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RESEARCH ARTICLE

DYNAMIC FUZZY EXPERT SYSTEM FOR MULTI OBJECTIVE CRITERIA FOR SELECTION OF MANUFACTURING METHOD USING MAMDANI MODEL

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ABSTRACT

Installing a manufacturing method might be very expensive and time consuming project. Organizations should examine and decide on how best to make this decision of selecting appropriate process meeting their requirements. In order to improve the manufacturing cycle more than 110 manufacturing processes have been proposed. The objectives aimed at and the functions focused on by these processes vary. The process should be flexible enough to accommodate reasonable changes in design. This poses a great challenge to a manager in selection of effective and economical manufacturing process. Different organizations have different objectives and based on their specific requirement they deploy suitable process conforming to their objective. Today's business scenario is highly competitive, complex and dynamic in nature which demands strategic planning meeting the challenges of changing time. Recently, the authors have developed a tool to enable the end user a quick selection of appropriate manufacturing method based on multiple objectives. The end user instead of querying the database directly will use the natural language, termed as Manufacturing Query Language (MQL) designed by the authors, which is interfaced with RDBMS using prolog. The methodology adopted is based on crisp sets which does not take into account uncertainties in model parameters and changing business scenarios. To incorporate ambiguity into the system, the authors have developed a fuzzy expert system dynamically based on the differing ranges of triangular membership functions. In this paper, the authors present an architecture for dynamic fuzzy expert system for multi objective criteria for selection of manufacturing method using Mamdani Model. Fuzzy expert system is created outside MATLAB and MATLAB is used only for creating user interface for querying methods based on objectives and for the evaluation of rules. A simulink model is developed for selective methods and objectives and is executed for different combinations of objectives in class S. The input is derived from a excel file which is converted into a MAT file as required by MATLAB. Similary, the output stored in MAT file is converted into an .xlsx file. The large number of xlsx. Files required are generated using Excel Object Library which is interfaced with Java. The results obtained using Fuzzy Expert System are compared with that obtained using crisp expert system. Mamdani type FIS offers more flexibility in method selection due to the nature of output members functions which are overlapping fuzzy sets. This yields the manager a greater freedom in method selection based on infrastructure and other resource availability.

INTRODUCTION

Manufacturing methods are of many different types based upon the technological solution, or software solution or modern management methods to meet the organizational objectives. To assist managers in selecting the best method to achieve certain criteria, two mapping methods are available, one based on the objectives of the method and the other based on the functions that the methods may serve. Based on the maturity of the manufacturing company, a particular manufacturing method may focus on manufacturing hardware, auxiliary software support, production planning and control, next generation production management, processing manufacturing methods, commercial aspects, organization, advanced organizational manufacturing methods, design methods, human factors in manufacturing, environmental manufacturing methods, or cost and quality manufacturing methods. Giden Halevi has presented a review of manufacturing methods and their objectives (Gideon Halevi). The author has listed 110 published manufacturing methods which fall in 5 different classes based on their nature. In this paper the authors consider the following objectives as proposed by Giden Halevi in selection of a particular manufacturing method.

- Meeting delivery dates

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- Reduce production costs.
- Rapid response to market demands
- Reduce lead time
- Progress towards zero defects
- Progress towards zero inventory
- Improve management knowledge and information
- Marketing – market share •
- Improve and increase team work collaboration
- Improve customer and supplier relationships
- Improve procurement management and control
- Management strategic planning
- Improve human resources management
- Improve enterprise integration
- Continuous improvement
- Environmental production

The suitability of each method to a specific objective is graded according to the following grades.

a – Excellent for specific dedicated objective
b – Very good
c – Good
d – Fair

Fuzzy Logic

The objective of fuzzy logic is to map an input space to an output space for which primary mechanism adopted is a list of if..then statements called rules which are evaluated in parallel. In fuzzy logic the truth of any statement becomes a matter of degree which is specified by degree of membership or degree of belongingness. In fuzzy logic each variable has a multi valued membership in contrast to crisp sets where each variable has two-valued membership. The curve that defines the value of the variable at any instance of time is a function that maps the input space to the output space which is commonly referred to as membership function. Hence a membership function is a curve that defines how each point in the input space is mapped to membership value between 0 and 1.

