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Research on Online Scheduling Method for Flexible Assembly Workshop of Multi-AGV System Based on Assembly Island Mode

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Abstract: In the context of intelligent manufacturing, traditional batch assembly line operations are difficult to meet the individualized and customized needs of customers. Aiming at the scheduling problem of flexible assembly workshop, this paper proposes a new assembly mode—assembly island mode, combined with multiple AGV systems, to meet the individual and customized needs of customers. Aiming at the uncertain characteristics of actual production, this paper proposes an online scheduling method for the assembly workshop of multiple AGV systems based on the static scheduling of the workshop, which is more suitable for the actual production process. In this paper, the online shop scheduling problem is decomposed into the assembly island allocation sub-problem and the AGV scheduling sub-problem to study. In the modeling of the assembly island allocation sub-problem, the AGV transportation system load is taken as part of the objective function to build the model. On the AGV scheduling sub-problem, the AGV system's anti-deadlock strategy is set, and the AGV scheduling method based on the task benefit value is proposed to solve the AGV task allocation problem. Finally, through simulation experiments, the feasibility and efficiency of the online scheduling method are verified.

Keywords: Flexible assembly workshop, multiple AGV system, task allocation, online scheduling

1 Introduction

The rapid increase in commodity diversification, customized demand and the continuous shortening of product life cycles make traditional rigid assembly workshops no longer suitable for modern production methods.

On the scheduling problem of multiple AGV system workshops, Hamed Fazlollahtabar proposed a two-stage optimization method to reduce penalties in advance and late [1]. Ghasemzadeh established a conflict-free scheduling and path model based on the mesh topology [2]. For the AGV scheduling problem with charging constraints, Maryam Mousavi et al. solved it by combining genetic algorithm and particle swarm algorithm [3]. Lixi Yang aimed at the algorithm design of FJSP, improved the initialization strategy, and got a better scheduling scheme of FJSP. However, the author only considered the transportation time of the process processing, and did not consider the scheduling of the transportation vehicle AGV [4]; Chuanze Long improved genetics The algorithm solves the flexible manufacturing system scheduling problem, but the number of AGVs considered by the author is too small [5]. Aiming at the scheduling problem of flexible job shop with AGV, Changzheng He and others established a dual-resource scheduling model of AGV and machine, and designed a three-chain coding structure [6]. Sainan Liu and others have studied the scheduling mechanism and path selection of AGV in depth, and have achieved relatively good results in AGV path planning and task allocation [7-8]. Aiming at the simultaneous scheduling of machine tools and automated guided vehicles in flexible job workshops, Haining Xiao proposed heuristic scheduling schemes and anti-deadlock strategies.

The current research on the problem of flexible assembly workshops is mainly focused on the problem of static scheduling in the workshop. Usually, the literature is optimized by selecting certain options of production scheduling, station allocation, AGV task allocation and AGV path selection, and most of the studies have separated machine scheduling and AGV path planning, ignoring the artifacts caused by car collisions or path conflicts. This article comprehensively considers the internal relationship between the assembly system and the handling system. Aiming at many dynamic events that may occur in the actual production workshop, such as machine failure, temporary order insertion, workpiece delay, etc., an online scheduling method is proposed, which greatly increases production logistics. And online scheduling is more in line with the actual production process.

2 Problem description and model building

2.1 Problem Description

The research in this paper is based on the situation that the layout has been determined, and the road network layout of literature [9] is selected, which can minimize the congestion phenomenon. As shown in Figure 1, the flexible workshop is composed of an assembly subsystem and a handling subsystem. Workpieces enter from the total input buffer area and output from the total output buffer area after assembly. M1 to M10 are assembly islands. The handling subsystem is composed of a unidirectional guide path network and several AGVs.

