An Estimate and Simulation Approach to Determining The Automated Guided Vehicle Fleet Size in FMS

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Abstract—One of the many design and control issues of Automated Guided Vehicles System (AGVS) is the AGV fleet size. This paper presents a new solution method to determining the number of vehicles in the AGVS based on Flexible Manufacturing System (FMS). The approach relies on two procedures—estimate and simulation. With estimate procedure, the mathematic method will be used to estimate the AGV fleet size. In the next procedure, the estimate value will be used in the simulation model of AGVS for further study. The reliable number of vehicles can be reached after two procedures. The objective of this paper is to increase the efficiency and accuracy of the process in determining the AGV fleet size.

Keywords-Automated guided vehicles system; Flexible manufacturing system; Simulation; Number of vehicles;

I. INTRODUCTION

Automated guided vehicles system (AGVS) is advanced material handling devices used to transport goods and materials between workstations and storehouses of an automated manufacturing system. An AGVS is a set of cooperative driverless vehicles, used within the same manufacturing floor and coordinated by a centralized or distributed computer-based control system. Thus, an AGVS possesses more flexibility and capacity than other conventional material handling systems and plays an important role in the flexible manufacturing system (FMS). Flexible manufacturing systems, which are equipped with several CNC machines and AGV-based material handling system are designed and implemented to gain the flexibility and efficiency of production [1]. So the AGV-based material handling system plays an important role in FMS.

The AGVS has some most key related issues including guide-path design, determining vehicle requirement, vehicle scheduling, idle-vehicle positioning, battery management, and deadlock resolution [2]. The number of AGVs required is the sum of the total loaded and empty travel time and waiting time (among other things due to congestion) of the AGVs in a busy time period, divided by the time an AGV is available during that period [3]. The number of vehicles heavily influences the performance of AGV systems. AGV are usually expensive, so determining the type and the appropriate number of vehicles is important. Practically, the precise number of required vehicles cannot be given by any models. The exact number can be smaller or higher than the estimated on depending on characteristics of the estimation model [4]. This paper introduces the estimate and simulation approach in order to get more accurate results.

II. THE ESTIMATE AND SIMULATION APPROACH

This approach consists of two steps: the ‘estimate the number of vehicles’ step and the ‘simulation of AGVS’ step, as shown in Fig. 1. In the first step, the AGV system has been built according to production requirements of the FMS. To minimum number of vehicles required in the system has to be determined when the AGV system is designed. But the optimal number of AGVs usually can’t be researched from using mathematic method. So the estimate approach has been used in this step in order to decrease the simulation times. In the second step, the simulation of AGVS has been operated to optimal the number of vehicles. The estimate value in first step has been used as the initial value in the simulation process. The simulation result must be evaluated to show the result is valid or not. The optimal result can be reached after this evaluation process.

Step: 1
- Design AGVS
- Estimate the number of vehicles

Step: 2
- Increase or decrease the number of vehicles.
- Simulation of AGVS according to the estimate results
- Change the setting of parameters.
- Is the result in the error range?
- Accept the result
- Stop

Yes

No

Figure 1. The flowchart of the estimate and simulation approach
Step: 2’s evaluation process is used to determine an optimal AGV fleet size; capable of meeting all requirements; many factors have to be taken into account. Several of these factors are: costs of the system, traffic congestion, and vehicle dispatching strategies, capacity of the vehicle. In this paper, the points in time at which units can be or need to be transported are the key point of evaluation process. If the simulation result passes the evaluation then the result can be accepted. Else if the result in the error range then from changing the number of vehicle by one to simulation again. On the other hand, if the result out of the error range then the parameters must be changed to estimate again.

