Designing Simulation of Flexible Manufacturing System Using Adaptive Neuro Fuzzy Hybrid Structure for Efficient Job Sequencing & Routing

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Abstract
Analysis and modeling of flexible manufacturing system (FMS) includes priority analysis of machining jobs and machining routing for efficient profit and production. Flexible manufacturing system (FMS) job Priority calculation and alternate routing problems become exceptionally complex when it comes to contain frequent variations in the part designs of incoming jobs. This paper is focused on priority analysis and routing of variety of incoming jobs into the system efficiently and maximizing system utilization and throughput of system where machines are equipped with different tools and tool magazines but multiple machines can be assigned to single operation. For the complete analysis of the proposed work, a cloud of four incoming jobs have been considered. The Jobs have been assigned the priority according to Slack per Remaining Operations. Usually the probability of incoming job priority is calculated based on three parameters based strategy. In this work an adaptive Neuro fuzzy inference system (ANFIS) is developed to calculate the priority of incoming jobs based on Slack per Remaining Operations (S/RO) parameter. The next part of this work deals with the development of fuzzy inference system (FIS) for the efficient machine job routing. The job of fuzzy inference system generated is to select the best alternative route with multi-criteria scheduling. There are three criteria for routing with 27 rules. With the help of the rules the best route is selected. Four horizontal CNC lathe machines have been utilized for this work. Therefore, in this paper, an ANFIS system is developed to generate best priority of incoming jobs and a FIS system is designed to generate best alternative routes.

Keywords
Flexible Manufacturing System (FMS), Adaptive Neuro Fuzzy Inference System (ANFIS), Slack Per Remaining Operations (S/RO), Incoming Job Priority

I. Introduction
A Flexible Manufacturing System (FMS) is a manufacturing system in which there is some quantity of flexibility that allows the system to respond in the case of changes. A FMS can be defining as a production system consisting of alike versatile numerically controlled machines (workstations), automatic material and tools managing system. It also consists load and unload stations, inspection stations, along with storage regions and a hierarchical managing and control system. In general when it is being planned, the purpose is to design a system which will be proficient in the fabrication of the entire range of parts. This cannot be completed until the entire stages work fine. Based on the required level of scheduling performance, many dissimilar 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 problematical, 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 originally introduced by Zadeh (1965), has been applied to a variety of industrial problems. The advantage of the fuzzy logic approach is that it 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 have proposed a new scheduling method which was designed to imitate human scheduler. The implemented Fuzzy Controller (FC). Sentieiro employed fuzzy set theory in a non-classic approach called FLAS (fuzzy logic applied to scheduling) for short term planning and scheduling.

Most of the time it is found that, the scheduling idea is lies around the individual logics like fuzzy, ANN and genetic optimization. This work brought forward a novel idea for scheduling by employing the fusion of two different fields neural network and Fuzzy logic. Two different parts, first incoming job priority calculation and then best route selection have been considered for this work.

An adaptive Neuro fuzzy inference system (ANFIS) is developed to calculate the priority of incoming jobs based on Slack per Remaining Operations (S/RO) parameter. In the next part of this work a fuzzy inference system (FIS) is developed for the efficient machine job routing. The job of fuzzy inference system generated is to select the best alternative route with multi-criteria scheduling. There are three criteria for routing with 27 rules. With the help of these rules the best route is selected.

II. Scheduling Service and Manufacturing Processes
The scheduling techniques can cut across the various process types found in services and manufacturing. Many service firms are characterized by a front-office process with high customer contact, divergent work flows, customization, and, consequently, a complex scheduling environment. Often customer demands are difficult to predict, which puts a high premium on scheduling employees to handle the varied needs of customers. At the other extreme in the service industry, a back-office process has low customer involvement, uses more line work flows, and provides standardized services. Inanimate objects are processed; these processes take on the appearance of manufacturing processes.

Manufacturing processes also benefit from operations scheduling techniques. The operations scheduling techniques in this chapter has application for job, batch, and line processes in services as well as in manufacturing. Schedules for continuous processes can be developed with linear programming. Although the scheduling techniques in this chapter provide some structure to the selection of good schedules, many alternatives typically need to be evaluated.

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A. Sequencing Jobs

Operations schedules are short-term plans designed to implement the sales and operations plan. Often, several jobs must be processed at one or more workstations. Typically, a variety of tasks can be performed at each workstation. If schedules are not carefully planned to avoid bottlenecks, waiting lines may develop. For example, Figure (2.1) depicts the complexity of scheduling a manufacturing process. When a job order is received for a part, the raw materials are collected and the batch is moved to its first operation. The colored arrows show that jobs follow different routes through the manufacturing process, depending on the product being made. At each workstation, the next job to process is a decision because the arrival rate of jobs at a workstation often differs from the processing rate of the jobs at a workstation, thereby creating a waiting line. In addition, new jobs can enter the process at any time, thereby creating a dynamic environment. Such complexity puts pressure on managers to develop scheduling procedures that will handle the workload efficiently.

In this section, we focus on scheduling approaches used in two environments: (1) divergent flow processes and (2) line flow processes. A manufacturer's operation with divergent flows is often called a job shop, which specializes in low- to medium-volume production and utilizes job or batch processes. The front office would be the equivalent for a service provider. Jobs in divergent flow processes are difficult to schedule because of the variability in job routings and the continual introduction of new jobs to be processed. (Fig. 1) depicts a manufacturer's job shop. A manufacturer's operation with line flows is often called a flow shop, which specializes in medium- to high-volume production and utilizes line or continuous flow processes. The back office would be the equivalent for a service provider. Tasks are easier to schedule because the jobs have a common flow pattern through the system. Nonetheless, scheduling mistakes can be costly in either situation.