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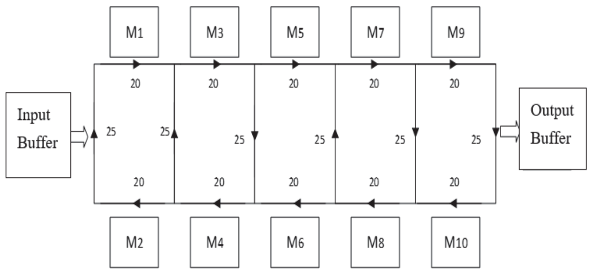

Figure 1 Multi-AGV system flexible workshop layout

In this paper, the problem is decomposed into the sub-problem of assembly island allocation and the sub-problem of AGV scheduling for research. The assembly island allocation sub-problem can be described as: In the assembly workshop, there are M assembly islands, N workpieces need to be assembled, each type of workpiece to be assembled has j procedures, and there are N×j assembly procedures in the entire system. Each workpiece can be assembled on at least 2 assembly islands, and the assembly time varies with assembly islands. The transportation system of the workshop is a multi-AGV system. The transfer of workpieces between assembly islands is completed by the AGV system. The AGV transportation time between different assembly islands is determined by the transportation distance. By minimizing the load of the AGV system and the load of a single assembly island of the assembly system and the balance of the assembly system, the problem of assembly island allocation and workpiece sequencing is solved.

2.2 Model building

According to the problem description, taking the load of the AGV handling system into account for the distribution of the assembly island, the construction model is as follows:

The objective function f for the assembly island sub-problem is:

$$\min f = \partial_1 f_1 + \partial_2 f_2 + \partial_3 f_3$$

∂_1、∂_2、∂_3 are weight coefficients. (1)

Restrictions:

$$s_{ij} + p_{ijk} \times x_{ijk} \le C_i \quad (2)$$

$$C_{ij} \le S_{i(j+1)} \quad (3)$$

$$S_{i1k} + L(1 - x_{i1k}) \ge 0 \quad (4)$$

$$C_i \le C_{\max} \quad (5)$$

$$s_{ij} + p_{ijk} \le S_{el} + L(1 - y_{ijekl}) \quad (6)$$

$$C_{ij} \le S_{i(j+1)} + L(1 - y_{iekl(j+1)}) \quad (7)$$

$$\sum_{k=1}^{m} x_{ijk} = 1 \quad (8)$$

$$T_{r(d+1)s} \ge T_{rde} \quad (9)$$

$$T_{rde} - T_{rds} = Trans_{kv} \quad (10)$$

$$f_1 = \max(C_M) \quad (11)$$

$$f_2 = C_{avg} + \frac{1}{N_m} \sum_{m=1}^{N_m} \sqrt{(C_m - C_{avg})^2} \quad (12)$$

$$f_3 = k_{ul} \frac{C_{Veh}}{N_G} \quad (13)$$

Variable definitions is shown in Table I :

Table I Variable definitions

variable	definition
i,e	the serial number of the work piece, the total pieces is N
k,v	serial number of the assembly island, the total assembly islands is M
j,l	the number of process
O_{ij}	the j-th process of the i-th workpiece
S_{ij}	the time when the j-th process of i-th workpiece starts to be assembled
C_{ij}	the time when the j-th process of i-th workpiece is assembled
C_i	the completion time of the i-th workpiece
$C_{\max}$	the maximum completion time of all processes
p_{ijk}	the assembly time of the j-th process of i-th workpiece on the k-th assembly island
T_{rds}	the start time of the *r-th* AGV transportation *d-th* task (*r=1,2,...,g* *g* is the total number of AGVs; *d=1,2,...u* *u* is the total number of AGV tasks)
T_{rde}	the start time of the *r-th* AGV transportation *d-th* task (*r=1,2,...,g* *g* is the total number of AGVs; *d=1,2,...u* *u* is the total number of AGV tasks)
$Trans_{kv}$	AGV transportation time, determined by the adjacent assembly island k and assembly island *v* transported by the AGV
x_{ijk}	decision variable, when O_{ij} selects the assembly island k, $x_{ijk} = 1$, otherwise $x_{ijk} = 0$
y_{ijkel}	decision variable, on the k assembly island, when the process O_{ij} precedes the process O_{el} , $y_{ijkel} = 1$, otherwise $y_{ijkel} = 0$
L	A very large positive number. When the sum and two decision variables are 0, the inequality is guaranteed to be true
C_M	The assembly time of the assembly island M, the load is defined as the assembly time of the assembly island

f_1	the maximum load of a single assembly island
f_2	Load imbalance of the assembly island. The smaller the balance, the smaller the load difference between the assembly islands
f_3	handling subsystem load
k_{ul}	AGV no-load total distance/load total distance, usually 1.2-1.8
N_G	The number of AGVs in the handling subsystem
C_{Veh}	The total handling time required for all the workpieces to be moved

3 Research on AGV Scheduling Sub-problem

3.1 AGV scheduling problem policy setting

(1) Mechanism for triggering AGV task scheduling

This article uses a combination of cycle and event to trigger AGV scheduling. The trigger cycle is T_{s2}. The event is defined as an AGV scheduling process that will be triggered immediately when the assembly island allocation is completed.

