doi:10.3772/j.issn.1006-6748.2019.03.013

Study on scheduling algorithm for multiple handling requests of single automated guided vehicles①

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Abstract

To solve the problem of small amount of machining centers in small and medium flexible manufacture systems (FMS), a scheduling mode of single automated guided vehicle (AGV) is adopted to deal with multiple transport requests in this paper. Firstly, a workshop scheduling mechanism of AGV is analyzed and a mathematical model is established using Genetic Algorithm. According to several sets of transport priority of AGV, processes of FMS are encoded, and fitness function, selection, crossover, and variation methods are designed. The transport priority which has the least impact on scheduling results is determined based on the simulation analysis of Genetic Algorithm, and the makespan, the longest waiting time, and optimal route of the car are calculated. According to the actual processing situation of the workshop, feasibility of this method is verified successfully to provide an effective solution to the scheduling problem of single AGV.

Key words: automated guided vehicle (AGV), flexible manufacturing, scheduling policy, makespan, genetic algorithm, priority

0 Introduction

At present, the logistics control system in flexible manufacture system (FMS) is usually composed of many automated guided vehicles (AGVs), but in small and medium scale, due to small amount of machining centers, the use of multiple AGVs will increase waiting time, thus, making car collision become more easily because of the overlapping of scheduling route. Therefore, the scheduling mode of single AGV that can handle multiple transport requests is a practical solution to this problem.

For the workshop scheduling scheme of AGV, researchers across the world focus primarily on the optimal value of the scheduling path of AGV through dynamic scheduling optimization algorithm. Ref. [1] proposed genetic algorithm under the constraint of machine tool/AGV, and searched for the best value of the car to provide the feasibility of this algorithm. Ref. [2] proposed to minimize the makespan of AGV through a hybrid heuristic algorithm. Ref. [3] improved the convergence and distribution uniformity of the hybrid particle swarm optimization algorithm based on learning strategy and the simulated annealing technology of Baldwin. Ref. [4] expanded the searching scope through the particle swarm optimization algorithm and introduced the improved simulated annealing algorithm to enhance neighborhood searching capability. Ref. [5] was based on the fuzzy satisfaction of scheduling rule in genetic algorithm, and calculated the overall satisfaction level to reach the optimal value. These algorithms could ensure that the optimal value was gathered, but since the process of solution was long, and the scope of search was large, the scale of calculation often increased exponentially. Therefore, on the basis of the optimization algorithm, by introducing the priority strategy of the car, the search area of the algorithm can be divided into several parts, and the optimal value of each part can be solved and compared together, so that the search result will be closer to the optimal value.

The workshop scheduling mechanism of AGV is analyzed, the process is encoded based on several sets of AGV transport priority, and the fitness function, selection, crossover and mutation methods are designed. By performing the simulation analysis of the genetic algorithm, the shortest makespan of handling priority is determined, which provides an effective solution to the scheduling problem of single AGV.

① Supported by the National Natural Science Foundation of China (No. 51765043).
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Received on July 14, 2018

1 Mathematical model

FMS formulated the following tasks of processing according to the production plan: there are n workpieces to be machined on m machine tools, each workpiece has k processes, and every process of the workpiece can be processed on any machine tool. It can be concluded that:

1) The workpiece set: $N = \{n_1, n_2, \cdots, n_n\}$, $n_i(i = 1,2,\cdots,n)$ is the No. i's workpiece;

2) The process set: $P = \{p_1, p_2, \cdots, p_n\}$, $p_i = \{p_{i1}, p_{i2}, \cdots, p_{ik}\}$, p_{ij} is the No. j's ($j = 1,2,\cdots,k$) process of the No. i's ($i = 1,2,\cdots,n$) workpiece;

3) Machine tool set: $M = \{m_1, m_2, \cdots, m_m\}$, $m_q(q = 1,2,\cdots,n)$ is the No. q's machine tool;

In the process of scheduling, the following optimization constraint condition should be met:

1) Each machine tool can only process one piece each time[6,7];

2) The process time of p_{ij} is constant;

3) The order of manufacturing process of each workpiece cannot be changed;

4) The time when the AGV takes the workpieces from the loading platform to the machine tool is the initial processing time of all workpieces;

5) When all the workpieces are finished, AGV will take the workpieces to the unloading platform, and the work is considered to be completed;

6) Priority conditions for carrying workpieces by AGV are: 1) Workpieces feeding to the processing center; 2) Workpieces which are finished in the processing center; 3) Workpieces near the final process. There are 6 priority strategies when combining the above 3 priority conditions.

