An Improved Algorithm based on Constraint Programming for Job Shop Rescheduling Problem with New Job Insertion

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Keywords: Job Shop Rescheduling, constraint programming, new job insertion.

Abstract: Due to a variety of unexpected situations, the shop needs to make adjustments on the original schedule. Aiming at job shop rescheduling caused by new job arrival, we build an optimal model based constraint programming to make a reschedule to minimize the makespan. And considering the advantage of constraint programming in solving combinatorial optimization problems, we combined constraint propagation techniques with construction search strategy, a rescheduling algorithm based on constraint programming is designed. Computational experiments of rescheduling problems are generated based on the benchmark of Job shop scheduling problem. Results reveal the proposed algorithm can solve the instances in short time.

1 INTRODUCTION

Job shop scheduling problem, as a NP hard problem, has been studied by a lot of scholars. The classical algorithm for solving job shop scheduling problem is generally divided into two categories: the optimization method and the approximate method. The optimization method includes integer programming and branch and bound method. The approximate algorithms mainly include the rule of priority allocation, artificial intelligence, neural network, Lagrange relaxation method, the conversion of the bottleneck method, local search method, etc. In order to get better result, many scholars improved these algorithms, such as the improved neural network algorithm, the improved genetic algorithm, the improved hybrid particle swarm algorithm, mixed integer programming algorithm and so on. Although these classical algorithms for static production have made great achievements in recent decades, but in recent years, scholars are increasingly aware that the production workshop will face with various emergency situations in the actual production, such as the insertion of the new job, machine failure, operation time change. In this dynamic environment, the original production plan will be disturbed and the production system cannot execute production plan, so the production plan need to be rescheduled.

Bierwirth et al proposed a genetic algorithm to solve rescheduling and scheduling problem in 1999(Bierwirth et al, 1999). Fang presented a periodic and event-driven rolling horizon scheduling strategy adapted to continuous processing in a changing environment, and presented a hybrid of genetic algorithms for the rescheduling problem (Fang et al, 1997).However, periodic rescheduling strategy cannot get very good stability solution for this problem. In order to obtain both the stability and effectiveness of the rescheduling problem, Rangsaritratsamee et al proposed a local search algorithm based on genetic algorithm ,and the experiments show that the solution of the algorithm compared with traditional algorithm more stable and effective(Rangsaritratsamee, 2004).Katragjini et al developed a rescheduling algorithms based on repair theory to solving the problem, and proposed a rescheduling methods to seek a good trade-off between schedule quality and stability(Katragjini et al, 2013).Zhang et al proposed a new rescheduling technique based on a hybrid intelligent algorithm for solving job shop scheduling problems with random job arrivals, the experimental results show that the proposed rescheduling technique is superior to other rescheduling techniques with respect to five objectives, different shop load level, and different due date tightness, the results also illustrate that the proposed rescheduling technique has a good robustness in the dynamic manufacturing

Chen S. and Yun-fang P.
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DOI: 10.5220/0006443900680073
In *ISME 2016 - Information Science and Management Engineering IV (ISME 2016)*, pages 68-73
ISBN: 978-989-758-208-0

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environment(Zhang et al, 2013). Gao et al proposed A two-stage artificial bee colony (TABC) algorithm with several improvements to solve FJSP(flexible job shop problem) with fuzzy processing time and new job insertion constraints, and compared against seven existing algorithms for solving five well-known benchmarks of FJSP , the results illustrated the competitiveness of the proposed algorithm(Gao, 2016) .

Although the optimization algorithms mentioned above have achieved good results in solving the job shop rescheduling problem, the solution time of these algorithms is too long which is not good enough to be applied in the actual production. In actual production, decision makers often need to make a relatively feasible decision in a short time.

Constraint satisfaction technique is an effective method to solve the above problem. This technique can not only simplify the complexity of the model, but also reduce the computational complexity of the problem by using the constraint relation between variables. In recent decades, researchers have made a lot of research on Constraint Satisfaction Based Job Shop scheduling algorithm, and the constraint programming is applied to job shop scheduling and some excellent research results have been obtained. For example, Nuijten, Sahraeian, Moukrim, Lacomme and other scholars, their research results show that constraint programming features in shop scheduling are quickly and effectively, it can provides a feasible scheme for the enterprise timely and effectively(Nuijten et al, 1998)(Sahraeian et al, 2014)(Moukrim et al, 2014)(Lacomme et al, 2011).

Based on the above, this paper applies the constraint programming to the job shop rescheduling problem, and adopts the global rescheduling strategy to achieve the goal of solving the shop Job rescheduling problem with the insertion of new job rapidly.

