AGV시스템에서 적응 규칙을 갖는 퍼지 급송알고리듬에 관한 연구

A Fuzzy Dispatching Algorithm with Adaptive Control Rule for Automated Guided Vehicle System in Job Shop Environment

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Abstract

A fuzzy dispatching algorithm with adaptable control scheme is proposed for more flexible and adaptable operation of AGV system. The basic idea of the algorithm is prioritization of all move requests based on the fuzzy urgency. The fuzzy urgency is measured by the fuzzy multi-criteria decision-making method, utilizing the relevant information such as incoming and outgoing buffer status, elapsed time of move request, and AGV traveling distance. At every dispatching decision point, the algorithm prioritizes all move requests based on the fuzzy urgency. The performance of the proposed algorithm is compared with several dispatching algorithms in terms of system throughput in a hypothetical job shop environment. Simulation experiments are carried out varying the level of criticality ratio of AGVs , the numbers of AGVs, and the buffer capacities. The rule presented in this study appears to be more effective for dispatching AGVs than the other rules.

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1. INTRODUCTION

Automated guided vehicle systems(AGVS) have proven to be very popular as a method of transporting pallets and parts between workstations in manufacturing shop floors. These vehicles are operated with or without wire guidance and are controlled by an on-board control equipment, remote terminal or central computer. Even though the central computer control systems pose serious and challenging operational control problems, it can significantly increase system efficiency and flexibility compared to the other two. Dispatching is recognized as the key element in AGVS control problem. The complex interaction between material flows and processes requires an efficient vehicle dispatching procedure to maximize system performance. There have been a number of research papers for AGV dispatching procedure.

Egbelu and Tanchoco[4] addressed several dispatching rules and classified them into vehicle initiated task assignment rules and workcenter initiated task assignment rules. At least one component of each class of rules must be present in the system in order to make dispatching decisions. Vehicle initiated task assignment rules are involved whenever a vehicle completes a delivery task and is to be reassigned to another task. The basic idea of these rules is prioritization of workstations with outstanding move requests based on some criteria such as distance from vehicle, length of outgoing buffer load queue and elapsed time since a move request was transmitted. On the other hand, workcenter initiated task assignment rules are invoked whenever a workcenter makes a request and there are two or more idle vehicles. Maxwell and Muckstadt[11] suggested a pre-planning dispatching rule in which the set of all outstanding transport orders are assigned simultaneously by using the classical assignment model. It should be emphasized that in such static models, times at which loads become available and occurrences of blocking or congestion in system can not be considered. Simulation has been recognized as an invaluable tool in a number of studies on AGV dispatching rules[2,3,6,8,10,13,14,16]. The simulation studies reported that for busy shop, the effect of workcenter initiated rules on system throughput is insignificant. System throughput was found to be sensitive only to the type of vehicle initiated rule[4]. In conclusion, there is no specific dispatching strategy that can be accepted as the best. The performance of a dispatching rule is highly dependent on the guide path layout, the pallet size and transport patterns in the network. In addition, the performance would vary depending on the criteria used for evaluation[2]. First-Encountered-First-Served(FEFS) rule[1] can be implemented for multiple-load AGVs where the AGVs pick up any load they encounter as long as there are empty positions on board. Loads are dropped off when their destinations are encountered. This rule is effective for single loop or simple layout[10].

Hodgson *et al.*[5] provided a heuristic rule for double load vehicles. The essence of this rule is that of a rolling schedule which continuously re-evaluates the weighting formula for the workstations at every station the vehicle encounters. No limit on queue size at workstation is assumed and much computational burden is required. Nayyar and Khator[12] compared the performances of AGVs comprising single-load vehicles with those of vehicles with multiple-load capacities. Under batch manufacturing system, the effects of the combinations of load pickup rules and AGV dispatching rules are evaluated. The results indicated that the 'shortest distance' dispatching rule had the best performance.

Kim *et al.*[8] proposed a fuzzy dispatching rule for single-load AGVs. The algorithm prioritizes all move requests based on the request's urgency. At every dispatching decision point pre-assigned jobs have completed, the urgency values for all move requests are measured by the following four system attributes: 1) incoming buffer queue length, 2) outgoing buffer queue length, 3) duration of part waiting time, and 4) travel distance from the AGV location to its candidate destination associated with the move request.

This paper proposes a new dispatching algorithm for AGVs with adaptive control rule. The algorithm is an extension of the fuzzy dispatching rule by Kim *et al.*[8].

The rest of this paper is organized as follows. In section 2, a new fuzzy dispatching algorithm with adaptive control rule is presented. In section 3, comparative study with several dispatching rules under job shop environment is carried out. Finally, conclusion appears in section 4.

2. FUZZY DISPATCHING WITH ADAPTIVE CONTROL RULE

2.1 System Environment

The system in this study(Figure 1) consists of single-load AGVs and workstations, each of which has one pickup station and one drop-off station corresponding to the outgoing buffer and the incoming buffer, respectively. This system has many-to-many pickup/drop-off configuration in which pickup stations as well as drop-off stations are treated as distinct points.

The unassigned loads waiting at the outgoing buffer are picked up firstly based on dispatching priority by AGVs and then dropped off at the incoming buffer of its subsequent workstation. In the control of AGV system, vehicle initiated task assignment rules are involved whenever a vehicle completes a delivery task and is to be reassigned to another task. On the other hand, workcenter initiated task assignment rules are invoked whenever a workcenter makes a request and there are two or more idle vehicles. Vehicle initiated task assignment rule is considered in this study, reflecting the simulation studies reported that the system throughput is sensitive only to the type of vehicle initiated rule[4]. If the vehicle is empty and no move request is waiting from the outgoing buffers of the workstations, it travels to a predetermined (dwelling) point. Upon arrival, it dwells at that point until new move requests are available.

One dimension of the AGV operational problem is that the incoming and outgoing queue capacities at workstations are limited. Therefore, there is always a possibility that a particular machine can be blocked or the system can be locked due to limited queue capacities. Blocking occurs when a machine can not move its part to its outgoing buffer if the buffer is full. Whereas, locking occurs when the system is totally prevented from functioning, i.e. when no part movement can be achieved in the system. Therefore queue capacities must be taken into account in operation of AGV system.