According to the above optimizing constraint conditions, the aim of scheduling scheme of AGV is to minimize the makespan of all workpieces[8]. The mathematical model is

$$\mathrm{Min}\{\max(c_i)\}, i = 1,2,\cdots, n \quad (1)$$

where, c_i is the makespan of workpiece n_i.

2 The design of algorithm

Since the genetic algorithm can search thoroughly and its convergence speed is fast, the genetic algorithm is adopted to solve the optimal solution of the objective function. The process of machine tool-AGV scheduling algorithm based on genetic algorithm is shown in Fig. 1.

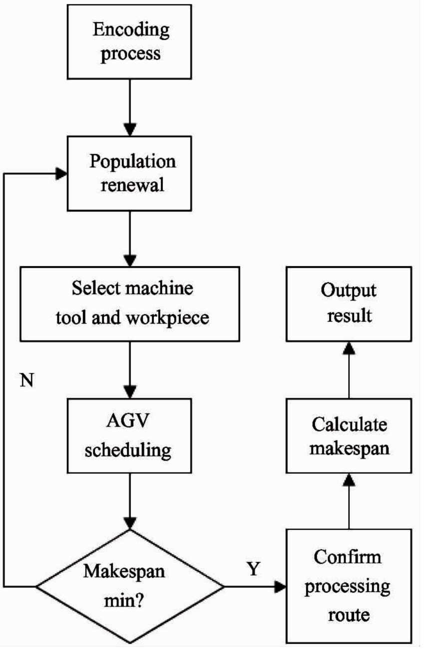


Fig. 1 Flow chart of machine tool-AGV scheduling algorithm

2.1 Encoding process

In the production scheduling process of workshop, the process set P of all the workpieces is regarded as a chromosome, and each process of every workpiece is regarded as a gene in the chromosome[9,10]. The genes are combined randomly on the condition that each workpiece is kept in the original order, and the same workpiece share the same code.

Assuming there are 4 workpieces, and each workpiece has 3 processes, then the encoding methods of one type of the chromosome can be seen from Table 1.

Table 1 Chromosome coding

Process	p_{21}	p_{11}	p_{12}	p_{31}	p_{41}	p_{22}	p_{13}	p_{32}	p_{42}	p_{23}	p_{43}	p_{33}
Encode	2	1	1	3	4	2	1	3	4	2	4	3

According to the coding sequence of chromosome, the set of chromosome can be referred as $Q = \{Q_1, Q_2, \cdots, Q_n\}$.

2.2 Confirm the fitness function

For the No. i's chromosome (Q_i) in the chromosome set Q, makespan c_i of this chromosome can be obtained based on the corresponding processing and handling time after the decoding of chromosome. Hence, the fitness function can be confirmed:

$$F(i) = T - c_i \tag{2}$$

where, T is the maximum processing and handling time of all the processes, $F(i) > 0$ should be ensured.

2.3 Selection, crossover, and mutation operation

2.3.1 Selection operation

Before population being reproduced, it is necessary to select excellent individuals to guarantee the continuation of the good genes in population[11]. The roulette method can be selected as a strategy, that is, to calculate the proportion of each individual's $f(i)$ in the entire population. Then the percentages will be ranked from low to high, and be assigned to the corresponding area according to the size of the proportion. Finally, a random number between 0 and 1 will be selected, and the individuals will be selected in the region where the random number falls into. Therefore, for any individual j, the probability of being selected is

$$P(j) = \frac{F(j)}{\sum_{i=1}^{n} F(i)} \tag{3}$$

The better the chromosome gene is, the bigger the value of the fitness function is, and the higher probability of being selected will be achieved.