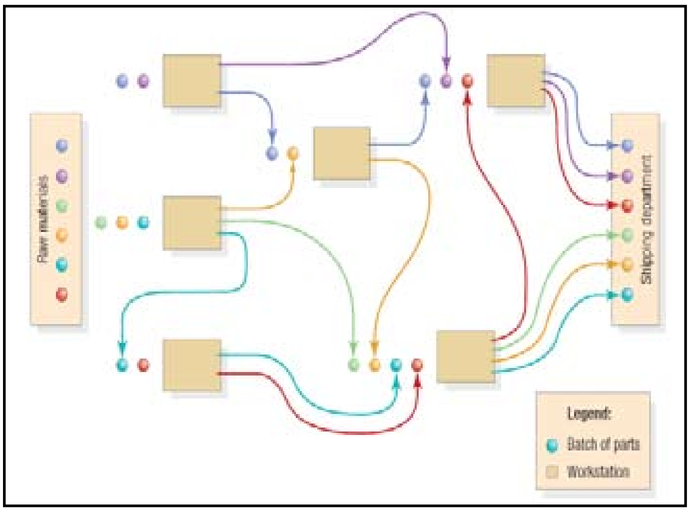


Fig. 1: Diagram of a Manufacturing Job Shop Process

B. Job Shop Sequencing

Just as many schedules are feasible for a specific group of jobs at a particular set of workstations; numerous methods can be used to generate schedules. They range from straightforward manual methods, such as manipulating Gantt charts, to sophisticated computer models for developing optimal schedules. One way to generate schedules in job shops is by using priority sequencing rules, which allows the schedule for a workstation to evolve over a period of time. The decision about which job to process next is made with simple priority rules whenever the workstation becomes available for further processing. One advantage of this method is that last-minute information on operating conditions can be incorporated into the schedule as it evolves.

The first-come, first-served (FCFS) rule gives the job arriving at the workstation first the highest priority. The Earliest Due Date (EDD) rule gives the job with the earliest due date based on assigned due dates the highest priority. Such rules can be applied by a worker or incorporated into a computerized scheduling system that generates a dispatch list of jobs and priorities for each workstation. There are some additional priority sequencing rules such as critical ratio, shortest processing time and slack per remaining operations. Among the three additional slack per remaining operations provide efficient job sequencing defined as

Slack per Remaining Operations

Slack is the difference between the time remaining until a job's due date and the total shop time remaining, including that of the operation being scheduled. A job's priority is determined by dividing the slack by the number of operations that remain, including the one being scheduled, to arrive at the slack per remaining operations (S/RO).

$$S/RO = \frac{(\text{Due Date} - \text{Todays Date}) - \text{Total Shop Time Remaining}}{\text{Number of Operations Remaining}} \quad (1)$$

The job with the lowest S/RO is scheduled next. Ties are broken in a variety of ways if two or more jobs have the same priority. One way is to arbitrarily choose one of the tied jobs for processing next.

III. Methodology

Analysis and modeling of flexible manufacturing system (FMS) consists of priority analysis of machining jobs and machining routing for efficient profit and production. Flexible Manufacturing System (FMS) job probability calculation and routing problems become extremely complex when it comes to accommodate frequent variations in the part designs of incoming jobs.

This work has focused on priority analysis of variety of incoming jobs into the system efficiently and maximizing system utilization. For the complete analysis of the proposed work, a cloud of four incoming jobs have been considered. The Jobs have been assigned the priority according to Slack per Remaining Operations.

Usually the probability of incoming job priority is calculated based on three parameters based strategy. In this work an adaptive Neuro fuzzy inference system (ANFIS) is developed to calculate the priority of incoming jobs based on Slack per Remaining Operations (S/RO) parameter.

The next part of this work deals with the development of fuzzy inference system (FIS) for the efficient machine job routing. The job of fuzzy inference system generated is to select the best alternative route with multi-criteria scheduling. For the practical data consideration this work utilized four horizontal lathe machines.

The FMS described in this work consists of 4 different CNC horizontal lathe 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 four different part types, A, B, C & D. The arrangement of the FMC hardware is shown in fig. 2).

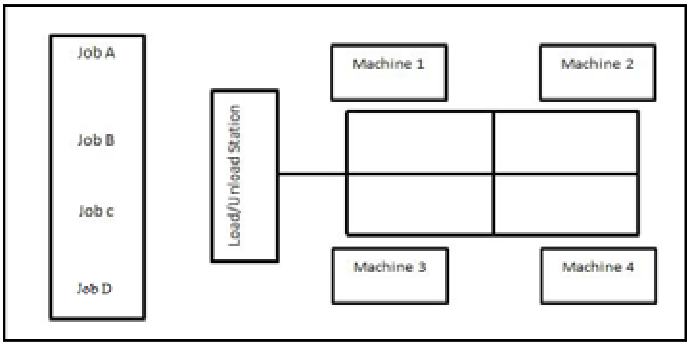


Fig. 3: Machining Setup

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.

The complete process of this work is shown in fig. 4) with the help of flow chart representation.

