AGV Dispatching Strategy Based on Theory of Constraints

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***Abstract*—Based on theory of constraints, according to bottleneck machine in production system and its buffer status, using buffer initiated task assignment, presented the automatic guided vehicle (AGV) dispatching strategy driven by bottleneck machine. Ensured bottleneck machine gather with the practical production load of machine and production assignment in system, and assigned relevant AGV to transport material for bottleneck machine of starvation and blocking preferentially according to the relation of its starvation and blocking time and transport time of free AGV. It makes bottleneck machine work fully without starvation and blocking. System simulation testifies this dispatching could reduce work-in-process inventory and increase system productivity.**

***Keywords*—theory of constraints, AGV dispatching strategy, bottleneck machine, material handling**

I. Introduction

Material handling system is an important composing of modern enterprise. According to statistic, only 5% time are used to machine, residuary 95% are used to deposit, load and unload, wait and transport [1]. The AGV is considered as an important transport tool because of extensive excellence, which developed fast lately, and is used widely in some scope. So, AGV system dispatching problem is concerned by more and more scholar. But known study didn't distinguish between bottleneck resource and non-bottleneck resource, and didn't consider load and productivity of bottleneck resource, which increased utilization rate and productivity of non-bottleneck resource. The result is producing undesirable part or production, increasing storage and overstock flow fund, which can't increase economy benefit.

Aiming at above problem, this paper presented the AGV dispatching strategy driven by bottleneck machine based on theory of constraints, using buffer initiated task assignment according to bottleneck machine and its buffer real time status. It seeks balance of material handling, makes every working procedure synchronized with bottleneck procedure, and increases system productivity and resource utilization.

II. Theory of Constraints

Theory of constraints (TOC) is founded and developed based on optimization production technology by Eliyahu M. Goldratt who is an Israel physical scientist in twenty century eighty years metaphase [2]. TOC is appeared as manufacture management idea firstly. It developed target system based on produce and sale rate, storage and circulation cost with improving lastly, formed a sort of management theory and tool to increase produce and sale rate don't decrease traditional cost gradually, and covered with all function of enterprise management finally.

TOC controls system rhythm with bottleneck by identifying system bottleneck, adopts the production fashion of draw, process sequence and push separately to arrange production plan according to before bottleneck, bottleneck and after bottleneck. It increases system output rate and reduce storage by rope mechanism to control material devotion [3][4]. TOC reduces work-in-process inventory and increases output rate and benefit by balancing material handling not production ability, which integrates production plan with control synthetically by using the predominance of push production fashion on output rate and high utilization rate of equipment, and draw production fashion on controlling storage of work-in-process inventory and satisfying requirement.

III. AGV Dispatching Strategy

A. *Study status and existent problem*

Material handling dispatching strategy affects greatly work-in-process inventory, machine utilization and AGV utilization, so rational AGV dispatching strategy becomes very important [5]. Now, AGV dispatching strategy could be class into two situations: one is work center initiated task assignment (WITA), it is that which AGV is chosen to respond work center's service when only one work center apply service and more free AGV, the other is vehicle initiated task assignment (VITA), it is that which work center is serviced by AGV when only one AGV and more work center apply service at one time.

Up to now, much study has been made in material handling dispatching strategy. Reference [6] has presented a WITA rule of shortest-travel-time (SST). Reference [7] has presented a VITA rule of first-come-first-served (FCFS). But these dispatching rules consider rarely the effect of equipment buffer capacity to AGV material handling. Suppose one finished part was waiting to be transported to objective buffer, and one free AGV, but objective buffer was filled with part, so AGV has to wait till objective buffer is empty. There are maybe more parts are waiting to transport and more AGV can be used when objective buffer is empty, so distribute rationally every part to different AGV. This rule called buffer initiated task assignment (BITA) [8]. Reference [9] presented a BITA rule of demand-driven (BEMD) based on machine starvation and blocking status. According to DEMD rule, AGV will transport firstly part to some machine input buffer in order to make it without starvation, next transport part from some machine output buffer to make it without blocking. Although DEMD rule has considered buffer status, hasn't distinguished bottleneck machine and non-bottleneck machine, it will bring abundant storage.

