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Intelligent RGV Scheduling Model Considering Advanced Movement under Repeated Single-Cycle Jobs †

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Abstract: At present, automated material processing systems have been adopted by numerous high-tech enterprises, which mainly include Rail Guided Vehicles (RGVs) and CNC Machines. However, in the actual operation process, RGVs are generally scheduled according to the preset procedures of the system, and the lack of intelligent models considering the advanced movement does not elevate the operation efficiency of the system. In this paper, we propose an intelligent scheduling model for RGVs with advanced movement, considering all the work of the RGVs and its matching CNCs in the system within the cycle time, and verify the accuracy and superiority of the model by taking an automated material processing system of a factory as an example.

Keywords: RGV; scheduling model; advanced movement; repetitive jobs; work efficiency

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1. Introduction

Automated material processing systems have been widely used in production plants with repetitive cycle work. As presented in Figure 1a, the system can be simplified to a number of CNCs, and RGVs. The CNCs are responsible for processing the raw material while the RGVs, with 2 grippers (as presented in Figure 1b), are responsible for loading the raw material and unloading the processed material. When one of the CNCs completes its work, a completion signal is sent and the RGV moves to the designated position for loading and unloading of the raw materials In actual production activities, the RGV may have to wait due to the different completion times of each CNC process, resulting in low productivity of the system.

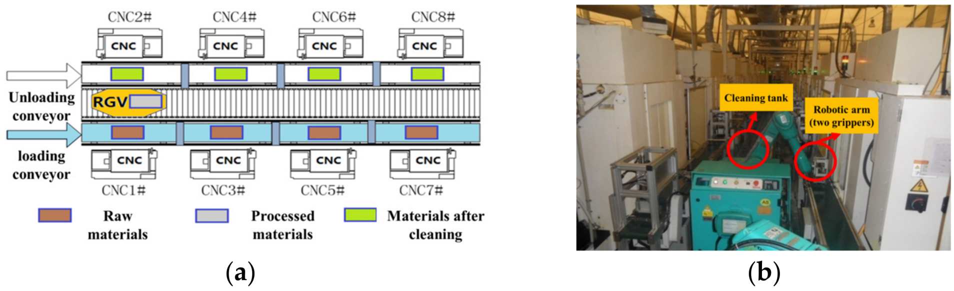


Figure 1. (**a**) Schematic diagram of an automatic material processing system. (**b**) Structure of RGV.

Therefore, how to schedule the RGV and improve the efficiency of the system is an important issue to promote high-speed development in the manufacturing industry. Liu et al. considered the impact of equipment failures on production in parallel equipment scheduling and developed a mathematical model with the objective of minimizing the maximum completion time and task lead/delay time weighting [1]. Wu et al. proposed a group transport method for dynamic scheduling of RGVs under large material flow in which a genetic algorithm was used, and a coding method was proposed for specific problems [2]. Liu et al. proposed a stochastic fault dynamic scheduling model based on the optimal path. The dynamic scheduling strategy of RGVs and the system operation efficiency are solved by example analysis [3]. Most of these research studies are focused on modeling the scheduling strategy when a fault state occurs in CNCs; however, according to statistics, in the actual production, the probability of a CNC failure at work due to fixed maintenance is less than 1%, and there are fewer research studies on how to design a model to improve the efficiency of RGVs. Therefore, this paper aims to design a model that enables RGVs to move in advance to improve the efficiency of the system.

2. Intelligent RGV Scheduling Model Considering Advanced Movement

2.1. Hypothesis

- Due to regular preventive maintenance, the probability of failure of CNCs and RGVs during the production process is extremely low;
- Only one production process is completed for each material.

2.2. Notations

The notations involved in the model and their definitions are listed in Table 1.

Table 1. Notations and their definitions within the model.