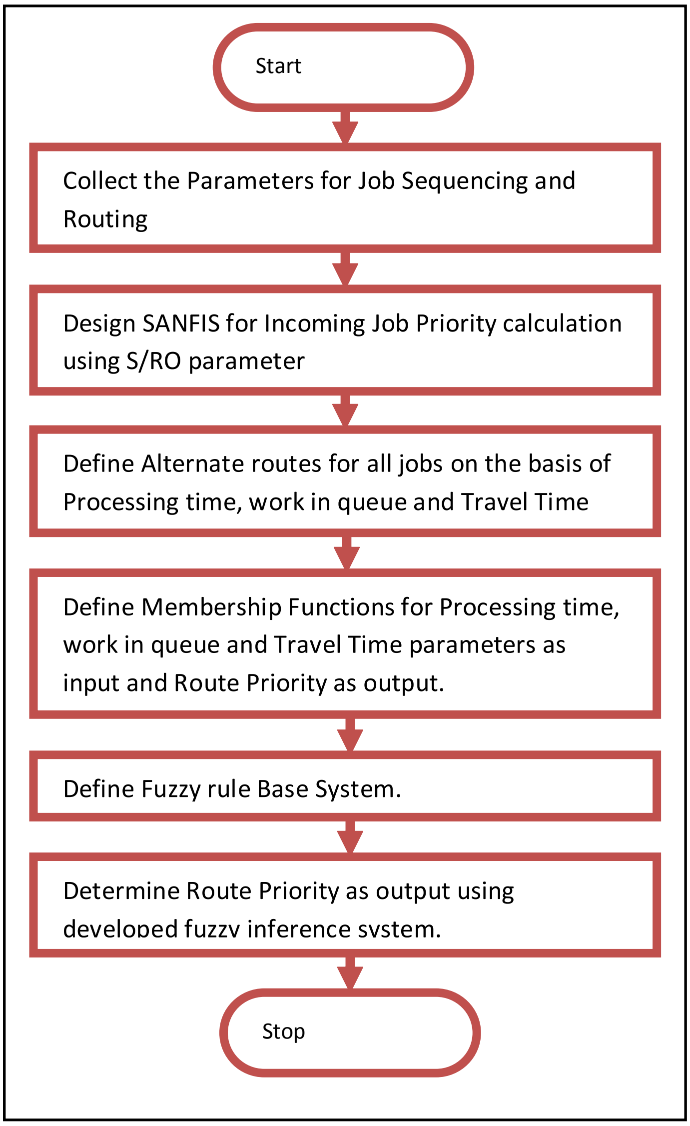


Fig. 4: Complete Methodology of Proposed Work

A. Development of Sugeno Type Adaptive Neuro Fuzzy Inference System for Incoming Job Priority Calculation

This section basically deals with the development and simulation of Sugeno Type Adaptive Neuro Fuzzy Inference System for incoming job priority Calculation based on Slack per Remaining Operations (S/RO) parameter. The basic steps taken in the development of above system are:

Step 1. Collection of parametric information for all incoming jobs.

Step 2. Development and training of Sugeno type Adaptive Neuro fuzzy inference system.

1. Collection of Parametric Information for All Incoming Jobs

This the first stage for the proposed ANFIS system development. This step basically deals with the all the data collection about all incoming jobs. Like Table 1 gives the collected data for four different jobs considered for this research work.

Table 1: Collected Data for Four Different Jobs Considered for This Work

Job	Processing Time at Lathe (PTL)	Time remaining until Due date (Days) (TRUDD)	Number of Operations Remaining (NOR)	Shop time remaining (Days) (STR)	S/RO
A	15	12	4	10	0.5
B	10	15	5	7	1.6
C	20.4	12	7	5.5	0.928
D	18	17	8	15	0.25

In Table 1 the first four columns represents the required data for all four incoming jobs A, B, C and D.Last column represents the output parameter Slack per Remaining Operations (S/RO). In this work S/RO is used for job priority calculation.

2. Development and Training of Sugeno Type Adaptive Neuro Fuzzy Inference System

Next step is the development and training of Sugeno type Adaptive Neuro fuzzy inference system (SANFIS) for the generation of exact mimic of Table 8.1. For the efficient generation of SANFIS model 4 experimental parameter values obtained has been used as shown in Table 8.1. Four parameters processing time at lathe, Time remaining until Due date in Days, Number of Operations Remaining and Shop time remaining in Days has been used as four inputs of SANFIS whereas S/RO is taken as the single output. Therefore the developed SANFIS is the four input and single output structure. The other parameters used for SANFIS structure development are given as follows:

name:	'MY_ANFIS_SRO'
type:	'sugeno'
andMethod:	'prod'
orMethod:	'probor'
defuzzMethod:	'wtaver'
impMethod:	'prod'
aggMethod:	'sum'
input:	[1x4 struct]
output:	[1x1 struct]
rule:	[1x81 struct]

After the successful training of SANFIS the average testing error obtained is$1.295x10^{-8}$. Fig. 5, shows the developed FSANFIS

('MY_ANFIS_SRO.FIS) basic layout.
The rule base designed to get desired S/RO values from SANFIS are given as:

1. If (PTL is in1mf1) and (TRUDD is in2mf1) and (NOR is in3mf1) and (STR is in4mf1) then (JOBPRIORITY is out1mf1) (1)
2. If (PTL is in1mf1) and (TRUDD is in2mf1) and (NOR is in3mf1) and (STR is in4mf2) then (JOBPRIORITY is out1mf2) (1)
3. If (PTL is in1mf1) and (TRUDD is in2mf1) and (NOR is in3mf1) and (STR is in4mf3) then (JOBPRIORITY is out1mf3) (1)
……………………………………………… ………………
and so on.

Fig. 6 shows the input membership functions for developed FSANFIS, and fig. 7 shows the basic structure of SANFIS. The output of developed SANFIS is a linear function.

