Determination of Routing and Sequencing in a Flexible Manufacturing System Based on Fuzzy Logic

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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 fuzzy output variable, showing the priority status of a job to be selected for next operation on a machine. The model will first assign operation of parts to machines under the given production plan and then determine the input sequence of the assigned operations for each machine based on a multi-criteria scheduling scheme. A complete fuzzy scheduling algorithm is developed to solve the operation allocation and operation scheduling problems in FMS environments aiming to approach the objectives of minimizing mean flowtime, maximizing machine utilization and balancing machine usage. The test results demonstrate the superiority of the fuzzy logic approach in most performance measures.

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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 [1]. In general, the approaches used for scheduling FMSs can be classified into analytical techniques, heuristic algorithms, simulation, expert system/ artificial intelligence techniques, and hybrid methods. The use of fuzzy logic approaches for scheduling FMS is considered due to its ability to deal uncertain and incomplete information and with multi-objective problems.

Fuzzy Logic has shown some interesting potentiality in different aspects of the scheduling problem in flexible manufacturing systems. Hintz et al. [2] applied fuzzy logic to build aggregated dispatching rules for solving the sub problems of scheduling programs in FMS. Chan et al. [3] developed a fuzzy approach for operation and routing selection via simulation. The proposed fuzzy approach was compared with some other conventional selection rules

and the results showed a good improvement in some performance measures. Mahdavi et al. [4] presented a fuzzy approach to solve the scheduling problems of a FMS. They defined four fuzzy input variables: processing time, workload, setup time and travelling time. In this study, the output fuzzy variable was the optimal route selection to satisfy multi-conflicting objectives. They used the MATLAB fuzzy logic toolbox to determine the route selection. The numerical results showed that the presented approach is easily applicable to finding the optimal flexible routing in FMS. Srinoi et al. [5] developed a new approach based on fuzzy logic to generate a scheduling model for solving the resource allocation problem in flexible manufacturing systems. They defined four fuzzy input variables of the model: processing time, due date, setup time and machine priority; the output variable of the model is the job priority. They conducted several experiments to prove the effectiveness of the developed approach. The experimental results indicated that the fuzzy logic approach is a powerful technique for scheduling problems in FMS, based on multi criteria objectives. Manvendra et al. [6] presented a fuzzy logic based scheduling of Flexible Manufacturing System. The scheduling problem is to decide the sequence of the jobs and which alternative routes should be selected for each job. The results show that time taken by shortest processing time is more than fuzzy logic method.

In this research work, Fuzzy Logic is applied to generate a Fuzzy Scheduling model for determining routing and sequencing problems in FMS, attempting to approach minimised mean flow time, maximised machine utilisation, and balancing machine usage

2. Application of fuzzy logic approach to FMS scheduling problems

Developing a production schedule involves determining the flow of parts and assignment of operations and tools on each machine that will result in the completion of a part and determining the start time and finish time of each operation at its allocated machine. Technological sequence of operations on each part has to be preserved and the ordering of operations on each machine has to be selected so as to achieve the desired objectives. The models for the optimal machining sequence for problems of this type are NP-hard, i.e., the time required to solve in optimally increases exponentially with problem size. Given that the nature of most of real factors are

subjective and to avoid the complexity of the associated scheduling problem, we adopt a fuzzy approach in this work. We introduce four suitable fuzzy input variables, namely machine allocated processing time, machine priority, machine available time and transportation priority. 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 Fig. 1.