B. *Integrating theory of constraints with AGV dispatching strategy*

According to theory of constraints, there is one constraint at least in every system, or else with infinite output. The lowest-productivity portion decides output of whole system in every system made up of more correlative portion. In enterprise production circumstance, bottleneck resource is the main constraint to restrict enterprise available production. The bottleneck resource mostly is the machine in workshop. The bottleneck machine in production changed with the production ability and assignment of enterprise, and confirmed with material handling. The simplest and most basic method of identifying bottleneck machine is comparing machine production assignment with really available production ability.

Supposed production assignment of machine M_i (i=1,2,…, m) are R_i, every machine practical production ability is C_i, so the bottleneck rate of machine M_i is the ratio of production assignment and its available production ability, namely $b_i=R_i/C_i$. The machine corresponded with bottleneck rate $b_i>1(l\leq i\leq m)$ is the bottleneck machine BM in production system. With the bigger bottleneck rate b_i, it indicates the contrast of machine production and available ability is bigger. The machine corresponded with biggest bottleneck rate is the biggest bottleneck machine in production system, namely b_k. Under non-increase new machine instance, must advance the utilization of bottleneck machine if it want to increase system productivity.

Under the environment of bottleneck machine limited production ability, set storage buffer in fore-and-back of bottleneck machine in order to insure bottleneck machine work with full load and advance production rate of whole system. The core idea of AGV dispatching strategy based on TOC is considering bottleneck machine firstly and assigning AGV to transport for bottleneck machine according to its input and output buffer practical status, make bottleneck machine without starvation and blocking. Supposed bottleneck machine start time of starvation and blocking are TS and TB. So every time expression as following [10]:

$$TS = R + \sum\nolimits_{j\in IN} t_j \tag{1}$$

$$TB = \begin{cases} R + \sum\nolimits_{i\in Q_E} t_i, & if\ IN + X > E \\ M, & otherwise \end{cases} \tag{2}$$

In formula, R is the remaining process time of the part in process at bottleneck machine, IN is the number of parts in the input buffer at bottleneck machine, t_i is the process time of part i at bottleneck machine, E is the number of empty buffer slots at the output buffer of bottleneck machine, Q_E is the set of first E part in machine, it is 1 if bottleneck machine is busy, otherwise is 0.

TS and TB are start time of starvation and blocking when bottleneck machine without part input and output. Supposed PS is the time of AGV transport part to input buffer of bottleneck machine, PB is the time of AGV transport part from output buffer of bottleneck machine. According to analysis, PS and PB can class into direct transport and indirect transport, as Fig. 1.

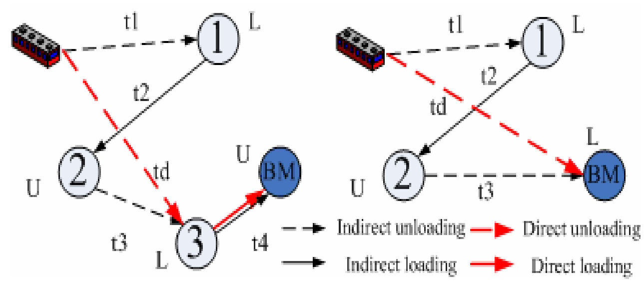

Figure 1. AGV transport mode

In figure 1, L and U denote loading and unloading time. So calculating PS indirect transport time PBI=t1+t2+t3+t4+2L+2U and direct transport time PSD=td+t4+L+U, PB indirect transport time PBI=t1+t2+t3+2L+U and direct transport time PBD=td+L. Apparently, indirect transport needs longer time but with high AGV utilization, direct transport needs shortest time but with lower AGV utilization. So, in order to advance AGV utilization, making indirect transport possibly under precondition of meeting bottleneck machine time request.