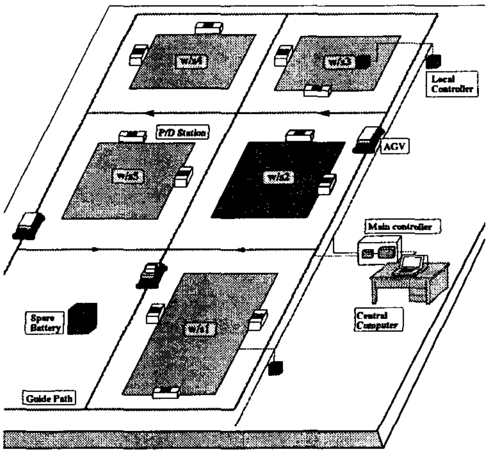


Figure 1. Configuration of an AGV system

For the links between the workstations and the AGV, a 'sequential pickup design' needs to be considered. Once a pickup request is selected, it is assumed that a part from the head of queue at pickup station is loaded to AGV.

2.2 Framework of the algorithm

Based on fuzzy set theory, a new AGV dispatching algorithm for AGVs, utilizing fuzzy multi-criteria decision-making method was proposed for more flexible operation of AGVs. Four dispatching criteria were considered: incoming buffer queue length, outgoing buffer queue length, elapsed time of move request, and distance between calling location and AGV position. In order to meaningfully aggregate the evaluation results with those criteria of different semantic dimensions, the outcome obtained by each criterion must be converted to a dimensionless index. The fuzzy urgency measure of move requests was introduced to assess their priorities. First to be defined were the fuzzy membership functions of the importance weight values for each dispatching criterion and the urgency values. Fuzzy relations were also defined to associate levels of criticality indices with urgency values for each criterion.

At a dispatching point, for each move request, the values of partial fuzzy urgency (i.e. fuzzy urgency with a single criterion) are determined according to criticality indices that are numerically computed. After that, the importance weight values for the criteria are determined utilizing the adaptive weight control scheme. And then, the overall fuzzy urgency index is computed using the importance weight values. Finally, the overall fuzzy urgency indices of the current requests are ranked to obtain the most urgent move request.

2.3 Design of the membership functions

The fuzzy set theory was introduced by Zadeh[17] to deal with problems in which the absence of sharply defined criteria is involved. It has been considered as a modeling language to approximate situations in which fuzzy phenomena and criteria exist. In a universe of discourse X, a fuzzy subset A in X is a set of ordered pairs, $A=\{(x,\mu_A(x)) \mid x \in X\}$, where $\mu_A(x)$ is called the membership function or grade of membership of x in A which maps X to the membership space M. When M contains only the two points 0 and 1, A is non-fuzzy and $\mu_A(x)$ is identical to the characteristic function of crisp set. The larger $\mu_A(x)$, the stronger the grade of membership for x in A.

A fuzzy number B in R is a trapezoidal fuzzy number(TrFN) if its membership function $\mu_B : R \to [0,1]$ is

$$\mu_B(x) = \begin{cases} (x-a)/(b-a) & a \le x \le b \\ 1 & b \le x \le c \\ (x-d)/(c-d) & c \le x \le d \\ 0 & \text{otherwise} \end{cases} \qquad (1)$$

where $a \le b \le c \le d$. The TrFN, as given by equation (1), can be denoted by B:(a,b,c,d). The membership function is 1 from b to c, and becomes 0 at the two end points, a and d.

The concept of linguistic variables is useful in dealing with situations which are too complex or ill-defined to be reasonably described in conventional quantitative expressions. A linguistic variable is a variable whose values are words or sentences in a natural or artificial language.

Fuzzy relations are fuzzy subsets of $X \times Y$, that is, mappings $X \to Y$. A fuzzy relation, R on $X \times Y$ is defined as $R=\{((x,y),\mu_R(x,y)) \mid (x,y) \in X \times Y\}$ where X, Y is universe of discourse. A fuzzy relation is characterized by a membership function μ_R which associates each pair (x,y) with its "grade of membership", $\mu_R(x,y)$, in R. For simplicity, it will be assumed that the range of μ_R is the interval [0,1]. A larger $\mu_R(x,y)$ implies that fuzzy relation R is more likely to be true with x and y.

The TrFNs, linguistic variables, and fuzzy relations were employed to assess the degree of urgency for all move requests at each decision point to dispatch AGVs.

It is assumed that the decision maker uses a set of values $W=\{AUI,UI,M,I,VI\}$ for importance weight, where AUI=Absolutely Unimportant, UI= -Unimportant, M=Medium, I=Important, and VI=Very Important, to linguistically represent the degree of importance of each dispatching criterion. The membership functions of the linguistic values in the importance weight set $\boldsymbol{W}$ are instantiated as: AUI:(0, 0, 0, 0.2), UI: (0, 0.2, 0.2, 0.4), M:(0.3, 0.5, 0.5, 0.7), I:(0.6, 0.8, 0.8, 1), VI:(0.8, 1, 1, 1).

Similarly, the linguistic value set $\boldsymbol{U}=\{ANU, NU, M, U, VU\}$ for urgency is defined, where ANU=Absolutely not urgent, NU=Not urgent, M=Medium, U=Urgent, and VU=Very urgent. The linguistic values in $\boldsymbol{U}$ are used to indicate both overall and partial urgency of a move request. The membership functions of each linguistic values in the urgency set $\boldsymbol{U}$ are also instantiated as ANU:(0, 0, 0, 0.2), NU:(0, 0.2, 0.2, 0.4), M:(0.3, 0.5, 0.5, 0.7), U:(0.6, 0.8, 0.8, 1), and VU:(0.8, 1, 1, 1).

2.4 Calculating the partial fuzzy urgency

First of all, we calculate the partial fuzzy urgency, i.e. the fuzzy urgency of a move request with each of the four criteria, as follows.

