

# Dynamic Fuzzy Expert System for Multi Objective Criteria for Selection of Manufacturing Method using Sugeno Model

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## Abstract

**Objectives:** Operational effectiveness is an ultimate objective of any manufacturing organization. On the shop floor the main focus is on elimination of waste and delays. The main target is designing a product for which manufacturing is a low cost process. Once organizations select appropriate tools and methods, the decision on performance measures can be taken through which progress can be monitored. The present work offers fuzzy expert system for manufacturing method selection in a dynamic environment where the organization's objectives are subject to constant amendments. **Methods/ Statistical Analysis:** In order to incorporate ambiguity into the manufacturing environment, the authors have designed and developed a fuzzy expert system using Sugeno model based on the dynamic ranges of triangular membership functions for input objectives which is extremely efficient as compared to the Mamdani method in classifying vague data. In this paper, the authors propose architecture for fuzzy expert system based on multi objective criteria for selection of manufacturing method employing Sugeno model with constant output. 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. **Findings:** As more than one manufacturing method may serve a single objective, each manufacturing method is encoded using a binary digit and the output is decimal representation of this binary encoding. Also, it is observed that, the number of fuzzy rules increase exponentially as a function of number of objectives. In order to cater to this problem, instead of generating so many rules the required modifications are performed at the code level to incorporate multi objective criteria. Finally a simulink model is developed for selective methods and objectives. The results obtained using Sugeno Fuzzy Expert System is compared with that obtained using Mamdani method and crisp expert system. **Results:** It is found that the crisp expert system and Sugeno type FIS yield similar results for classification while 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.

**Keywords:** Expert System, Fuzzy Logic, Manufacturing, MATLAB, Membership Functions, Simulink.

## 1. Introduction

The main objective of manufacturing system design is to lower cost and eliminate wastes and delays. The systematic

analysis of organizational objectives and functional requirements is a basis for manufacturing method selection. Hence more than 110 manufacturing methods belonging to different classes have been proposed. For

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in the rule base without thinking in terms of mathematical model. Fuzzy systems are the good candidates for problem solution in two different scenarios, firstly in situations where highly complex systems whose behavior is not understood very well are involved so that mathematical modeling becomes complex and secondly in situations where an approximate but fast solutions are desirable as fuzzy inference system evaluates the rules in parallel. The results based on fuzzy logic prove to be superior to traditional logic if the correct rule set and type and range of fuzzy membership functions are input to the system which is an extremely challenging and time consuming.

Fuzzy logic employs a set of rules based on if..then statements for mapping an input space to the corresponding output space which are evaluated in parallel for efficiency improvisation. In fuzzy logic the truth of a given statement is specified by degree of membership or degree of belongingness. This technique plays a vital role in analysis of problems which cannot be explicitly defined. In fuzzy logic each variable has a multi valued membership in contrast to crisp sets where each variable has two-valued membership.

### 1.3 Comparison Between Mamdani Type and Sugeno Type Fuzzy Inference System

In Mamdani type Fuzzy Inference System both the antecedent and consequent of the rules are fuzzy where as in Sugeno type Fuzzy Inference System consequent of the rules are not fuzzy, they are either linear or constant which results in improvisation of processing time as time consuming defuzzification process is not present.

### 1.4 Simulink

Simulink is an extension of MATLAB which offers modeling, simulating, and analyzing of dynamic systems employing a Graphical User Interface (GUI) environment. Simulink comprises of a comprehensive block library of toolboxes for modeling both linear and non-linear systems. In the current work, following toolboxes are employed for simulation.

- Fuzzy Logic
- Sources
- Sink
- Signal Routing

A simulink model is developed for 21 different inputs comprising of 16 manufacturing objectives and 5 classes and a single output corresponding to decimal representation of binary encoded different manufacturing methods, for the time ranging from 1 to 16, at which different combinations of inputs are supplied. The input is read from 21 distinct Excel files which are then converted into the corresponding MAT files and output is finally routed to a MAT file. The MAT file so generated is then converted into the corresponding Excel File to generate a report for various needs of the organization. Figure 2 depicts the file transfer process employed in the simulink model.