In this paper, the operation allocation and operation scheduling 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. 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.
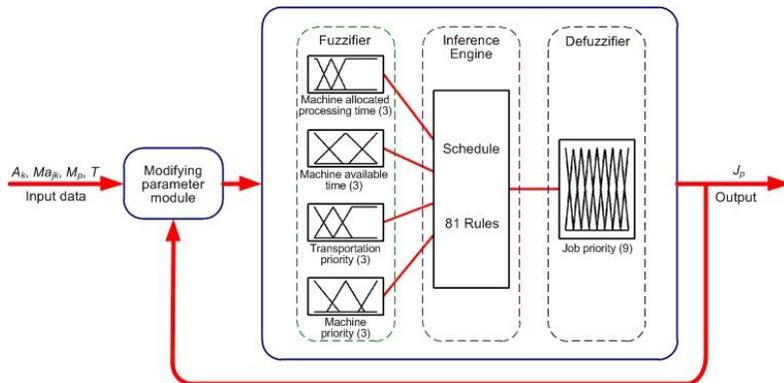

Fig. 1. Fuzzy model for route selection

3. The proposed model

Given a set of parts to be produced by an FMS, where each part type has a routing; there are two major problems to be solved. First the parts must be allocated, then the operations scheduling determines the sequence in which the operations will be conducted by the machine. The aim would be to minimum mean flowtime, maximum machine utilization and balance machine usage. A fuzzy based mathematical model is developed to deal with this set of objectives.

3.1 Definition of problem

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.

Consider an FMS with M different machines $M = \{M_1, M_2, M_3,…, M_k,…, M_M\}$ and a set of L part types (jobs) $J = \{J_1, J_2, J_3,…, J_L\}$ in an FMS system, where each job J_i consists of Q_i parts, and a sequence of N_i operations, $O_i = \{O_{1i}, O_{2i}, O_{3i},…, O_{Ni}\}$, 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 the next section.

Notations:

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 developments. This will not change the nature of the work.

3.2 Fuzzy logic model

The model considers two measures namely mean flowtime and system utilization in an FMS environment. Four fuzzy input variables are defined. As the definitions and notations are quite cumbersome, we would use an example 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.

Table 1 Example input data for each part type

Part types	M/C	Operation 1 Time (min)	Operation 2 Time (min)	Operation 3 Time (min)	Operation 4 Time (min)
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	

We need to define a measure of load allocated to each machine at any given event (e.g. completion of an operation). This is accomplished via two Procedures. Consider stage j where operations 1, … j-1 have already been assigned for every job.

Procedure 1: Machine load allocation for an operation j

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

At stage j, consider an operation j where

$$j \in \{1, \dots \max_{\forall i \,/\, J_i \in J} \{N_i\}\} \ .$$

Operation O_{ij} will be assigned to machine k where,

$$A_k = \min_{\substack{z \in E_i \\ P_{ijz} > 0 \\ j = 1, \dots, N_i}} \{A_z + P_{ijz}\} \tag{1}$$

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The Journal of Industrial Technology, Vol. 13, No. 3 September – December 2017

Eq. (1) also updates A_k ■

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

$O_{11} \longrightarrow M_1$, $O_{21} \longrightarrow M_2$, $O_{31} \longrightarrow M_5$, and $O_{41} \longrightarrow M_4$, resulting in $A_1 = 15$, $A_2 = 20$, $A_3 = 0$, $A_4 = 30$, $A_5 = 40$

Note 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 $\quad U = \{J_{x_1}, J_{x_2}, ..., J_{x_p}\}$

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

Example 2. in example 1. O_{51} is unassigned

$U = \{J_5\}$

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

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

So $b_5 = 1$

Machine available time, Ma_{jk}. This time variable identifies the machine with the most slack time available, relative to other machines, to take up a new operations at any stage. This input variable would be implemented in the model only when the number of local input buffers (IB) capacity are considered. On the other hand, if the local input buffers of all machines are infinite, this input variable will not need to be considered.