1) Incoming buffer queue criterion

To reduce occurrences of workstation starvation, the incoming buffer queue length is considered at each dispatching decision point.

Let,

i = move request index

k = job type index, k= 1,2,...,K

N_k = the number of job type k

l = workstation index, l=1,2,...,L

t = time at which dispatching decision is made

$P_{k,l}$ = the processing time of job type k on workstation l [time]

IQ_l = incoming buffer capacity of workstation l [unit]

$I_l(t)$ = set of the indices of job types waiting at or on their way to the incoming buffer of workstation l

$n_{k,l}(t)$ = the number of job type k at incoming buffer of workstation l at time t

$$X_{k,l} = \begin{cases} 1 & \text{if job type } k \text{ requires workstation } l \\ & \text{for its operations} \\ 0 & \text{otherwise} \end{cases}$$

$\overline{P}_l$ = average processing time of job on workstation l

$$= \frac{\sum_k N_k \cdot X_{k,l} \cdot P_{k,l}}{\sum_k N_k \cdot X_{k,l}}$$

$IQ_l(t)$ =amount of workloads waiting at incoming buffer of workstation l at time t (expressed in terms of processing time)

$$= \sum_{k \in I_l(t)} n_{k,l}(t) \cdot P_{k,l}$$

R_1 = criticality index for a move request to workstation l with incoming buffer queue criterion

$$= \frac{IQ_l(t)}{IQ_l \cdot \overline{P}_l} \qquad (2)$$

We define the membership function of fuzzy relations between R_1 and urgency value as shown in Table 1.

2) Outgoing buffer queue criterion

The outgoing buffer queue criterion is adopted to reduce the possibility of workstation blockages due to exhaustion of outgoing queue space. The fuzzy urgency for outgoing buffer queue of each workstation is derived from the criticality index which is a function of outgoing buffer capacity and current queue length.

Let,

$OQ_l(t)$ = the number of unassigned jobs waiting at the outgoing buffer of workstation l at time t

R_2 = criticality index for a move request to workstation l with outgoing buffer queue criterion

$$= \frac{OQ_l(t)}{OQ_l} \quad (3)$$

The membership function of fuzzy relations between R_2 and urgency adopted in this study is shown in Table 2.

3) Elapsed time criterion

The elapsed time of a move request at outgoing buffer is the amount of waiting time until the current dispatching decision point. Introduction of this criterion reduces the time interval between the placing of a move request and its fulfillment.

Let,

$t_{i,l}$ = the time move request i appears at workstation l. Note that at the completion of required operation, the processed job places a move request.

$\bar{t}_e$ = average elapsed time for the previous move requests satisfied

t_{std} = standard deviation of elapsed time for the previous move requests satisfied

R_3 = criticality index for a move request to workstation l with elapsed time criterion

$$= \frac{t - t_{i,l}}{\bar{t}_e + 2t_{std}} \quad (4)$$

Table 2 shows the membership function of fuzzy relations between R_3 and urgency.

4) AGV travel distance criterion

To reduce the traveling time of empty vehicles, the required travel distance of AGVs is also considered as a criterion for dispatching.

Let,

D_l = travel distance from the location of empty AGV to the picking point of workstation l

$D_{Max} = \max_l D_l$

$D_{Min} = \min_l D_l$

$d_i(t)$ = travel distance from current location of AGV to the picking or dropping off point of move request i at time t

R_4 = criticality index for a move request to workstation l with AGV travel distance criterion

$$= \frac{d_i(t) - D_{Min}}{D_{Max} - D_{Min}} \quad (5)$$

Based on R_4, the membership function of fuzzy relations between R_4 and urgency is defined as shown in Table 1.

Table 1. The membership function of fuzzy relations between R_1 (R_4) and urgency

Criticality index	level	Urgency value				
		ANU	*NU*	*M*	*U*	*VU*
R_1, R_4	~0.2	0.0	0.0	0.0	0.0	1.0
	0.2~0.4	0.0	0.0	0.0	1.0	0.5
	0.4~0.6	0.0	0.5	0.5	0.0	0.0
	0.6~0.8	0.5	1.0	0.0	0.0	0.0
	0.8~	1.0	0.0	0.0	0.0	0.0

Table 2. The membership function of fuzzy relations between R_2 (R_3) and urgency

Criticality index	level	Urgency value				
		ANU	*NU*	*M*	*U*	*VU*
R_2, R_3	~0.2	1.0	0.0	0.0	0.0	0.0
	0.2~0.4	0.5	1.0	0.0	0.0	0.0
	0.4~0.6	0.0	0.5	0.5	0.0	0.0
	0.6~0.8	0.0	0.0	0.0	0.1	0.5
	0.8~	0.0	0.0	0.0	0.0	1.0

Once all the criticality indices are obtained, the partial fuzzy urgency of a move request is determined as follows.

$$U_{ij} = \frac{1}{\sum_{n} p_{ijn}} \left[\underset{n=ANU}{\overset{VU}{(+)}} U_{ijn} \otimes p_{ijn} \right] \qquad (6)$$

where,

j = dispatching criterion index, $j = 1,\ldots,4$

$n = ANU, NU, M, U, VU$

U_{ijn} = fuzzy number of the urgency value n for alternative i with criterion j

p_{ijn} = membership function value of the urgency value n for alternative i with criterion j

2.5 Determining fuzzy importance weight values

It is complex and difficult to solve the problems of how to determine the importance weights for the criteria in response to the dynamic operational conditions of the system

1) Criticality ratio of AGV resource

The performance of dispatching rule is highly dependent on the system configurations such as the guide path layout, number and speed of AGVs, number of workstations, buffer queue capacities, part processing time, and part route etc. If the system has more vehicles than needed, discriminating power among dispatching rules disappears[4,8]. The *criticality ratio*(*CR*) of AGV is introduced, which is a measure correlated positively to the possibility that the AGV resource becomes a bottleneck resource in the system.