III. ESTIMATING THE NUMBER OF VEHICLES

According to Egbelu [5] there are three main factors affecting the required number of vehicles: (1) guide path layout, (2) locations of load transfer points and (3) vehicle dispatching strategies. To determine the number of required vehicles, one of the non-simulation approaches proposed by Egbelu in estimating the vehicle requirement is adopted. The estimating approach uses Eq. (1)-(5) to calculate the vehicle requirement. The notations appearing in these equations are summarized and defined as below.

\[
g_{ij} = \left( \sum_{k=1}^{a} f_{ki} \right) \left( \sum_{j=1}^{n} f_{jk} \right)
\]

(1)

\[
D_{ij} = g_{ij} d_{ij}
\]

(2)

\[
\bar{D}_{ij} = f_{ij} d_{ij}
\]

(3)

\[
TT = \frac{\sum_{i=1}^{a} \left( D_{ij} + \bar{D}_{ij} \right)}{V} + \left( \sum_{j=1}^{n} \sum_{i=1}^{a} f_{ij} \right) (t_l + t_u)
\]

(4)

\[
nv = \frac{TT}{60T} - lt
\]

(5)

- \(f_{ij}\) number of loads from workstation i to j during the period or shift. Since it is assumed here that all vehicles are single-load AGVs, \(f_{ij}\) is also equal to the number of loaded trips from workstation i to j during the period or shift.
- \(g_{ij}\) expected number of empty trips from workstation i to j during the period or shift.
- \(D_{ij}\) expected total distance of empty trips from workstation i to j
- \(\bar{D}_{ij}\) expected total distance of loaded trips from workstation i to j
- \(d_{ij}\) distance between workstation i and j
- \(V\) average vehicle travel speed (ft/min)

The main purpose of this step is decrease the simulation times, and reaches the optimal number of vehicles in a quick way. The setting of this parameters must be suit to the FMS. The warehouse in system can be seen as workstation. Other units are set as definitions of notations.

IV. THE SIMULATION MODEL OF AGVS

The workstations in FMS are connected by a material handling system which transfers parts, tools, and fixtures between these workstations. The AGVS of the material handling system is an important element in most of the present day FMS. The essential capability of an AGVS is the ability to transfer loads to distant locations and through complex path [6]. In addition, the FMS has multiple targets in processing that is why it can be chosen as the research background for AGVS.

The simulation model of FMS is built by eM-Plant. EM-Plant allows simulating and optimizing production lines in order to accommodate different order sizes and product mixes. Object-oriented technology and customizable object libraries create well-structured hierarchical simulation models that include supply chain, production resources and control strategies as well as production and business processes. Extensive analysis tools, statistics and charts evaluate different manufacturing scenarios and to make fast and reliable decisions in the early stages of production planning [7].

![Figure 2. The physical structure of FMS](image)

A. Simulation model structure

The physical structure of the FMS is shown in Fig. 2. The physical structure reflects the specific form of the FMS. The simulation model is established according to physical structure. There are four areas in the simulation model, which are warehouse, AGVS, CNCs, and the simulation results. The last one is the important one. The area of simulation results not only can display the results but also can supply the tool to optimize the simulation model. EM-Plant’s object library can provide for the CNC, AGVS, the routing of AGVS, warehouse, buffers and so on. According...
to the different characteristics of various equipments, the proper object must be chosen to simulate, in order to achieve the best effect of the simulation. Otherwise, if the object’s attribute can’t satisfy the need of simulation model, then the simtalk can be used to program the procedure of simulation.

B. The simulation process of AGVS

Each kinds of workpiece have its own processing routing from the workpiece enter into the system to leave out the system. Despite there are much more routings, the workpiece must be transported from using the AGVS. The main purpose of this simulation is to enhance the efficiency of the FMS. The research results indicate that the reasonable scheduling strategy can improve the production efficiency of flexible manufacturing system [8]. In this paper, the flexible manufacturing system’s scheduling strategy can be determined from using the LP model in the FMS. The LP model which aims at maximizing the production rate of the FMS has the following form [9]:

\[
\text{Max } X(x) = \sum_{k=1}^{K} \sum_{r=1}^{k_R} x_{kr} \tag{6}
\]