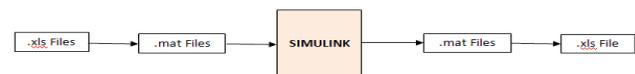


Figure 2. File Transfer Process in Simulink Model.

## 2. Existing Methods

Manufacturing methods can be systematically categorized on the basis of their main focus. Methods like Computer Aided Design (CAD) / Computer Aided Manufacturing (CAM), flexible manufacturing systems and manufacturing execution systems are supported by manufacturing hardware<sup>1,2</sup>. In order to cater the needs of industry, knowledge management emerged as key area of research which resulted in focus on areas like expert system, artificial intelligence etc<sup>3,4</sup>. During the recessionary trends survival of organizations was crucial. This led to focus on improvement in productivity and to sustain lean phase in business cycle, organizations employed total cost management to remain competitive which resulted in emergence of methods like lean manufacturing, optimized production technology, theory of constraints etc. focusing on production planning and production control<sup>5,6</sup>. Then focus shifted to more simplification of production processes, this led to emergence of group technology, just-in-time, constant work in process for the efficient utilization of organizational resources<sup>7</sup>. Cost leadership equips organizations with competitive advantage. Cost efficiency of organization's activities reflects its ability to perform similar activities better than its competitors. This led to emergence of methods like activity based costing, cost estimation, statistical process control etc.<sup>8</sup>. Competitive environment compelled organizations to fine tune their product design

strategies. As a long term strategy, many organizations focused on building capacities for product design and development. The challenges faced by the organizations were controlling engineering costs against targets and mainly conforming product development process to meet time to market targets. These strategic initiatives led to emergence of methods related to product design and development<sup>9</sup>. Efficient human resource management removes redundancy and powers productivity. Efficient performance management is proving to be an excellent cost optimization tool in the hands of smart organizations. It is the employee who drives the process rather than organization. The individuals input ensures an achievement oriented culture especially where change management is concerned. The main objective was to build learning organization to meet future challenges through development of high performing, energetic and enthusiastic human resource. This led to dedicated efforts in the direction of human resource development and management related methods such as executive excellence, cross functional leadership etc.<sup>10</sup>. Most of the organizations during tough times focused on productivity improvement for their survival; in order to sustain lean phase demand focused on total cost management during stiff competition and in order to attain strategic advantage organizations focused on their quality improvement efforts. This focus led to development of methods focusing on entire value chain of business to improve throughput, resulting in development of processes like supply chain management, outsourcing, customer relationship management etc.<sup>11</sup>. The main goal of organizations is to reduce manufacturing lead time, manage process cost, production cost, delivery cost and structural cost to improve market share and attain competitive edge over other business rivals. This objective led to emergence of methods like business process re-engineering, total quality management and enterprise resource planning etc.<sup>12</sup> Organizations later on started focusing on manufacturing excellence. Process of globalization started new trends resulting in new technologies, new competitive standards. This led foundation for advanced organizational manufacturing methods like world class manufacturing, agile manufacturing, and performance management system etc.<sup>13</sup>. The challenges in this new era are many. Organizations are constantly researching on development of tools based on system modeling, self optimizing control, artificial

intelligence applied to manufacturing systems in order to meet the challenges of new age dynamic business scenario. This led to development of methods focusing on next generation production management like cooperative manufacturing, e-manufacturing, matrix shop floor control etc. The environmental norms are more stringent. The global standards must be met in order to qualify for open market competition. This fact necessitated organizations to invest in environment conscious manufacturing. The life cycle management of a product, environmental impact assessment and factors like recyclability and sustainability assessment led to development of methods focusing mainly on environmental aspects. Due to this awareness methods like, environmental conscious manufacturing, life cycle management and waste management and recycling emerged<sup>14</sup>.