Let,

PT = pickup time of AGV at outgoing buffer

DT = drop-off time of AGV at incoming buffer

$\bar{T}$ = the average travel time of AGV between two workstations

$\bar{R}$ = the average number of routes of a part

N = the number of AGVs

$\bar{P}$ = the average processing time of a part at each workstation

CR = criticality ratio of AGVs

$$= \frac{\left[\begin{array}{c}\text{Estimated transport time of a move}\\ \text{request served by one AGV}\end{array}\right]}{\left[\begin{array}{c}\text{Average processing time}\\ \text{of a part}\end{array}\right]}$$

$$= \frac{(PT + DT + 2\bar{T})(\bar{R}/N)}{\bar{P}}$$

It may be worthwhile to compare the *criticality ratio* in this paper with the cycle ratio presented by Tanchoco *et al.*[15], the P/T ratio proposed by Kim and Tanchoco[7], and the travel time/process time ratio mentioned by Han and MacGinnis[6]. The cycle ratio is defined as the ratio of average time that a part is processed on a workstation to the sum of pure transport times required to move a part from the first workstation to the last workstation. The P/T ratio is the ratio of the processing time per operation to the average transport time per transfer. The TT/PT ratio is the ratio of the pure travel time for one transfer to the pure processing time on a workstation. With these definitions, the cycle ratio, P/T ratio, and TT/PT ratio may not provide enough information on the criticality of the transport system. The number of AGVs and the time required to do pickup and drop-off operations are also major factors that affect the criticality of the transport system.

To find the relationship between *CR* of AGV and system throughput, experimental investigation was carried out. The *CR* was varied using part processing time and number of AGVs, where the other parameters were set fixed. Two dispatching rules such as the Modified First Come First Serve(MFCFS) rule[4] and the Fuzzy Multi-Criteria Decision-Making algorithm(FMCDM)[8] were tested. Under MFCFS, AGVs are assigned to the workstations sequentially in chronological order as requests for empty vehicles are received from workstations. The move request with the highest ranking value of fuzzy urgency has the highest priority in FMCDM.

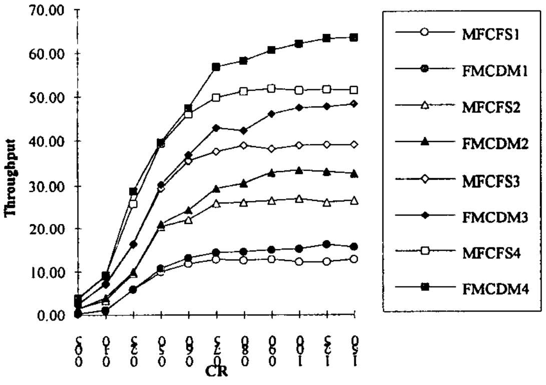


Figure 2. The effects of criticality ratio of AGVs

The experimental results are shown in Figure 2. In the legend of the figure, MFCFS2 is interpreted as the MFCFS rule used two AGVs. It is observed that if the value of *CR* is less than 0.5, there are no performance differences between the two rules. When the *CR* of AGV is a higher value than 0.5, the performances between dispatching rules are differentiated. In this case, the AGV resource becomes a bottleneck resource.

2) Adaptive control rule for the fuzzy importance weight values

First of all, to find the best weight value combination, for example $W_1=VI$, $W_2=VI$, $W_3=VI$, $W_4=VI$, pilot simulation and animation with the fuzzy dispatching algorithm proposed by Kim *et al.*[8] were made. The weight combinations of 625(5×5×5×5) were tested. Each combination was applied equally to the criteria at every dispatching decision point. The system throughput was adopted as the performance measure and the results were obtained varying the experimental conditions such as system layout, buffer capacity, part processing time, and number of AGVs. In conclusion, there was no specific weight value combination that can be accepted as the best. The performance of a weight combination was highly dependent on the experimental condition. But the following three weight combinations are well performed at every experiment conditions.

$$W_1=M,\ W_2=M,\ W_3=UI,\ W_4=VI$$
$$W_1=M,\ W_2=I,\ W_3=M,\ W_4=VI$$
$$W_1=M,\ W_2=M,\ W_3=M,\ W_4=VI$$

Through pilot simulation and animation studies, we also find that the following two situations need a particular attention in determining urgency.

1) When both the incoming and outgoing buffers of some workstation are full, then it is preferable for the associated move request to have a high priority.
2) If an AGV arrives at some workstation and finds no empty space at the incoming buffer, it is better to carry out other remaining jobs instead of waiting.

The above situations can not be handled with constant values of the importance weight, no matter how appropriate they are. For instance, consider the workstation l whose incoming buffer is full. If the partial fuzzy urgencies of move request i are approximately: $U_{i1}=NU$, $U_{i2}=VU$, $U_{i3}=NU$, $U_{i4}=ANU$, its overall urgency aggregated with constant weight values may be a lower value and then, the possibility of pickup of the request i will be rare. If this situation occurs frequently, drop-off to the workstation l does not accomplished effectively and then, dispatching will not be well performed consequently. Thus we present a control scheme for the importance weight which is adaptable to the dynamic situation at each dispatching point. Note that two additional input variables, RX_{i1} and RX_{i2}, are introduced which measure the degree of congestion of incoming buffer.

Let,

$IQL_l(t)$ = the incoming buffer queue length of workstation l at time t [unit]

$A_l(t)$ = the number of parts scheduled to workstation l but not delivered at time t [unit]

RX_{i1} = the degree of congestion of the incoming buffer of the destination workstation l associated with move request i

$$= \frac{IQL_l(t)+A_l(t)}{IQ_l}$$

RX_{i2} = the degree of congestion of the incoming buffer of workstation l associated with move request i

$$= \begin{cases} \dfrac{IQ_l(t)+A_l(t)}{IQ_l}, & \text{if } OQ_l(t)=OQ_l \\ 0 & \text{, otherwise} \end{cases}$$

The following five weight combinations(WC) are selected to use in the control statements.