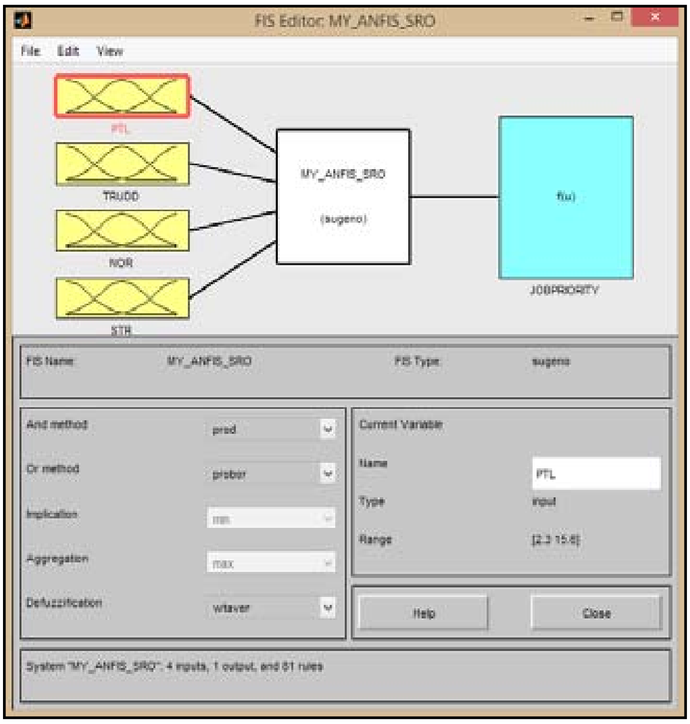
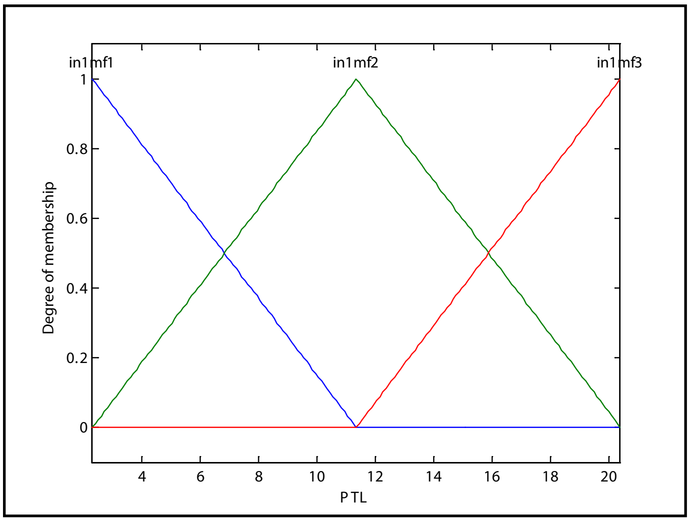
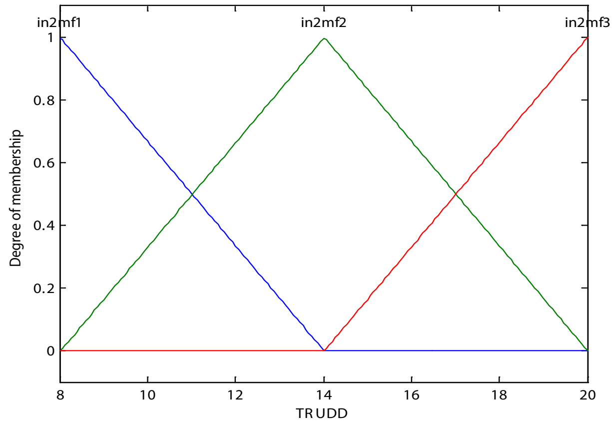


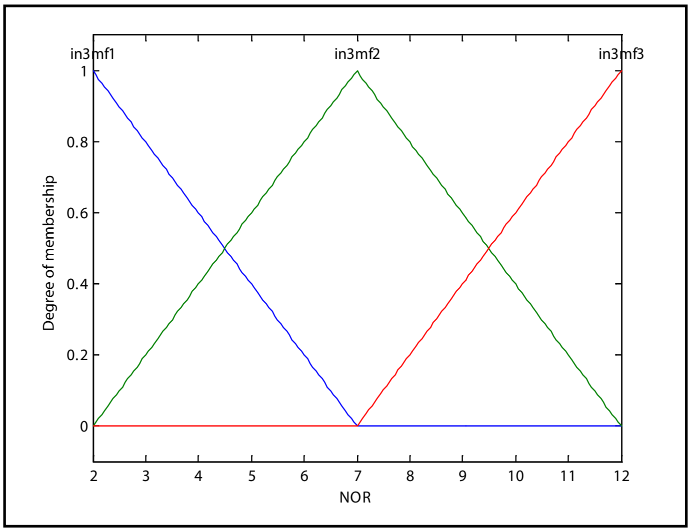
Fig. 5: Developed SANFIS (MY_ANFIS_SRO.FIS) Layout



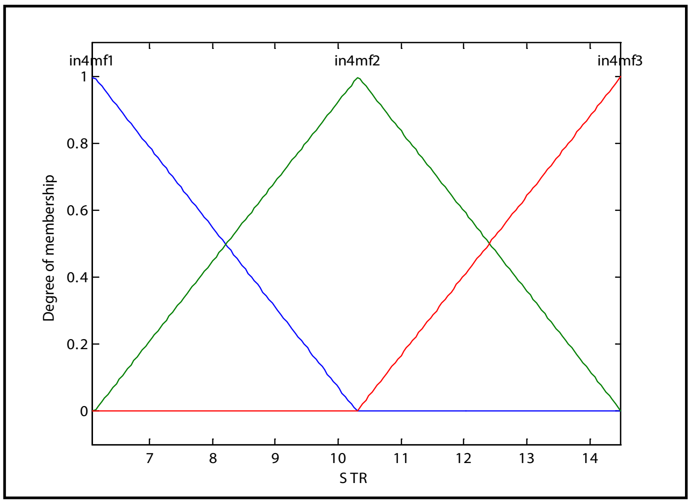
(a) First Input membership functions used to fuzzify PTL.



(b) Second Input membership functions used to fuzzify TRUDD.



(c) Third Input Membership Functions Used to Fuzzify NOR



(d) Fourth Input membership functions used to fuzzify STR.
Fig. 6: Input Membership Functions for Developed SANFIS.