2.3.2 Crossover operation

In the process of gene crossover, the parental chromosome is crossed by two and two, and the sequence of the processes in the chromosome is changed to form a new filial chromosome. Assuming that there are two parental chromosomes Q_1 and Q_2, the operation steps of the crossover operation are as follows.

1) Gene p_{ik} is randomly selected from the parental chromosome Q_1, the corresponding workpiece of this gene is referred as n_i.

2) The gene that contains n_i in Q_1 is removed, and the gene segment σ_1 is obtained.

3) The corresponding position of n_i in the parental chromosome Q_2 is found, and all gene codeshare rewritten as 0 except n_i, and the gene segment σ_2 is attained.

4) The gene fragment σ_1 is sequentially covered by the gene encoded as 0 in the gene fragment σ_2 to obtain the progeny chromosome Q'_1.

5) Gene p_{jk} is randomly selected from the parental chromosome Q_2, the corresponding workpiece of this gene is referred as n_j, the progeny chromosome Q'_2 are obtained by the above crossover operation.

The principle of crossover operation of chromosomes is shown in Fig. 2.

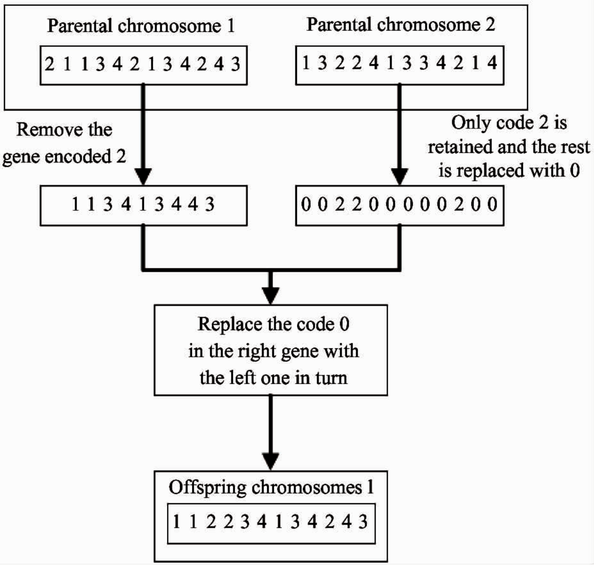


Fig. 2 The principle of crossover operation

2.3.3 Mutation operation

In the mutation operation, the processes of two different workpieces are exchanged to obtain a new chromosome while keeping the processing sequence of each workpiece constant (see Fig. 3).

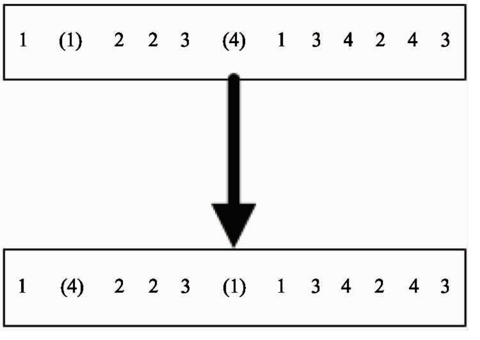


Fig. 3 The principle of mutation operation

2.4 Analysis of algorithm

In this algorithm, T_{ij} is set as the time that AGV takes the No. i's workpiece to the machine tool for the No. j's process; T_{ijs} is the start time of the No. ij's task of the AGV; T_{ije} is the end time of the No. ij's task of AGV; p_{ij} is the processing time of the No. j's process of the No. i's workpiece; s_{ij} is the start processing time of the No. j's process of the No. i's workpiece; e_{ij} is the completion processing time of the No. j's process of the No. q's workpiece; m_q is the idle time of the No. q's machine tool; a_q is the waiting time of AGV; f_i is the finish time of the No. i's iteration.

1) It can be seen from the above conditions that $T_{ije} = t_{ij} + T_{ijs}$, $T_{i1s} = 0$, $p_{ij} = e_{ij} - s_{ij}$. According to the setting of the workpiece handling priority given in the previous problem description, as well as the six sched-

uling strategies the first workpiece needs to be processed and machine tools can process are selected, thus the starting processing time of the workpiece is calculated.