Types of Fuzzy Inference Systems

There are two types of fuzzy inference systems Mamdani and Sugeno. These two types of inference systems vary somewhat in the way outputs are determined. Mamdani type inference expects the output member function to be fuzzy sets after the aggregation process. There is a fuzzy set for each output variable that needs defuzzification. Sugeno type systems can be used to model any inference system in which the output membership functions are either linear or constant. In the current study authors have employed Mamdani type of fuzzy inference system. Mamdani type fuzzy inference gives an output that is a fuzzy set. Sugeno-type inference gives an output that is either constant or a linear (weighted) mathematical expression. For Example,

Mamdani: If A is X1, and B is X2, then C is X3. (X1, X2, X3 are fuzzy sets).

Sugeno: If A is X1 and B is X2 then C = ax1 + bx2 + c (linear expression) (a, b and c are constants)

In the current work, authors have employed Mamdani type of Fuzzy Inference system. Architecture of Fuzzy Inference System is depicted in the following Figure 1.

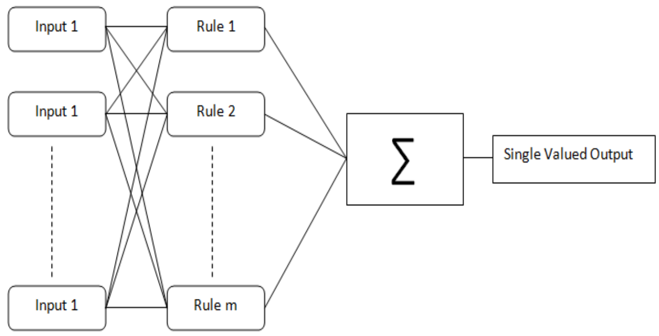


Figure 1. Architecture of Fuzzy Inference System

Information flows from left to right from n inputs to a single output. The parallel nature of the rules is one of the most important aspects of fuzzy logic systems. Fuzzy inference process comprises of five steps.

- Fuzzification of input variable.
- Application of the fuzzy operators (AND/OR) in the antecedent.
- Implications from the antecedent to the consequent.
- Aggregation of the consequents across the rules.
- Defuzzification

Fuzzification is the process of making a crisp quantity with uncertainty a fuzzy quantity. The uncertainties in the input parameters arising due to imprecision, ambiguity or vagueness can be modeled very effectively with the help of membership functions. This is an intuitive type involving to a great deal a contextual and semantic knowledge about the system. The combination of fuzzy conditions is determined by the minimum or average membership functions of the element of each proposition to the concerned fuzzy set. On quantification of fuzzy conditions of all rules fuzzy conclusions can be evaluated. Defuzzification is the process of conversion of a fuzzy quantity to a crisp quantity. The output of a fuzzy process can be a logical union of two or more fuzzy membership functions defined on the universe of discourse of the output variable. Different methods are used for defuzzification, among which the center of gravity is the most prevalent and appealing of all the defuzzification methods.

Literature survey

There exists a vast amount of literature on manufacturing process monitoring using both crisp and fuzzy logic approach (Mikhailov and Singh 2003; Zha and Du, 2003) which focus mainly on software selection, technology selection and system project selection. Chenhui Shao *et al.,* (2013) have developed a novel algorithm for parameter tuning and feature selection. Quality monitoring is used for monitoring a quality of a manufacturing process. Multiple criteria decision making method is employed by Rao, Rajesh (2009). The authors have presented a decision making framework using a multiple criteria decision making method viz., Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) which has been integrated with analytic hierarchy process (AHP) and the fuzzy logic. The framework enables the manager a software selection in manufacturing industries. Mohammad Akhshabi (2011) has developed a Fuzzy Multi Criteria Model for Maintenance Policy which is used for the optimized decision making. In literature, there is a considerable amount of work on the use of hybrid models such as ANFIS model which captures historical data for modeling present membership functions and/or rules. Input variables can be adjusted and tuned by scaling mechanism. By modifying fuzzy membership functions of neural networks the advantages offered by both fuzzy logic and neural networks, such as expert's knowledge and inference capability with fuzzy logic and learning capabilities of neural networks can be integrated. Most of the work is focusing in speed control of induction motor drives (Zhang and Edmunds, 1991; Maeda and S. Murakami, 1992; Bose, 1994; Simoes and Bose, 1995). But such hybrid systems yield best results only under the situation where past can be accurately extrapolated to the future which is very rare in changing business scenarios. But to our knowledge, there is no considerable work so far on generation of dynamic fuzzy inference systems. To account for this research gap, in the current work we have developed a dynamic fuzzy expert system which responds to the dynamic changes in business scenarios. ANFIS uses the hybrid learning procedure which employs the back propagation type gradient descent and the least square fit estimate to estimate parameters of the model which enables implementation of faster decision making.