WC 1 : $W_{i1}=M$, $W_{i2}=M$, $W_{i3}=UI$, $W_{i4}=VI$

WC 2 : $W_{i1}=M$, $W_{i2}=I$, $W_{i3}=M$, $W_{i4}=VI$

WC 3 : $W_{i1}=M$, $W_{i2}=M$, $W_{i3}=M$, $W_{i4}=VI$

WC 4 : $W_{i1}=VI$, $W_{i2}=VI$, $W_{i3}=VI$, $W_{i4}=VI$

WC 5 : $W_{i1}=AUI$, $W_{i2}=AUI$, $W_{i3}=AUI$, $W_{i4}=AUI$

W_{ij} is the fuzzy importance weight value for criterion j of move request i. Note that W_{ij} is adjusted reflecting to the RX_{i1}, RX_{i2} at every dispatching decision point. The WC 1, WC 2, and WC 3 were adopted because they were well performed in the simulation experiments. WC 4 is used to make a higher urgency value for a certain move request. With WC 5, a move request has relatively lower urgency value.

Utilizing the *CR* of AGV resource, RX_{i1}, RX_{i2}, and the five weight combinations, the control rule is defined as conditional statements of the type:

```
If $CR > 0.5$ then
    if $RX_{i1} \ge x_1$
        then WC 5 is applied
    else if $RX_{i2} \ge x_2$
        then WC 4 is applied
    else
        then WC r is applied
Else
    then WC 4 is applied
```

where WC *r* is the best one among the WC 1, WC 2, and WC 3. When the value of *CR* of AGV is less than and equal to 0.5, the system has more vehicles than needed. In this case, dispatching is dominated by the workstation initiated rule and then, system throughput is not sensitive to the type of dispatching rule. Hence the WC 4 is applied arbitrarily.

To determine the values x_1, x_2, and the weight combination WC *r*, simulation was carried out with 27 experimental combinations(3 levels of x_1 × 3 levels of x_2 × 3 levels of WC *r*). The x_1 and x_2 are varied with the values of 0.6, 0.8, and 1.0. And the WC *r* is varied with WC 1, WC 2, and WC 3. The results of each experimental combination were obtained varying system conditions such as system layout, buffer capacity, and number of AGVs. Two different system layouts were tested: a system with five workstations and a system with nine workstations. For each system layout, three different buffer capacities were tested: buffer capacities with three, five, and seven spaces. For the condition of nine workstations and five buffer capacities, three different numbers of AGVs were tested: numbers with one, tree, and five vehicles.

There was no the best one among the experimental combinations of x_1, x_2, and WC *r*. But a specific combination, x_1=0.8, x_2=0.8, and WC *r* = WC 1, which is well performed at various system conditions, is adopted and proposed as the control rule of importance weight values as follows.

```
If $CR > 0.5$ then
  if $RX_{i1} \geq 0.8$
    then $W_{i1} = AUI$, $W_{i2} = AUI$, $W_{i3} = AUI$,
         $W_{i4} = AUI$
  else if $RX_{i2} \geq 0.8$
    then $W_{i1} = VI$, $W_{i2} = VI$, $W_{i3} = VI$, $W_{i4} = VI$
  else
    then $W_{i1} = M$, $W_{i2} = M$, $W_{i3} = UI$, $W_{i4} = VI$
Else
  then $W_{i1} = VI$, $W_{i2} = VI$, $W_{i3} = VI$, $W_{i4} = VI$
```

In this rule, a move request gets relatively a higher importance weight value if its outgoing buffer is blocked and also its incoming buffer is highly congested. And a move request gets a relatively lower importance weight value if its destination incoming buffer is highly congested. The above scheme is expected to reduce the occurrences of shop locking.

2.6 Calculating the overall fuzzy urgency and its ranking value

There are many methods used to aggregate fuzzy assessments including mean, median, maximum, and mixed operator. As the average operation is commonly used, we adopt it for pooling the partial fuzzy urgency of a move request.

Let, $U_{ij} = (o_{ij}, p_{ij}, q_{ij}, r_{ij})$, $i = 1,\ldots,I$, $j = 1,\ldots,4$ be the fuzzy urgency assigned to move request *i* with dispatching criterion *j*. Also, let W_{ij} = $(a_{ij}, b_{ij}, c_{ij}, d_{ij})$ be the fuzzy urgency importance weight value for criterion *j* of move request *i*.

W_{ij} is determined by the adaptive control rule considering the degree of congestion of incoming buffer. Then U_{ij} is aggregated by averaging the corresponding products with fuzzy weight values W_{ij}. That is, the overall fuzzy urgency index F_i of the move request *i* can be obtained by the following formula:

$$F_i = \frac{1}{4} \otimes \left[\overset{4}{\underset{j=1}{(+)}} U_{ij} \otimes W_{ij} \right]$$

Applying the extension principle proposed by Zadeh[17], the following approximation formula can be used which results in a trapezoidal fuzzy number.

$$F_i \cong (A_i, B_i, C_i, D_i) \tag{7}$$

$$\text{where, } A_i = \sum_{j=1}^{4} \frac{o_{ij} a_{ij}}{4}, \quad B_i = \sum_{j=1}^{4} \frac{p_{ij} b_{ij}}{4}$$

$$C_i = \sum_{j=1}^{4} \frac{q_{ij} c_{ij}}{4}, \quad D_i = \sum_{j=1}^{4} \frac{r_{ij} d_{ij}}{4}$$

After calculating the overall fuzzy urgency index F_i , each move request is to be ranked. Fuzzy numbers may only form a partial order and thus comparison of fuzzy numbers to obtain a linear order can be a problem. Among many methods proposed for ranking fuzzy sets, the method of generalized mean value(GMV)[9] is adopted for its ease of implementation and power of prioritizing. The GMV for the fuzzy urgency index F_i becomes[8],

$$m(F_i) = \frac{(C_i + D_i)^2 - (A_i + B_i)^2 + A_i \cdot B_i - C_i \cdot D_i}{3 \cdot \{(C_i + D_i) - (A_i + B_i)\}} \tag{8}$$

A fuzzy number with a higher GMV is ranked higher than one with a lower GMV. AGV is dispatched to accomplish the move request of the highest GMV value.