2) On the basis of the starting processing time, each workpiece will select the shortest completion time ($\min e_{ij}$), machinable machine tool ($T_{ije} >= m_q$) and waiting AGV ($a_q >= 0$) for the machining task, and calculate the finish time f_1.

3) The genetic operation is performed under the condition that the handling priority is satisfied. In the iterative process of the algorithm, if $F(i) > F(i-1)$, the makespan $C = f_i$.

4) If the iteration is completed, the minimum makespan min C is minimized; if the iteration is not completed, return to step 1) to continue the iteration[12-15].

3 Simulation and analysis

Assume that there are 5 machine tools available for processing and 4 workpieces in this scheduling system. The first workpiece has three processes, the second has two, the third has four and the fourth has three processes. The processing time of each process on each machine tool is shown in Table 2 (0 indicates that the machine cannot process this process). The handling time of the AGV between the charging table and each machine tool is shown in Table 3.

The distribution of machine tools and loading/unloading area are shown in Fig. 4. The handling time of the AGV is shown in Table 3. The handling time of each adjacent loading/unloading area and machine tool is 30 s.

Table 2 Processing schedule of machine tool (min)

		m_1	m_2	m_3	m_4	m_5
n_1	p_{11}	2	0	4	0	0
	p_{12}	0	4	0	0	2
	p_{13}	4	0	0	5	0
n_2	p_{21}	2	1	4	0	0
	p_{22}	6	0	5	6	5
n_3	p_{31}	8	0	2	10	9
	p_{32}	4	5	7	6	3
	p_{33}	0	0	5	4	0
	p_{34}	7	7	0	0	6
n_4	p_{41}	7	9	0	0	8
	p_{42}	0	4	3	0	6
	p_{43}	6	4	0	6	0

Table 3 Handling schedule of AGV (min)

	Loading platform	m_1	m_2	m_3	m_4	m_5	Unloading platform
Loading platform	0	0.5	1	1.5	1	0.5	0
m_1	0.5	0	0.5	1	1.5	1	0.5
m_2	1	0.5	0	0.5	1	1.5	1
m_3	1.5	1	0.5	0	0.5	1	1.5
m_4	1	1.5	1	0.5	0	0.5	1
m_5	0.5	1	1.5	1	0.5	0	0.5
Unloading platform	0	0.5	1	1.5	1	0.5	0

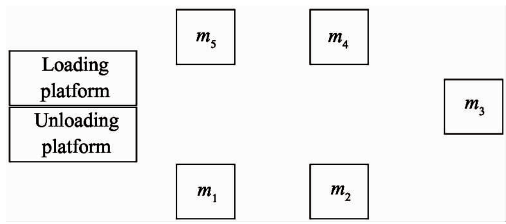


Fig. 4 Distribution map of machine tools

The initial parameters of the genetic algorithm are: population size $p_{size} = 40$, genetic algebra generation $= 50$, crossover rate $p_c = 0.8$ and mutation rate $p_m = 0.03$. It can be concluded from Tables 2 and 3 that the sum of the processing time of all processes and the handling time of the AGV is $T = 95$.

The handling priority of AGV is: the workpieces feeding to the processing center > workpieces which were finished in the processing center > the workpieces near the final process. When the priority level is the same, the workpieces will be moved according to the workpiece number from small to large.

According to the handling priority of AGV, the scheduling Gantt chart of AGV is obtained by genetic algorithm (Fig. 5).