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

$A_{k*} = \max_k A_k$

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

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

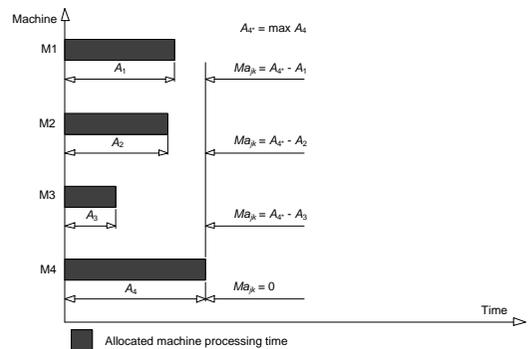Ma_{jk} can also be graphically clarified as shown in Fig. 2.

Fig. 2. Machine available time

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

$$Ma_{jk} = (A_{k*} - A_k) \frac{f_j}{100} \qquad , \ k \neq k* \qquad , \ \forall j \qquad (2)$$

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

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

$$Define, \ Mp = \begin{cases} 0 & if \ A_l = A'_{k*}, \\ Positive, & if \ A_l < A'_{k*}, \quad \forall l \in E_j \quad (3) \\ Negative, & if \ A_l > A'_{k*}, \end{cases}$$

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,

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

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

Criterion2: Assign job J_x to machine k based on Mp rule

Criterion3: Assign job J_x to machine k based on Ma_{jk} rule

Criterion4: Assign job J_x to machine k based on T rule

3.2.2 Membership functions for the fuzzy variables

The machine related fuzzy variables are in fact functions of the processing time. Therefore the fuzzy system would only need the processing time to be defined as a fuzzy number. For our tests we define all input variables independently. The fuzzy sets of each universe of discourse are labeled as the term sets shown in Table 2.

Table 2 Definition of fuzzy variable

| Linguistic variable	Term set	Term set values
machine allocated processing time, A_t	SA, MA, LA	short, medium, and long
machine available time, Ma_{ik}	SM, MM, LM	short, medium, and long
machine priority, Mp	NE, ZE, PO	negative, zero, and positive
Transportation priority, T	ST, MT, LT	short, medium, and 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, and maximum

At this stage of our research, we assume that the membership functions for each fuzzy set are triangular except at the extreme left as shown in Fig. 3 (a) ~ (d). The membership functions of output fuzzy variable is also shown in Fig. 4.
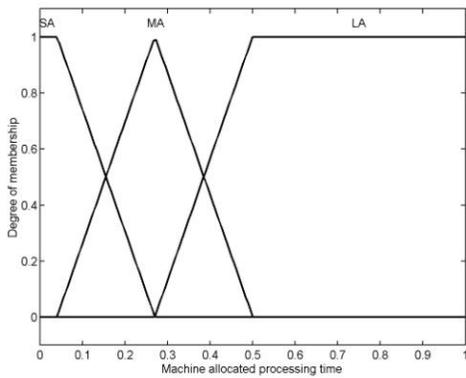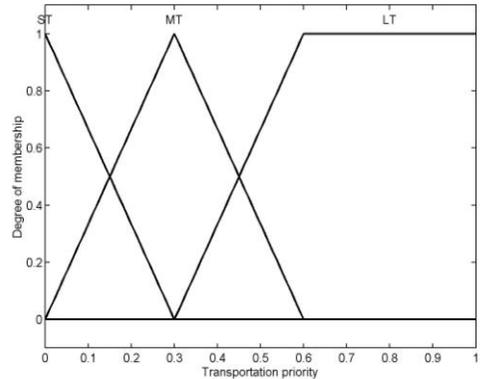

(a)
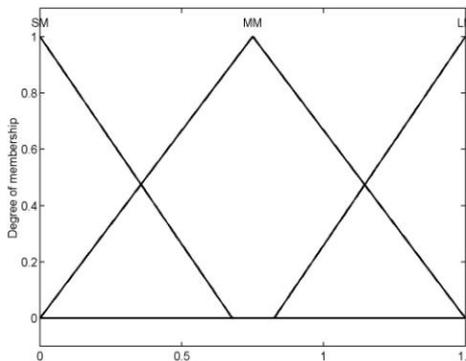
(b)
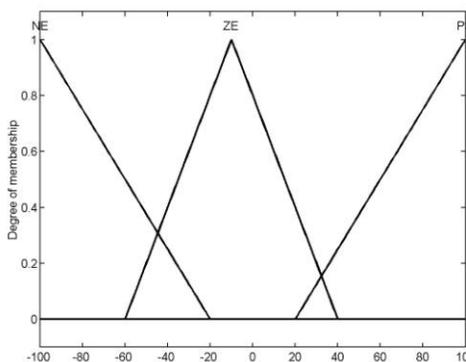
(c)

