SIMULATION OF FLEXIBLE MANUFACTURING SYSTEM (FMS) USING FUZZY LOGIC

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This paper focuses on the simulation of the flexible manufacturing system. Flexible manufacturing systems (FMS) are production systems consisting of identical multipurpose numerically controlled machines (workstations), automated material handling system, tools, load and unload stations, inspection stations, storage areas and a hierarchical control system. The model will prioritize the job and select the best alternative route with multi-criteria scheduling through an approach based on a fuzzy logic. There are three criteria for both the job sequencing and routing with 27 rules. With the help of the rules the sequence of the jobs are done and the best route is selected.

Key Words : Flexible Manufacturing System (FMS), Fuzzy Logic, Scheduling, Job Sequencing, Routing.

1. Introduction

A flexible manufacturing system (FMS) is a manufacturing system in which there is some amount of flexibility that allows the system to react in the case of changes. A FMS can be defined as a production system consisting of identical multipurpose numerically controlled machines (workstations), automated material and tools handling system, load and unload stations, inspection stations, storage areas and a hierarchical control system. Generally when t is being planned, the objective is to design a system which will be efficient in the production of the entire range of parts. This cannot be done until all the stages work well. Depending on the required level of scheduling performance, many different approaches can be generated. They may be classified as heuristic rule based, artificial intelligence, multi criteria decision making, simulation based scheduling etc. However, scheduling of an FMS is very complicated, particularly in dynamic environment. Many manufacturing systems, therefore, need scheduling for dynamic and unpredictable conditions. So, simulation based scheduling have been considered in FMS scheduling.

Fuzzy logic, which was introduced by Zadeh (1965), has been applied to various industrial problems. The advantage of the fuzzy logic system approach is that in incorporates both numerical results from previous solutions or simulation and the scheduling expertise from experience or observation or hypothetical data, and it is very easy to implement. Several Fuzzy logic based scheduling systems have recently been developed.

Watanabe proposed a fuzzy scheduling mechanism for job shops, that they name FUZZY. The only problem that they actually attack is the priority setting problem for a free machine choosing in its buffer the next job to serve. Grabot proposed a routing mechanism that embodies expert knowledge and that reacts to resource failures by using fuzzy logic and possibility theory. Angsana and Passino proposed a new scheduling technique which was designed to emulate human scheduler. The implemented Fuzzy Conroller (FC). Sentieiro use fuzzy set theory in a non-classic approach called FLAS (fuzzy logic applied to scheduling) for short term planning and scheduling.

In this research work, Fuzzy logic is applied to generate a fuzzy scheduling model in order to select the best job sequence and part routing for the jobs.

2. Fuzzy logic Approach to Simulate FMS

The present industrial trend of manufacturing low cost low-to-medium volumes of modular products with high variability demands manufacturing systems with flexibility and low delivery times. This led to manufacturing systems with small batch productions, low setup times and many decisional degrees of freedom. The scheduling problem consists of several decisional points. A first division into four parts can be made:

· Timing: that is, when to insert a part into the system;

· Sequencing: that is, defining the order with which different parts (batches, orders) are inserted into the system;

· Routing: that is, defining the route (machine, AGV, etc.) for a part in presence of alternatives;

· Priority setting: that is, defining a priority for parts, machine and resources in general so that a choice is directly implied.

Fuzzy logic has the ability to simultaneously consider multiple criteria. Furthermore, the advantage of the fuzzy logic system approach is that it incorporates both numerical and linguistic variables. In this paper, we apply fuzzy logic to simulate FMS. The fuzzy based simulation, in this paper, is designed to solve the problem of determine the job sequence and selecting the best part route. In particular, we will show how to obtain the simulation via a proposed fuzzy model as shown in figure 1.