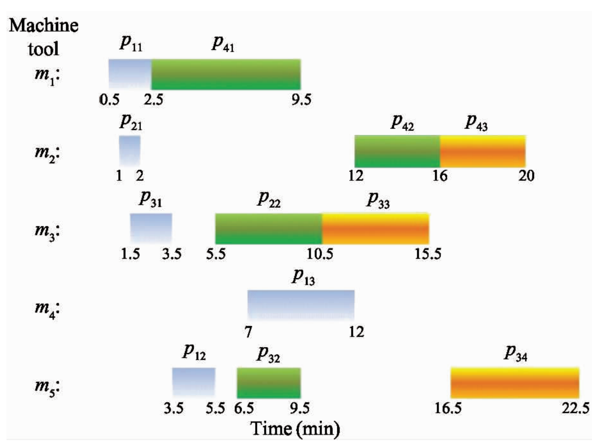
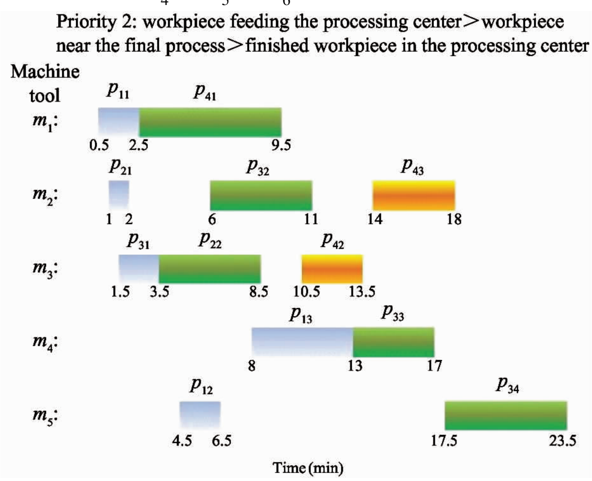


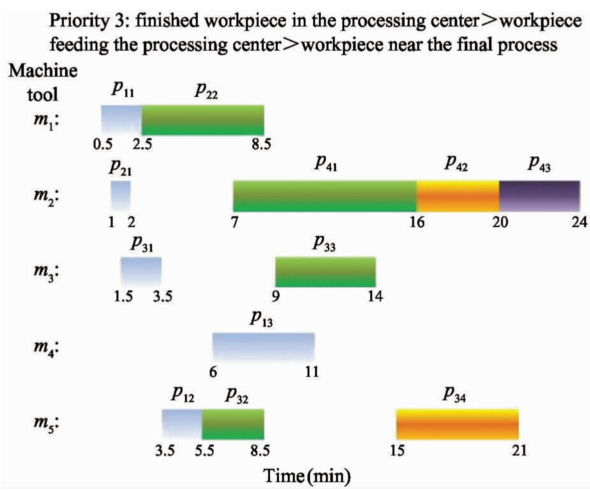
Fig. 5 Gantt chart of AGV scheduling

All the workpieces are finished in 22.5 min. The AGV takes out workpiece n_3 from machine tool m_5 and carries it to the unloading platform, so the minimum make span of the AGV is $t_1 = 23$ min. According to the handling priority of AGV, there are 6 scheduling strategies, and the Gantt chart under the other 5 priority scheduling strategies can be obtained as shown in Fig. 6(a) – (e).

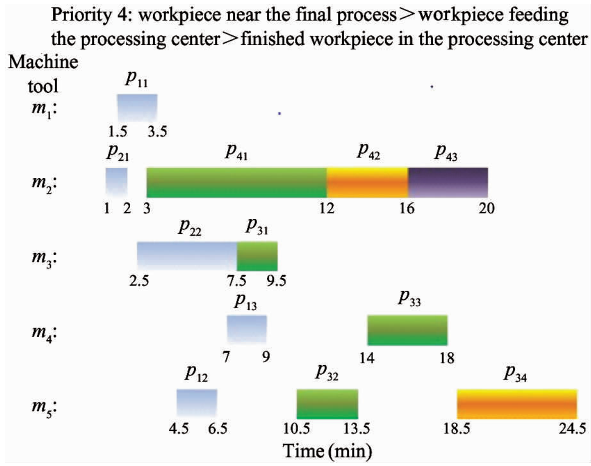
Under the scheduling strategy of priority 2, all the workpieces are finished in 23.5 min. The AGV takes out workpiece n_3 from machine tool m_5 and carries it to the unloading platform. The minimum makespan of the AGV is $t_2 = 24$ min; under the scheduling strategy of priority 3, all the workpieces are finished in 24 min, the AGV takes out n_4 from m_2 and carries it to the unloading platform, so the minimum makespan of the AGV is $t_3 = 25$ min; under the scheduling strategies of priority 4, 5 and 6, all the workpieces are finished in 24.5 min. The AGV takes out n_3 from m_5 and carries it to the unloading platform, so the minimum makespan of the AGV is $t_4 = t_5 = t_6 = 25$ min.