Continuous research and urge for better and more efficient, more effective and more versatile manufacturing methods is constantly increasing. Enhancement in technology, new materials and modern techniques for change management constantly demand research for new methods in order to meet challenges posed by dynamic business environment. Hence the current study of manufacturing method selection based on single/multi objectives, and/or single/multi functions based on organizational requirements is extremely crucial in deciding the success factor of an organization all the time.

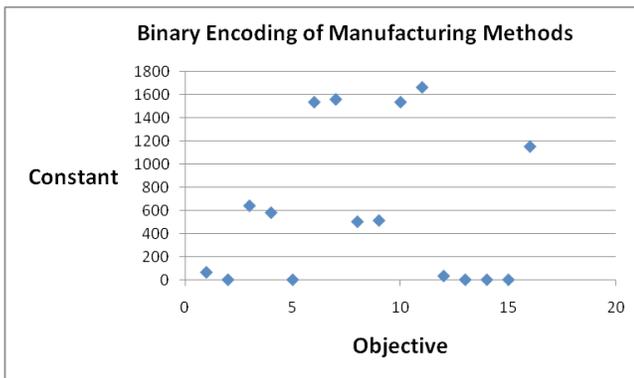
To account for this research gap, in the current work the authors have developed a dynamic fuzzy expert system which responds to the dynamic changes in business scenarios.

## 2.1 Modeling Sugeno-Type FIS using Constant Output

Manufacturing method selection system is designed and developed using Sugeno type FIS with constant output. It consists of 21 inputs of which 16 are the manufacturing objectives and 5 are the different classes to which the objectives belong and 10 outputs corresponding to the manufacturing methods. More than one manufacturing method may serve a single objective. To cater to this problem, each manufacturing method is encoded using a binary digit. Output contains the decimal representation of this binary encoding as shown in Table 1 and Figure 3 depicts the following graphical representation.

**Table 1.** Binary Encoding of Manufacturing Methods

| Manufacturing Objective | Methods Available | Binary Method Encoding | Decimal Equivalent |
|-------------------------|-------------------|------------------------|--------------------|
| Objective1              | 6                 | 000000000100000        | 64                 |
| Objective2              | 0                 | 0000000101000000       | 0                  |
| Objective3              | 7,9               | 0000000100100110       | 640                |
| Objective4              | 2,3,6,9           | 0000001100000000       | 580                |
| Objective5              | 0                 | 0000001100001100       | 0                  |
| Objective6              | 9,10              | 0000000100000000       | 1536               |
| Objective7              | 3,4,9,10          | 0000000100000000       | 1560               |



**Figure 3.** Binary Encoding of Manufacturing Methods.

Each of the input comprises of four triangular membership functions. On evaluation of FIS the output contains the decimal representation of the selected methods which is decoded to obtain the manufacturing method names corresponding to the objective under consideration.

The prime difference between Mamdani and Sugeno models lies in the fact that the output in Mamdani type of fuzzy inference system is represented by a fuzzy membership function. In contrast to this, the output in Sugeno type of fuzzy inference system is merely a constant. Both Fuzzy Inference Systems accept the similar input, however, they most fundamentally differ in the way they produce output, in Mamdani type of FIS defuzzification technique of a fuzzy output is employed, whereas Sugeno type FIS uses the weighted average for computation of crisp output.

The Sugeno rule for

*“If Objective1 is Excellent and class S is Excellent Then Output is mf4”* is

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

where mf4 represents a constant output.