Fuzzy Inference System Based on Mamdani Model

In this section authors present a model for manufacturing method selection based on Mamdani model.

Format of FIS

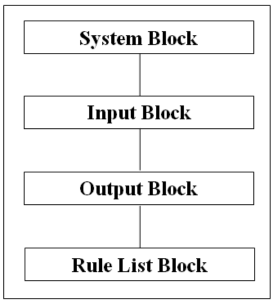


Fig. 1. FIS is a plain text file containing the following sections

System Block: System block documents the information regarding the type and version of fuzzy logic employed in model development, number of input variables, output variables and rules, and fuzzification and defuzzification methods employed.

Input Block: This block documents information about input variables which involves name, number of membership functions, their type and range.

Output Block: This block documents information about each output variable which involves name, number of membership functions, their type and range.

Rules Block: It employs RuleList for documenting fuzzy rules.

Rule List is a matrix of one or more rows, each of which represents a given rule. The format that the rule list matrix must take is very specific. If there are *m* inputs to a system and *n* outputs, there must be exactly $m + n + 2$ columns in the rule list.

The first *m* columns refer to the inputs of the system. Each column contains a number that refers to the index of the membership function for that variable.

The next *n* columns refer to the outputs of the system. Each column contains a number that refers to the index of the membership function for that variable.

The $m + n + 1$ column contains the weight that is to be applied to the rule. The weight must be a number between zero and one and is generally left as one.

The $m + n + 2$ column contains a 1 if the fuzzy operator for the rule's antecedent is AND. It contains a 2 if the fuzzy operator is OR.

The rule for

***"If Objective1 is Excellent and classs is Excellent Then Method32 is Excellent*"** is

4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 0 0 0 0, 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 (1) : 1

A sample FIS file is depicted below:

[**System]**

Name='manufacturing'
Type='mamdani'
Version=2.0
NumInputs=1
NumOutputs=1
NumRules=1
AndMethod='min'
OrMethod='probor'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

[**Input1**]

Name='Objective1'
Range=[0 10]
NumMFs=4
MF1='Fair':'trimf',[-3 0 3]
MF2='Good':'trimf',[2.5 4 5.5]
MF3='VeryGood':'trimf',[5 6.5 8]
MF4='Excellent':'trimf',[8 9 500]

[**Output1**]

Name='Method1'
Range=[0 10]
NumMFs=4
MF1='Fair':'trimf',[-3 0 3]

MF2='Good':'trimf',[2.5 4 5.5]
MF3='VeryGood':'trimf',[5 6.5 8]
MF4='Excellent':'trimf',[8 9 500]

[**Rules**]

4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 0 0 0 0, 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 (1) : 1

In this paper, the authors have dynamically generated FIS file based on the parameters specified by an end user. User interface is developed in Java Swing and proper data validations are carried out to preserve the structure of FIS file.

Simulink

Simulink is an extension of MATLAB which offers modeling, simulating, and analyzing of dynamic systems under a graphical user interface (GUI) environment. Simulink includes a comprehensive block library of toolboxes for both linear and non-linear analyses. In the simulation experiment, the authors have used the following toolboxes.

Fuzzy Logic: It allows for manipulation for fuzzy systems and membership functions.

Sources: Sources are the blocks that provide input to the other blocks They allow input from desperate devices. From File is used for reading data from a mat file. The proposed model retrieves input from an Excel file and converts it into a mat file using xlsRead() and save() MATLAB commands as shown below:

a=xlsRead('Excel File Name', 'Range');
save a 'MAT File Name';

Sink: Sinks are the blocks that receive output from other blocks. They route output to desperate devices. To File writes data to a mat file. Our model routes mat file output to an Excel file using xlsWrite() command as shown below:

xlsWrite('Excel File Name', 'MAT File Name');

Signal Routing: From this toolbox, the authors have employed Multiplexer, for creating a single vector by reading input from multiple MAT files and DeMultiplexer for splitting the vector and routing output to multiple MAT files. In this paper the authors have developed a simulink model for 21 different inputs comprising of 16 manufacturing objectives and 5 classes and 10 outputs corresponding to 10 different manufacturing methods, for the time ranging from 1 to 16, at which different combinations of inputs are supplied.

