AN AGV SCHEDULING ALGORITHM FOR SMART WORKSHOPS WITH LIMITED LOGISTICS CAPACITY

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ABSTRACT: AGV (Automatic Guided Vehicle) is a key equipment for the material transportation in smart workshops, the scheduling of AGV is an important link of resource logistics, and a reasonable scheduling plan is an important means to ensure fast and effective operations of the smart workshops. This study took a Tablet PC manufacturing workshop as an example to study the AGV scheduling algorithm of smart workshops; the paper analyzed the structure of the Tablet PC manufacturing workshop and related issues, constructed a simulation platform for the AGV scheduling problem of smart workshops and proposed a Window scheduling rule based on soft time windows; moreover, this paper applied the constructed simulation platform and comparative analysis method to compare the effects of the proposed rule with other four commonly used scheduling rules, and the simulation results suggested that, although under the five rules, the differences in equipment and AGV utilization were not significant, the equipment utilization and product output of the workshop under the proposed rule were the highest, and the equipment starving time and the maximum completion time were the shortest, its comprehensive performance outperformed the other four rules, which had verified the effectiveness of the proposed scheduling rule.

KEYWORDS: smart workshop, Automatic Guided Vehicle (AGV), Window rule, simulation analysis

1 INTRODUCTION

The manufacturing industry is an important indicator of a country’s industrial level. As science and technologies are developing constantly, the manufacturing industries of all countries in the world are transforming, upgrading and becoming more intelligent; moreover, the competition in the manufacturing industry is becoming increasingly fierce, and China has announced the intelligent manufacturing as an important part of its national strategy, the “Made in China 2025” plan.

In China, consumer electronics are upgrading frequently in recent years. For 3C (Computer, Communication and Consumer products) manufacturing companies, shortening the order response cycle is a key factor to win in the fierce market competition. Besides mobile phone, Tablet PC is another mobile communication device that is very popular among people, and its market demand is expanding day by day. The manufacturing of tablet shells has the characteristics of fast takt time and long product alternation cycle, which is a kind of typical labor-intensive and volume-produce manufacturing industry (Hidehiko & Takayoshi, 2010). Smart workshops usually have automated logistics storage and transportation systems composed of many intelligent equipment and AGVs, which can improve handling efficiency, reduce production and transportation costs and save manpower (Zou et al., 2020), therefore, smart workshop is an inevitable development trend of 3C manufacturing enterprises in the future. However, under such manufacturing mode, it’s required that the scheduling of smart workshops should be more accurate and reasonable. As the key equipment for material transportation in smart workshops, whether the scheduling of the AGVs is reasonable or not directly affects the utilization of the production resources of the system (Christensen & Lind, 1993). Therefore, a reasonable AGV scheduling plan is an important guarantee for the fast and effective operation of smart workshops.

The task scheduling and path planning of AGVs are the two main issues in AGV system optimization (Hao et al., 1996). Researchers divide AGV path planning into two types: dynamic planning and static planning (Dai, 2009). In terms of dynamic planning, some scholars used the idle time window and reserved time window of the nodes to plan the motions of the AGVs, and some scholars used artificial intelligence, meta-heuristics, simulation, mathematical optimization, and other methods to solve the path planning problem (Xu et al., 2019). In terms of static planning, scholars mostly made improvements based on the Dijkstra
shortest path algorithm and proposed a few accurate solutions (Mekni et al., 2010). In terms of AGV task scheduling, many scholars used indicators such as AGV handling distance and minimal time limit to research the AGV task scheduling of workshops or flexible manufacturing systems (Rabelo & Camarilha-Matos, 1998); they used genetic algorithm, improved genetic algorithm, fuzzy decision-making algorithm, two-stage heuristic algorithm, and other algorithms to establish the corresponding AGV job scheduling models to solve the AGV task scheduling problem (Chen & Lee, 2008).

Based on above analysis and literature review, this paper took a Tablet PC manufacturing workshop as an example to study the AGV scheduling problem of smart workshops; it constructed a simulation platform for the AGV scheduling problem of smart workshops and proposed a Window scheduling rule based on soft time windows; then the paper used comparative analysis to verify the effectiveness of the proposed rule.

2 THE AGV SCHEDULING PROBLEM IN SMART WORKSHOPS

2.1 Composition of smart workshops

The manufacturing of tablet shells includes multiple processing procedures; generally, each smart workshop is responsible for the processing of a certain procedure, after the processing is completed, it’s transferred to the next smart workshop to continue the processing of the next procedure. Generally speaking, a number of automated manufacturing cells and an automated material storage and transportation system are the two important components of a smart workshop (Wang & Lee, 2010). Figure 1 shows the composition of a typical smart workshop. The workshop adopts a single loop layout, which makes the AGV system easier to be scheduled and has better scalability. The design of the stop fork road in front of the cell conveyor and the single loop can effectively reduce traffic jams and deadlocks.