A sample FIS file for Sugeno model is depicted below:

```
[System]
Name='sugenomanufacturing2'
Type='sugeno'
Version=2.0
NumInputs=21
NumOutputs=1
NumRules=1
AndMethod='prod'
OrMethod='probor'
ImpMethod='prod'
AggMethod='sum'
DefuzzMethod='wtaver'

[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='output1'
Range=[0 65]
NumMFs=10
MF1='mf1':constant,[0]
MF2='mf2':constant,[16]
MF3='mf3':constant,[32]
MF4='mf4':constant,[64]
MF5='mf5':constant,[128]
MF6='mf6':constant,[512]
MF7='mf7':constant,[520]
MF8='mf8':constant,[588]
MF9='mf9':constant,[1024]
MF10='mf10':constant,[1152]

[Rules]
4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 0 0 0, 0 (1) : 1
4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 0 0 0, 4 (1) : 1
4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 0 0, 0 (1) : 1
4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 0, 0 (1) : 1
4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4, 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.

The GUI is developed in MATLAB for the

- 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 multiple objectives
- Selection of manufacturing method based on multi objectives and multiple classes

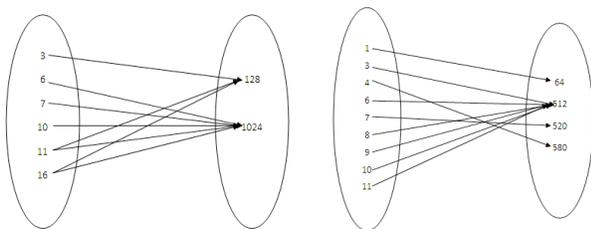
The total number of rules that can be formulated for different cases involving one or more objectives and one or more classes is depicted below:

**Case 1: No. of rules for single objective, single class criterion.**

Total number of objectives: 16  
 Total number of classes : 5  
 Total Rules: 80

$$16 \times 5 = 80$$

However, it is found that out of these 80 rules only 21 rules are non-trivial and hence significant which map to 10 different constant values corresponding to decimal representation of binary encoded objectives. Figure 4(a)-(b) depict non-trivial function mapping for class s and class m, respectively. Similar mappings exist for other classes.



**Figure 4(a)-(b).**Non -trivial Objective-Method Mapping for Class S and Class M.

**Case 2: No. of rules for single objective, one or more class criterion.**

Total Objectives: 16

| No. of Classes | No. of different Combinations | No. of Rules         |
|----------------|-------------------------------|----------------------|
| 1              | ${}^5C_1=5$                   | $16 \times 5 = 80$   |
| 2              | ${}^5C_2=10$                  | $16 \times 10 = 160$ |
| 3              | ${}^5C_3=10$                  | $16 \times 10 = 160$ |
| 4              | ${}^5C_4=5$                   | $16 \times 5 = 80$   |
| 5              | ${}^5C_5=1$                   | $16 \times 1 = 16$   |

Total Rules: 496

$$16 ( 2^5-1)$$

**Case 3: No. of rules for multi objective, single class criterion.**

Total number of rules involving one or more objectives is given by

$${}^{16}C_1 + {}^{16}C_2 + {}^{16}C_3 + {}^{16}C_4 + \dots + {}^{16}C_{16} = 2^{16} - 1$$

Hence total number of rules involving a single class and one or more objectives is given by

$$5 (2^{16} - 1)$$

**Case 4: No. of rules for multi objective, multi class criterion.**

Total number of rules involving a single class and one or more objectives is given by

$${}^{16}C_1 + {}^{16}C_2 + {}^{16}C_3 + {}^{16}C_4 + \dots + {}^{16}C_{16} = 2^{16} - 1$$

Total number of rules involving one or more classes is given by

$${}^5C_1 + {}^5C_2 + {}^5C_3 + {}^5C_4 + {}^5C_5 = 2^5 - 1$$

Hence the total number of rules for multi objective, multi class criteria is

$$(2^{16} - 1)( 2^5-1)$$

Table 2 summarizes the results.

**Table 2.** No. of Rules for one or more Manufacturing Objectives in one or more Classes

| Class  |              | Objective |              | Total No. of Rules                        |
|--------|--------------|-----------|--------------|---|
| Type   | Combinations | Type      | Combinations |   |
| Single | 5            | Single    | 16           | $5 \times 16 = 80$                        |
| Multi  | $2^5-1$      | Single    | 16           | $(2^5-1) \times 16=496$                   |
| Single | 5            | Multi     | $2^{16} - 1$ | $(2^{16} - 1) \times 5 = 327675$          |
| Multi  | $2^5-1$      | Multi     | $2^{16} - 1$ | $(2^{16} - 1) \times (2^5 - 1) = 2031585$ |

The variation of no. of rules as a function of no. of objectives is depicted in the following Figure 5.



**Figure 5.** Variation of number of Rules as a function of number of Objectives.

As seen from Figure 5, the number of rules increase exponentially as a function of no. of objectives. To account for this situation, instead of generating so many rules we have performed modifications at the code level.

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