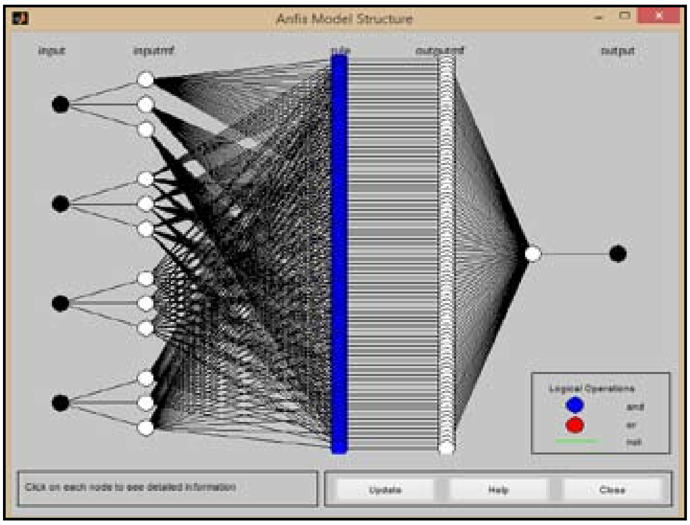


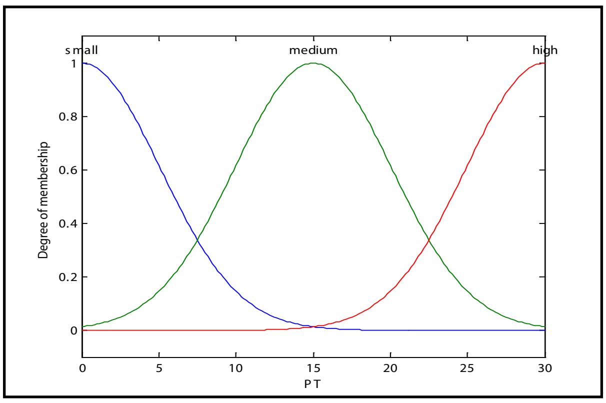
Fig. 7: Developed SANFIS (MY_ANFIS_SRO.FIS) Basic Structure

Table 2: Experimental Parameter Value Used for Development and Training of SANFIS

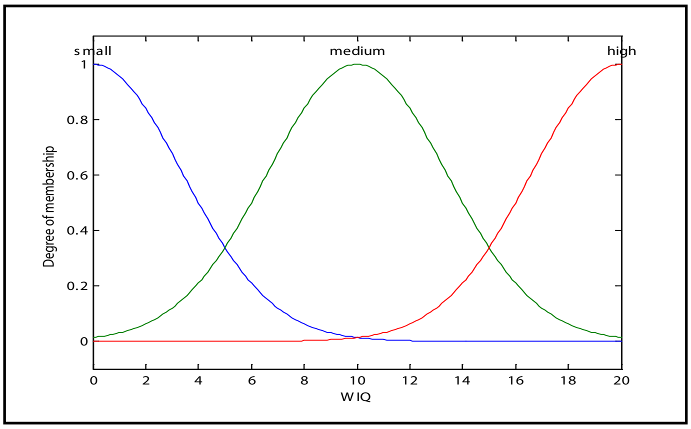
Job	Processing Time at Lathe (PTL)	Time remaining until Due date (Days) (TRUDD)	Number of Operations Remaining (NOR)	Shop time remaining (Days) (STR)	S/RO
A	15	12	4	10	0.5
B	10	15	5	7	1.6
C	20.4	12	7	5.5	0.928
D	18	17	8	15	0.25

3. Development and Simulation of Mamdani type fuzzy inference system (FIS) for Incoming Job Routing

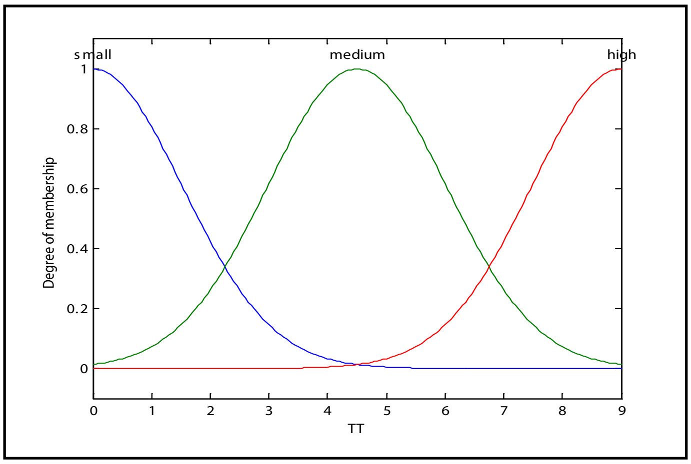
This section deals with the development of fuzzy inference system based on fuzzy logic for incoming job routing priority determination. Three variables are selected to identify the best route, named, Work in Queue (WIQ), Travel Time (TT) and Processing Time (PT). All the variables are assigned with Gaussian membership function and divided into three zones: Small, Medium and High. The output of these variables is routing priority varying from 0 to 1. The priority variable is also assigned with Gaussian 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. 8: Membership Functions of Fuzzy Input Variables; (a) Processing Time (b) Travel Time (c) Work in Queue.

Similarly the plot of output membership functions is shown in fig. 9.

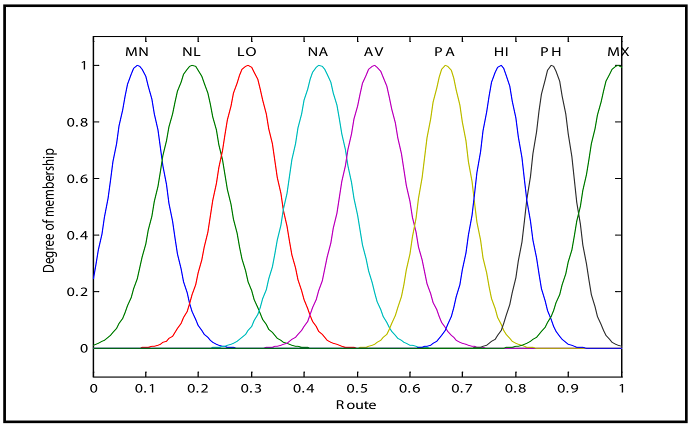


Fig. 9: Membership Functions of Fuzzy Output Variables

In case of job routing, the variables of processing time, work in queue and travel time 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. The 27 rules defined are given as

1. If (PT is small) and (WIQ is small) and (TT is small) then (Route is MX) (1)
2. If (PT is small) and (WIQ is small) and (TT is medium) then (Route is MX) (1)
3. If (PT is small) and (WIQ is small) and (TT is high) then

(Route is PH) (1)

-- and so on.