It reduces AGV speed so much as stop when every transport line blocking. So considering every line's blocking degree and multiply blocking coefficient when calculating AGV transport time. Reference [11] presented blocking coefficient to measure AGV blocking degree based on modifying whole available time. The number i line's blocking coefficient C_i is:

$$\begin{cases} C_i = 1 - \dfrac{I_i \bullet N_i}{\sum_{j=1}^{N_i} A_{ij}} & i = 1,2,\cdots,M \\ I_i = \dfrac{L_i}{S} \end{cases} \tag{3}$$

Among this, A_{ij} is the practical transport time of AGV passing number i line at j times, N_i is the number of passing AGV at i line, I_i is the ideal transport time at i line, L_i is the length of number i line, S is the speed of AGV [12].

After getting the parameter value of TS, TB, PS and PB according to calculating, gotten the following four different instances.

1) TS<PS and TB>PB: In this circumstance, starvation may occur but not blocking at bottleneck machine. So AGV should transport part to input buffer of bottleneck machine immediately.

2) TS>PS and TB<PB: In this circumstance, blocking may occur but not starvation at bottleneck machine. So AGV should transport part from output buffer of bottleneck machine immediately.

3) TS<PS and TB<PB: In this circumstance, starvation and blocking may occur at bottleneck machine. So AGV should transport part to input buffer firstly and transport part from output buffer of bottleneck machine later immediately.

4) TS>PS and TB>PB: In this circumstance, starvation and blocking may not occur at bottleneck machine. So could use the shortest-travel-time dispatching strategy.

C. Realization of BMD dispatching strategy

AGV dispatching strategy based on theory of constraints pursue material handling balance, meet the requirement of bottleneck machine furthest to make non-bottleneck machine synchronize with bottleneck machine, and get shortest production period and least work-in-process inventory. In production process, there are many factors affected AGV dispatching strategy [13]. In order to analyze conveniently, bring forward the following supposition: (1) every AGV only transport one part at a time, (2) every free AGV stop in current position if no part transport requirement, (3) every equipment only machine one part at a time, (4) every AGV wouldn't take place trouble in material system, (5) every AGV move with the same speed, which has same fully loaded speed and free loaded speed in material handling system.

According to above suppose, the concrete method of whole BMD dispatching strategy as following:

- According to practical production load status of every machine and production assignment, calculating bottleneck rate b_i. When $b_i>1$, it shows production assignment bigger than production ability in planned period, so the corresponded machines are bottleneck machine of production system, records H_1 as bottleneck machine gather, and sorts bottleneck machine by bottleneck rate. The machine corresponded with biggest b_k is the first bottleneck machine in production system. When $b_k<1$, the corresponded machine is non-bottleneck machine in production system, so records H_2 as non-bottleneck machine gather.
- Based on buffer capacity of bottleneck machine $M_i(i=1,2,\ldots,m)$ and current part number of input and output buffer, calculating the starting starvation time TS_i and starting blocking time TB_i of bottleneck machine without part input and output.
- Ensuring real time status of every AGV_j $(j=1,2,\ldots n)$. When AGV_j is free, it narrates AGV_j without material handling assignment currently, records A_1 as free AGV gather, contrarily, and records A_2 as loaded AGV gather. The element of A_1 and A_2 are variation, they will change with produce and finish of transport assignment.
- Calculating time PS_{ij} of transporting part to input buffer of bottleneck machine and time PB_{ij} of transporting part from output buffer of bottleneck machine by every AGV_j. Taking PS_{iI} and PB_{iO} are the shortest time among PS_{ij} and PB_{ij}, so corresponded AGV are assigned to bottleneck machine M_i input and output separately.
- With the comparing TS_i, TB_i, PS_{iI} and PB_{iO} of every bottleneck machine, ensuring each bottleneck machine whether starvation or blocking according to different calculation result.
- Sorting bottleneck machine starved or blocked by bottleneck rate b_i, assigning corresponded AGV to handle material for bottleneck machine with bigger bottleneck rate preferentially.

IV. SIMULATION TEST AND ANALYSIS

There is automobile electrical machine production system in some enterprise, taking it as example, which includes eight machine equipment and three AGV. The input and output buffer capacity of every machine is four, and the speed of AGV is 60 meters per minute in system. Currently, there are five kinds of part pass different machine to finish machining process separately, the detailed process course and production capacity as Tab. 1. Load and unload time of AGV are 0.8 minute and 1 minute separately.