```
Function pushbutton2_Callback (hObject, eventdata, handles)
% hObject handle to pushbutton2 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
```

```
b=get(handles.popupmenu1,'value');
m1=char('Activity Based Costing', 'Agent Driven Approach', 'Agile Manufacturing', 'Artificial Intelligence', 'Autonomous Enterprise', 'Autonomous Production Cells', 'Benchmarking', 'Bionic Manufacturingn System', 'Borderless Corporation', 'Business Intelligence and Data warehousing');
```

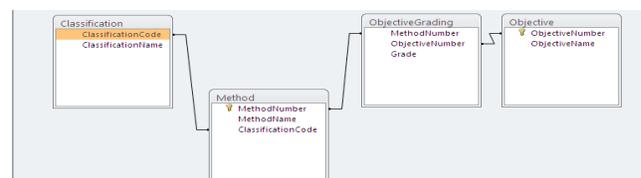
```
c(1)=0;
.
.
c(16)=0;
c(b-1)=7;
a=readfis('sugenomanufacturing.fis');
evalfis(c,a);
display(ans);
```

```
result=0;
for i=1:16
    result=result+ans(i);
    m(i)=0;
end
display(result);
count=1;
while result > 1
    q=fix(result/2);
    rem=result - q* 2;
    m(count)=rem;
    display(rem);
    display(q);
    result=q;
    count=count+ 1;
end
display(count)
display(q)
m(count)=q;
display(m);
display('Methods');
sresult=""
for i=1:16
    if (m(i)==1)
        ss=strcat('Method',num2str(i-1));
        sresult=strvcat(sresult,m1(i-1,:));
    end
end

