Research on Two-stage RGV Scheduling Based on Simulated Annealing and Tabu Search

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Abstract. The scheduling problem of an intelligent machining system, with multiple Computerized Numerical Control Machine (CNCs) and one Rail Automatic Guidance Vehicle (RGV) with manipulator as its core, in a deterministic environment is studied. It is necessary to determine the ratio of the number of CNCs responsible for the first stage to the number of CNCs responsible for the second stage, the location and the moving path of the manipulator. Starting from the scheduling theory of parallel machines, the RGV algorithm based on simulated annealing is used to determine the optimal route of RGV by analyzing the type of machines and the processing time of work pieces. The experimental results show that the scheduling rule can effectively improve the efficiency of intelligent workshop.

Keywords: quasi-simulated annealing algorithm; tabu search; RGV scheduling; Roulette.

1. Introduction
RGV is mostly used in stereoscopic warehouse. Some literatures have studied RGV in warehouse. Li Guo [1] et al. proposed a scheduling rule based on complete traversal path planning (CCPP) for RGV under uncertain environment. Chen Yingge and Xianlong [2] use 0-1 integer programming to study such problems. Cao Hongtao et al. [3] used dynamic programming to solve similar problems. [4] Study the application of logistics system. Multiple (even) CNCs are divided into two columns and emitted at equal distances. Each CNC can only process one job at a time. Initially, RGV is in the initial position between CNC1\# and CNC2\#, and all CNCs are idle. Under normal working conditions, the idle CNC sends the feeding demand signal to RGV. RGV chooses a CNC as its feeding according to the demand signal. During the processing time, RGV can complete the feeding work according to the feeding request of other idle CNC. When a CNC machine is finished, RGV arrives at the position, completes the cutting and new raw material feeding, and then the finished material is cleaned in the cleaning tank and placed on the feeding conveyor belt to make it leave the processing system. The RGV returns to its original position until all the jobs that need to be processed leave the system. Many CNCs share the two following processes[5-9] of processing job. Each job must go through two processes before it can leave the processing system. RGV is dispatched to meet CNC's feeding and cutting requirements, which makes the whole system the most efficient. The intelligent system works continuously for one day (8 hours) per shift to determine the ratio of the number of CNC responsible for the first stage to the number of CNC responsible for the second stage, the location and the moving path of the manipulator.
2. **Hypothesis**

(1) For the convenience of studying the problem, we make the following assumptions. The transmitter will not fail and will not affect RGV scheduling. When RGV is ready for feeding, the conveyor belt conveys the material to the designated position. When RGV is ready for feeding, the conveyor belt can quickly remove the finished job.

(2) RGV only feeds CNC when CNC does not process any workpiece in the initial stage of processing; RGV only feeds CNC when CNC no longer has other tasks in the final stage of processing; RGV always feeds CNC at the same time in the process of processing.

(3) For convenience of calculation, it is assumed that CNC is idle when the system starts to run.

(4) When calculating the maximum completion time, the conveyor belt transportation time after the last workpiece is discharged is neglected.

3. **Symbolic Description**

- \( n \): Number of jobs to be processed
- \( N_i \): Number of CNC signals emitted at point \( i \) at the same time
- \( I \): CNC Number Set for the First Procedure in Two-Stage Problem
- \( J \): CNC Number Set for Second Procedure in Two-Stage Problem
- \( S \): CNC label set
- \( \text{signals} \): set of the labels of the signaling machine
- \( \text{signals}_1 \): set of the labels of the signaling machine in \( I \)
- \( \text{signals}_2 \): set of the labels of the signaling machine in \( J \)
- \( T_p^1 \): The Processing time of the first procedure in the two-stage problem
- \( T_p^2 \): Processing time of the second process in two-stage problem
- \( T_{c, j} \): Time required for loading and unloading of the \( j \)th machine
- \( T_{w} \): The time required to clean a job
- \( T_{F_j} \): Uploading or unloading time of machine \( j \)
- \( T_w \): Time required for RGV movement
- \( T_w(i, j) \): The time required for RGV to move from \( i \) position to \( j \) position
- \( t_{ij} \): The time when the first job begins to be processed on CNC \( j \)
- \( t_{ik}^1 \): The processing time of job \( i \) begins with the first stage machine CNC \( j \)
- \( t_{ik}^2 \): job \( i \) processing time starting from the second stage machine CNC \( k \)

\[
x_{ij} = \begin{cases} 
1, & \text{i is processed on machine } j \\
0, & \text{else if } \\
& i \in \{1, 2, \ldots, n\}, j \in S 
\end{cases} 
\]