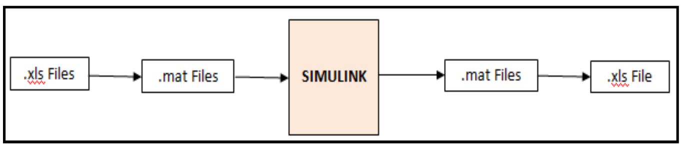


Figure 2. File Transfer Process in Simulink

The input is read from 21 different Excel files which are converted into the corresponding MAT files and output is routed to 10 different MAT files which are converted into corresponding Excel Files. The output from 10 different files is then consolidated to generate a report for various needs of the organization. Figure 2. depicts the file transfer process.

The GUI is developed in MATLAB for

- Selection of manufacturing method based on single objective.
- Selection of manufacturing method based on single objective in a particular class.
- Selection of manufacturing method based on multi objectives.

The format of the callback function for selection of manufacturing methods based on multiple objectives is given below:

function pushbutton1_Callback(hObject, eventdata, handles)

```
a=readfis('manufacturing8.fis');
 b=get(handles.popupmenu1,'value');
m=char('Activity Based Costing','Agent Driven
Approacj','Agile Manufacturing','Artificial
Intelligence','Autonomous Enterprise','Autonomous Production
Cells','Benchmarking','Bionic Manufacturingn
System','Borderless Corporation','Business Intelligence and
Data warehousing');

c(1)=0;
.
.
c(21)=0;
c(b-1)=9;
evalfis(c,a);
set(handles.edit3, 'string','No Methods Selected');
count=1;
result='';
for i=1:10
  if (ans(i)> 9)
    result=strvcat(result,m(i,:));
    count=count+1;
  end
end
set(handles.edit3, 'string',result);
```

RESULTS AND ANALYSIS

The results presented above are implemented in Java and MATLAB with MS-Access as back end for storing domain information. The structure of the database is shown in Figure 3.

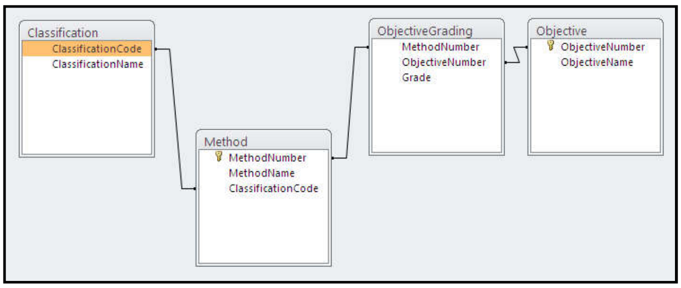
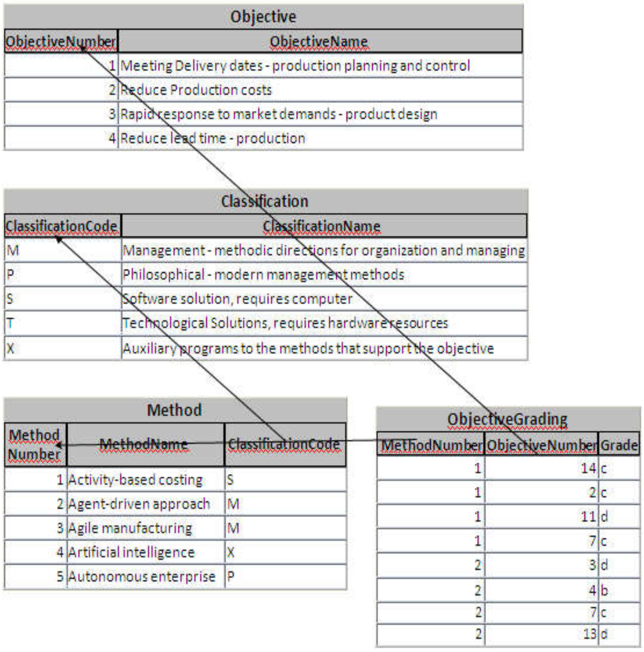


Figure 3. Structure of Manufacturing Database

Figure 4 depicts some sample tables and the relations among them. The Graphical User Interface (GUI) is developed in Java Swing to accept system, input and output information for an FIS file from end user.



