Scheduling of Flexible Manufacturing Systems Using Fuzzy Logic

by

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Abstract

This paper presents a research project undertaken at Industrial Research Institute Swinburne (IRIS) in the area of fuzzy scheduling. The research commenced in March 2001 and the full project is expected to be completed in February 2004. The fuzzy based scheduling model, in this paper, will only deal with the part routing problem. The model will select the best alternative route with multi-criteria scheduling through an approach based on a fuzzy logic. This model is applicable to the scheduling of a flexible manufacturing cell (FMC) and also a multi-machine flexible manufacturing system (MMFMS).

1. Introduction

Generally, when a Flexible Manufacturing System (FMS) 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 achieved until the design, production planning, scheduling, and controlling stages work well. Depending on the required measure of scheduling performance, many different approaches to the scheduling problem can be generated. Scheduling methods can be classified into different approaches, such as combinatorial optimisation, artificial intelligence, simulation-based scheduling with dispatching rules, heuristics-oriented, and multi-criteria decision making. However, production scheduling in an FMS is usually very complicated, particularly in dynamic environments. Many manufacturing systems, therefore, need scheduling for dynamic and unpredictable conditions, so artificial intelligence and heuristic-based approaches have been considered in FMS scheduling.

Fuzzy logic, which was introduced by Zadeh (1965), has been applied to various industrial problems including production systems. Recently, there has been significant attention given to modelling scheduling problems within a fuzzy framework. The advantage of the fuzzy logic system approach is that it incorporates both numerical results from a previous solution or simulation and the scheduling expertise from experiences or observation, and it is easy to implement. Several fuzzy logic based scheduling systems have recently been developed, although direct comparisons between them are difficult due to their different implementations and objectives. Grabot *et al.* (1994) proposed some approaches based on fuzzy logic to build aggregated dispatching rules, which obtain a compromise between the satisfaction of several criteria. Two priority rules, Shortest Processing Time (SPT) and ST rules were combined for the job prioritisation purpose. A fuzzy logic system that integrates both dispatching rules and scheduling expertise has been proposed to guide a dynamic selection of dispatching rules in job shops with objective to minimize the total weighted tardiness (Wan and Yen, 1999). However, only simple dispatching rules were incorporated in this fuzzy logic system. Subramaniam *et al.* (2000) proposed a fuzzy scheduler that uses the prevailing conditions in the job shop to select dynamically the most appropriate dispatching rule from several candidate rules. The results indicate that the fuzzy scheduler is effective.

Angsana and Passino (1994) proposed a new scheduling policy which was designed to emulate a human scheduler. In particular, they presented how to perform scheduling via a class of intelligent controllers called fuzzy controller (FC). Nahavandi and Solomon (1995) applied a fuzzy logic to shopfloor scheduling for prioritisation and ordering of jobs in a Factory Controller queue of the FMS. For this problem the chosen fuzzy variables are Slack Time (ST) and Slack Time (ST) of a work order and External Priority (EP) of a job. Politano *et al.* (2000) proposed a system that made the scheduling of machining operations, part production alternative routes and transportation operations simultaneously through an approach based on fuzzy logic.

In this research work, Fuzzy Logic is applied to generate a Fuzzy Scheduling model in order to select the best part routing for a given job.

2. Industrial Implications

Scheduling is the process of organizing, choosing and timing resource usage to carry out all the activities necessary to produce the desired outputs of activities and resources. In an FMS, the objective of scheduling is to optimise the use of resources so that the overall production goals are met. A Fuzzy Based Scheduling Model for FMS which is developed here aims at making real-time control decisions that include dynamic scheduling and variable part routing used to solve scheduling problems in FMS environments. Attempts will be made to use a an industrial implementation for experimentation. Otherwise the model will be verified using data from literature.

3. Fuzzy Logic Approach to FMS Scheduling Problem

Fuzzy logic, although a mathematical technique, defines its behavioural framework through a compact linguistic rule base. It has the ability to simultaneously consider multiple criteria and to model human experience in the form of simple rules. Furthermore, the advantage of the fuzzy logic system approach is that it incorporates both numerical and linguistic variables.

In this paper, we apply a fuzzy logic to the dynamic scheduling problems in an FMS environment. The fuzzy based scheduling, in this paper, is designed to solve the problem of selecting the best part routing for a given job which is the sub-problem of scheduling in an flexible manufacturing cell (FMC). In particular, we will show how to obtain scheduling via a proposed fuzzy model as shown in Figure 1.

