IEMS Vol. 7, No. 1, pp. 99-107, June 2008.

Dynamic Scheduling of FMS Using a Fuzzy Logic Approach to Minimize Mean Flow Time

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Selected paper from APIEMS2005

Abstract. This paper is concerned with scheduling in Flexible Manufacturing Systems (FMS) using a Fuzzy Logic (FL) approach. Four fuzzy input variables: machine allocated processing time, machine priority, machine available time and transportation priority are defined. The job priority is the output fuzzy variable, showing the priority status of a job to be selected for the next operation on a machine. The model will first select the machines and then assign operations based on a multi-criteria scheduling scheme. System/machine utilization, minimizing mean flow time and balancing machine usage will be covered. Experimental and comparative tests indicate the superiority of this fuzzy based scheduling model over the existing approaches.

Keywords: Flexible Manufacturing System, Scheduling, Part Routing, Fuzzy Logic.

1. INTRODUCTION

The FMS scheduling problem, like many other practical problems, involves multiple objectives that must be considered simultaneously. In many situations, some of these objectives can be conflicting in nature, and have different importance to decision-makers according to the changes in the environment of the production system. Another major issue in many scheduling problems is the intrinsic vagueness and imprecision of human-assigned constraints and evaluation criteria. Furthermore, in general, the aim of a workshop manager is not to optimize a single criterion but to satisfy many criteria at the same time (Srinoi, 2004). FMS scheduling problems can be solved using the following techniques - mathematical programming approach, heuristic or dispatching rules approach and AI approaches. Nowadays, however, Fuzzy Sets Theory and Computational Intelligence methods offer more and more practiced alternatives to conventional methods in many areas of production control (Timothy, 1995).

Fuzzy Logic has shown some interesting potentiality in different aspects of the scheduling problem in flexible manufacturing systems. Hintz *et al*. (1989) applied fuzzy logic to build aggregated dispatching rules for solving the sub problems of scheduling programs in FMS. The scheduling was focused on the derivation of the date criterion of Slack Time (ST) and Waiting Time (WT). Nahavandi *et al*. (1995) employed the same basic idea as Hintz and Zimmer-mann by applying fuzzy logic to shop floor scheduling for prioritization and ordering of jobs in a Factory Controller queue of the FMS. The fuzzy variables chosen are ST and WT, of a work order and External Priority (EP) of a job. A method of aggregation of dispatching rules by using a fuzzy logic approach to realize the scheduling decision for FMS

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with multiple objectives was also proposed by Yu *et al*. (1999) to decide the assignment of jobs to suitable machines and ordering of all jobs assigned to a given machine. Naso *et al*. (1998) proposed a fuzzy multi-criteria algorithm for dynamic routing in an FMS. Four heuristic routing strategies, which are Minimum Work in Queue (MWQ), Shortest Processing Time (SPT), Shortest Distance (SD) and Deadlock Avoidance are used as fuzzy variables for selecting the best alternative routes. They used the following performance indices; makespan, mean and maximum flow time, mean resource utilization, mean tardiness, mean queue length and the fuzzy multiple performance measure combining all the above indices with equal weights. Srinoi *et al*. (2006) applied fuzzy logic to generate a Fuzzy Scheduling model for first selecting the machine and then assigning operations based on a multi-criteria scheduling scheme. The scheduling process aims at meeting due dates while approaching minimum setup times and work in process, as well as maximum system utilization.

In this research work, Fuzzy Logic is applied to generate a Fuzzy Scheduling model for solving operation allocation and operation scheduling problems in FMS that can cope with several objectives of FMS scheduleing.

2. FUZZY LOGIC APPROACH TO FMS SCHEDULING PROBLEMS

In this paper, the operation allocation (routing) and operation scheduling (sequencing) problems for a given production plan are considered. The operation allocation problem is to assign operations of parts to machines under the given production plan, while the operations scheduling problem is to determine the input sequence of the assigned operations for each machine (Gamila *et al*. 2003). Fuzzy logic will be implemented to solve this FMS scheduling problem in selecting the machine for each job operation and determining the processing sequence for each machine simultaneously. This schedule will be able to improve performance criteria in system and machine utilization, work in process, mean flow time, and also balancing machine usage. Four suitable fuzzy input variables, namely machine allocated processing time, machine priority, machine available time and transportation priority, are introduced. A fuzzy model is developed incorporating some rules to generate the single output reflecting job priorities for allocation to each machine in the given FMS, see Figure 1.

3. THE PROPOSED MODEL

A fuzzy based mathematical model is developed to deal with the objectives set in section 2. The proposed Fuzzy model for job priority is shown in Figure 1.

3.1 Notations

This paper is concerned with dynamic routing, i.e. the selection of a part's next destination machine, as soon as the part has completed the previous operation. The solution to this problem defines the operations to be performed on each machine and a route through the machines for each job. The parameters and fuzzy variables used in the model are listed below.