![Diagram](image_url)

**Fig. 1 Composition of a typical smart workshop**

Loading area, unloading area, automated manufacturing cells, transport unit and parking lot together constitute an intelligent manufacturing system with an AGV material storage and transportation system. Table 1 shows the specific functions of each area.

<table>
<thead>
<tr>
<th>Composition</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading area</td>
<td>workpieces enter the manufacturing system through the loading area, where they wait for AGVs to move them to the manufacturing cells.</td>
</tr>
<tr>
<td>Automated manufacturing cells</td>
<td>(1) Manipulator: used for handling and unloading workpieces.</td>
</tr>
<tr>
<td></td>
<td>(2) Conveyor: a buffer with a capacity of 2, it can effectively improve the production efficiency of the cell.</td>
</tr>
<tr>
<td></td>
<td>(3) CNC machine tools: workpiece processing tools, this paper targets at non-equal parallel units, so the number of machine tools varies among 4, 6, 8</td>
</tr>
<tr>
<td>Transport unit</td>
<td>(1) AGV: transport material resources within a single process</td>
</tr>
<tr>
<td></td>
<td>(2) Forklift: transport material resources between adjacent processes</td>
</tr>
<tr>
<td>Unloading area</td>
<td>When processing is completed, workpieces leave through the unloading area</td>
</tr>
<tr>
<td>Parking lot</td>
<td>Start and stops points of AGVs when completing handling tasks in the process</td>
</tr>
</tbody>
</table>

2.2 Problem description

The working cells adopt a two-bin system. When the work has just started, the AGV is responsible for material loading of working cells until the conveyors of all working cells have two trays at work; at this time, AGVs are in an idle state, the system will scan the task list regularly, when workpiece processing of a tray is completed, the system will dispatch an idle AGV to load or unload the cell; when an AGV has completed the handing of all trays in the loading area, it will transport the completed trays to the unloading area. Through analysis we now know that, during AGV scheduling, there is an association coupling effect among the limited logistic resources, production and processing, and material storage and transportation, and there are differences in working cell processing capacity and material transportation time. To facilitate problem simulation and modeling in subsequent research, this paper assumed that each
AGV is identical; under load and unload conditions; the speed of AGVs is the same; the routes of the AGVs are determined; AGVs won’t collide during operation; each task can only be executed by one AGV; each AGV can only perform one task at a time.

3 SIMULATION AND MODELING OF AGV SCHEDULING ALGORITHMS

3.1 Simulation model

To verify the effectiveness of the AGV scheduling algorithms, based on actual smart workshop environment and production scenarios, this paper constructed a simulation platform for the smart workshop AGV scheduling algorithms; this platform was built using the Plant Simulation software developed by Siemens.

3.1.1 Parameter setting

After investigating the manufacturer of the tablet PC shells, according to the actual situations of the company, the main parameters of the smart workshop simulation model were set, as shown in Table 2.

Table 2. Main parameters of the simulation model

<table>
<thead>
<tr>
<th>Number of four-machine cells</th>
<th>12</th>
<th>Number of processing equipment</th>
<th>255</th>
<th>Robot speed</th>
<th>1.5m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of six-machine cells</td>
<td>15</td>
<td>Tray loading capacity</td>
<td>8</td>
<td>AGV speed</td>
<td>1.5m/s</td>
</tr>
<tr>
<td>Number of eight-machine cells</td>
<td>15</td>
<td>Conveyor capacity</td>
<td>2</td>
<td>Cell loading and unloading time</td>
<td>16s</td>
</tr>
<tr>
<td>Number of robot cells</td>
<td>42</td>
<td>Processing time</td>
<td>10min</td>
<td>Machine loading and unloading time</td>
<td>8s</td>
</tr>
</tbody>
</table>

3.1.2 AGV scheduling rules

Reasonable scheduling rules are very important for the scheduling of smart workshops. Based on the actual situations of smart workshops, this paper proposed 5 AGV scheduling rules, as shown in Table 3. In these rules, only the Window rule based on soft time windows is a rule based on multiple indicators, and it has considered the differences in the processing capacity and distance of the robot cells; the other four rules, Random, SPT, Nearest and Farthest, are common AGV scheduling rules based on a single indicator.