Objective

ObjectiveNumber	ObjectiveName
1	Meeting Delivery dates - production planning and control
2	Reduce Production costs
3	Rapid response to market demands - product design
4	Reduce lead time - production

Classification

ClassificationCode	ClassificationName
M	Management - methodic directions for organization and managing
P	Philosophical - modern management methods
S	Software solution, requires computer
T	Technological Solutions, requires hardware resources
X	Auxiliary programs to the methods that support the objective

Method

Method Number	MethodName	ClassificationCode
1	Activity-based costing	S
2	Agent-driven approach	M
3	Agile manufacturing	M
4	Artificial intelligence	X
5	Autonomous enterprise	P

ObjectiveGrading

MethodNumber	ObjectiveNumber	Grade
1	14	c
1	2	c
1	11	d
1	7	c
2	3	d
2	4	b
2	7	c
2	13	d

Figure 4. Sample Tables

Figure 5 a) – d) depict fuzzy inference system, format of input and output functions and rules.

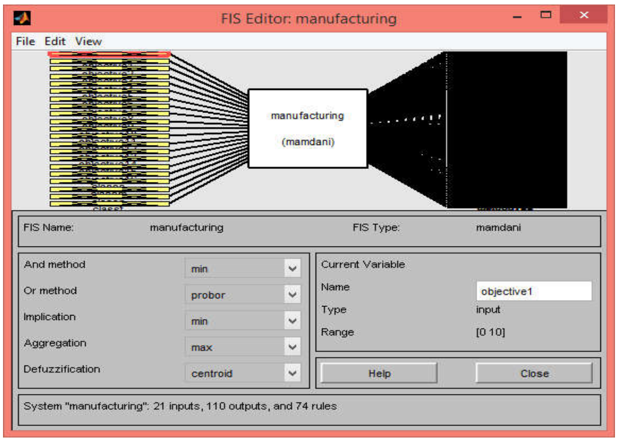


Figure 5a. Fuzzy Inference System

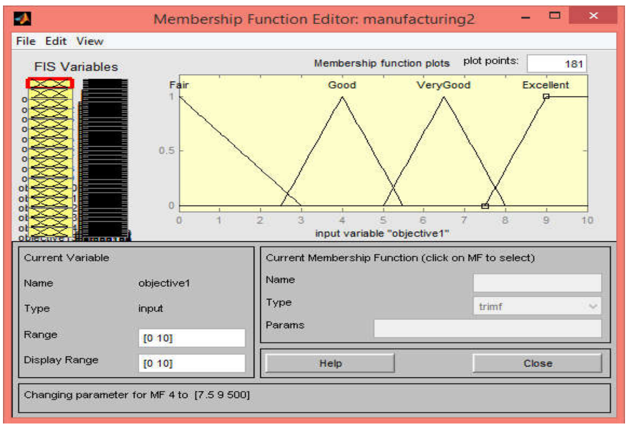


Figure 5b. Membership Function for Input Variable

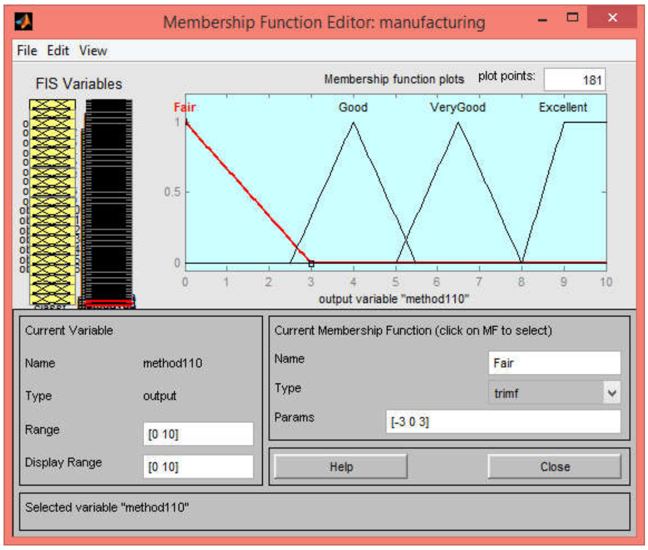


Figure 5c. Membership Function for Output Variable

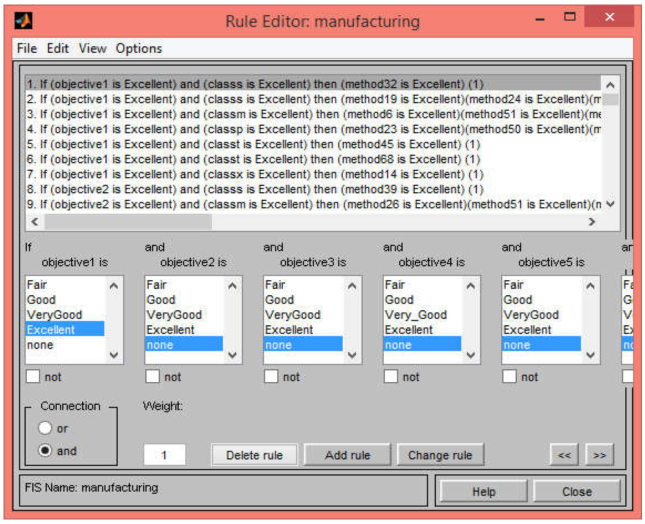


Figure 5d. Rule Editor

The FIS model comprises of 21 input variables and 110 output variables and only 74 rules are found to be significant. Triangular membership functions are adopted with the following overlapping ranges for linguistic variables, objective1. objective16.

$$\mu_{Fair}(x) = (3 - x)/3 \qquad x \leq 3$$

$$\mu_{Good}(x) = \begin{cases} (x - 2.5)/1.5 & 2.5 \leq x < 4 \\ 1 & x = 4 \\ (5.5-x)/1.5 & 4 \leq x < 5.5 \end{cases}$$