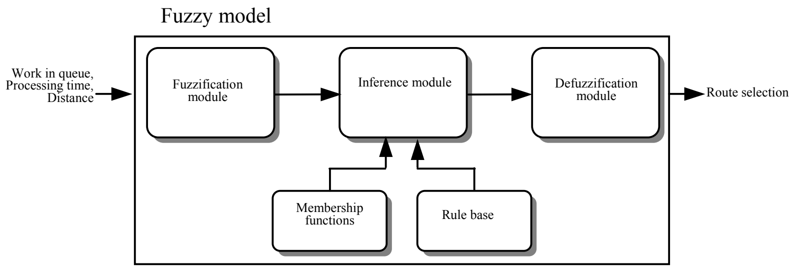


Figure 1- Fuzzy model for Route selection

4. A Case Study

4.1 The Routing Sub-Problem

The routing sub-problem allocates operations to machines in order to balance the workload on the machines by minimizing the highest load level. Operation sequencing and the available times for machines are not considered in this model. However, the work in queue in terms of sum of processing time, processing times for each operation, and the route travel times are considered. This is expected to improve the performance of the solution procedure, because the solution result of this subproblem sets conditions for the routing subproblem. For this reason, the work in queue is defined here as the minimum time period that indicates the machine which has least work in que in terms of processing times of the operations assigned to the machine is selected, rather than the time point of machine available time.

4.2 Operating Environment and Problem Definition

The FMS described by Ro and Kim (1990) for a job shop is used as a case study in this paper. The overall system comprises 4 different CNC machining centres (MCs) with finite local buffer capacity (3 parts) all capable of performing the required operations on each part type, a load/unload station and material handling system with 2 automated guided vehicle (AGVs) 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 put the pallet on or to take it off the AGV is assumed to be 0.8 minutes. The arrangement of the FMC hardware is shown in Figure 2.

There are p different part types, which each part type requires four operations. Each operation can be done by any of the machines with different processing time. A Job consists of the work to be done for the current scheduling horizon. A job has n parts to be processed on 4 machines, where parts can follow different routings among 4 MCs.

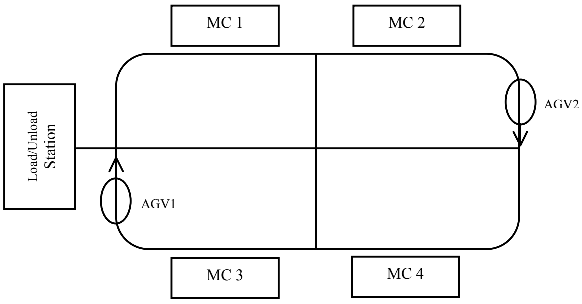


Figure 2- Configuration of flexible manufacturing cell

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 on which alternative routes should be selected for each part type. The alternative routes, the sequence of operations along with unit processing time, the shortest route travel times, and the total processing times for each part type are given in Table 1. The set of alternative operations are sought by the ARP (Alternative Routeings Planned) and ARPD (Alternative Routeings Planned and Directed Dynamically) rules using the LP model (Ro and Kim, 1990).

Part type (a job in units)		A (8)						B (6)								C (12)					
Alternative routes		1	2	3	4	5	6	1	2	3	4	5	6	7	8	1	2	3	4	5	6
Production Steps:	1st	1(4)	1(4)	2(6)	1(4)	2(6)	2(6)	2(4)	2(4)	2(4)	3(7)	2(4)	3(7)	3(7)	3(7)	1(5)	1(5)	1(5)	1(5)	1(5)	1(5)
Workstation no.	2nd	3(7)	3(7)	3(7)	3(7)	2(5)	3(7)	1(3)	1(3)	1(3)	1(3)	1(3)	1(3)	1(3)	1(3)	3(1)	4(2)	3(1)	4(2)	2(4)	2(4)
(processing time	3rd	1(3)	2(5)	1(3)	3(7)	2(5)	3(7)	2(1)	2(1)	3(3)	2(1)	3(3)	2(1)	3(3)	3(3)	3(1)	3(1)	4(3)	4(3)	3(1)	4(3)
in min)	4th	4(2)	4(2)	4(2)	4(2)	4(2)	4(2)	4(10)	1(12)	4(10)	4(10)	1(12)	1(12)	4(10)	4(10)	2(1)	2(1)	2(1)	2(1)	2(1)	2(1)
Route Travel time (min)		2.0	2.0	2.2	1.3	2.2	1.8	1.8	1.6	1.8	2.0	2.0	1.8	2.0	2.2	1.6	1.6	1.8	1.6	2.0	2.0
Total Processing time(min)		18.0	20.0	20.2	21.3	22.8	23.8	19.8	21.6	21.8	23.0	24.0	24.8	25.0	27.2	9.6	10.8	11.8	12.6	13.0	15.0