Fig. 10 shows the developed Mamdani type FIS (MY_FIS_Routing.FIS) basic layout.

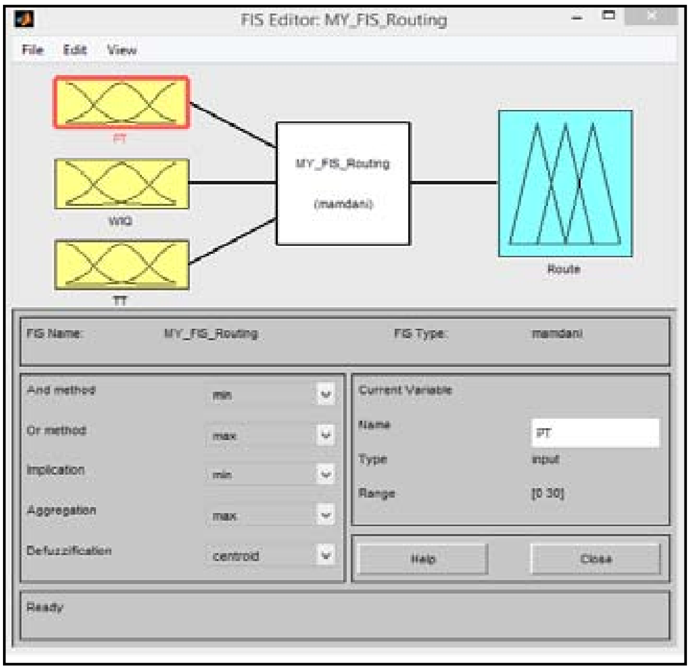


Fig. 10: Developed Mamdani Type FIS (MY_FIS_Routing.FIS) Layout

Finally the actual simulation model developed for the project work for the efficient job sequencing and routing is shown in fig. 11.

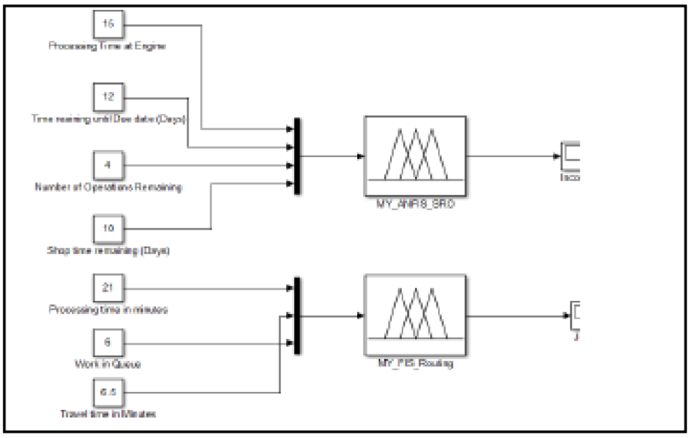


Fig. 10: Actual Simulation Model Developed for the Work

IV. Results and Discussions

A. Results of Job sequencing based on priority calculation using Sugeno Type Adaptive Neuro Fuzzy Inference System (SANFIS)

Four jobs are considered here with four different processing times, due dates, number of operations and shop time remaining. They are determined based on customer requirements and number of operations they perform on machines. Processing time here is the ideal time, means time needed if it was machined in just one machine. Table 3 shows the S/RO obtained for each jobs. Lower the value of S/RO parameter higher the priority.

Table 3: S/RO Obtained using SANFIS

Job	Processing Time at Lathe (PTL)	Time remaining until Due date (Days) (TRUDD)	Number of Operations Remaining (NOR)	Shop time remaining (Days) (STR)	S/RO
A	15	12	4	10	0.5
B	10	15	5	7	1.6
C	20.4	12	7	5.5	0.928
D	18	17	8	15	0.25

From Table 3 it is clearly observable that, the lowest S/RO belongs to the job D and highest S/RO belongs to job B. Hence the obtained job sequence is D, A, C and then B.

B. Results of Job Routing Using Mamdani Type Fuzzy Inference System

The overall system comprises 4 different CNC horizontal lathe 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 four different part types, A, B, C and D. For the routing priority calculation the experimental information taken are tabulated in the following tables.

Table 4: Processing Times in Different Machines

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

Table 5: Route Times for Job A

Route Machine Sequence	Total Processing Time	Work in Queue	Travel Time
1-3-1-4	21	6	6.5
2-3-1-4	17	12	7
2-3-3-1	22	9	6

Table 6: Route times for Job B

Route Machine Sequence	Total Processing Time	Work in Queue	Travel Time
2-1-2-4	23	7	6
3-1-2-4	21	11	6
1-4-4-2	26	8	5.5

Table 7: Route Times for Job C

Route Machine Sequence	Total Processing Time	Work in Queue	Travel Time
1-3-3-2	10	8	5.5
1-4-3-2	11	6	6.5
1-2-3-4	11	9	5

Table 8: Route Times for Job D

Route Machine Sequence	Total Processing Time	Work in Queue	Travel Time
1-4-3-2	10	7	6.5
1-2-3-2	12	6	5.5
1-3-2-4	13	8	5