Subject to the following constraints:

\[
\sum_{k=1}^{K} \sum_{r=1}^{k_R} x_{kr} = \alpha_k \sum_{k=1}^{K} \sum_{r=1}^{k_R} x_{kr} , \quad k = 1, 2, ..., K, \tag{7}
\]

\[
\sum_{k=1}^{K} \sum_{r=1}^{k_R} x_{kr} W_{kmr} \leq S_m \quad m = 1, 2, ..., M, \tag{8}
\]

\[
x_{kr} \geq 0 \quad k = 1, 2, ..., K, \quad r = 1, 2, ..., k_R, \quad \alpha_k = \sum_{r=1}^{k_R} q_{kr} , \quad k = 1, 2, ..., K, \tag{10}
\]

\[
W_{kmr} = v_{kmr} b_{kmr} \quad m = 1, 2, ..., M, \quad r = 1, 2, ..., k_R, \quad k = 1, 2, ..., K, \tag{11}
\]

where:

- \( h_{kmr} \) average number of operation at station \( m \) for a work piece of product type \( k \) that is manufactured according to route \( r \)
- \( x_{kr} \) production rate of product type \( k \) according to route \( r \)
- \( X(x) \) production rate of the FMS

Eq. (6) aims at maximizing the production rate of the FMS. Eq. (7) defines the relationships of the production rates of the different product types. Eq. (8) describes the capacity limits of the stations. Eq. (10) describes the relationship between the route-dependent production ratio \( q_{kr} \) and the total production ratio \( \alpha_k \) of each product type. Eq. (11) defines the workload of station \( m \) with respect to route \( r \) of product type \( k \). There are so much more parameters which are involved in large number, and randomness in this model. So it’s hard to solve this model from using mathematical method.

The main purpose of the AGVS is maximum the efficiency of the FMS. The LP model is the mathematic model of the FMS. The simulation model of AGVS is built from the LP model of the FMS. The dispatching and scheduling strategy can be written into the simulation model according to the LP model’s constraint.

C. The dispatching rule of AGVS

In this simulation model, the dispatching strategy (Fig. 3) for AGVS can be decided according to this LP model. The simulation process has been determined, according to the related parameters of input. The final goal of AGVS keeps the FMS working, and makes the high efficiency of the FMS. At the same time, the vehicle can be used reasonably.

![Figure 3. The dispatching strategy of AGVS](image-url)
V. ANALYSIS OF THE SIMULATION RESULTS

In this part, the results of the simulation will be analysis. Because of the system is very complex, and there are many aspects of results can evaluate the AGVS. To make the analysis easy and clearly, one out of 12 CNCs was chosen. The estimate number of AGV is 3 in this model. This result is calculated from using Eq(1)-(5). The setting of parameters is according to the model of FMS.

The flow time with different number of vehicles in one CNC can be seen in Fig 4. The results was shown that the CNC can’t work regularly when the number of AGVs less then 3. But the CNC could keep working better when the number of vehicles more than 3. This chart demonstrates that the estimate value is reliably for the simulation.

The estimate result from step: 1 directs the simulation process in the second step from shown in Fig 5. The average make span is the average value between 30 delivery times in this CNC. The curve of the chart shown that the estimate result: 3 is the special point during four times simulation. The processing time changed obviously when the number of AGV is bigger or less than 3. As the AGV number more the 3, the processing of this CNC become more satisfied. This two steps approach is verify form the simulation results.

VI. CONCLUSIONS

In this paper, a two steps approach to determining the automatic guided vehicle fleet size in FMS has been introduced. From this way, the number of AGVs in FMS can be reached more quickly and reliably than using those methods independently. The simulation result shown that the estimate can direct the simulation, and decrease the simulation times efficiently. There is only one evaluate factor used in step: 2’s evaluation process, the problem can be simplified in this way, but this hypothesis make the evaluation process became less accuracy. That will be the key point in the future research.

REFERENCES