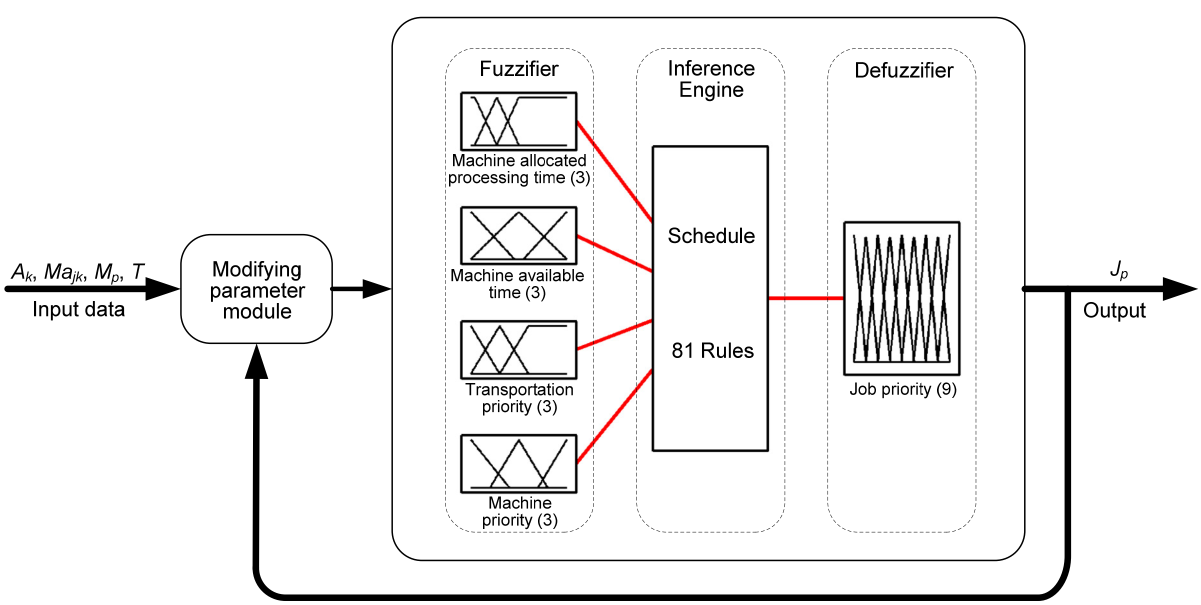


Figure 1. Fuzzy model for route selection

Consider an FMS with M different machines $M = \{M_1, M_2, M_3, \cdots, M_k, \cdots, M_M\}$ and a set of L part types (jobs) $J = \{J_1, J_2, J_3, \cdots, J_L\}$ in an FMS system, where each job J_i consists of Q_i parts, and a sequence of N_i operations, $O_i = \{O_{1i}, O_{2i}, O_{3i}, \cdots, O_{Ni}\}$, where each operation may be performed on a specified subset E_i of M. We will use the following notations, which will be further defined, in section 3.2.

Parameters and sets:

N_i : number of operations for job J_i;
Q_i : number of parts in job J_i;
f_j : input buffer capacity of machine M_j.

Fuzzy Variables:

P_{ijk} : processing time of operation O_j of job J_i, on machine k;
A_k : machine allocated processing time at any given event; (a function of P_{ijk})
Ma_{jk} : machine available time;
Mp : machine priority;
T : transportation priority;
Jp : job priority.

Note: Despite the fact that some variables are functions of the others and can in fact be derived from them, they are introduced separately in the develop-ments. This will not change the nature of the work.

3.2 Fuzzy Logic Model

In order to meet the objectives, four fuzzy input variables are defined. As the definitions and notations are quite cumbersome, an example is used for clarification. Consider the data in Table 1.

3.2.1 Definition of the fuzzy variable

Machine Allocated Processing time, A_k: Each job J_i has a set E_i of machines to perform all its operations, example: $E_1 = \{M_1, M_2, M_3, M_5\}$ in Table 1. Note that there may alternative machines available for some operations. For example O_{11} can be done on M_1 or M_2. Also the same machine M_k can be used on different jobs. Example O_{11} and O_{21} can be done by M_2.

In order to balance the machine loads (or minimize makespan), a measure of load allocated to each machine at any given event (e.g. completion of an operation) needs to be defined. This is accomplished via two Procedures. Consider stage j where operations 1, $\cdots$ j-1 have already been assigned for every job.

Procedure 1: Machine load allocation for an operation j

Set $A = 0, \quad \forall k$

At stage j, consider an operation j where $j \quad \{1, \cdots \max_{i / J_i \ J} \{N_i\}\}$. Operation O_{ij} will be assigned to machine k where,

$$A_k = \min_{\substack{z \ E_i \\ P_{ijk} > 0 \\ i=1,\cdots,L}} \{A_z + P_{ijz}\} \qquad (1)$$

(1) also updates A_k ■

Example 1: Assignment of operation j = 1, Table 1.