(1)

\[
x_{ijk} = \begin{cases} 
1, & \text{job i is processed on j in the first stage and on machine j in the second stage, } \\
& i \in \{1, 2, \ldots, n\}, j \in I, k \in J \\
0, & \text{else if } 
\end{cases} 
\]

(2)

\( C_{\text{max}} \): Maximum completion time

4. **Model Establishment and Solution of Two-stage RGV Model**

4.1. **Selection of Machine Number and Location Determination**

In the two-stage processing process, the number of machines responsible for each stage needs to be
determined first. According to the data analysis given in the title, the order of magnitude of processing
time is obviously larger than that of loading and unloading time and cleaning time in the whole
production process, so the classification basis is only machine processing time.

4.2. Mathematical Model of Two-stage RGV Scheduling Problem

\[
\text{Min } C_{\text{max}} = \sum_{j \in I} \sum_{k \in J} x_{nj} (t_{ik}^2 + T_p^2 + T_{Fk} + T_{ws})
\]

\[
\sum_{k \in J \cup I} x_{jk} = 1, \quad i = 1, 2, \ldots, n \quad (1)
\]

s.t.

\[
\sum_{j = 1}^{n} x_{ijk} \leq 1, \quad j \in I, \quad k \in J \quad (2)
\]

\[
\sum_{j \in I \cup J} t_{ijk} x_{ijk} \geq \sum_{k \in J \cup I} (t_{ij}^1 + T_{p,j} + T_{c,j}) x_{ijk}, \quad i = 1, 2, \ldots, n \quad (3)
\]

4.3. Two-stage RGV Scheduling Algorithm

The position efficiency is only related to the position, and is independent of the number of signals at
the location. Let the evaluation function of the current position be \( T_w(i, j) \). Obtaining the Probability
Transfer Function \( \text{exp}( - T_w(i, j)/T ) \). In this way, the RGV algorithm based on simulated annealing
can be used to study RGV scheduling problem.

Constructing an evaluation function for other locations that takes account of both the number of calls
and the distance of calls \( p_{ij} \), to evaluate the superiority of the next choice of location i:

\[
p_i = \frac{T_w * + N_i T_{ws} * + N_i T_p * + N_i T_{Fj} *}{N_i} \quad (4)
\]

A transformation probability function similar to the simulated annealing probability function in the simulated annealing algorithm is introduced. \( P_i : P_i = \text{exp}( - p_i / T ) \)

4.3.1. Algorithmic Steps. Step 1. Initially, all CNCs are empty, and RGV is between CNC1 and CNC2.
Step 2. If the RGV’s location sends the feeding signal, the raw material will be discharged in situ.
Otherwise, the evaluation functions of three places except RGV are calculated.
Step 3. Calculate the transition probability function, and take the maximum two values as the optimal
and suboptimal.
Step 4. Generates a random number with a larger value and compares it with that. If the value is larger,
the local optimal solution is abandoned and the location of the sub-optimal solution is chosen as the
moving target location; otherwise, the local optimal position is chosen as the target location.
Step 5. Compare the time consumed at this time with the time limit (8 hours).
If it is greater than or equal to the time limit, it will stop working and end production.
Otherwise, return to Step 2.

4.3.2. Outer Tabu Search Algorithm Steps. Step 1. Given an initial empty tabu table A, the output
solution of the inner ”RGV algorithm based on simulated annealing” is selected as the initial solution
X.
Step 2. If T is more than 8 hours, stop the calculation and output the results.
Step 3. Select the non-taboo candidate set N (X) from the neighborhood of X. Select a solution X_next
with the lowest evaluation value in N (X) and make X = X_next. Then update A and repeat Step 2.
4.3.3. Two-stage RGV Scheduling Problem Algorithm Steps. Step1. Initially, all CNCs are empty and RGV is between CNC1 and CNC2.  
Step2. Start the outer tabu search algorithm.  
Step3. Call the inner layer "RGV algorithm based on simulated annealing idea".  
Step4. Determine whether to terminate, if so, output the result, and if not, return to step 2.  