$$\mu_{VeryGood}(x) = \begin{cases} (x - 5)/1.5 & 5 \leq x < 6.5 \\ 1 & x = 6.5 \\ (8-x)/1.5 & 6.5 \leq x < 8 \end{cases}$$

$$\mu_{Excellent}(x) = \begin{cases} (x - 8)/1.0 & 7.5 \leq x < 9 \\ 1 & x >= 9 \end{cases}$$

Similar, membership functions exist for classes and output variables.

The system is tested for various combinations of input and output variables and different numbers of output variables as shown below:

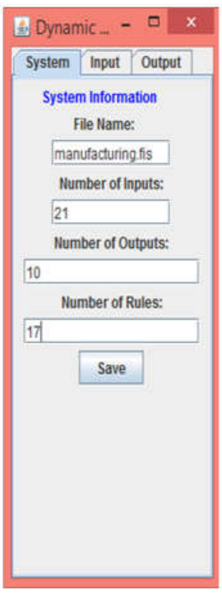
No. of Output Variables	No. of Significant Rules
110	74
75	59
50	39
10	17

Figure 6(a)-(c) show the user interface implementation in Java Swing for generating FIS file dynamically, while Figure 7(a)-(e) show the user interface implementation in MATLAB for deciding the selection of manufacturing method based on single/multi objectives and any/specific class. As shown in Figure 7(f), if the organization's focus is on objective2, objective3, objective6, objective7 and objective13 with the corresponding weights 9, 8, 8, 6 and 6, respectively and if the weights 9, 8, 6, 9, 2 are assigned to classes S, M, P, X, T, respectively, then the two methods

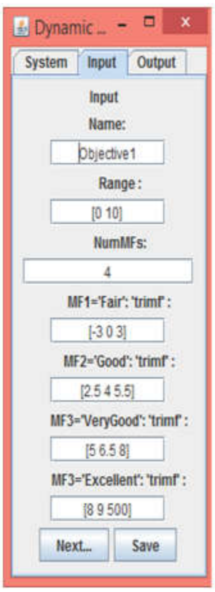
- Enterprise Resource Planning and
- Manufacturing Execution System

are applicable. The same situation with crisp expert system yields Enterprise Resource Planning as the only method of selection. As such fuzzy expert system offers a greater flexibility in method selection. Based on the availability of human resource and infrastructure constraints, the management can decide on the selection of one of the closely existing methods.

