fast Elitist Non-dominated Sorting Genetic Algorithm for Multi-objective Optimization: NSGA-II. In, Parallel Problem Solving from Nature PPSN VI, 1917. Springer Berlin. Heidelberg; 2000. p. 849-858.

[JE1] Jain, A. and Elmaraghy, H. Production scheduling/rescheduling in flexible manufacturing. International Journal of Production Research 1997; 35; 281-309.

[LG1] Lenstra, J., Graham, R., et al. Optimization and approximation in deterministic sequencing and scheduling: a survey. Annals of Discrete Mathematics 1979; 5; 287-326.

[O1] O'kane, J. A knowledge-based system for reactive scheduling decision-making in FMS. Journal of Intelligent Manufacturing 2000; 11; 461-474.

[SS1] Shabtay, D. and Steiner, G. A survey of scheduling with controllable processing times. Discrete Applied Mathematics 2007; 155; 1643-1666.

[TU1] Tamer Unal, A., Uzsoy, R., et al. Rescheduling on a single machine with part-type dependent setup times and deadlines. Annals of Operations Research 1997; 70; 93-113.

[ZL1] Zhang, C., Li, P., et al. A tabu search algorithm with a new neighborhood structure for the job shop scheduling problem. Computers and Operations Research 2007; 34; 3229-3242.

[ZL2] Zhang, C. Y., Li, P., et al. A very fast TS/SA algorithm for the job shop scheduling problem. Part Special Issue: Applications of OR in Finance 2008; 35; 282-294.