2 JOB SHOP RESCHEDULING PROBLEM

2.1 Problem description

In the reality of job shop production, there are often a lot of dynamic factors leading to the job shop need to rescheduling, this paper focuses on the job shop rescheduling problem of the insertion of new job. When a new job arrives and insert into the original schedule, some conflicts may arise and the original schedule may not be executed. Hence, it is necessary to reschedule in this situation. And most importantly, the machines are available for rescheduling only when the operations on them are all completed. That means machines and jobs may have different start times in the rescheduling.

In order to facilitate the establishment of the model, we assume a new job arrives at the time of T_b. If o_{ib} is processing on the machine b at the time of Tb, this operation will be considered as an operation which has been processed in rescheduling, and the earliest start time of machine b is equal to $c_{i,j}$. If a machine j does not process any job, the earliest starting time of machine j is equal to T_b.

In this paper, all operations of original schedule are included in the set Ω. Since the insertion of new job, we reset n as the total jobs in the rescheduling, and m as the total machines. All operations need rescheduling are included in the set Ω'.

2.2 Rescheduling model

In the JSRP, each job consists of a sequence of operations. An operation can be executed by a set of candidate machines and each operation of a job is processed only on one machine at a time, while each machine can only process one operation at a time. Minimizing the total completion time is the most important objective of the job shop production in the dynamic shop floor. In this paper, we use constraint programming to establish the model, and solve the rescheduling problem. The following notations and assumptions are used for the formulation of JSRP.

- i: job index (i=1,…,n) , a set of n jobs to be scheduled;
- j: machine index (j=1,…,m) , a set of m machines;
- $c_{i,j}$ denotes the completion time of the operation $o_{i,j}$;
- $y_{i,j}$ denotes the start time of the operation $o_{i,j}$;
- $Xiuj$=1denotes job i should be processed on the machine j after on the machine u(otherwise, $Xiuj$=0);
- $Zikj$=1 denotes machine j should process the job i before job k (otherwise, $Zikj$ =0);
- $p_{i,j}$ denotes the processing time of $o_{i,j}$;
- M is a large enough value;
- S_j denotes the earliest starting time of machine j in the rescheduling;
- $x_{i,j}$ denotes the ending time of $o_{i,j}$ in the original scheduling

$$\text{Min } C_{max} \tag{1}$$

s.t.

$C_{max} \ge c_{i,j}$ (i =1,…,n; j=1,…,m)

$c_{i,j}=y_{i,j}+p_{i,j}$ (i=1,…,n; j=1,…,m)

$MX_{iuj}+(y_{i,u}-y_{i,j}) \ge p_{i,j}$ (i=1,…,n; $1 \leqslant u<j \leqslant m$)

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$$M(1-X_{iuj})+(y_{i,j}-y_{i,u}) \geq p_{i,u} \quad (i=1,\ldots,n;\ 1\leq u<j\leq m)$$
$$MZ_{ikj}+(y_{i,j}-y_{k,j}) \geq p_{k,j} \quad (1\leq i<k\leq n;\ j=1,\ldots,m)$$
$$M(1-Z_{ikj})+(y_{k,j}-y_{i,j}) \geq p_{i,j} \quad (1\leq i<k\leq n;\ j=1,\ldots,m)$$
$$y_{i,j}\geq S_j; \quad (i=1,\ldots,n;\ j=1,\ldots,m)$$
$$X_{iuj}=0 \text{ or } 1; \quad (i=1,\ldots,n;\ 1\leq u<j\leq m)$$
$$Z_{ikj}=0 \text{ or } 1; \quad (1\leq i<k\leq n;\ j=1,\ldots,m)$$

The objective C'_{max} (1) is to minimize makespan. Eq.(2) states C_{max} is the latest ending time of all the operation in the rescheduling. Eq.(3) states the ending time $c_{i,j}$ is equal to the ending time $y_{i,j}$ add the duration time $p_{i,j}$. Eqs.(4)(5) states each operation of a job is processed only on one machine at a time. Eqs.(6)(7) states each machine can only process one operation at a time. Eq.(8) states the starting time of $o_{i,j}$ should be equal or greater than the earliest time of machine j. In the Eqs.(9)(10), the variable X_{iuj} is binary variable and the variable Z_{ikj} is decision variable.

3 RESCHEDULING ALGORITHM BASED ON CONSTRAINT PROGRAMMING

In this paper, a new job shop rescheduling algorithm based on constraint programming is proposed. This algorithm mainly uses the job shop scheduling algorithm based on constraint satisfaction problem, and combined with the constructive search algorithm to solve the problem of job shop rescheduling.