Table 1 –Processing time and alternative routes

4.3 The Fuzzy Based Scheduling Model

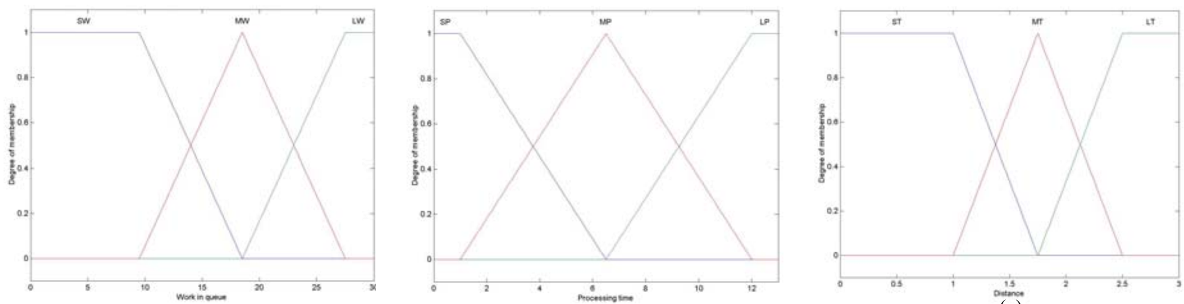
This fuzzy based scheduling model is developed by using the Fuzzy Logic TOOLBOX of MATLAB. A prototype of this is shown in Figure 1, and the procedures of modelling the fuzzy based scheduling are as follows:

The route selection depends on three fuzzy time factors; the number of parts already waiting in each machine buffer in terms of sum of processing time, how long it will take to complete the requested operation and the travelling time of part through the route. Therefore, for our problem the chosen fuzzy variables are named as *Work In Queue, Processing time, and Distance*, whose base variables are t_{ijk}, t_i, and t_{ij} respectively. They are the input variables used for the *Route selection* purpose which is chosen as the output variable.

Linguistic variable	Term set
Work in queue (t_{ijk})	SW, MW, LW
Processing time (t_i)	SP, MP, LP
Distance (t_{ij})	ST, MT, LT
Route selection (Rs)	MN, NL, LO, NA, AV, PA, HI, PH, MX

Table 2- Definition of fuzzy variable

The fuzzy sets of each universe of discourse are labelled as the term set shown in Table 2. The fuzzy sets of work in queue are indexed as SW, MW, and LW, indicating short, medium and long work in queue. The fuzzy sets of processing time are indexed as SP, MP, and LP, indicating short, medium and long processing time. The fuzzy sets of distance are also indexed as ST, MT, and LT, indicating short, medium and long travel time. The universe of discourse for these variables is [0, max], and each universe of discourse is explained by three fuzzy sets. The membership functions for each fuzzy set are triangular except at extreme left and right as shown in Figure 3 (a), (b), and (c) respectively.



(a) (b) (c)

Figure 3- Membership functions of fuzzy input variables; (a) Work in queue, (b) Processing time, and (c) Distance

Intuitively, we need to define another linguistic variable representing the route selection. Let us denote it by *Route selection* and its base variable by *Rs*. Assume that $Rs \in [0, 10]$ and that we want the fuzzy model to deal with the nine distinctions characterizing the route selection. In other words, the universe of discourse of *Rs* has nine fuzzy sets. The membership functions for each fuzzy set are triangular. These fuzzy sets are labelled as the term sets shown in table 2. This term's sets are MN, NL, LO, NA, AV, PA, HI, PH and MX, which stand for minimum, negative low, low, negative average, average, positive average, high, positive high, and maximum, respectively.