(d)

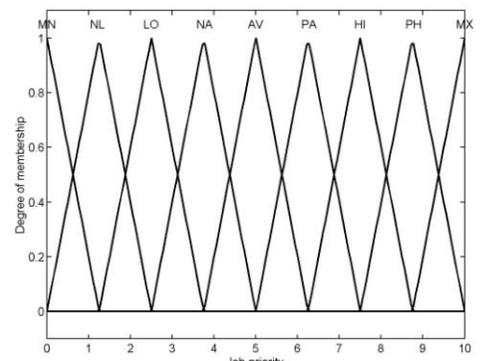**Fig. 3.** Membership functions of input fuzzy variables

Fig. 4. Membership functions of output fuzzy variable

As shown in Fig. 3 (a), it can be seen that the allocated machine processing times increases 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, the A_k is then normalized.

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 processing 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 [7], consisting of 81 (3×3×3×3) rules. This matrix cannot be physically shown due to its dimensions. Furthermore, all units and symbols presented in manuscript should be SI unit. Specific symbol need to have clearly explanation. 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 by Kosko [7] 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 Fig. 1, a crisp output will be obtained for job priority. This value is calculated using Mamdani's [8] method as the inference mechanism.

4. Case study

4.1 Flexible manufacturing system description

An FMS consists of three CNC machines (M_1 = Lathe, M_2 = Milling machine and M_3 = Machining center), two Automated Guided Vehicles (AGVs), a Robot = R and a Automated Storage/Retrieve System (AS/RS) as shown in Fig. 5 [9]. There are three different part types J_1, J_2, J_3 to be produced.
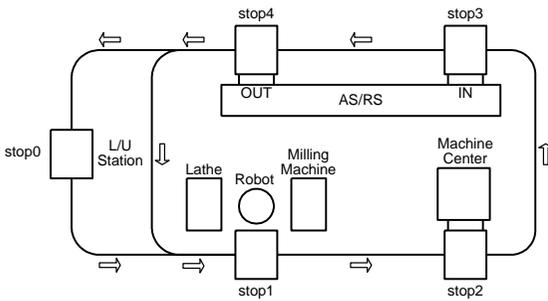

Fig. 5. The layout of the FMS

4.2 Sequence of operations

Three different part types are considered, each requiring thee operations. The sequence of operations for each part type along with the processing time for each operation is shown in Table 3. The operation time of each operation in each job are given in Table 3. The transportation time of AGV between each pair of workstations or stops are given in Table 4. The time loading/unloading operation (L/U) and robot transportation (ROB) are also given in this table.

Table 3 Operation times for different part types

Part types	M/C	Operation 1 Time (min)	Operation 2 Time (min)	Operation 3 Time (min)
J_1	M_1	82		45
	M_2	102		32
	M_3		27	
J_2	M_1		53	
	M_2		25	
	M_3	50		
J_3	M_1			112
	M_2	95		94
	M_3		98	

Table 4 Transportation of Material Handling Systems ($T_{i,j}$ means that the transportation times between stop i and stop j)

Work station	Transportation time
$T_{0,1}$	5
$T_{1,2}$	2
$T_{2,3}$	4
$T_{3,4}$	1
$T_{4,0}$	6
$T_{4,1}$	5
ROB	2
L/U	2

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. No breakdowns occur in machines or material handling systems.