Table 9: Route Priority for Job A

Route Machine Sequence	Total Processing Time	Work in Queue	Travel Time	Priority	Normalized Priority
1-3-1-4	21	6	6.5	0.6097	38.36762948
2-3-1-4	17	12	7	0.4694	29.53873262
2-3-3-1	22	9	6	0.51	32.09363791

Table 10: Route Priority for Job B

Route Machine Sequence	Total Processing Time	Work in Queue	Travel Time	Priority	Normalized Priority
2-1-2-4	23	7	6	0.5552	36.33745664
3-1-2-4	21	11	6	0.4842	31.69055566
1-4-4-2	26	8	5.5	0.4885	31.9719877

Table 11: Route Priority for Job C

Route Machine Sequence	Total Processing Time	Work in Queue	Travel Time	Priority	Normalized Priority
1-3-3-2	10	8	5.5	0.5837	32.59619143
1-4-3-2	11	6	6.5	0.6502	36.30982297
1-2-3-4	11	9	5	0.5568	31.09398559

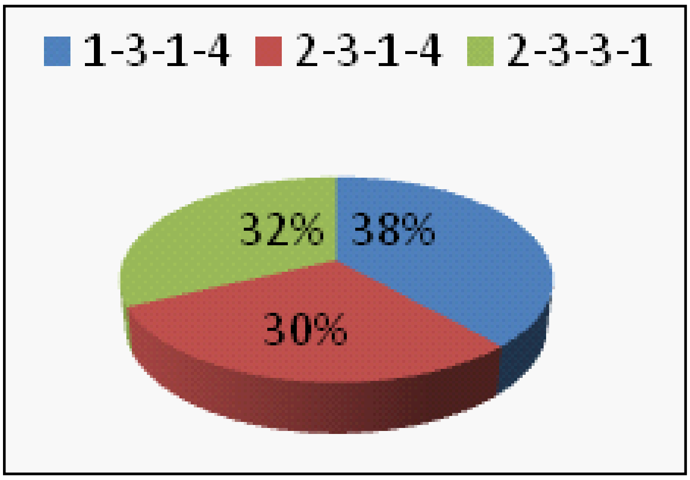
Table 12: Route Priority for Job D

Route Machine Sequence	Total Processing Time	Work in Queue	Travel Time	Priority	Normalized Priority
1-4-3-2	10	7	6.5	0.6248	34.33344324
1-2-3-2	12	6	5.5	0.63	34.61918892
1-3-2-4	13	8	5	0.565	31.04736784

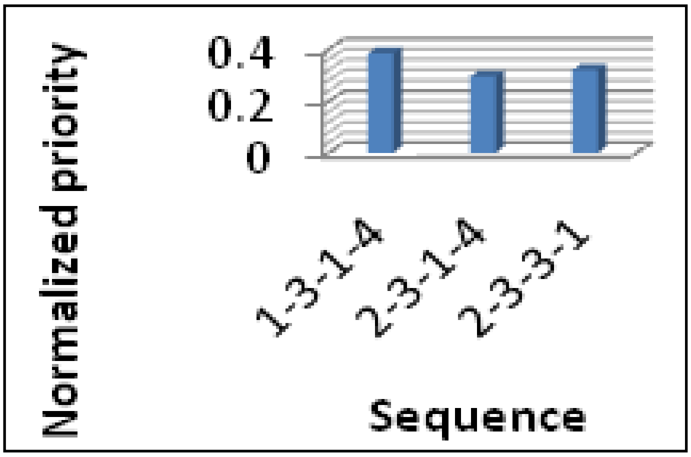
Now Table 13 shows the final sequence of incoming jobs with their respective higher priority routs.

Table 13: Final Job Sequence and Routs

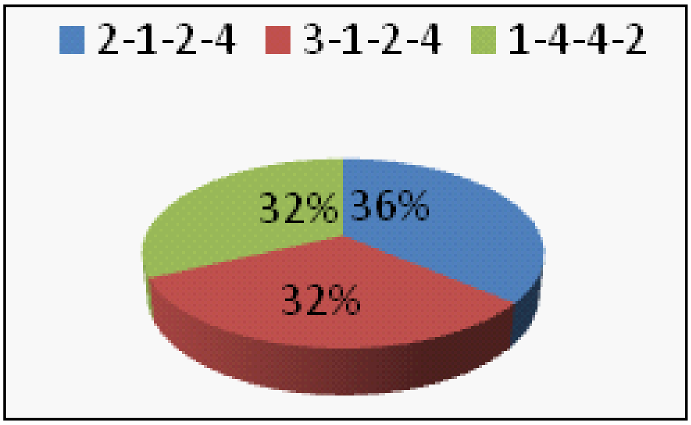
Job sequence	Routs obtained
D	1-2-3-2
A	1-3-1-4
C	1-4-3-2
B	2-1-2-4



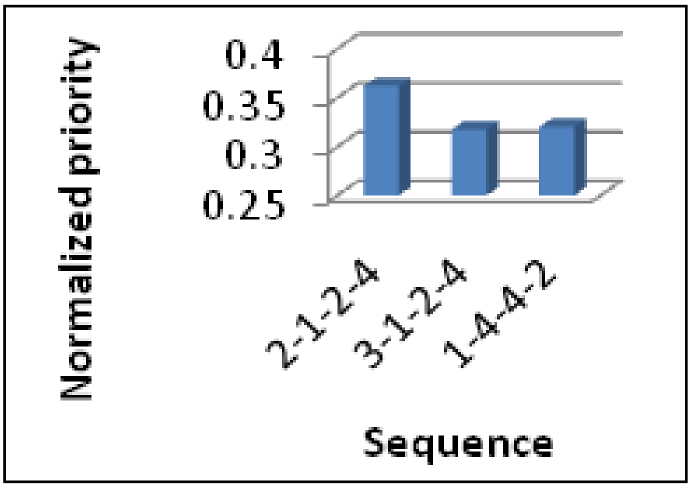
(a) Pie Chart - Route Priority for Job A