3.1 The principle of rescheduling algorithm based on Constraint Programming

Constraint satisfaction algorithm includes repair method and construction method. In this paper, we use the construction method. In this algorithm, a solution of job shop rescheduling is the processing order of all the operation with a set of machines. The

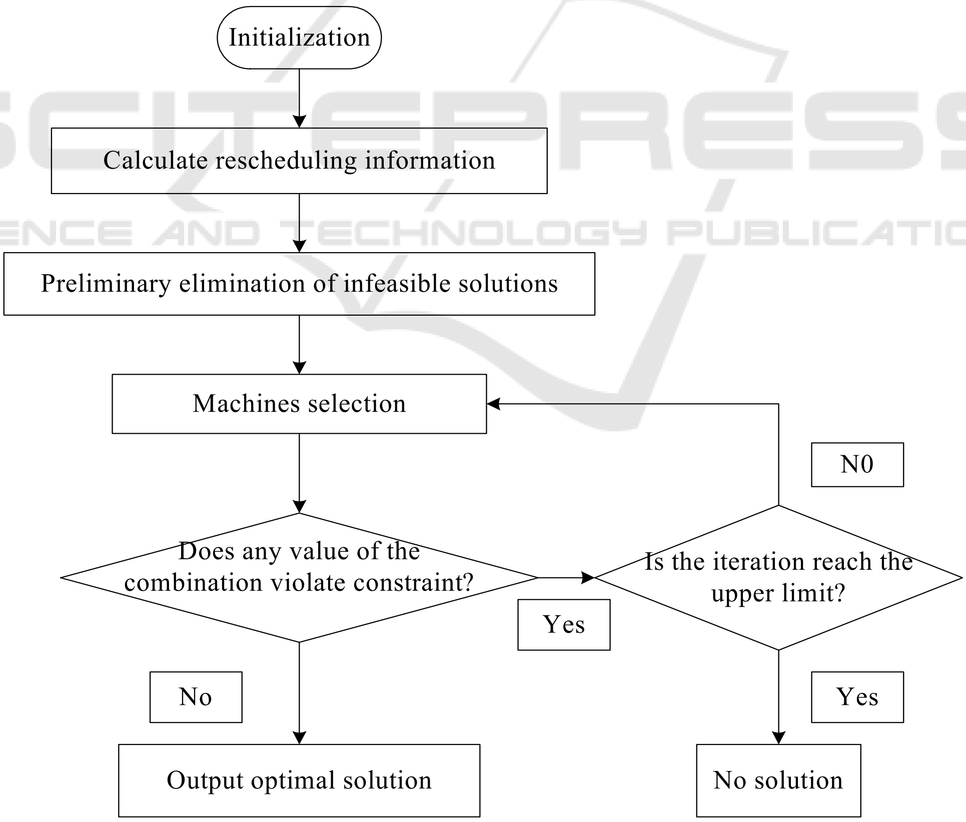

Figure 1: The flow chart of rescheduling algorithm

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algorithm includes machine selection and process selection. It will start from the machine selection, then select a machine which hasn't been selected to process a job, until all the machines and all processes are selected. If the search is failure, it will take a backtracking strategy forward search.

Precedence constraints can be used to strengthen the time window of all operations. The earliest start time of all operation is updated according to Eqs. (11) (12). The latest start time of all operations is updated in Eqs.(13)(14). The algorithm will detect the contradiction whenever there is no schedule can satisfy all the precedence constraints of the problem.

$$est_{i1}=0 \quad \forall i \tag{11}$$

$$est_{i1}=\max(est_{i(j-1)}+p_{i(j-1)}) \quad \forall i,\forall j \tag{12}$$

$$lct_{i,m}=UB \quad \forall i \tag{13}$$

$$lct_{i,j}=lct_{i(j+1)}-p_{i(j+1)} \quad \forall i,\forall j\in[1,m-1] \tag{14}$$

The disjunctive constraints limit the sequence of the operations processing on the same machine. Two operations requiring the same machine cannot overlap in time. As stated in Eq.(15), whenever the earliest completion time of $o_{i,j}$ exceeds the latest start time of oxy, $o_{i,j}$ cannot precede oxy, hence oxy must precede $o_{i,j}$. Once the precedence of two operations assigned to the same machine is fixed, a new precedence constraint is propagated based on the rule (16)

$$est_{i,j}+pi,j>lstx \Rightarrow o_{x,y}\prec o_{i,j} \tag{15}$$

$$o_{x,y}\prec o_{i,j} \Rightarrow est_{i,j}+pi,j>lstx \text{ and } lct_{x,y}\le lct_{i,j}-p_{i,j} \tag{16}$$

3.2 The rescheduling algorithm based on constraint programming for JSRP

In this paper, an algorithm based constraint programming for job shop rescheduling is proposed to solve the scheduling problem with the objective of minimizing the maximum completion time.