Notations	Definitions	Unit
$x_{ij} \equiv \begin{cases} 1 \\ 0 \end{cases}$	Whether the *ith* CNC is processing the *jth* material; 1 if yes, 0 otherwise.	
$w^{lr} = \begin{cases} 1 \\ 0 \end{cases}$	Whether RGV completes its left and right CNC loading and unloading work; 0 if yes, 1 otherwise.	
P	Work efficiency of the system in a single cycle.	
T_0	Processing time for each raw material.	s
λ	The time for RGV to service the entire CNC.	s
N_0	The maximum number of finished products that can be produced in the time period.	
y_i^{ud}	Loading and unloading time of the *ith* CNC single job.	s
T	Total time of the system working at once.	s
$x_i^w(j)$	Waiting time of the *ith* CNC before processing the *jth* material.	s
t_0	RGV cleaning time for a processed material.	s
t_i	RGV moves i units of distance on the track $(i = 1.2.3)$.	s
C_T	The number of CNC.	s
y_j^m	The moving time for the RGV when the CNC is processing the *jth* material.	s
y_j^w	The waiting time for the RGV when the CNC is processing the *jth* material.	s
$x_i^u(j)$	The loading start time of the *jth* material produced by the *ith* CNC.	s
$x_i^d(j)$	The unloading start time of the *jth* material produced by the *ith* CNC.	s
τ_1	Time required for one CNC loading and unloading for odd numbered CNCs.	s
τ_2	Time required for one CNC loading and unloading for even numbered CNCs.	s

2.3. Model Description

The RGV scheduling model considering advanced movement is shown below.

$$p = \max \frac{\sum_{i=1}^{C_T} \sum_{j=1}^{N_0} x_{ij}}{N_0}$$

$$
s.t.\begin{cases}
N_0 = \sum\limits_{i=1}^{C_T}\left[\frac{T}{T_0+y_i^{ud}}\right] \\
\sum\limits_{j=1}^{N_0}\left[T_0+y_i^{ud}+w^{lr}x_i^{w}(j)\right] \le T \\
\sum\limits_{i=1}^{C_T}\sum\limits_{j=1}^{N_0} x_{ij}\left[y_j^{m}+y_j^{w}+y_i^{ud}+t_0\right] \le T \\
\sum\limits_{i=1}^{C_T}\sum\limits_{j=1}^{N_0} x_{ij}y_j^{m} \ge (n_1t_1+n_2t_2+n_3t_3)\frac{N_0}{C_T} \\
\lambda = n_1t_1+n_2t_2+n_3t_3+\frac{C_T}{2}\tau_1+\frac{C_T}{2}\tau_2 \\
x_i^{u}(k+1) = x_i^{u}(k)+\lambda+w^{lr}x_i^{w}(k)+(C_T-1)t_0\left(k=1,2,\ldots,\left[\frac{N_0}{T}\right]\right) \\
x_i^{d}(k) = x_i^{u}(k+1) \\
x_i^{d}(j)-x_i^{u}(j) = x_{ij}\left[T_0+y_i^{ud}+w^{lr}x_i^{w}(j)\right]
\end{cases} \quad (1)
$$