$O_{11} \to M_1$, $O_{21} \to M_2$, $O_{31} \to M_5$, and $O_{41} \to M_4$, resulting in

$A_1 = 15, A_2 = 20, A_3 = 0, A_4 = 30, A_5 = 40$

Note that the job which has the shortest processing time will be prior assigned, so that M_3 is unallocated while O_{51} is unassigned.

When an operation O_{lj} is unassigned for some l, j then assignment at stage j is completed by procedure 2.

Procedure 2: Completion of assignment of operation j

Define U as a set of jobs for which operation j is yet unassigned,

Let $U = \{J_{x_1}, J_{x_2}, \cdots, J_{x_p}\}$

Define a matrix $B_{(p \times 3)}$ which stores three values in each row

$t = 0$

For each $J_z \quad U$ Do

{ $t = t+1$

Calculate

$$b_z = \min_{l \ E_{J_z}} \{A_l + P_{J_z, j, l}\}$$

Set $B(t) = ()(b_z, J_z, l_z)$

where l_z shows the machine for which the b_z was found

Remove J_z from U

}

Find row t^* of $B()$ with $\min_t(b_z)$, mark it as (b_{z^*} J_{z^*} l_{z^*})

Set $k = l_{z^*}$

Update $A_k = A_k + P_{z^*, j, k}$ ■ (2)

Example 2: In example 1, O_{51} is unassigned

$U = \{J_5\}$

$E_1 = \{M_1, M_2, M_3, M_4, M_5\}$

$$b_5 = \min \begin{Bmatrix} 15+16, & l=1 \\ 30+45, & l=4 \end{Bmatrix}$$

So $l_5 = 1$, therefore O_{51} is allocated to M_1 and A_1 = 15+16 = 31. Deleting J_5 from U, leaves $U = \varnothing$, so assignment at stage 1 is now complete.

Machine available time, Ma_{jk}: This variable identifies the machine with the most slack time available, relative to other machines, to take up a new operation at any stage. This input variable would be implemented in the model only when the number of local input buffers

Table 1. Example input data for each part type.

`	Machine	Operation 1	Operation 2	Operation 3	Operation 4
		Time	Time	Time	Time
J_1	M_1	15			25
	M_2	18			30
	M_3		24		
	M_5			10	
J_2	M_2	20	16		
	M_3	24	10		
	M_4				25
	M_5			35	
J_3	M_1		25		
	M_2				15
	M_3			27	
	M_4			30	
	M_5	40			
J_4	M_1				15
	M_2		30		
	M_3				25
	M_4	30			
	M_5			20	
J_5	M_1	16			
	M_2			15	
	M_3		20		
	M_4	45			30
	M_5			20	

(IB) capacity is considered. On the other hand, if the local input buffers of all machines are infinite, this input variable will not need to be considered (Ro *et al*., 1990).

At the completion of assignments of operations at stage *j*, calculate,

$$A_{k*} = \max_k A_k$$

$$Ma_{jk} = 0, \ k = k*$$

$$Ma_{jk} = A_{k*} - A_k, \ k \neq k*, \ \forall j$$

If f_j is the input buffer capacity of machine M_j, then Ma_{jk} must be adjusted as

$$Ma_{jk} = (A_{k*} - A_k)\frac{f_j}{100}, \ k \neq k*, \ \forall j \quad (3)$$

In case of infinite local input buffer, f_j can be assumed to be 100.

Ma_{jk} will be considered as a fuzzy number and rules will be provided to assist further allocation, see later sections.

Machine priority, Mp: This variable forces the assignment of the next operation of a given job to start at the closest possible time to the finishing of the previous operation of the same job.

When selecting operation O_{ij} to be assigned to a machine, find the machine *k*, which performed $O_{ij\text{-}1}$.

Get A'_{k*} which is the point of completion of $O_{ij\text{-}1}$ on a machine *k**

Note, this may not be the last operation performed by this machine.

$$\text{Calculate, } Mp \begin{cases} 0 & \text{if } A_l = A'_{k*}, \\ \text{Positive,} & \text{if } A_l \quad A'_{k*}, \qquad l \quad E_i \\ \text{Negative,} & \text{if } A_l > A'_{k*}, \end{cases} \quad (4)$$

This variable will be used by the fuzzy rules to select the machine for O_{ij}.

Transportation priority, T: The traveling time of jobs between machines are used as input variables to establish the highest priority of part transportation between machines.

Let *T* be a matrix of transportation time of jobs between machines,

$t_{ij} =$ travel time (units) between machines *i*, *j*,

$$T = \{t_{ij}\}, \ t_{ij} = 0, \ i = j \quad (5)$$

When the time to put a pallet on or to take it off the AGV is considered, it would be included in the transportation priority.