2.7 Adaptive fuzzy dispatching algorithm

At a dispatching decision point, for each move request, the values of partial fuzzy urgency are determined according to criticality indices that are numerically computed as described in section 2.4. And then fuzzy importance weight values for each criterion of each move request are determined using the adaptive control rule. The overall fuzzy urgency index is calculated using the importance weight values. Finally, the overall fuzzy urgency indices of the current requests are ranked utilizing the generalized mean value.

The fuzzy dispatching algorithm with adaptive control rule for the importance weight values is summarized as follow.

Step 1: At a dispatching decision point *t*, identify dispatching requests.

Step 2: Determine the membership function value p_{ijn} and partial fuzzy urgency U_{ij}.

Step 3: Determine the importance weight value W_{ij} using the adaptive control rule proposed.

Step 4: Calculate the aggregated urgency index F_i for each request based on U_{ij} and W_{ij}.

Step 5: Calculate the ranking value $m(F_i)$ associated with each request.

Step 6: Select the request with the highest ranking value.

Step 7: Repeat steps 1 to 6 at every dispatching decision point.

2.8 A numerical example

We demonstrate the computational process of the fuzzy dispatching algorithm with adaptive control rule with a job shop which has an AGV system for material handling.

Step 1 : Identifying move requests

It is assumed that three alternative move requests A_1, A_2, and A_3 exist at an AGV dispatching decision point.

Step 2 : Calculating partial urgency

Let C_1 be incoming buffer queue criterion, C_2 outgoing buffer queue criterion, C_3 elapsed time criterion, and C_4 AGV travel distance criterion. Using the fuzzy urgency set *U* and the fuzzy relations described in section 2.4, the fuzzy relation of each alternative is calculated. Table 3 shows a possible outcome.

The partial fuzzy urgency U_{ij} is determined with equation (6) and they are:

$$U_{11} = \frac{1 \otimes (0.6,0.8,0.8,1) \oplus 0.5 \otimes (0.8,1,1,1)}{1+0.5}$$
$$= (0.667,0.867,0.867,1)$$

$U_{12} = (0,0.133,0.133,0.333)$

$U_{13} = (0.667,0.867,0.867,1)$ $U_{14} = (0,0,0,0.2)$

$U_{21} = (0.15,0.35,0.35,0.55)$

$U_{22} = (0,0.133,0.133,0.333)$ $U_{23} = (0,0,0,0.2)$

$U_{24} = (0.15,0.35,0.35,0.55)$

$U_{31} = (0,0.133,0.133,0.333)$ $U_{32} = (0.8,1,1,1)$

$U_{33} = (0.667,0.867,0.867,1)$ $U_{34} = (0.8,1,1,1)$

Table 3. The fuzzy relations between alternatives and criteria

Alternative	Fuzzy Relation			
	C_1 (ANU, NU, M, U, VU)	C_2 (ANU, NU, M, U, VU)	C_3 (ANU, NU, M, U, VU)	C_4 (ANU, NU, M, U, VU)
A_1	(0,0,0,1,0.5)	(0.5,1,0,0,0)	(0,0,0,1,0.5)	(1,0,0,0,0)
A_2	(0,0.5,0.5,0,0)	(0.5,1,0,0,0)	(1,0,0,0,0)	(0,0.5,0.5,0,0)
A_3	(0.5,1,0,0,0)	(0,0,0,0,1)	(0,0,0,1,0.5)	(0,0,0,0,1)

Table 4. The importance weight values for the criteria

Alternative	Criterion			
	C_1	C_2	C_3	C_4
A_1	*VI*	**VI**	*VI*	*VI*
A_2	*VI*	**VI**	*VI*	*VI*
A_3	*M*	*M*	*UI*	*VI*

Step 3 : Determining fuzzy importance weights

Based on the weight control rule described in section 2.5, the importance weight values for each criterion of each request are determined. Suppose weight values are determined as shown in Table 4.

Based on fuzzy membership function in section 2.3, the fuzzy importance weight W_{ij} is obtained as:

$$W_{11} = (0.8, 1, 1, 1) \quad W_{12} = (0.8, 1, 1, 1)$$

$$\ldots$$

$$W_{33} = (0, 0, 0, 0.2) \quad W_{34} = (0.8, 1, 1, 1)$$

Step 4 : Computing overall fuzzy urgency

With equation (7), each alternative's overall fuzzy urgency index F_i becomes:

$$F_1 = (0.267, 0.467, 0.467, 0.633)$$

$$F_2 = (0.060, 0.208, 0.208, 0.408)$$

$$F_3 = (0.220, 0.435, 0.435, 0.583)$$

Step 5 : Calculating ranking value

Based on equation (8), the ranking value $m(F_i)$ for each alternative's fuzzy urgency index is given by:

$$m(F_1) = 0.456$$

$$m(F_2) = 0.225$$

$$m(F_3) = 0.413$$

Step 6 : Dispatching

The ranking order of fuzzy urgency for the three alternatives is $m(F_1) > m(F_3) > m(F_2)$. Therefore, AGV is dispatched to the move request A_1.

3. EVALUATION OF THE ALGORITHM

3.1 Experimental conditions and assumptions

Figure 3 shows the layout of a hypothetical job shop with nine workstations studied in this paper. Workstation 1 is the loading station for the raw material and workstation 9 represents the unloading station for the finished products. There is no buffer capacity restriction on the incoming buffers of workstation 1 and 9. The capacities of the incoming and outgoing buffers of the remaining workstations are limited and the same. The maximum number of jobs allowed in the shop is set to the sum of the workstations and the total number of buffer capacities. A job is released to the shop only when the total number of jobs in the system is less than the allowed maximum limit. Parts are transferred in the system by single-load AGV system. The AGVs move parts between the workstations along predetermined paths, which are assumed to be unidirectional. If there exists no more move request in the system, the AGV travels empty to the dwell point to stay there until a new move request appears.

A critical problem with this system is shop locking which occurs when the system is totally prevented from functioning[4]. To avoid the shop locking, the following preventive scheme is used: when an AGV arrives at the subsequent workstation's incoming buffer and finds that there is no space to drop off, the AGV moves the part to the loading station (workstation 1). After dropping, the AGV asks for a new dispatching decision. The part is added to the outgoing queue of the loading station and transferred later to the originally designated workstation after some delays.