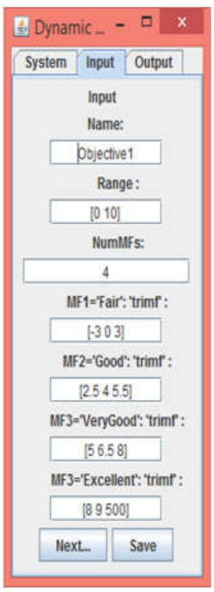
The simulink model is developed for 21 inputs and 10 output variables as shown in Figure 8. The format of .xls file for storing input and output is depicted in Figure 9 and Figure 10, respectively. Tables 1 and 2 summarize simulink results.



a

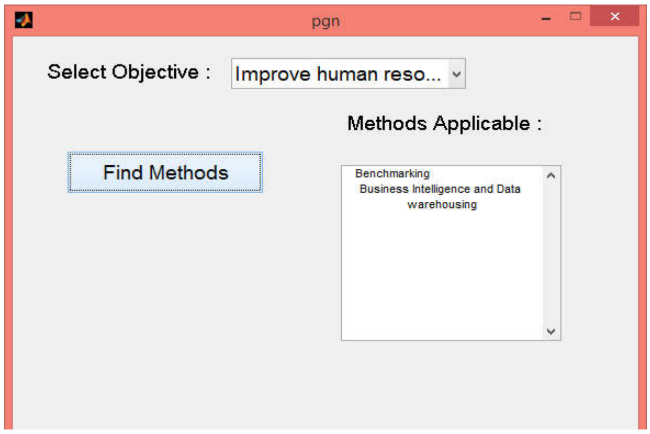


b

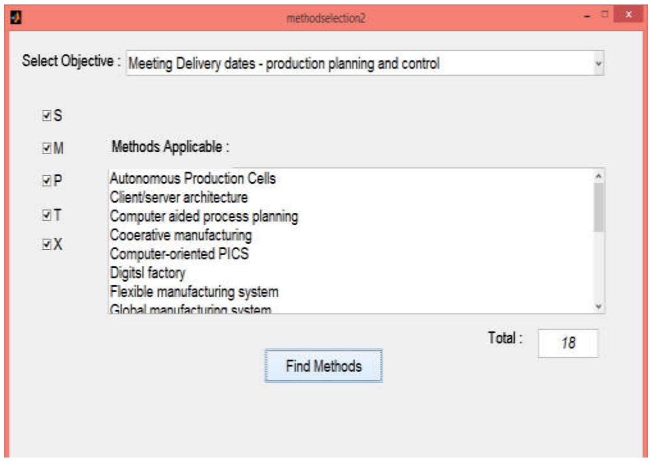


c

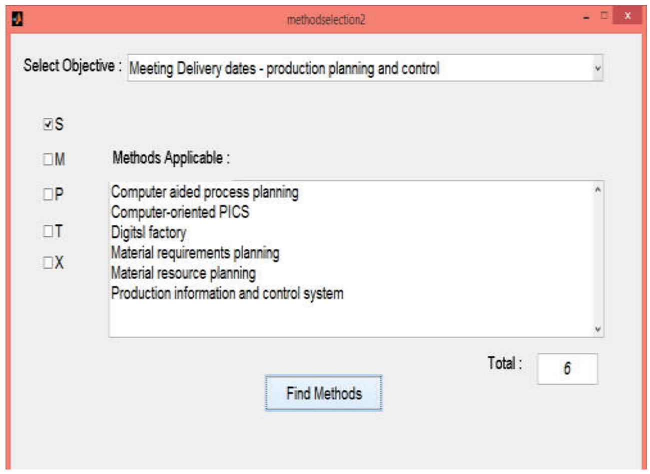
Figure 6a-c. User interface implementation in Java Swing for dynamic generation of FIS