These fuzzy values are used as inputs to the fuzzy module to generate a priority for the next allocation.

***Job priority, Jp*:** Given several machines are available to receive a job j_x, job priority *Jp* determines the machine to perform the next operation for job j_x. The job priority is the output variable produced by the fuzzy system. It depends on four fuzzy time factors explained earlier. These criteria are summarized below:

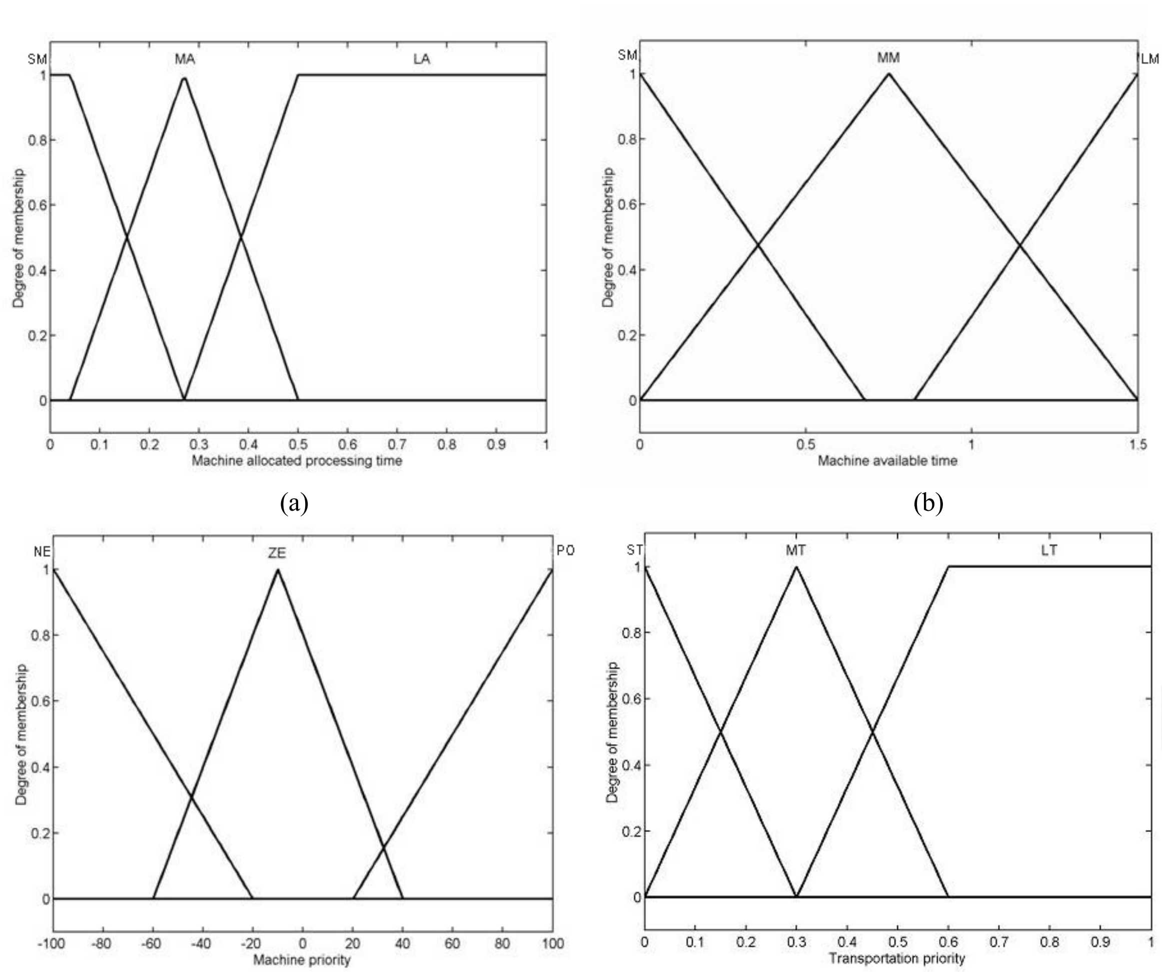
Criterion1: Assign job J_x to machine k based on A_k rule (see section 3.2.3)

Criterion2: Assign job J_x to machine k based on Ma_{jk} rule (see section 3.2.3)

Criterion3: Assign job J_x to machine k based on *Mp*

Table 2. Definition of fuzzy variable

Linguistic variable	Name	Term set	Term set values
machine allocated processing time machine available time machine priority transportation priority	A_k Ma_{jk} Mp T	SA, MA, LA SM, MM, LM NE, ZE, PO ST, MT, LT	short, medium, long short, medium, long negative, zero, positive short, medium, long
job priority	Jp	MN, NL, LO, NA, AV, PA, HI, PH, MX	minimum, negative low, low, negative average, average, positive average, high, positive high, maximum



(a) (b) (c) (d)

Figure 2. Membership functions of input fuzzy variables

rule (see section 3.2.3)

Criterion4: Assign job J_x to machine k based on T rule (see section 3.2.3)

3.2.2 Defining membership functions

The fuzzy sets of each universe of discourse are labelled as the term sets shown in Table 2.