3. Set up times are independent of the job sequence and can be included in processing times.

4. Operations are not divided or interrupted when started.

5. Where a part is started it will leave the FMS only after all operations are completed.

6. Each machine is capable of performing different operations, but no machine can process more than one part at a time.

7. No collisions occur along the AGV path.

8. Demand for each part type is known.

9. All the machines, robot and AGVs are ready and available to use at the initial stage.

4.4 Fuzzy logic procedures

In this case study only three inputs, machine allocated processing time, machine priority and transportation priority, and one output fuzzy variable, job priority, are considered. Universe of discourse of the variables are defined as:

A_k = [0.1, 0.5]

Mp = [-150, 0, 150]

T = [0, 17]

Jp = [0, 10].

The membership functions of three input variables take the same for as in Fig 3. (a), (c) and (d). In this case study the universe of discourse of Jp has nine fuzzy sets which are MN, NL, LO, NA, AV, PA, HI, PH and MX, and the membership functions for this fuzzy set is also similar to what is shown Fig. 4 except for number of fuzzy sets.

5. Experimentation and results

In this case study, the traveling time of jobs between workstations, load/unload operation time and robot transportation time are concerned. The transportation time in Table 4 is modified into the matrix form as shown below.

$$T = \begin{array}{c} \\ S0 \\ S1 \\ S2 \\ S3 \\ S4 \end{array} \begin{array}{ccccc} S0 & S1 & S2 & S3 & S4 \\ \left[\begin{array}{ccccc} 0 & 17 & 13 & 9 & 8 \\ 9 & 0 & 12 & 8 & 7 \\ 9 & 4 & 0 & 8 & 7 \\ 13 & 8 & 4 & 0 & 11 \\ 14 & 9 & 5 & 1 & 0 \end{array} \right] \end{array}$$

Table 5 Demand for each part type with different production volume

Lot No.	Production volume	Demand for each part type		
		J_1	J_2	J_3
1	6	2	2	2
2	15	5	5	5
3	30	10	10	10

It should be notified that Load/Unload operation time and robot transportation are already included.

Several different job sizes of this example are tested, the product data are shown in Table 5. Fig. 6 shows the Gantt chart of routing and sequencing for the case study.

Table 6 shows that using the proposed model resulted (compared with the performance measures of the existing methods for lot 3) in:

1. Decreasing mean flowtime from 502 to 498, a decrease of 0.8%.

2. Increasing the average machine utilization from 65 to 67, an increasing 1.5%

3. Balancing machine usage of the proposed method is slightly different (1:0.75:0.82).

6. Conclusions

The paper developed the mathematical relationships between variables representing machine allocated processing, machine available time, machine priority and transportation priority. Input and output fuzzy variables for the job priority have been derived. The objectives of a fuzzy approach in FMS scheduling presented in this paper were the improvement of maximizing machine utilization, minimizing mean flow time and balancing machine usage. The comparison of performance measures of the proposed method with the performance measures of the existing method was shown. It can be seen that scheduling FMS using a fuzzy logic technique provide good results in most performance measures.