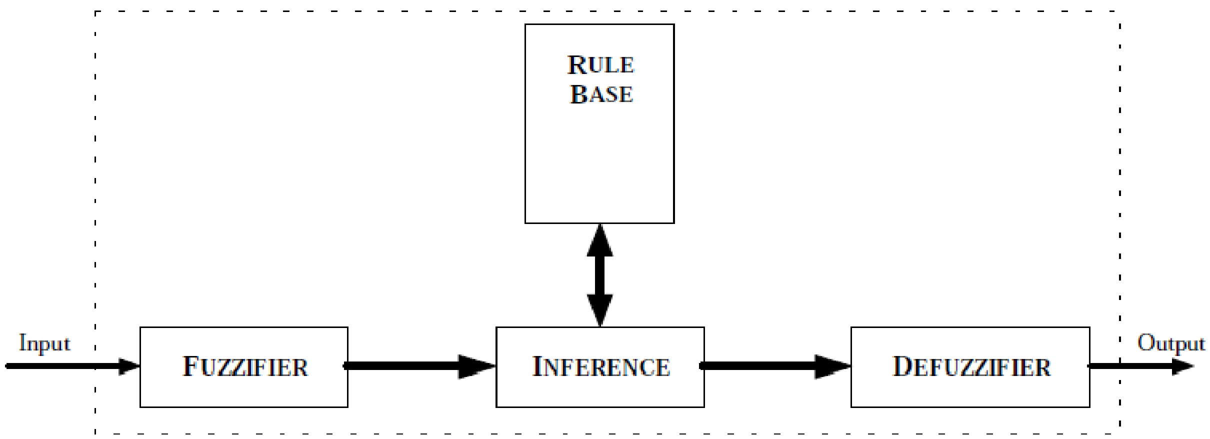


Fig. 1

Structure of a Fuzzy Logic System

3. A Case Study

The Fuzzy scheduler considers two particular rules in the scheduling problem: Sequencing of job and routing. The sequencing of jobs was approached using fuzzy controllers having rules with three antecedents (Processing time, Due date and Profit over Cost) and one consequent (Priority). The FLSs determine the priority of each job waiting for loading or in a machine buffer, so that whenever the load station or the machine are free the job with the highest priority among those waiting is chosen. The last decisional point that was considered is the routing problem, that is, the choice of one among many possible routes. In the problem considered this is equivalent to choosing the machine for next processing of a job, among the possible alternatives for that job.

The following assumptions on the FMS were made:

1. Tool management is not considered, i.e. it is supposed that all the tools are available where needed.
2. Failure of workstations and/or transport systems is not considered, i.e., the machines and/or transport subsystem are not subject to failure.
3. Orders arrive to the FMS as Poisson processes with a fixed inter-arrival time.
4. Production of orders occurs in batches, and the movement of the whole batch is considered, so that batch dimensions are not important.
5. Setup times are independent of the order in which operations are executed, i.e. they are constant and embodied in the operation times of each job (batch).
6. There are as many pallets and fixtures as are needed (this assumption is mitigated by the fact that the number of jobs in the system is constantly controlled).
7. The routing of every job is random and directly defined as a sequence of workstations the job has to go through. Thus, the route of a job is not defined in terms of the operations needed by the job. In other words, every operation corresponds directly to the workstation that will execute it, i.e., the routing is defined as a sequence of workstations (i.e., workstation 1, 5, 6, 2).
8. There can be multiple routing choices, i.e. at a certain point a job can be equivalently sent to different workstations (as specified in its routing plan) having different processing times.
9. Loading, unloading and processing times are random.
10. Due dates are assigned according to the total processing time of a job.

11. Each workstation can work only one job at a time.

12. The transport system is composed of automated guided vehicles (AGVs) and each AGV can transport only one job at a time.

13. Neither the weight of a piece nor the dimension of a batch affects the speed of AGVs, which is assumed to be constant.

14. Every workstation has one input buffer and no output buffer, therefore it will be free as soon as there is one free AGV that can transport the processed job to another workstation.

15. Delays in accessing the state information are neglected.

16. Among all the possible scheduling rules (Fanti contains a list of rules for a quite general FMS), the following are considered:

· Sequencing for a job (selection of a piece among those waiting to receive service from a machine);

· Routing decisions concerning the next required workstation.