(2) Determine idle AGV and handling tasks

All workpieces in the output buffer that have been allocated to the assembly island and not yet allocated to the AGV are used as tasks to be transported. and they are recorded as set Y_A, and the schedulable AGV is defined as all the idle AGVs in the system, and all the schedulable AGVs form a set $Y_{(agv)}$.

(3) Rules to prevent system deadlock

During the operation of the system, system blockage and deadlock will greatly affect the operating efficiency of the system. This paper uses the remaining capacity of the assembly island to determine the blocking state of the AGV. The remaining capacity $U_{(m)}$ of the assembly island M_m is defined as fllows.

$$U_{(m)} = X_{in(m)} + X_{out(m)} + L_{out(m)} + 1 - x_{in(m)} - x_{out(m)} - L_{in(m)} - P_{(m)} \quad (14)$$

Variable definitions is shown in Table II :

Table II Variable definitions

variable	definition
$X_{in(m)}$	Total capacity of the input buffer area of the assembly island
$X_{out(m)}$	The total output buffer capacity of the assembly island *m*
$L_{out(m)}$	The number of workpieces that have been assigned AGV but have not left the assembly island *m*
$x_{in(m)}$	The number of workpieces in the input buffer
$x_{out(m)}$	The number of workpieces in the output buffer
$L_{in(m)}$	The number of workpieces that have been assigned AGV but have not yet reached the assembly island m
$P_{(m)}$	The number of workpieces being processed on the assembly island *m*, when it is being processed, it is 1, otherwise it is 0

A blocked AGV can be defined as the AGV that has accepted the handling task but the remaining capacity the target assembly island i $U_{(m)}$<0. If all the AGVs in the handling system are in a blocked state, the assembly system will always be unable to obtain the released space. This state is called a system deadlock.

3.2 AGV scheduling method based on task benefit value

In the work process of the handling subsystem, different tasks have different effects after execution, so the tasks carried need to be quantified: they are recorded as T_{ij}; calculate the attributes of each task and record them as task attributes $p(P_i, E_j)$ (P_i is the workpiece, loading point of the starting assembly island, and E_j is the task unloading point of the target assembly island).

For the assembly island, the capacity of its input buffer and output buffer is limited. If the handling task T_{ij} is not executed in time, then the initial assembly island M_i will be blocked because the output buffer has no remaining capacity, or the target assembly island M_j will be blocked due to The input buffer has no workpiece input and is always in an idle state. These two situations will greatly reduce the assembly efficiency of the assembly subsystem. Therefore, this paper uses the state of the input and output buffers to predict when the assembly island will be idle or blocked, so as to quantify the urgency of the task to be transported.

First determine the index of the distance to the idle state of the assembly island as $F_{(m)}$:

$$F_{(m)} = \frac{x_{in(m)} + L_{in(m)}}{X_{in(m)}} \quad (15)$$

Assembling island distance blockage indicator $B_{(m)}$:

$$B_{(m)} = \begin{cases} 1 (U_{(m)} > X_{in(m)}) \\ \dfrac{X_{out(m)} - x_{out(m)} + L_{out(m)}}{X_{out(m)}} (others) \end{cases} \quad (16)$$

The task attribute $p(P_i, E_j)$ is:

$$p(P_i, E_j) = \min(B_{(i)}, F_{(j)}) + \frac{\max(B_{(i)}, F_{(j)})}{10} \quad (17)$$

$B_{(i)}$: The index that indicates the distance blockage of the starting assembly island of the task

$F_{(j)}$: The indicator that the distance to the target assembly island of the task is free

In order to improve the efficiency of the handling subsystem, it is necessary to reduce the no-load distance of the AGV during the handling process.