The efficiency can be expressed as (Actual quantity of finished products) in the time period dividing by the maximum number of finished products that can be produced, which is $\frac{\sum_{i=1}^{C_T}\sum_{j=1}^{N_0} x_{ij}}{N_0}$, where N_0 is denoted as $\sum_{i=1}^{C_T}\left[\frac{T}{T_0+y_i^{ud}}\right]$. As the working contents of CNCs and RGVs are different, the working time of CNCs includes the manufacturing process, loading, unloading and waiting time, while the working time of RGVs only includes the loading, unloading, moving, waiting time; therefore, the working time of CNCs and RGVs needs to be constrained separately according to the actual system working time. These two constraints are reflected in $\sum_{j=1}^{N_0}\left[T_0+y_i^{ud}+w^{lr}x_i^{w}(j)\right] \le T$ and $\sum_{i=1}^{C_r}\sum_{j=1}^{N_0} x_{ij}\left[y_i^{m}+y_j^{w}+y_i^{ud}+t_0\right] \le T$. In a single-cycle multi-cycle working time, the time used in each cycle can be found and then the relationship between the unloading time of each CNC and the loading time of the next CNC can be established to dynamically represent the process of change; they are $x_i^{d}(k) = x_i^{u}(k+1)$ and $x_i^{d}(j)-x_i^{u}(j) = x_{ij}\left[T_0+y_i^{ud}+w^{lr}x_i^{w}(j)\right]$. When the RGV completes the existing work, it will evaluate the received signal strength (the default judgement factors change the greater the signal, the greater the distance, the stronger the signal), and it will choose the CNC with the stronger signal for service, which saves the cost of waiting time for the RGV, and reduces the proportion of the system's moving time for the RGV. Using the unique constraints of the above model, the dynamics of the system over a cycle can be modelled using MATLAB.

3. Numerical Examples

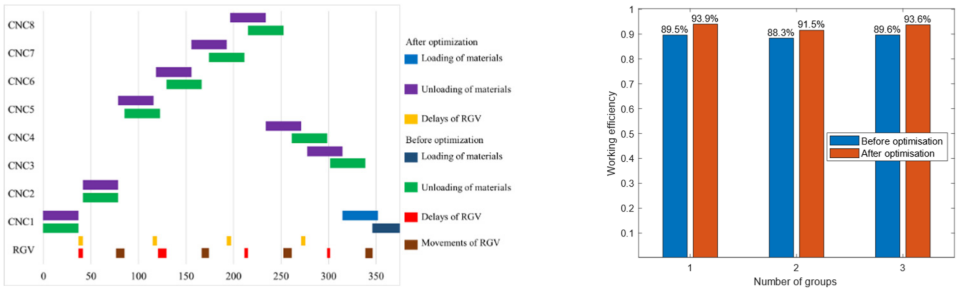
In order to test the improved model, three sets of operational parameters of an automated material processing system of a high-tech enterprise were collected in this paper, as presented in Table 2. The existing model without considering advanced movement [4] was compared; the comparison results are presented below.

Table 2. Three sets of data for the operating parameters of the intelligent processing system (Unit: s).

System Operation Parameters	Group 1	Group 2	Group 3
The time for an RGV to move 1 unit (t_1)	20	23	18
The time for an RGV to move 2 units (t_2)	33	41	32
The time for an RGV to move 3 units (t_3)	46	59	46
The time for a CNC to complete a one-step material (T_0)	560	580	545
Time required for one CNC loading and unloading for odd numbered CNCs (T_1)	400	280	455
Time required for one CNC loading and unloading for even numbered CNCs (T_2)	378	500	182
The time for an RGV to complete the cleaning operation of a material (t_0)	28	30	27

Note: The data were obtained from the literature [4].

The parameters are brought in, and the model is solved to obtain the optimal movement route of the RGV in a single cycle: 1,2→3,4→7,8→5,6→1,2. The comparison of the working process and efficiency of the system before and after optimization is shown in Figure 2a,b.



(**a**) (**b**)

Figure 2. (**a**) Gantt chart of the system working before and after optimization. (**b**) The total efficiency of the system before and after optimization in terms of working time.

As can be clearly seen in Figure 2, the movement time of the RGV becomes less after optimization, leaving only the unoptimizable waiting time (due to the rotation of the mechanical gripper of the RGV), At the same time, the three sets of data collected throughout the working time are brought into the model and the calculated productivity increases are all above 90%. These 5% increases in efficiency are formally due to the reduction in wait times and excess movement time of the RGV.

4. Conclusions

In response to the low production efficiency in the RGV scheduling process, an intelligent RGV scheduling model considering advanced movement is designed. The feasibility of the model is verified based on data provided in an actual factory production, and it is found that the production cycle time is shortened, and efficiency is improved.

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