Table 3. AGV scheduling rules

<table>
<thead>
<tr>
<th>Rule name</th>
<th>Scheduling rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random</td>
<td>Random Service Robot Unit</td>
</tr>
<tr>
<td>SPT</td>
<td>Give priority to robot cells with more equipment, $S &gt; 6 &gt; 4$</td>
</tr>
<tr>
<td>Nearest</td>
<td>Give priority to the robot cells that are close to the loading area</td>
</tr>
<tr>
<td>Farthest</td>
<td>Give priority to robot cells far from the loading area</td>
</tr>
<tr>
<td>Window</td>
<td>Give priority to robot cells with earlier lower limit of the service time window</td>
</tr>
</tbody>
</table>

When assigning AGV tasks, this paper adopted the principle that gives priority to AGV that arrives and waits at the station earlier, and it defined the concept of soft time window $(ET_i, LT_i)$. Under the soft time window, the goal of scheduling is to have AGVs respond to the handling tasks as much as possible within the soft time window, avoiding cell idle.

\[
ET_i = R_i \tag{1}
\]

\[
LT_i = S_i - H^\prime_i - L_i \times 3 \tag{2}
\]

where, $L_i$ is cell loading/unloading time, $S_i$ is work stop time, $R_i$ is cell request handling time, $H^\prime_i$ represents the time it takes for the AGV from responding to task $i$ until delivering materials to cell $c$.

Figure 2 shows the specific steps of the Window rule algorithm in the simulation model.

\[
S_i = R_i + CT_3^c \tag{3}
\]

\[
S_i = BP_i^c + CT_5^c \times r_k \tag{4}
\]

where, $p$ is the tray number, $k=(4, 6, 8), r_k$ is the correction coefficient of Type-k cells, $BP_i^c$ is the processing start time of tray $p$ which had assigned the task $i$, $CT_2^c$ and $CT_4^k$ represent the cell production cycles of Type-k cells when the number of on-shift AGVs is 2 and 14, respectively.
3.2 Simulation results

3.2.1 Utilization of equipment and AGVs

The simulation was carried out under the conditions listed in Table 4, and the results showed that there’s not much difference in the utilization of equipment and AGVs under the five scheduling rules. Therefore, this paper took the Random scheduling rules as an example to analyze its impact on the utilization of equipment and AGVs. Figure 3 shows the statistics of equipment utilization of 4-machine, 6-machine and 8-machine cells, it can be seen from the figure that, the equipment utilization of 6-machine cells was quite close and it showed an upward trend; as for 4-machine cells and 8-machine cells, the equipment utilization was remained the same. Figure 4 shows the statistics of AGV utilization, the figure suggested that under the Random scheduling rule, the utilization of each AGV was not that different.

### Table 4. Experimental conditions

<table>
<thead>
<tr>
<th>Number of orders</th>
<th>Number of AGVs</th>
<th>Number of machines in the cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>35000</td>
<td>12</td>
<td>4 6 8</td>
</tr>
</tbody>
</table>

3.2.2 Comparison of AGV scheduling rules

The simulation results showed that under the 5 scheduling rules, the equipment utilization and product output of the workshop under the Window rule were the highest, and the equipment starving time (the equipment is idle and waiting for workpiece) and maximum completion time were the shortest; as for the Nearest rule and the Farthest rule, the equipment utilization and product output were the lowest, and the maximum completion time was the longest; in terms of the SPT rule, the production efficiency was good, but the cells were not evenly utilized; under the Random rule, the production efficiency was average. Generally speaking, the performance of the Window rule proposed based on soft time windows and multiple indicators was the best. Figures 5-8 show the comparative analysis of different indicators under the 5 scheduling rules.
4 CONCLUSION

This paper took the manufacturing of tablet PC shells as an example to study the AGV scheduling algorithms of smart workshops with limited logistics capacity. The specific conclusions are as follows:

(1) This paper analyzed the structure of a typical smart workshop, described related issues, and gave assumptions, which laid a basis for the simulation and modeling of the problem.

(2) This paper constructed a simulation platform for the AGV scheduling problem in smart workshops. Based on actual situations of the manufacturing company, this paper gave main parameters of the simulation model and proposed the Window scheduling rule based on soft time windows; moreover, four commonly used scheduling rules were selected as the contrast rules to make comparisons.

(3) Simulation and comparative analysis results suggested that, although under the five rules, the differences in equipment and AGV utilization were not significant, the equipment utilization and product output of the workshop under the proposed rule were the highest, and the equipment starving time and the maximum completion time were the shortest, the comprehensive performance of the proposed rule outperformed the other four rules, which had verified the effectiveness of the proposed scheduling rule.

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6 REFERENCES