The experiments are carried out with the following system parameter values and operational rules.

1) Part pickup and drop-off times of AGV are 0.5 minute each. The AGV travels at the speed of 80 feet/min along the shortest distance path.
2) Upon job completion at workstation, if AGV becomes idle, the 'workcenter initiated task assignment' rule is invoked. Nearest vehicle (NV) rule is used.
3) Each workstation and AGV is continuously operational without any breakdown.
4) Ten job types are to be produced whose routings and processing times are shown in Table 5.

A discrete simulation model was programmed in SLAM.

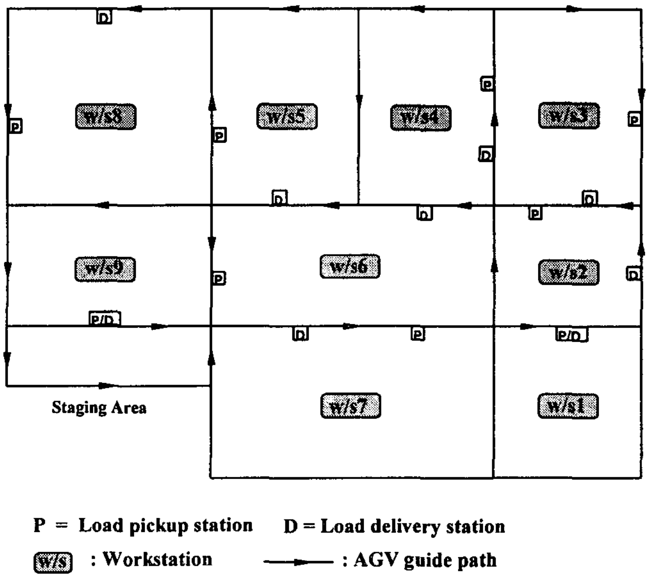


Figure 3. A hypothetical job shop

Table 5. Part routings and processing times

Part type	Route	Processing time(min)	**Part mix**
1	1,6,4,7,9	1,15,25,20,1	0.1
2	1,7,5,4,2,8,3,9	1,5,20,15,15,5,15,1	0.1
3	1,8,6,2,5,3,7,9	1,8,10,20,15,5,15,1	0.1
4	1,6,2,5,9	1,20,10,15,1	0.1
5	1,3,5,2,7,8,9	1,15,5,15,18,20,1	0.1
6	1,2,3,9	1,20,25,1	0.1
7	1,4,7,3,6,5,9	1,15,20,12,8,15,1	0.1
8	1,5,3,8,4,2,9	1,20,5,15,20,8,1	0.1
9	1,3,5,8,7,4,6,9	1,8,20,10,10,5,5,1	0.1
10	1,8,6,7,4,9	1,15,15,20,13,1	0.1

3.2 Performance evaluation

The performance of the proposed rule is compared with several well-known dispatching rules in a hypothetical job shop environment. Three kinds of dispatching rules are selected for the comparison with the Adaptive Fuzzy Multi-Criteria Decision-Making algorithm proposed in this paper(in short, we will call AFMCDM hereafter). They are the Modified First Come-First Serve rule(MFCFS), Shortest Travel Time/Distance rule(STTD) and Fuzzy Multi-Criteria Decision-Making rule (FMCDM)[8]. Under MFCFS, AGVs are assigned to the workstations sequentially in chronological order as requests for empty vehicles are received from workstations. STTD dispatches the empty vehicle to the workstation whose unit load pickup point is closest to the vehicle. If any workstation is found whose outgoing buffer is full, the workstation is assumed to have the highest priority to avoid blocking. FMCDM selects the workstation with the highest urgency among all move requests. And the value of the importance weight was set to VI(Very Important) for each criterion, i.e. $\{W_1, W_2, W_3, W_4\}$ = $\{VI, VI, VI, VI\}$.

The system throughput was adopted as the major evaluation criterion. Throughput is defined as the total number of parts completed and removed from the shop floor during a unit time. And 'transaction times to move requests', 'workstation utilization', and 'number of returns to the system loading station' were investigated additionally. Transaction time is defined as the time duration from AGV calling point of move request to its drop-off point. The return of a request occurs at the situation that its drop-off is impossible. This return mechanism is used to prevent from shop locking. The proposed algorithm was tested varying the level of criticality ratio of AGVs, the numbers of AGVs, and the capacity of the buffer queue.

To evaluate the performance of AGV dispatching rules on steady state, pilot simulation runs were made. To reduce the bias due to system initialization, the test results for the first 2000 minutes were discarded. The results of the simulation experiments are obtained with twenty replications per rule at each level of each experiment condition. Each replication was observed over one unit time(8 hours) at steady state.

1) Testing performance under different criticality ratio of AGVs

Table 6 shows the results of simulation experiments at the levels of criticality ratio of AGVs. Two AGVs and five buffer queue capacities were employed. The table entries are the average and standard deviation of the system throughput(in unit loads), workstation utilization, transaction time, and number of returns. The levels of criticality ratio were set varying the processing time of each part.