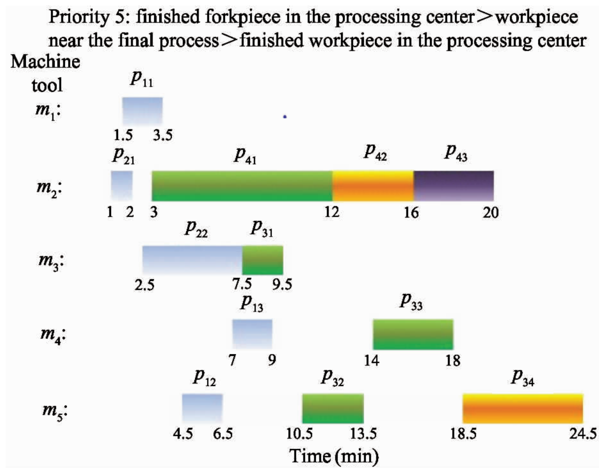
(a) Gantt chart under priority 2



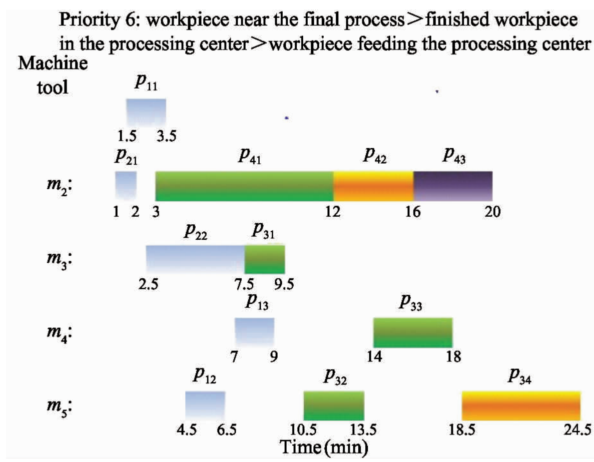
(b) Gantt chart under priority 3



(c) Gantt chart under priority 4



(d) Gantt chart under priority 5



(e) Gantt chart under priority 6

Fig. 6 Gantt chart of the other 5 scheduling policies

Therefore, the makespan of the AGV is the shortest under the priority scheduling strategy 1, so in the actual production process, workpiece feeding the processing center > workpieces which are finished in the processing center > workpiece near the final process.

According to the scheduling strategy of priority 1, the handling route of AGV is shown in Fig. 7. There are a total of 32 handling routes, the handling time of AGV is $t_d = 16$ min, the waiting time is $t_w = t_1 - t_d = 7$ min.

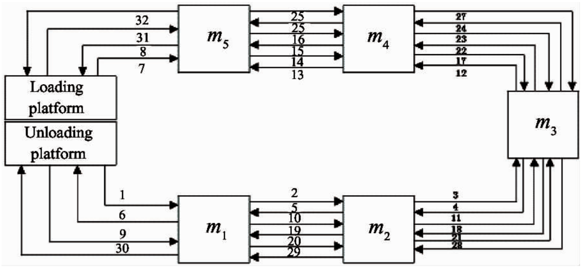


Fig. 7 The scheduling route of AGV

4 Conclusion

The genetic algorithm is used to solve the scheduling problem when a single AGV car handles multiple handling requests. In the solution process, the handling priority of AGV is added to narrow the solution range, so as to search for the optimal solution quickly. The simulation results show that the scheduling scheme of the AGV[16] can be used in small and medium flexible production lines. The influence of different priority scheduling strategies under the scheduling results of AGV also provides a possible solution for the workshop scheduling of AGV.

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