TABLE I. PARTS PROCESS COURSE

part	Process course (minute)	Production capacity
1	2(2)-5(3)-6(1.2)-7(2.2)	1500
2	3(1.5)-4(1)-7(5)-5(3.5)-8(4)	1200
3	2(4)-6(1.5)-3(2)	2000
4	1(6)-4(1)-8(3.2)-6(2)-7(2.6)	800
5	5(2.5)-3(3)-6(1)-8(4)	1000

The main aim of simulation test is to verify capability of BMD dispatching strategy, so compared with some common dispatching methods, which included STT, FCFS and DEMD dispatching strategy. This simulation test made five times under precondition of finishing whole production assignment, and compared system capability target under different dispatching strategy, which included work-in-process inventory, machine utilization and AGV utilization.

Work-in-process inventory is the important target of dispatching strategy affects system. According to above test, the system average work-in-process inventory is 34, 33, 36 and 26 under STT, FCFS, DEMD and BMD dispatching strategy. By this token, BMD differentiates bottleneck machine and non-bottleneck machine in dispatching strategy process, takes bottleneck machine work fully and makes non-bottleneck machine synchronized with bottleneck machine in order to reduce work-in-process inventory to low degree. AGV utilization and machine utilization under different dispatching strategy are illustrated in Fig. 2 and Fig. 3, which narrates the advance of this method then other methods farther. The reason is BMD method could produce a priority service strategy according to bottleneck machine dynamically, and decide some AGV finish which material handling assignment when it is free or ensure which AGV to respond requirement when there is part transport requirement.

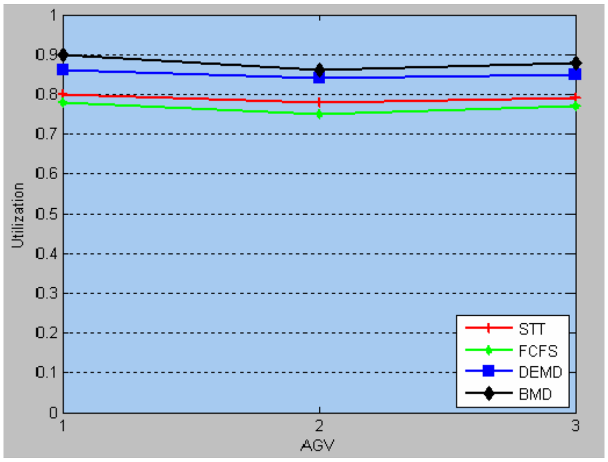

Figure 2. Average AGV utilization

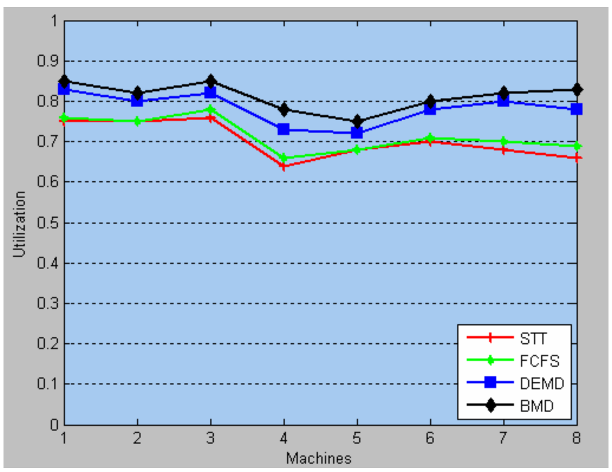

Figure 3. Average machine utilization

V. CONCLUSIONS

With the using of material handling technology widely, AGV become the important tool to realize agility material disposal in workshop material handling system. This paper presented the AGV dispatching strategy driven by bottleneck machine integrated with theory of constraints. According to practical production load of every machine and production assignment in enterprise production system, ensured the bottleneck machine and differentiated bottleneck machine and non-bottleneck machine. Based on buffer real time status of bottleneck machine, produced a priority service strategy dynamically to insure bottleneck machine work fully. The simulation test of a AGV dispatching system testifies the excellent capacity of dispatching strategy based on TOC then traditional AGV dispatching method, and which increases system productivity and utilization rate of resource finally.

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