Step1. Initialization. All processes are accessed as interval variables, and each parameter is initialized to 0.

Step2. Calculate the rescheduling information. Read the source file data of the information of new job and the insert time T_b. According to this information, the earliest start time S_j of machine j will be calculated by this algorithm.

Step3. Preliminary elimination of infeasible solutions. The initial constraint propagation removes all values from domains that will not take part in any solution.

Step4. Machines selection. This algorithm will randomly chose a starting time of machine j for operation $o_{i,j}$ by using the constructive search, the machine j should not be selected to process a job, until all the machines and all processes are selected. If all the value has been chosen, there still have conflict in the constraint, this problem has no solution.

Step5. Consistency check. Constraint propagation during this selection (step4) will removes all values from the current domains that

Table.1: Information of Rescheduling

Instance	Time	M	T	M	T	M	T	M	T	M	T	M	T	M	T	M	T	M	T	M	T
la03	79	1	12	4	21	0	65	3	23	2	12										
abz5	816	2	63	4	55	9	45	8	63	0	74	1	51	3	49	5	52	7	63	6	43
la27	103	2	45	3	18	8	29	6	42	4	32	7	87	1	11	0	28	9	26	5	25
la31	406	4	19	8	24	7	18	2	63	1	16	0	29	5	18	6	9	3	78	9	12
swv11	596	5	12	3	9	2	23	6	23	9	11	4	23	1	21	0	23	8	34	7	27

Table.2: Comparison of 6 sets of rescheduling

Type	10×5	10×10	20×10	30×10	50×10
Search limit	100000	100000	100000	100000	100000
Original scheduling objective	597	1237	1218	1784	3358
Rescheduling objective	659	1375	1279	1813	3460
Number of branches	1462	256501	118213	23040	315954
Number of fails	375	100465	37447	8999	100390
Time spent	0.09s	3.14s	1.92s	0.58s	8.03s

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violate the constraints. This check will not stop in the machine selection, until a solution is found. If failed, it will jump to the step4, and reselect a starting time for $o_{i,j}$. If success, get this objective and jump to step6.

Step6. Check iteration number. If the iteration number is reach the upper limit, jump to step7.otherwise, jumping to step4.

Step7. Output optimal solution. Compare all the feasible solutions, and select the minimum objective as the optimal solution.

4 EXPERIMENT EVALUATION AND COMPARISONS

Since there is no standard rescheduling example for analysis of the effectiveness of the model and algorithm of job shop rescheduling problem, this paper select 5 instances from OR as a basis for rescheduling problem. We design 5 rescheduling instances from small scale to large scale to analyse the performance of the proposed algorithm.

In this paper, rescheduling is caused by the

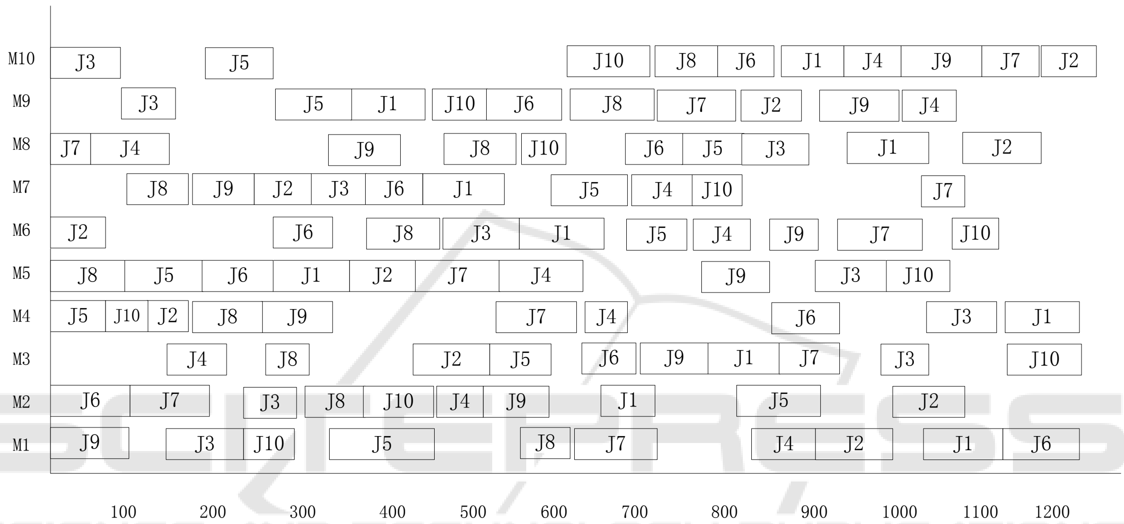

Figure 2 : 10×10 Gantt chart of original scheduling.