3.1 Problem Definition

The FMS described in this paper consists of 4 different CNC machining centers with finite local buffer capacity, all capable of performing the required operations on each part type, a load/unload station and material handling system with a automated guided vehicle (AGV) which can carry one pallet at a time. The system produces three different part types, A, B and C, as shown in Table 1. It is assumed that it takes 3 minutes to load and unload a part on a pallet at load/unload station. The time to cross the distance between two consecutive MCs is assumed to be 0.5 minute. The arrangement of the FMC hardware is shown in Figure 2.

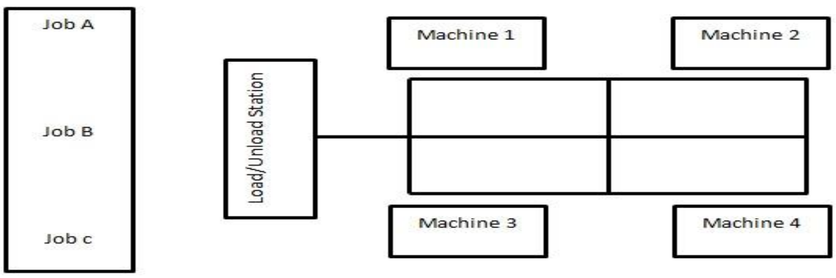


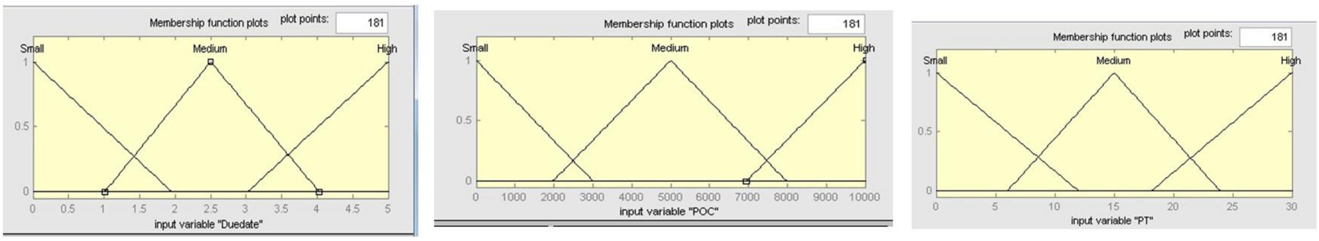
Fig. 2
Diagram of the Case Study

Each machine is capable of performing different operations, but no machine can process more than one part at a time. Each part type has several alternative routings. Operations are not divided or interrupted when started. Set up times are independent of the job sequence and can be included in processing times. The scheduling problem is to decide the sequence of the jobs and which alternative routes should be selected for each job.

4. The Fuzzy Based Simulation Model :

Proposed approach of this research is to identify different scheduling parameters such as, Processing time, due date and profit over cost for Job sequencing and processing time, travel time, work in que for routing and construct their membership functions and fuzzy rules. Using these membership functions and fuzzy rules a fuzzy interference system (FIS) is developed to identify the priority of jobs and to identify the best route using MATLAB fuzzy logic toolbox.

Three variables are selected to identify the job priority, named, processing Time (PT), De Date and Profit over Cost (POC). All the variables are assigned with triangular membership function and divided into three zones : Small, Medium and High. The output of these variables is priority varying from 0 to 1. The priority variable is also assigned with triangular membership function and divided into 9 portions. Minimum (MN), Negative Low (NL), Low (LO), Negative Average (NA), Average (AV), Positive Average (PA), High (HI), Positive High (PH) and Maximum (MX). The membership functions for each fuzzy set are shown in figure .