Table 6 The utilization and completion time of machines

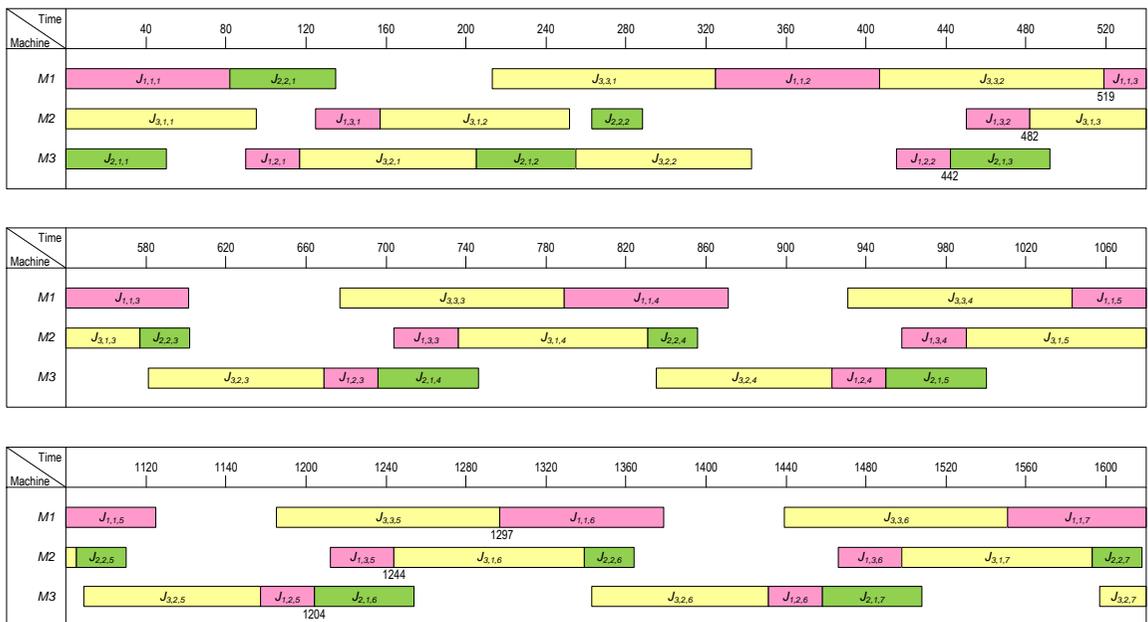| Machine	Processing time			Completion time			Utilization			Balancing
	Lot 1	Lot 2	Lot 3	Lot 1	Lot 2	Lot 3	Lot 1	Lot 2	Lot 3	M1:M2:M3
M_1	441	1023	1993	519	1297	2567	0.85	0.79	0.78	
M_2	279	735	1495	482	1244	2514	0.54	0.57	0.58	**1:0.75:0.82**
M_3	330	825	1650	442	1204	2474	0.64	0.64	0.64	
Average				**481**	**1248**	**2527**	**67.7%**	**66.7%**	**66.8%**	

Fig. 6. Scheduling of parts on machines for the case study
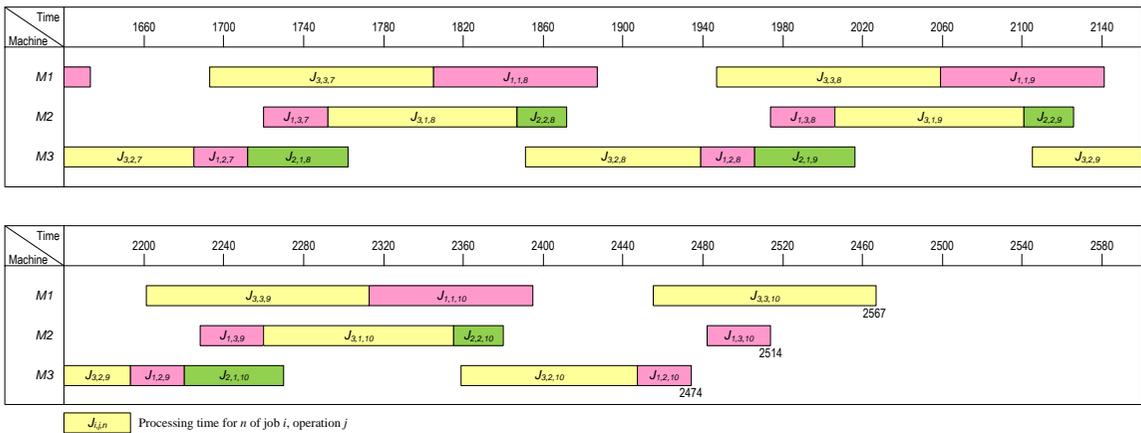
Fig. 6. Scheduling of parts on machines for the case study (Cont.)

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