The universe of discourse for machine allocated processing time, machine available time, and transportation priority are (0, max), and the universe of discourse for machine priority variable is (–, 0, +). Each universe of discourse is explained by three fuzzy sets.

In this research, the membership functions for each fuzzy set are triangular except at the extreme left are assumed as shown in Figure 2 (a) to (d). In practice choice of the membership function depends on the actual data available.

As shown in Figure 2 (a), the allocated machine processing times increase in each subsequent operation. It is therefore, very difficult to determine precisely the numerical range of this fuzzy variable. In order to solve this problem, A_k is normalized.

Intuitively, another linguistic variable representing the job priority needs to be defined. Assume that the universe of discourse of *Jp* = (0, 10) and that fuzzy model will deal with the nine distinctions characterizing the job priority. In other words, the universe of discourse of *Jp* has nine fuzzy sets. These fuzzy sets are labelled as the term sets shown in Table 2. The membership functions for each fuzzy set are triangular as shown in Figure 3.

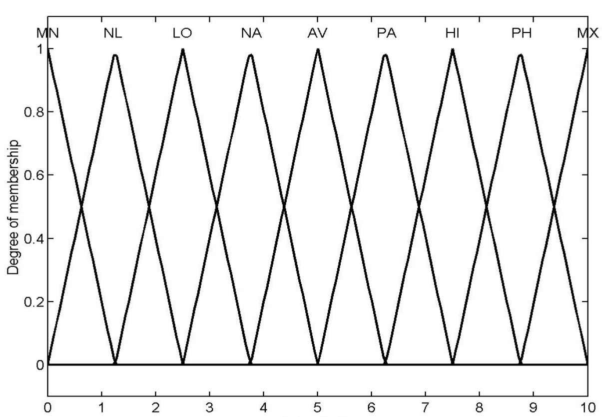


Figure 3. Membership functions of output fuzzy varible

3.2.3 Fuzzy logic mechanism

When the inputs are entered into the system, they are first fuzzified according to the membership functions of input fuzzy variables. Then the proper fuzzy estimation decision is inferred based on a defined set of linguistic rules.

The generic form of a rule can be expressed as conditional fuzzy propositions in the form:

If (Machine_allocated_processing_time is □) and (Machine_available_time is □) and (Transportation_priority is □) and (Machine_priority is □) then (Job_priority is □)

Where appropriate states of the four linguistic variables are placed into the empty boxes for each particular proposition. Since the variables of machine allocated pro- cessing time, machine available time, transportation priority, and machine priority have three states each, the total number of possible ordered pairs of these states is eighty one (81). For each of these ordered pairs of states, an appropriate state of the variable job priority has to be determined. A convenient way of defining all required rules is a decision Table that is also called a fuzzy association memory (FAM) bank matrix (Kosko, 1993), consisting of 81 (3×3×3×3) rules. This matrix cannot be physically shown due to its dimensions.

Every entity in the decision table represents a rule. The antecedent of each rule conjuncts variation in relative sum of processing time and machine priority fuzzy set values.

The job priority criteria used to derive fuzzy inference rules are shown as an example:

1. *If (Machine_allocated_processing_time is SA) and (Machine_available_time is LM) and (Transportation_priority is ST) and (Machine_priority is ZE) then (Job_priority is MX) (1)*
2. *If (Machine_allocated_processing_time is SA) and (Machine_available_time is LM) and (Transportation_priority is MT) and (Machine_priority is ZE) then (Job_priority is MX) (1)*

81. *If (Machine_allocated_processing_time is LA) and (Machine_available_time is SM) and (Transportation_priority is LT) and (Machine_priority is PO) then (Job_priority is MN) (1)*

Here the first rule implies that if the "machine allocated processing time" is "short" and "machine available time" is "long" and "transportation priority" is "short" and "machine priority" is "zero" then the "job priority" should be "maximum."

Normally rule definition is based on common sense, the engineer's knowledge and the operator's experience. However, it has been noticed in practice that for monotonic systems a symmetrical rule table is appropriate, although sometimes it may need slight adjustment based on the behavior of the specific system. Trial-and-error procedures and experience play an important role in defining the rules.

When four inputs are entered into the system as shown in Figure 1, a crisp output will be obtained for job priority. This value is calculated using Mamdani's (1975) method as the inference mechanism.

4. CASE STUDY

The FMS described by Chan (2002) for a job shop is used as a case study in this paper.