set(handles.edit1, 'string',sresult);
```

### 3. 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 storing schema is shown in Figure 6.



**Figure 6.** Structure of Manufacturing Database.

Figure 7 depicts some sample tables and the relations among them.

| 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        |                         |                    | ObjectiveGrading |                 |       |
|---------------|-------------------------|--------------------|------------------|-----------------|-------|
| Method Number | MethodName              | ClassificationCode | MethodNumber     | ObjectiveNumber | Grade |
| 1             | Activity-based costing  | S                  | 1                | 14              | c     |
| 2             | Agent-driven approach   | M                  | 1                | 2               | c     |
| 3             | Agile manufacturing     | M                  | 1                | 11              | d     |
| 4             | Artificial Intelligence | X                  | 1                | 7               | c     |
| 5             | Autonomous enterprise   | P                  | 2                | 3               | d     |
|               |                         |                    | 2                | 7               | c     |
|               |                         |                    | 2                | 13              | d     |

Figure 7. Sample Tables with Relations.

The Graphical User Interface (GUI) is developed in Java Swing to accept system, input and output information for an FIS file from end user. Figure 8 a– d depicts fuzzy inference system, format of input and output functions and rules.

The FIS model comprises of 21 input variables and 110 output variables and only 21 out of 80 rules are found to be significant. Triangular membership functions are adopted with the following overlapping ranges for linguistic variables, objective1..objective16.

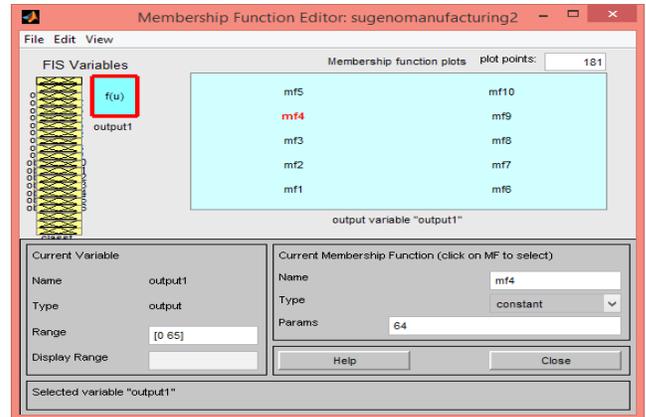


Figure 8(c). Format or Output Function.

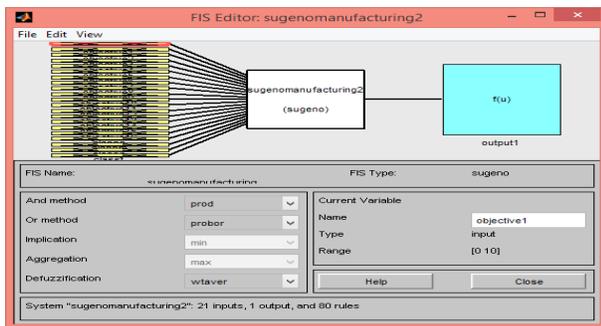


Figure 8(a). Fuzzy Inference.

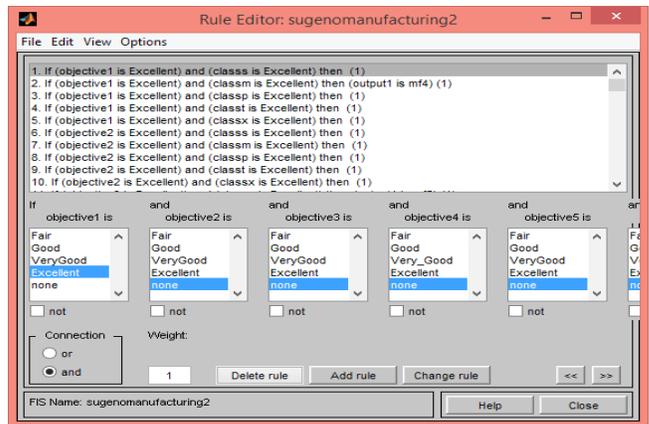