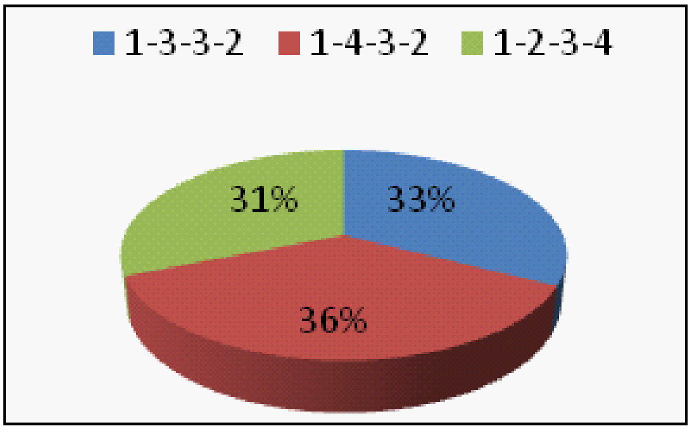
(b) Column Chart -Route Priority for Job A



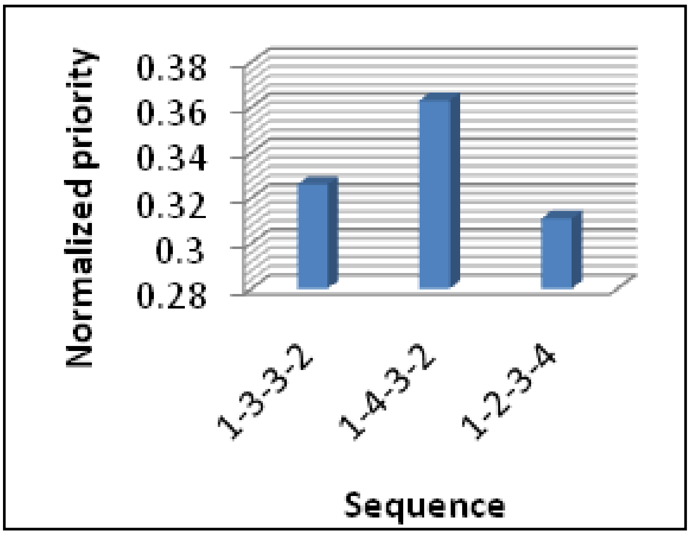
(a) Pie Chart -Route Priority for Job B



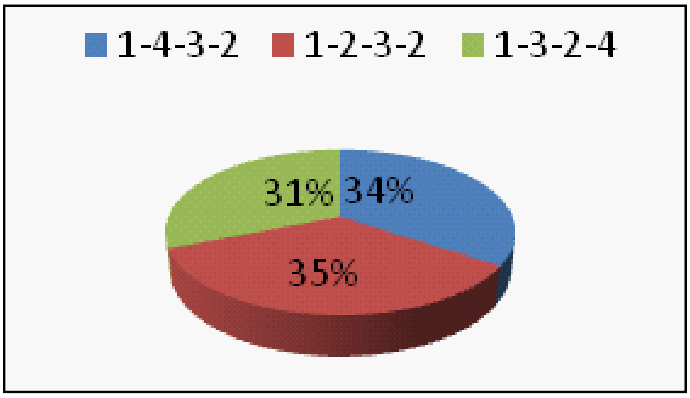
(b) Column Chart - Route Priority for Job B



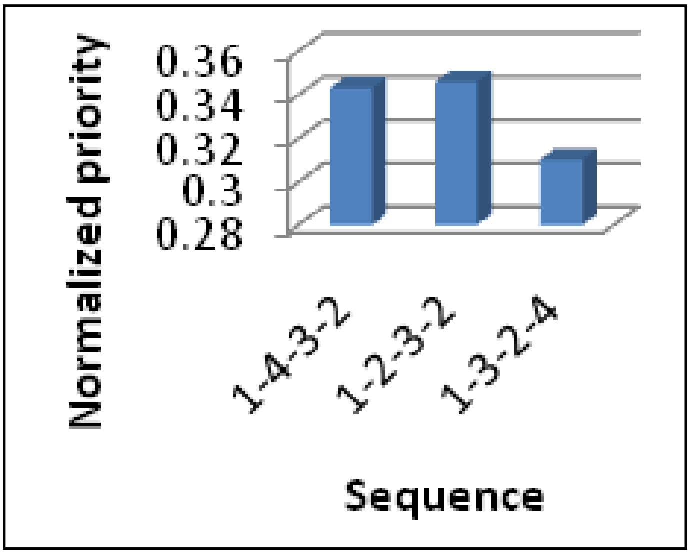
(a) Pie Chart - Route Priority for Job C



(b) Column Chart –Route Priority for Job C



(a) Pie Chart –Route Priority for Job D



(b) Column Chart-Route Priority for Job D

Fig. 11: Pie Chart & Column Chart for Route Priority of Job A, B, C& D

V. Conclusions and Future Scope

The work presented in this thesis work was directed towards investigating the applicability of fuzzy and adaptive Neuro techniques as a decision aid in the short-term control of flexible manufacturing systems. For this purpose a flexible manufacturing system for four incoming job cloud composed of four machines, one AGV, one load and one unload station and with routings and arrivals with fixed statistical characteristics was considered. A Sugeno type adaptive Neuro fuzzy scheduler for job sequencing and a fuzzy inference system was developed for job routing. This scheduler employs adaptive Neuro fuzzy logic system for calculation of incoming job priority based on S/RO parameter. This paper has brought forward a novel technique to increase performance by using Neuro fuzzy hybrid structure 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, practical data are used to determine the job priority and routing. Again, only job priority and routing are taken into account, in future 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, Gaussian 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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