4.1 Flexible Manufacturing System Description

The layout plan of the FMS is shown in Figure 4. This FMS model consists of five CNC machines with an input buffer (IB) at each of the CNC machines. It is assumed that the AGVs always park at the last location after delivery. Because the time taken by the AGVs to carry the part type is small compared to the production time, they are therefore combined and it is assumed that it will take 60 seconds for an AGV to travel between any pairs of machines.

4.2 Sequence of Operations

Eight different part types are considered, each requiring four operations. The sequence of operations for each part type along with the processing time for each operation is shown in Table 3.

4.3 Assumptions

The following assumptions are made with respect to the FMS model developed for the experiments:

1. The machines are not identical.
2. Each machine is capable of performing different operations, but no machine can process more than one part at a time.
3. Set up times are independent of the job sequence and can be included in processing times.
4. No breakdowns occur in machines or material handling systems.
5. No collisions occur along the AGV path.
6. All pallets can be used interchangeably by each part

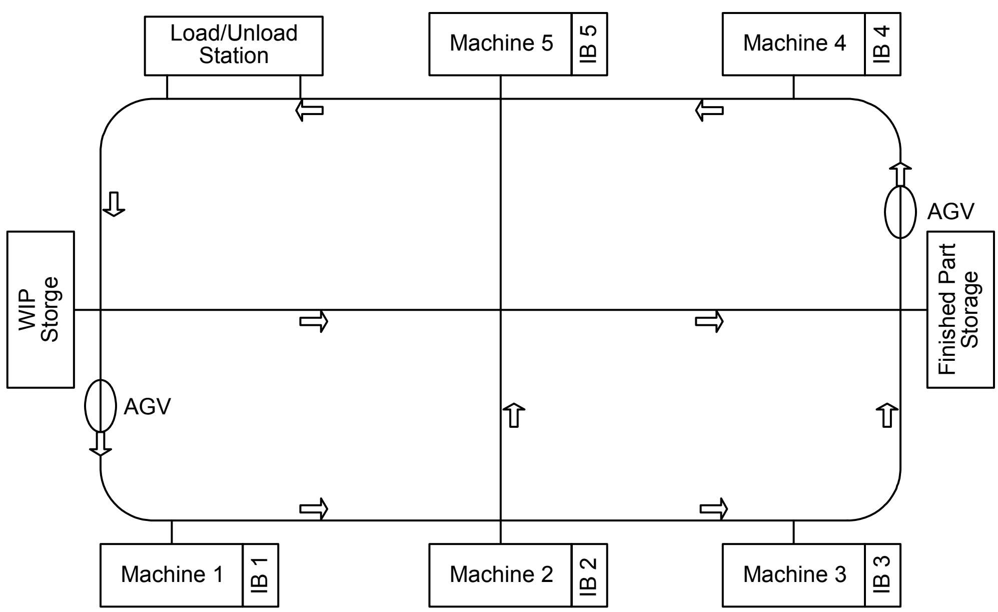


Figure 4. The layout of the FMS model(Chan, 2002)

Table 3. Machining times for different part types with alternative routings

	Operation 1		Operation 2		Operation 3		Operation 4	
Part type	Machine	Time	Machine	Time	Machine	Time	Machine	Time
J_1	1 (2)	15 ⟨18⟩	3	24	5	10	2 (1)	30 ⟨25⟩
J_2	2 (3)	20 ⟨24⟩	3 (2)	10 ⟨16⟩	5	35	4	25
J_3	5	40	1	25	4 (3)	30 ⟨27⟩	2	15
J_4	4	30	2	30	5	20	3 (1)	25 ⟨15⟩
J_5	1	10	3	20	2 (5)	15 ⟨20⟩	4	30
J_6	3 (5)	25 ⟨20⟩	2	12	1	25	5 (3)	10 ⟨23⟩
J_7	4 (1)	35 ⟨38⟩	5	10	1 (4)	10 ⟨15⟩	2	15
J_8	5 (4)	15 ⟨10⟩	4 (5)	40 ⟨30⟩	3	25	1	20

Note: The numerical data in ( ) and ⟨ ⟩ represent the alternative machine and the corresponding machining time respectively.

type.
7. No new part types are added.
8. Raw materials, tools, jigs and fixtures, and pallets are always available.
9. Demand for each part type is known.
10. Operations are not divided or interrupted when started.
11. All parts are available for processing at the start of the experimentation.
12. Where a part is started, it will leave the FMS only after all operations are completed.
13. Infinite input buffer capacities for all machines.