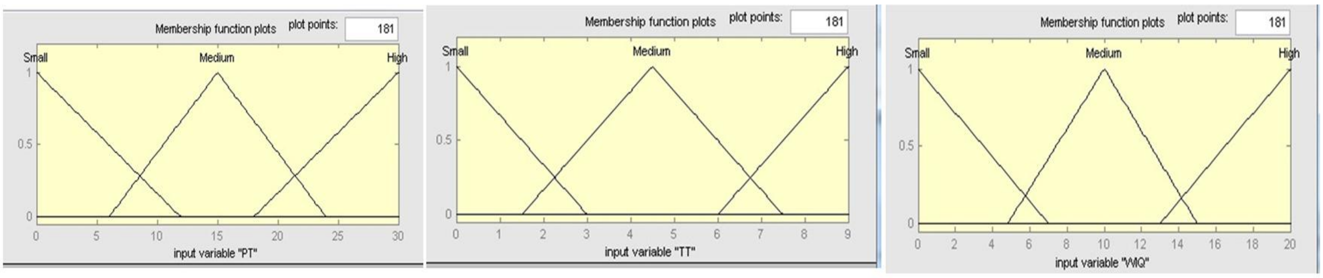


(a) (b) (c)

Fig. 3

Membership functions of fuzzy input variables; (a) Due Date (b) Profit Over Cost (c) Processing Time

Three variables are selected to identify the best route, named, Work in Queue (WIQ), Tavel Time (TT) and Processing Time (PT). All the variables are assigned with triangular membership function and divided into three zones : Small, Medium and High. The output of these variables is priority varying from 0 to 1. The priority variable is also assigned with triangular membership function and divided into 9 portions. Minimum (MN), Negative Low (NL), Low (LO), Negative Average (NA), Average (AV), Positive Average (PA), High (HI), Positive High (PH) and Maximum (MX).



(a) (b) (c)

Fig.4
Membership functions of fuzzy input variables; (a) Processing Time (b) Travel Time (c) Work in Queue

In case of job sequencing, the variables of processing time, due date and profit over cost have three states each. The total number of possible ordered pairs of these states is 27. For each of these ordered pairs of states, we have to determine an appropriate state of variable job priority. A convenient way of defining all required rules is a decision table, which is given below.

Table 1

Inference Rules for Job Sequencing using Three Inputs and One Output

Processing Time	Profit Over Cost			Due Date
	Small	Medium	High	
Small	HI	PH	MX	Small
Medium	PA	HI	PH	Medium
High	AV	PA	HI	High
Small	AV	HI	PH	Small
Medium	LO	NA	NA	Medium
High	NL	NA	PA	High
Small	NA	NA	NH	Small
Medium	NL	NA	AV	Medium
High	MN	NL	NA	High

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

1. If (Processing Time is Small) and (Profit over Cost is Small) and (Due date is Small) then (Priority is High)
2. If (Processing Time is Small) and (Profit over Cost is Medium) and (Due date is Small) then (Priority is Positive High)

   ....

27. If (Processing Time is High) and (Profit over Cost is High) and (Due date is High) then (Priority is Negative Negative Average)

In case of route selection, the variables of processing time, work in queue and travel time have three states each. Similar to job sequencing, the total number of possible ordered pairs of these states is 27 and or each of these ordered pairs of states, we have to determine an appropriate state of variable route priority. The decision table is given below :

Table 2

Inference Rules for Route Selection using Three Inputs and One Output

Processing Time	Work in Queue			Travel Time
	Small	Medium	High	
Small	MX	PA	NA	Small
Medium	MX	PA	PL	Medium
High	PH	AV	PL	High
Small	PH	AV	LO	Small
Medium	PH	AV	NL	Medium
High	HI	AV	NL	High
Small	HI	AV	NL	Small
Medium	HI	NA	MN	Medium
High	PA	NA	MN	High

The route priority criteria now used to derive fuzzy inference rules shown as an example :

1. If (Processing Time is Small) and (Work in Queue is Small) and (Travel Time is Small) then (Route Priority is Maximum)
2. If (Processing Time is Small) and (Work in Queue is Medium) and (Travel Time is Small) then (Route Priority is Positive Average)

....