Figure 8(d). Sample FIS Rules.

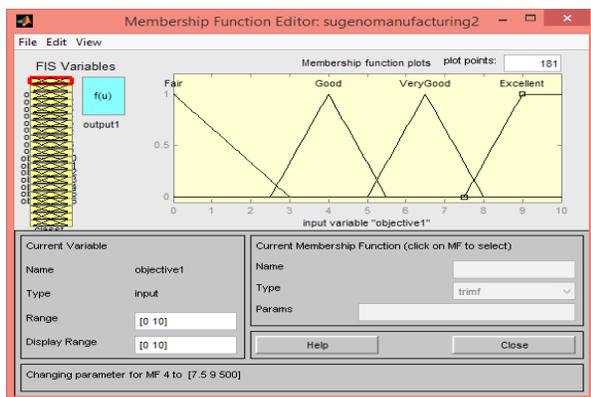


Figure 8(b). Format of Input Functions.

$$\mu_{Fair}(x) = \begin{cases} (3-x)/3 & 0 \leq x < 3 \\ 1 & 3 \leq x < 4 \\ (5.5-x)/1.5 & 4 \leq x < 5.5 \end{cases}$$

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

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

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

Similar, membership functions exist for classes.

Figure 9(a)-(b) show the user interface implementation in Java Swing for generating FIS file dynamically, while Figure 10(a)-(c) show the user interface implementation in MATLAB for deciding the selection of manufacturing method based on single/multi objectives and any/specific class.

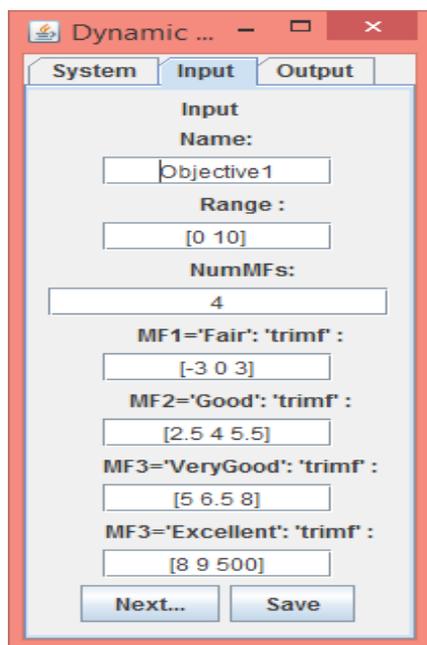
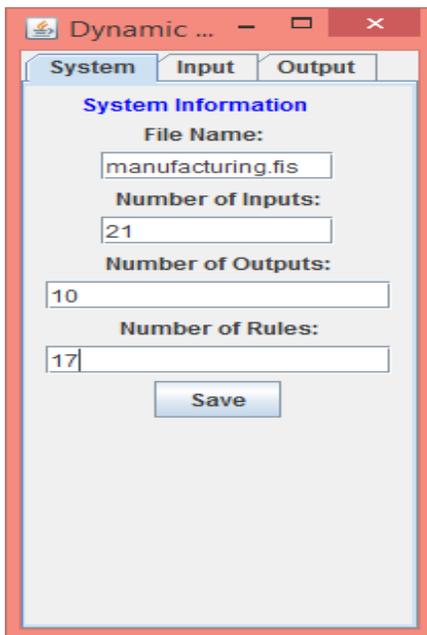


Figure 9(a)-(b). User Interface for Building FIS.

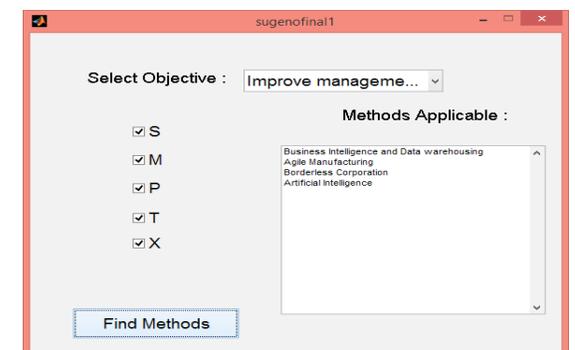
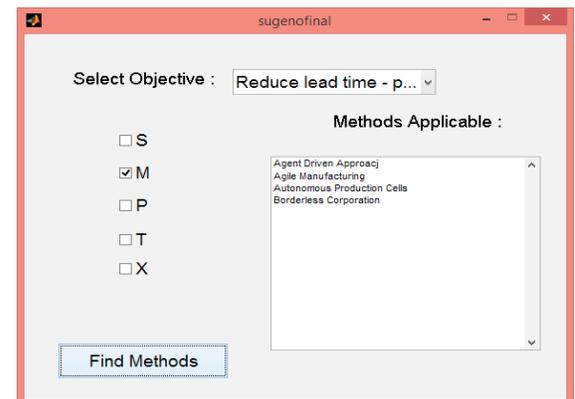
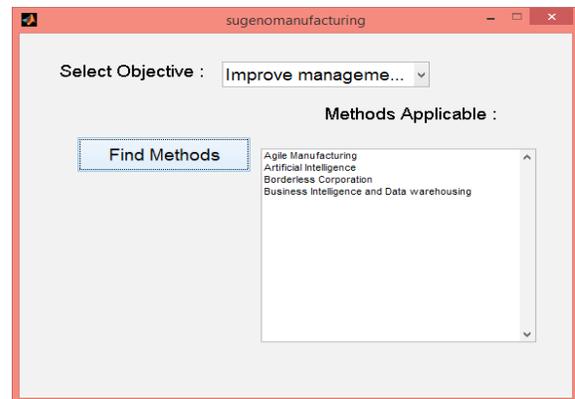


Figure 9(a)-(c). User Interface in MATLAB for Selection of Manufacturing Method based on Single Objective and One or More classes.

It is found that 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 method

is applicable. The same result is obtained with the crisp expert system. The same situation with Mamdani type FIS however, yields i) Enterprise Resource Planning and ii) Manufacturing Execution System as the two methods of selec-

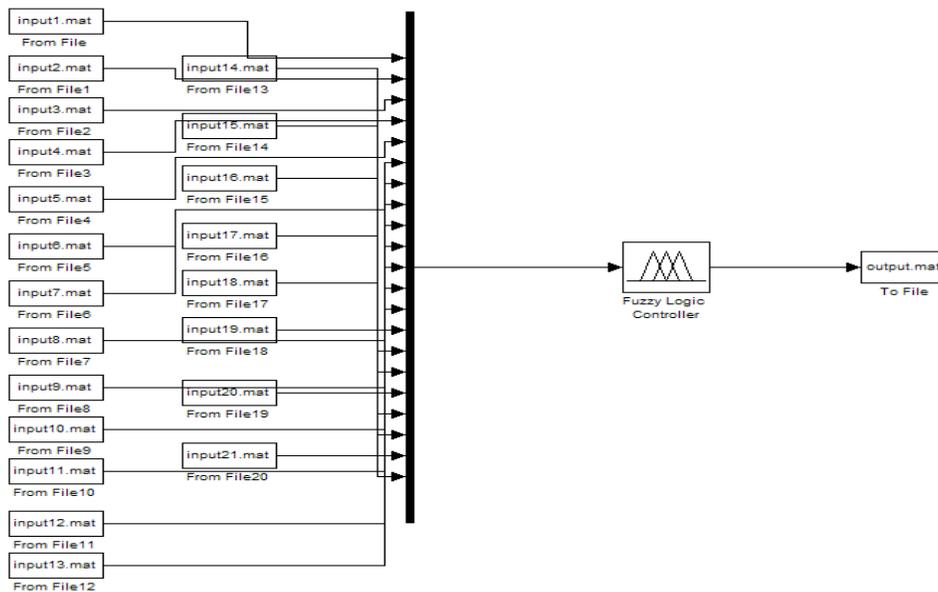


Figure 10. Simulink Model for Selection of Manufacturing Method.

tion. This difference can be attributed to the overlap of fuzzy output membership functions in Mamdani type system. 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 10. The format of .xls file for storing output and input is depicted in Figure 11 and Figure 12 respectively. Tables 3 and 4 summarize simulink results.

| Time       | 1 | 2 | 3   | 4 | 5 | 6    | 7    | 8 | 9 | 10   | 11   | 12 | 13 | 14 | 15 | 16   |
|------------|---|---|-----|---|---|------|------|---|---|------|------|----|----|----|----|------|