4.4 Fuzzy Logic Procedures

In this experiment, only two inputs, machine allocated processing time and machine priority, and one output fuzzy variable, job priority, are considered. Universe of discourse of the variables is defined as:

$$A_k = [0.03, 0.14]$$
$$Mp_k = [-50, 0, 50]$$
$$Jp = [0, 10]$$

The membership functions of two input variables take the same form as in Figure 2 (a) and (c). In this experiment, the universe of discourse of Jp has five fuzzy sets, which are MN, LO, AV, HI and MX, and the membership functions for this fuzzy set are also similar to what is shown in Figure 3, except for the number of fuzzy sets.

5. EXPERIMENT AND RESULTS

To compare our model to the performance of exist-

Table 5. Assignment of operations to machines and the utilization of machines, J_{ijn} means that it is a part n of job i, operation j

Machine	Operations assigned	Processing time	Completion time
M_1	$(J_{5,1,1})$ $(J_{3,2,1})$ $(J_{7,3,1})$ $(J_{6,3,1})$ $(J_{1,4,1})$ $(J_{8,4,1})$ $(J_{5,1,2})$ $(J_{3,2,2})$ $(J_{7,3,2})$ $(J_{6,3,2})$ $(J_{1,4,2})$ $(J_{8,4,2})$ $(J_{5,1,3})$ $(J_{3,2,3})$ $(J_{7,3,3})$ $(J_{6,3,3})$ $(J_{8,4,3})$ $(J_{5,1,4})$ $(J_{7,1,4})$ $(J_{3,2,4})$ $(J_{7,3,4})$ $(J_{6,3,4})$ $(J_{8,4,4})$ $(J_{4,4,4})$ $(J_{5,1,5})$ $(J_{3,2,5})$ $(J_{7,3,5})$ $(J_{6,3,5})$ $(J_{1,4,5})$ $(J_{8,4,5})$ $(J_{1,1,6})$ $(J_{6,3,6})$ $(J_{8,4,6})$ $(J_{1,4,6})$ $(J_{1,1,7})$ $(J_{6,3,7})$ $(J_{8,4,7})$ $(J_{1,4,7})$	748	1049
M_2	$(J_{1,1,1})$ $(J_{6,2,1})$ $(J_{4,2,1})$ $(J_{5,3,1})$ $(J_{7,4,1})$ $(J_{3,4,1})$ $(J_{1,1,2})$ $(J_{2,1,2})$ $(J_{2,2,2})$ $(J_{6,2,2})$ $(J_{4,2,2})$ $(J_{5,3,2})$ $(J_{3,4,2})$ $(J_{7,4,2})$ $(J_{1,1,3})$ $(J_{6,2,3})$ $(J_{4,2,3})$ $(J_{1,4,3})$ $(J_{3,4,3})$ $(J_{7,4,3})$ $(J_{1,1,4})$ $(J_{6,2,4})$ $(J_{4,2,4})$ $(J_{5,3,4})$ $(J_{7,4,4})$ $(J_{1,4,4})$ $(J_{3,4,4})$ $(J_{1,1,5})$ $(J_{6,2,5})$ $(J_{4,2,5})$ $(J_{5,3,5})$ $(J_{7,4,5})$ $(J_{3,4,5})$ $(J_{2,1,6})$ $(J_{2,2,6})$ $(J_{6,2,6})$ $(J_{7,4,6})$ $(J_{2,1,7})$ $(J_{2,2,7})$ $(J_{6,2,7})$ $(J_{7,4,7})$	732	1026
M_3	$(J_{2,1,1})$ $(J_{2,2,1})$ $(J_{1,2,1})$ $(J_{5,2,1})$ $(J_{3,3,1})$ $(J_{8,3,1})$ $(J_{6,4,1})$ $(J_{4,4,1})$ $(J_{6,1,2})$ $(J_{1,2,2})$ $(J_{5,2,2})$ $(J_{3,3,2})$ $(J_{8,3,2})$ $(J_{4,4,2})$ $(J_{2,1,3})$ $(J_{2,2,3})$ $(J_{5,2,3})$ $(J_{1,2,3})$ $(J_{3,3,3})$ $(J_{8,3,3})$ $(J_{4,4,3})$ $(J_{2,1,4})$ $(J_{2,2,4})$ $(J_{1,2,4})$ $(J_{5,2,4})$ $(J_{8,3,4})$ $(J_{6,4,4})$ $(J_{2,1,5})$ $(J_{2,2,5})$ $(J_{5,2,5})$ $(J_{1,2,5})$ $(J_{8,2,5})$ $(J_{4,4,5})$ $(J_{6,1,6})$ $(J_{1,2,6})$ $(J_{8,3,6})$ $(J_{6,4,6})$ $(J_{6,1,7})$ $(J_{1,2,7})$ $(J_{8,3,7})$ $(J_{6,4,7})$	927	1026
M_4	$(J_{8,1,1})$ $(J_{7,1,1})$ $(J_{4,1,1})$ $(J_{8,2,1})$ $(J_{5,4,1})$ $(J_{2,4,1})$ $(J_{7,1,2})$ $(J_{4,1,2})$ $(J_{8,2,2})$ $(J_{2,4,2})$ $(J_{5,4,2})$ $(J_{7,1,3})$ $(J_{4,1,3})$ $(J_{8,2,3})$ $(J_{5,4,3})$ $(J_{2,4,3})$ $(J_{8,1,4})$ $(J_{4,1,4})$ $(J_{8,2,4})$ $(J_{3,3,4})$ $(J_{5,4,4})$ $(J_{2,4,4})$ $(J_{7,1,5})$ $(J_{4,1,5})$ $(J_{8,2,5})$ $(J_{3,3,5})$ $(J_{2,4,5})$ $(J_{5,4,5})$ $(J_{7,1,6})$ $(J_{7,3,6})$ $(J_{2,4,6})$ $(J_{7,1,7})$ $(J_{7,3,7})$ $(J_{2,4,7})$	935	1065
M_5	$(J_{6,1,1})$ $(J_{3,1,1})$ $(J_{7,2,1})$ $(J_{4,3,1})$ $(J_{1,3,1})$ $(J_{2,3,1})$ $(J_{8,1,2})$ $(J_{3,1,2})$ $(J_{7,2,2})$ $(J_{2,3,2})$ $(J_{1,3,2})$ $(J_{4,3,2})$ $(J_{6,4,2})$ $(J_{8,1,3})$ $(J_{6,1,3})$ $(J_{3,1,3})$ $(J_{7,1,3})$ $(J_{5,3,3})$ $(J_{1,3,3})$ $(J_{4,3,3})$ $(J_{2,3,3})$ $(J_{6,4,3})$ $(J_{6,1,4})$ $(J_{3,1,4})$ $(J_{7,2,4})$ $(J_{1,3,4})$ $(J_{4,3,4})$ $(J_{2,3,4})$ $(J_{8,1,5})$ $(J_{6,1,5})$ $(J_{3,1,5})$ $(J_{7,2,5})$ $(J_{1,3,5})$ $(J_{2,3,5})$ $(J_{4,3,5})$ $(J_{6,4,5})$ $(J_{8,1,6})$ $(J_{8,2,6})$ $(J_{7,3,6})$ $(J_{1,3,6})$ $(J_{2,3,6})$ $(J_{8,1,7})$ $(J_{8,2,7})$ $(J_{7,2,7})$ $(J_{1,3,7})$ $(J_{2,3,7})$	950	1039
Sum		4292	5205