Table 6. Average performance under varying criticality ratio of AGVs

Dispatching rule	Criticality ratio	System throughput Avg.	Std.	W/S utilization Avg.	Std.	Response time Avg.	Std.	Number of reruns Avg.	Std.
MFCFS	0.6	24.4	1.67	0.8	0.05	37.7	4.34	6.0	0.91
	0.8	26.0	2.05	0.7	0.18	37.1	4.42	3.9	1.21
	1.0	25.4	1.67	0.5	0.03	34.4	3.13	0.0	0.00
	1.2	25.2	1.51	0.4	0.07	38.5	4.86	0.0	0.00
	1.4	25.6	1.90	0.4	0.19	40.4	3.64	0.0	0.00
STTD	0.6	24.2	2.19	0.8	0.08	114.6	5.68	38.5	3.21
	0.8	27.6	1.67	0.7	0.13	122.1	6.23	3.6	0.14
	1.0	26.6	2.80	0.6	0.09	127.9	5.90	0.6	0.47
	1.2	26.2	2.19	0.6	0.13	129.1	9.54	0.0	0.00
	1.4	26.2	1.64	0.5	0.02	129.8	8.32	0.0	0.00
FMCDM	0.6	25.4	2.80	0.8	0.13	51.6	6.65	26.3	4.54
	0.8	30.4	2.11	0.8	0.03	74.0	5.43	9.0	0.53
	1.0	31.4	1.39	0.7	0.11	82.2	6.87	0.8	0.02
	1.2	33.2	2.71	0.6	0.08	83.8	3.38	0.0	0.00
	1.4	33.2	2.55	0.6	0.05	82.9	4.72	0.0	0.00
AFMCDM	0.6	25.6	1.54	0.8	0.17	36.1	4.43	13.6	2.52
	0.8	31.8	2.46	0.8	0.07	48.0	5.45	0.6	0.01
	1.0	35.4	2.21	0.8	0.14	63.4	3.63	0.0	0.00
	1.2	36.0	2.51	0.6	0.13	60.1	3.62	0.0	0.00
	1.4	36.2	1.44	0.6	0.10	61.8	2.88	0.0	0.00

To analyze the relative performance of each rule, equality of sample means was tested via the method of the analysis of variance. General Linear Models Procedure of SAS, a statistical analysis package, was used and the following hypothesis was tested.

$$H_0 : \mu_{MFCFS} = \mu_{STTD} = \mu_{FMCDM} = \mu_{AFMCDM}$$

where, μ_i = mean for rule i

H_1 : at least two of the means are unequal

At the test level of $\alpha = 0.05$, degrees of freedom of 3 and 396, the computed F-statistic of 125.23, and p-value of 0.0001 were significant. This indicates the mean throughputs of the five rules are not the same. Through Duncan's Multiple Range Test, it was subsequently established that the system throughput for AFMCDM rule gives the highest performance.

The Figure 4 visualizes the system throughput results of Table 6. The figure shows the AFMCDM rule shows substantial improvements in throughput as the level of criticality ratio of AGVs is increased.

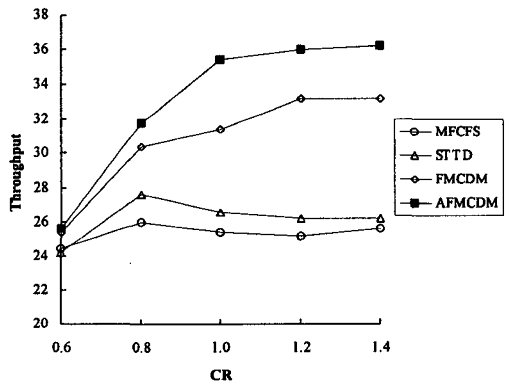
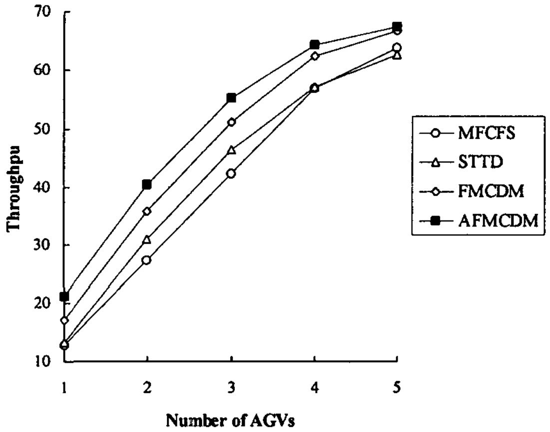


Figure 4. System throughput under varying criticality ratio of AGVs

2) Testing performance under differen

The effect of the different number of AGVs was also investigated and the results are shown in Figure 5. Three buffer queue capacities are used. The AFMCDM algorithm performs better compared to the other rules. With one AGV, the improvement of 23 % in system throughput was achieved by the AFMCDM rule over the FMCDM rule. If the system has more vehicles than needed, idle vehicles tend to appear, which calls for the workstation initiated rule. In this case, discriminating power among dispatching rules disappears as depicted in the figure.

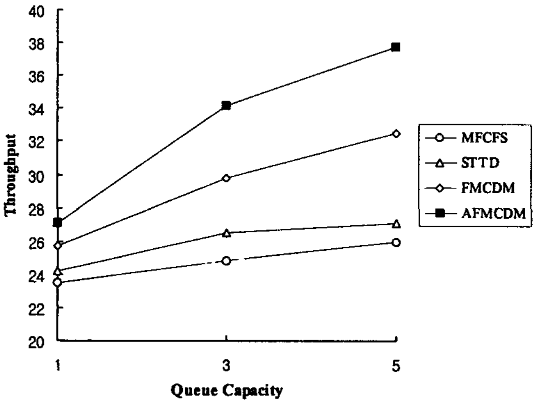
Figure 5. System throughput under varying number of AGVs



3) Testing performance under different buffer queue capacity level

Figure 6 shows the results of simulation experiments at the levels of buffer queue capacities. Two AGVs are involved. The figure shows the proposed algorithm still outperforms the other rules regardless of the buffer capacities.

Figure 6. System throughput under varying queue capacity



4. CONCLUSION

In this paper, an adaptive control scheme for the fuzzy dispatching algorithm is proposed. In order to control the importance weight for dispatching criteria, the information of the criticality ratio of AGVs and the degree of congestion of incoming buffer were utilized. The proposed adaptive dispatching algorithm was compared with several dispatching rules on the system throughput measure. And the response time, the utilization of workstation, and the number of returns were investigated additionally. The comparative study was carried out varying the capacity of buffer size, the level of criticality ratio of AGVs, and the number of AGVs. The proposed algorithm was shown to perform substantially better than the other rules. Although the results presented in this paper should be interpreted with reference to the hypothetical job shop and the experimental conditions described earlier, it is believed that the demonstrated advantages may be quite general. Further research is needed on the issue of how to adjust the fuzzy relations between criticality index and urgency in operation to enhance the performance.

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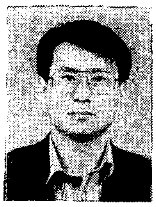

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