Assume that the set $Y_{(agv)}$ of idle AGVs is:

$$Y_{(agv)} = \{agv_1(E_k),...,agv_R(E_v)\} \tag{18}$$

R: the number of idle AGVs

E_k , E_v : The parking place of idle AGV

According to the deadlock avoidance rules, remove the tasks that caused the deadlock, and the remaining tasks to be moved are set as

$$Y_a = \{T_{kv}^1,...,T_{vm}^{N_m}\} \tag{19}$$

N_m : Indicates the number of tasks to be transported

Then the benefit value I_{ij} between the idle AGV and the task to be transported T_{ij} is:

$$I_{ij} = \varphi d_{ij} + p(P_i, E_j) \tag{20}$$

d_{ij} : The location where the idle AGV is located is the shortest directed distance from the loading point of the handling task.

φ : Coefficient, used to unify the dimensions of the two sub-functions.

By determining the task benefit value between the idle AGV and the task to be carried, selecting the task with the smallest task benefit value and assigning it to the corresponding AGV can improve the efficiency of the handling subsystem.

3.3 Multi-AGV system scheduling process

Figure 2 shows the scheduling flowchart of the multi-AGV system. The scheduling process as shown in Figure 2:

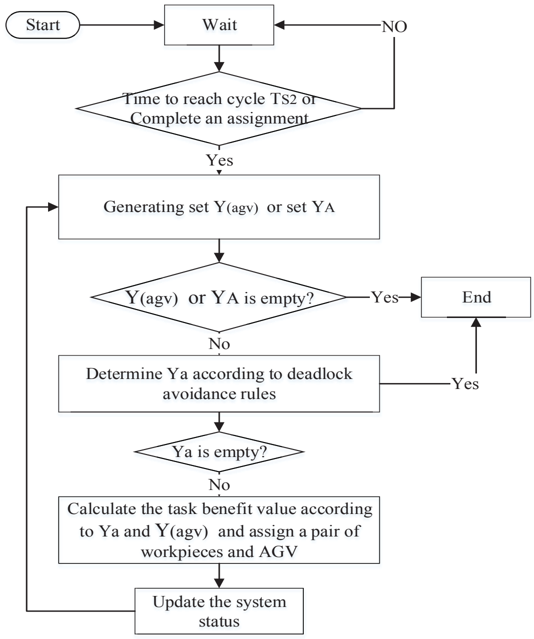

Figure 2 AGV subsystem scheduling flowchart

4 Simulation and result analysis

As shown in Figure 3, a simulation model is built using Siemens' Plant Simulation software.