27. If (Processing Time is High) and (Work in Queue is High) and (Travel Time is High) then (Route Priority is Minimum)

5. The experiment and Result

Three jobs are considered here with three different processing times, due dates and profit over costs. They are determined based on customer requirements and the cost of the raw materials needed to finish the jobs. Processing time here is the ideal time, means time needed if it was machined in just one machine.

Table 3

Priority of jobs are calculated using Fuzzy Interference System (FIS)

Job Name	Processing Time (Minute)	Profit over Cost (Tk)	Due Date (Day)
A	17	6500	4
B	19	6000	1
C	8	4000	2

Table 4
Priority of Jobs

Job Name	Priority	Normalized Priority
A	0.375	0.223
B	0.708	0.422
C	0.593	0.355

The overall system comprises 4 different CNC machining centers (MCs), all capable of performing the required operations on each part type, a load/unload station and material handling system with one automated guided vehicle (AGV) which can carry one pallet at a time. The system produces three different part types, A, B and C. It is assumed that it takes 3 minutes to load and unload a part on a pallet at load/unload station.

Table 5

Processing Times in Different Machines

Machine	Job A	Job B	Job C
1	6	5	7
2	2	5	1
3	7	3	1
4	2	8	2

Table 6
Route times for Job A

Route (Machine Sequence)	Work in Queue (In minutes)	Total Processing Time	Travel Time (Including Load/Unload time)
1-3-1-4	6	21	6.5
2-3-1-4	12	17	7
2-3-3-1	9	22	6

Table 6
Route times for Job B

Route (Machine Sequence)	Total Processing Time	Travel Time (Including Load/Unload time)	Work in Queue (In minutes)
2-1-2-4	23	6	7
3-1-2-4	21	6	11
1-4-4-2	26	5.5	8

Table 7
Route times for Job C

Route (Machine Sequence)	Total Processing Time	Travel Time (Including Load/Unload time)	Work in Queue (In minutes)
1-3-3-2	10	5.5	8
1-4-3-2	11	6.5	6
1-2-3-4	11	5	9

Table 8
Route priority for Job A

Route	Priority	Normalized Priority
1-3-1-4	0.584	0.387
2-3-1-4	0.5	0.331
2-3-3-1	0.425	0.282

Table 9
Route priority for Job B

Route	Priority	Normalized Priority
2-1-2-4	0.401	0.328
3-1-2-4	0.447	0.365
1-4-4-2	0.375	0.307

Table 10
Route priority for Job C

Route	Priority	Normalized Priority
1-3-3-2	0.534	0.313
1-4-3-2	0.658	0.385
1-2-3-4	0.516	0.302

Table 11
The final sequence

Job	Route
B	3-1-2-4
C	1-4-3-2
A	1-3-1-4

6. Conclusion and Recommendation

The work presented in this paper was directed towards investigating the applicability of fuzzy techniques as a decision aid in the short-term control of flexible manufacturing systems. For this purpose a flexible manufacturing system for three jobs composed of four machines, one AGV, one load and one unload station and with routings and arrivals with fixed statistical characteristics was considered. A fuzzy scheduler for job sequencing and routing was developed. This scheduler uses fuzzy logic systems as well as fuzzy multiple attribute decision-making techniques. The thesis was done to increase performance by using fuzzy techniques and also in giving a systematic design procedure (lacking in the literature) that takes into account multiple objectives and needs no interface with linguistic directions from human experts (e.g., management).

In this research, hypothetical data are used to determine the job priority and routing. But, it would be more appropriate if actual data from a production system are used. Again, only job priority and routing are taken into account, some other criteria's can also be added. Several parameters are used to design the problem, but, yet there may be other parameters which can be added to make the model more accurate. Here, triangular membership functions were used. There are some other membership functions which could give different results. All possible rules are taken, but if more parameters were added, number of the rules would have been increased. All this changes may lead the model to better results.

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