Experienced users of an FMS scheduling can express conditional fuzzy propositions in the form:

If work in queue is □ and processing time is □ and distance is □ then route selection is □

where appropriate states of the four linguistic variables are placed into the empty boxes for each particular proposition. Since the variables of work in queue, processing time, and distance have three states each, the total number of possible ordered pairs of these states is twenty-seven. For each of these ordered pairs of states, we have to determine an appropriate state of variable *Route selection*. A convenient way of defining all required rules is a decision table which is also called a fuzzy association memory (FAM) bank matrix. It consists of 27 (3×3×3) rules and is constructed for *Route selection* as shown in Table 3.

Processing time	Work in queue			Distance
	SW	MW	LW	
SP	MX	PA	NA	ST
SP	MX	PA	LO	MT
SP	PH	AV	LO	LT
MP	PH	AV	LO	ST
MP	PH	AV	NL	MT
MP	HI	AV	NL	LT
LP	HI	AV	NL	ST
LP	HI	NA	MN	MT
LP	PA	NA	MN	LT

Table 3- Inference rules for Route selection using three inputs and one output

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

1. If (Work_in_queue is SW) and (Processing_time is SP) and (Distance is ST) then (Route_selection is MX)
2. If (Work_in_queue is SW) and (Processing_time is SP) and (Distance is MT) then (Route_selection is MX)
:
27. If (Work_in_queue is LW) and (Processing_time is LP) and (Distance is LT) then (Route_selection is MN)

4.4 The Experimentation and Results

As the fuzzy based scheduling model has already been modelled, three sets of data then are entered as the crisp inputs of the model. The input data for each part type indicating the total processing time, unit processing time, and route travel time used in our example is shown in Table 1.

Part A		Part B		Part C	
Alternative routes	Route selection	Alternative routes	Route selection	Alternative routes	Route selection
1	6.02	1	5.39	1	9.46
2	4.38	2	4.71	2	7.90
3	3.88	3	4.06	3	7.80
4	3.43	4	4.41	4	7.39
5	3.75	5	3.64	5	7.19
6	2.90	6	3.87	6	6.83

Table 4 -The crisp output (Route selection)

Each time, when three inputs are entered into the system as shown in Fig. 1, a crisp output will be obtained. The crisp output of the fuzzy based scheduling model is calculated using the fuzzy inference system. The obtained crisp output (route selection), which corresponds to three crisp inputs is shown in Table 4. The 3D surface view of the route selection estimator is shown in Figure 5.

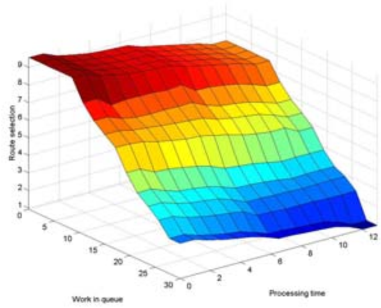


Figure 5- 3D surface view of the route selection

	SD	MWQ	SPT	ARD	Fuzzy
Makespan	3097.20	2356.46	2456.42	2290.30	2230.50
Resource Utilization	38.3	48	40.7	47.4	47.05
Mean Flow Time	80.14	54.08	54.61	50.92	49.5
Mean Tardiness	278.12	158.22	98.32	105.67	88.3
Mean Queue Length	0.87	0.52	0.59	0.47	0.45

Table 5 –Experimental Results

To compare our model to the performance of existing models, this fuzzy model will be tested by the use of production data which are the data from a simulation. Table 5. shows performance indices for the heuristics SD (Shortest Distance), MWQ (Minimum Work in Queue), STP (Shortest Processing Time), ARD (Alternative

Routings Directed Dynamically), and the fuzzy strategies with the highest value of fuzzy multiple performance measure for the reference production cycle (100 parts of type A, 75 of type B and 150 of type C (Naso and Turchiano, 1998)).

5. Conclusions

The results of comparisons of the four process selection rules and our fuzzy model for each performance measure are as follows:

Makespan	Fuzzy < ARD < MWQ < SPT << SD
Resource Utilization	SD < SPT << Fuzzy < ARD < MWQ
Mean Flow Time	Fuzzy < ARD < MWQ < SPT << SD
Mean Tardiness	Fuzzy < SPT < ARD < MWQ << SD
Mean Queue Length	Fuzzy < ARD < MWQ < SPT << SD

The test results indicate that fuzzy logic gives the best results in four performance measures except for resource utilization. It is shown that fuzzy logic provides a technique to select the routes based on multiple, conflicting criteria which will be obviously better than the conventional optimisation, based on single criteria.

6. References

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