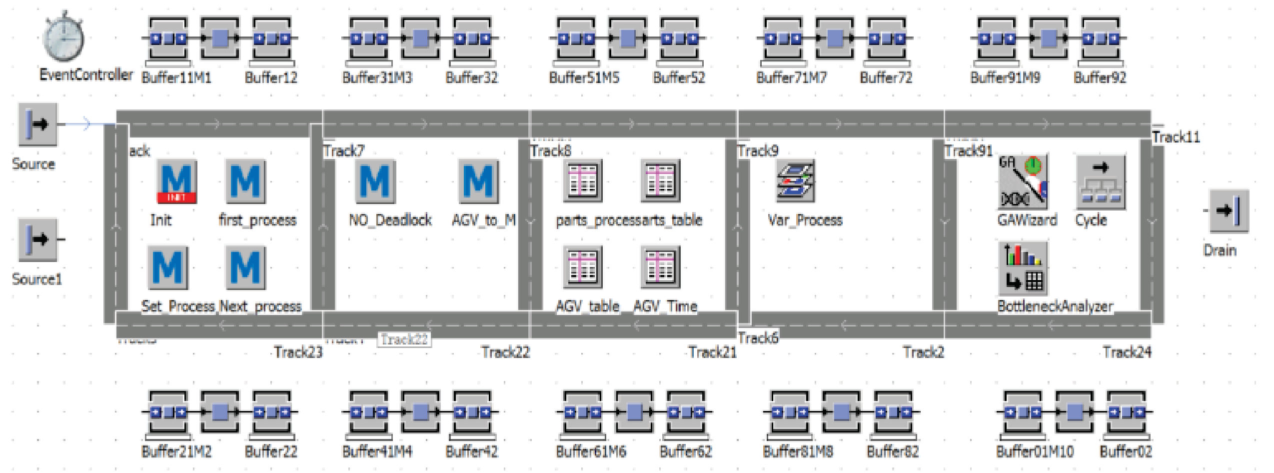

Figure 3 Online scheduling simulation interface

According to the initial experimental data of static scheduling and the design of the comparative test [10]. The parameter settings of each module of the online scheduling model are as follows, AGV operating speed is 1m/s, scheduling period $T_{s1} = T_{s2} = 30s$, buffer capacity is set to 3, and AGV task scheduling adopts deadlock avoidance rules. In order to avoid the influence of the number of AGVs on the online scheduling effect, there are four groups of experiments with the number of AGVs of 3, 6, 9, and 12 set up. The simulation settings are also set to arrive in batches according to the workpieces, and the number of each batch is set to 6. After the simulation runs for 24 hours, the production performance indicators between 12 hours and 24 hours are counted.

Through the statistics of 12h simulation experiment data, the resource utilization rate of the assembly island when the handling system is four different numbers of AGVs is calculated. As shown in the broken line graph in Figure 4, it can be seen from the figure that when the number of AGVs is large, the assembly island's Resource utilization is high and relatively balanced. In addition, according to the online scheduling experiment data, the average load of the assembly island, the balance rate of the assembly subsystem, and the average number of workpieces output per hour of the four experimental results are also calculated, and compared with the static scheduling indicators, such as Table Ⅲ shows.

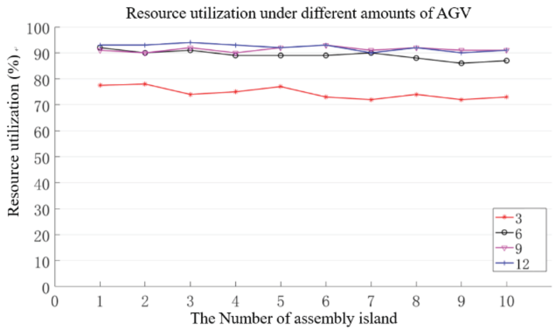

Figure 4 Resource utilization of different AGVs

Table Ⅲ Variable definitions

Scheduling type	Output artifacts per hour on average	η_{AVG}	η_{bl}
Online scheduling（3 AGVs）	9．67	0.75	1.86%
Online scheduling（6 AGVs）	12．50	0.89	1.32%
Online scheduling（9 AGVs）	12．67	0.91	1.02%
Online scheduling（12 AGVs）	12．75	0.92	1.12%
Static scheduling（enough AGVs, Ideal state）	12．91	0.92	1.16%

Since the result of static scheduling is the result of ignoring the congestion in the AGV transportation process, it is the result of the flexible assembly scheduling workshop in an ideal state, and the final static scheduling simulation data is better than the result of online scheduling, but its ability to respond to external dynamic events is poor. Compared with static scheduling, online scheduling has higher flexibility. When external dynamic events occur, the scheduling plan can be adjusted in time, and AGV congestion and congestion are considered during the scheduling process, and the scheduling results are slightly worse than the ideal state. Under static scheduling. When the number of AGVs is sufficient, the utilization of assembly resources in the online scheduling situation has also reached a high level, which proves that online scheduling is very feasible.

5 Conclusions

Aiming at the diversified customer needs and the limitations of traditional assembly lines, this paper adopts the idea of modular assembly and proposes an online scheduling model of flexible assembly workshop based on assembly island mode, which can realize the goal of flexible assembly of multiple varieties and cross stations. It has great practical significance and application significance. Based on the static scheduling problem of flexible assembly workshop that the author has studied before, this paper conducts multiple sets of simulation experiments on the online scheduling model to evaluate the overall efficiency of the assembly workshop and the balance of the system. And by setting up different numbers of AGVs, to study the influence of the number of AGVs on the assembly system. Finally, the comparison between the online scheduling simulation results and the static scheduling effect proves the feasibility and efficiency of the online scheduling method.

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