Table 6. Comparison between fuzzy logic and combined dispatching and routings strategies

Performance measure	Control strategy						Other approaches		Proposed method	% Change against	
	1	2	3	4	5	6	Best	Average		Best	Average
Makespan (min.)	1212	1140	1078	1084	978	1120	**978**	1102	***908***	+7.71	+21
Average machine utilization. (%)	68.5	66.5	79	78.5	80	79.5	**80**	76	***81***	+1	+5
Mean flowtime (min.)	670	780	580	720	770	663	**580**	697	***650***	–10.77	+7.23

Note: Bold figures are best values for other methods. % is w.r.t. best figures.

ing models, the same product data as shown in Table 4 are used.

Table 4. Demand for each part type

Part type	J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8
Demand	7	7	5	5	5	7	7	7

The results achieved by our model are shown in Table 5. Table 6 shows a comparison of the best performance indices of combined dispatching and routing strategies achieved by simulation (Chan, 2002) with results of the fuzzy system.

The list of the other methods and their abbreviations in Table 6 are defined as follows:

1. NAR/SPT: No Alternative Routings/Shortest Processing Time
2. NAR/LPT: No Alternative Routings/Longest Processing Time
3. ARD/SPT: Alternative Routings Dynamic/ Shortest Processing Time
4. ARD/LPT: Alternative Routings Dynamic/Longest Processing Time
5. ARP/SPT: Alternative Routings Planned/Shortest Processing Time
6. ARP/LPT: Alternative Routings Planned/Longest Processing Time

The results indicate that overall the Fuzzy logic model performed reasonably well in most of the performance measures. It produces results that are superior to the best produces by Chan (2002), in 2 out of 3 measures. Accordingly, the proposed method has the potential of being improved to a working scheme. Further experimentations are required to fine-tune the parameters/ assumptions.

6. CONCLUSION

This paper describes the design, development and application of a fuzzy logic approach for selecting real-time part routes in an FMS. In particular, the input variables for the fuzzy logic model are developed. Experimental results indicate that fuzzy logic can provide good results in most performance measures. It is shown that fuzzy logic provides a technique to select the routes based on multiple, conflicting criteria. This enhances the existing approaches such as conventional optimization based on single criteria. Our study indicates the suitability and desirability of a Fuzzy logic approach in FMS scheduling. Further investigations are required to establish a practical method.

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