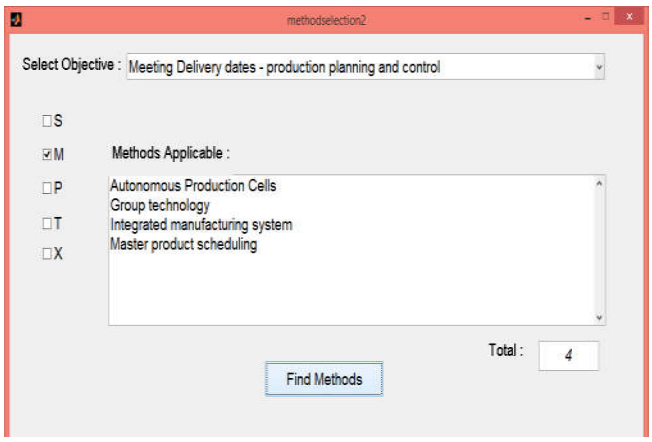
a



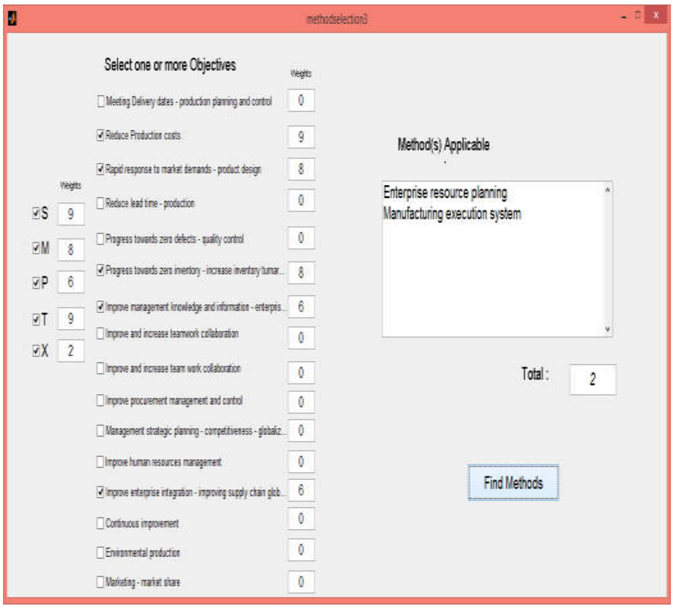
b



c



d



e

Figure 7a-e. User interface implementation in MATLAB for selection of manufacturing method

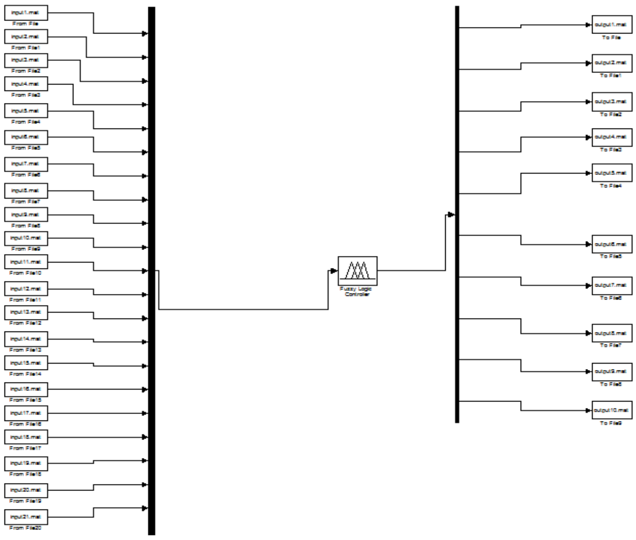


Figure 8. Simulink model for selection of Manufacturing Method based on Multi Objectives

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
input1.mat	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
input2.mat	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
input3.mat	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0
input4.mat	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0
input5.mat	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0
input6.mat	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0
input7.mat	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0
input8.mat	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0
input9.mat	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0
input10.mat	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0
input11.mat	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0
input12.mat	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0
input13.mat	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0
input14.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0
input15.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0
input16.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
input17.mat	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
input18.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
input19.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
input20.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
input21.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 9. Format of .xls file for storing simulink Input

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
output1.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
output2.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
output3.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
output4.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
output5.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
output6.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
output7.mat	0	0	9	0	0	0	0	0	0	0	9	0	0	0	0	0
output8.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
output9.mat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
output10.mat	0	0	0	0	0	9	9	0	0	9	9	0	0	0	0	0

Figure 10. Format of .xls file for storing simulink Output

The result is summarized in Table 1 and 2

Table I. Simulink Results

Method → Objective ↓	class ↓	1	2	3	4	5	6	7	8	9	10
1	S										
2	S										
3	S							✓			
4	S										
5	S										
6	S										✓
7	S										✓
8	S										
9	S										
10	S										✓
11	S							✓			✓
12	S										
13	S										
14	S										
15	S										
16	S										

Table 2. Simulink Results

Required Objective	Method Selected
Objective3	Method7
Objective6	Method10
Objective7	Method10
Objective10	Method10
Objective11	Method7, Method10

Conclusion and scope for future work

In this paper, the authors have presented an architecture for dynamic fuzzy expert system for multi objective criteria for selection of manufacturing method. Fuzzy expert system is created outside MATLAB and MATLAB is used only for creating user interface for querying methods based on objectives and for the evaluation of rules. A simulink model is developed for selective methods and objectives. The results obtained using Fuzzy Expert System are compared with that obtained using crisp expert system. Our future work focuses of using Fuzzy – GA hybrid model for selection of strong rules and Neuro-Fuzzy hybrid model for generation of member functions.

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