4.4. Solution and Conclusion of Two-stage RGV Static Scheduling Problem  
The following three sets of data are given for different working procedures and different machine processing time (unit second):  

| Parameters                                      | Group 1 | Group 2 | Group 3 |
|------------------------------------------------|---------|---------|---------|
| Time required for RGV to move one unit          | 20      | 23      | 18      |
| Time required for RGV to move two units         | 33      | 41      | 32      |
| Time required for RGV to move three units       | 46      | 59      | 46      |
| The time required to complete a process in CNC processing | 560     | 580     | 545     |
| The time required for CNC to complete the first of the two processes | 400     | 280     | 455     |
| The time required for CNC to complete the second of the two processes | 378     | 500     | 182     |
| loading or unloading of RGV for machine 1357    | 28      | 30      | 27      |
| loading or unloading of RGV for machine 2468    | 31      | 35      | 32      |
| RGV cleaning time                                | 25      | 30      | 25      |

4.4.1. The first group of data. In the first set of data, four machines are arranged in the first stage. In the second group of data, three machines are arranged. For the third group of data, six machines are arranged in the first stage.  
The first group of data, RGV access path is: 1 -> 2 -> 5 -> 6 -> 3 -> 4 -> 7 -> 8 cycles. In 8 hours, the number of job processed is 240. The second group of data, RGV access path: 1 -> 6 -> 5 -> 4 -> 3 -> 8 -> 7 -> 2 cycles. In 8 hours, the number of jobs processed is 224. The third group of data, path: 7 -> 8 -> 1 -> 2 -> 5 -> 6 -> 3 -> 4 cycles. In 8 hours, the number of jobs processed is 215.  
The following conclusions can be drawn:  
(1) The RGV access loops in the choice of three kinds of data in static problems. This is because it is relatively simple in machine environment. Once an optimal scheduling strategy is determined, the optimal solution of the problem can be obtained by a long-term cycle of the scheduling strategy.  
(2) According to the different processing time of the two stages, the number of jobs calculated by the algorithm varies, but the change is not significant, which shows that the algorithm has better generality. In the first set of data, the shortest time for each job to complete two-stage processing is 280+500+30+35+30=875. In 8 hours, a pair of machines (two-stage and two-machine) can process up to 32 jobs and up to 32*8=256 jobs. The gap between the solution and the boundary is 8/128=6.25%. In the second set of data, the shortest time for each job to complete two-stage processing is 350+30+280=345, and the maximum processing time is 83.48 in 8 hours, so the upper bound of the whole system processing room is 250. The gap between the solution we obtained and the boundary of the problem is 10.4%.  
(3) In the second group of data, the upper bound of the system is 337, and the gap is 35.6%. This may be due to the complexity of the machine environment, the boundaries we choose are too large, or the algorithm may be unstable to the data in the special machine environment.  

5. Conclusion  
In this problem, the order of magnitude of processing time is obviously larger than the loading and unloading time and cleaning time, so machine processing time is used as the basis for distinguishing machine types. Based on the principle that the average processing time of each type of machine is as equal as possible, the number of each type of machine is determined, and the location of each type of
machine is determined according to the minimum RGV movement in the scheduling process. It is concluded that the first type of machine is 1-3-5-7, the second type is CNC2-4-6-8, the first type is 1-5-7, the second type is CNC2-3-4-6-8, and the second type is CNC2-3-4-6-8. The third type is CNC1-3-4-5-7-8 and the second type is 2-6.

The mathematical model of this problem is given clearly. Based on this, a combined algorithm of simulated annealing and tabu search is designed to solve the two-stage problem. The inner layer RGA scheduling algorithm based on simulated annealing algorithm gives a near optimal RGA scheduling strategy, and the outer tabu search algorithm improves the solution to make it close to the optimal as soon as possible. Through the analysis of calculation results, we found that the first group of data, RGV access path is: CNC1 -> 2 -> 5 -> 6 -> 3 -> 4 -> 7 -> 8 cycle, the number of processed jobs is 240, the gap between the number of processed jobs and the upper bound of the number of processed jobs in the system is 6.25%; the second group of data, RGV access path is: CNC1 -> 6 -> 5 -> 4 -> 3 -> 8 -> 7 -> 2 cycle. For the third group of data, RGV access path is CNC7 -> 8 -> 1 -> 2 -> 5 -> 6 -> 3 -> 4 cycle, and the number of processed jobs is 215.

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