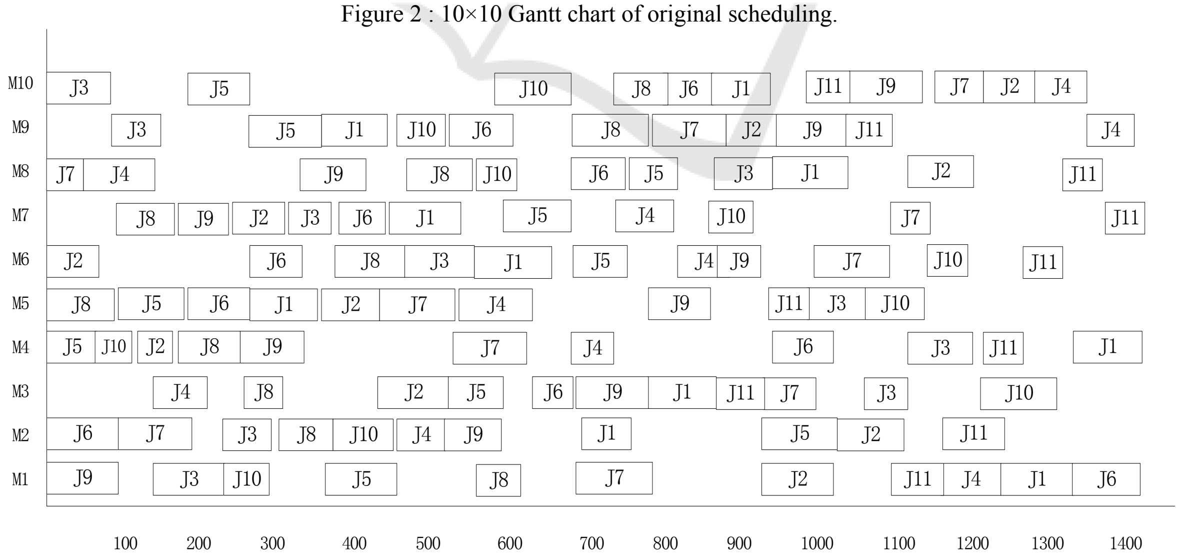

Figure 3 : 10×10 Gantt chart of rescheduling

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insertion of new job, and the arrival time of new job is selected randomly. The arrival time is $Tb=Random_1*c$, where the $Random_1$ value range is [0,1], and the c is the maximum completion time of the original scheduling. The information of new job is created randomly.

Taking into account the feasibility of the algorithm, this algorithm sets the upper limit to 100000. The job shop rescheduling parameters are shown in table 1, including the insert time and the information of new job's operations. Table 2 is the comparison of the results of rescheduling. Figure 2 is the Gantt chart of original scheduling (10 x 10), and figure 3 is the Gantt chart of rescheduling (10 x 10). The values in bold in table 2 are the best objectives of 5 job shop rescheduling problem, and the objectives of rescheduling are closer to the original scheduling. The last row of table 2 shows that in solving the rescheduling, this algorithms obtained high quality solutions in a short time for the JSRP.

5 CONCLUSIONS AND FUTURE WORK

This paper proposed a rescheduling algorithm based on constraint programming for the job shop rescheduling problem with new job arrival. This algorithm adopted constructing search theory and constraint propagation to minimize the maximum completion time of all jobs. We selected 5 classical instances released from the OR to analyse this rescheduling problem. Experimental results showed that this algorithms obtained high quality solutions in a short time for the JSRP. The result showed the proposed algorithm can be used in the practical production and obtain more benefits for the enterprise.

This paper focused on the job shop rescheduling problem with new job arrive. But in the reality, the practical production will meet more kinds of emergency like advance delivery time and machine breakdown. In the future study, we also needs studied the job shop rescheduling problem from other aspects and developed a more perfect rescheduling algorithm.

ACKNOWLEDGEMENTS

This paper is supported by National Natural Science Foundation of China (No.51405283).

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