| Output.mat | 0 | 0 | 128 | 0 | 0 | 1024 | 1024 | 0 | 0 | 1024 | 1152 | 0  | 0  | 0  | 0  | 1152 |

Figure 11. Format of .xls file for storing simulink Output.

| 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 12. Format of .xls file for storing simulink Input for Class S.

Table 3. 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 4. Simulink Results

| Required Objective | Method Selected   |
|--------------------|-------------------|
| Objective3         | Method7           |
| Objective6         | Method10          |
| Objective7         | Method10          |
| Objective10        | Method10          |
| Objective11        | Method7, Method10 |
| Objective16        | Method7, Method10 |

## 4. Conclusion and Scope for Future Work

The authors have presented architecture for dynamic fuzzy expert system for multi objective criteria for selection of manufacturing method based on Sugeno model with constant output. Fuzzy expert system is developed outside

MATLAB and MATLAB is used only for creating user interface for querying methods based on objectives and for the evaluation of rules. As more than one manufacturing method may serve a single objective, each manufacturing method is encoded using a binary digit and the output is decimal representation of this binary encoding. Also, it is observed that, the number of fuzzy rules increase exponentially as a function of number of objectives. In order to cater for this problem, instead of generating so many rules we have performed the required modifications at the code level to improve efficiency while at the same time incorporating multi objective criteria. A simulink model is developed for selective methods and objectives. It is found that the crisp expert system and Sugeno type FIS yield similar results for classification while Mamdani type FIS offers more flexibility in method selection due to the nature of output member's functions which are overlapping fuzzy sets. This yields the manager a greater freedom in method selection based on infrastructure and other resource availability. 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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