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Fuzzy Synthetic Evaluation Model for Smart Washing Machine

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Abstract

Generally fuzzy control system (FCS) is worked in washing machine. For the fuzzy set theory, membership functions are the building blocks. In a fuzzy set, fuzziness is determined by its membership functions. The shapes of membership functions are important, because it has an effect on fuzzy inference system. The shapes of membership functions can be triangular, trapezoidal and gaussian. The most widely used triangular membership function is used in this paper, because it can capture the short time period. In washing machine, open loop control system is found. This paper applies a fuzzy synthetic evaluation method (FSEM) for washing cloth in washing machine as FSEM can handle the multiple criteria with the help of evaluation matrix generated from membership function and weight matrix generated by Analytical Hierarchy Process (AHP). The purpose of this research is to minimize the wash time. By applying FSEM, we get a wash time which is less than that wash time got from applying the Mamdani approach in FCS. An example is given for illustration. For more reduction of wash time, statistical averaging method is also used. To reduce the wash time, statistical averaging method can be used in Mamdani approach also.

Keywords

Fuzzy Control System, Fuzzy Synthetic Evaluation Method, Analytic Hierarchy Process Method, Mamdani Approach, Statistical Averaging Method

1. Introduction

Washing machine is one of the most popular household appliances in modern life. It reduces human efforts and washing time which is very crucial for modern busy life. In addition, manual washing of clothes is all the way expensive in terms of use of water and washing power, because the water and washing powder may not be selected exactly as much required for a certain amount of clothes. There is a chance that requirement of water and washing powder may be wrongly estimated for a certain amount of clothes, which causes waste of water and washing powder. It is obvious that the washing powder may pollute the water mass. Therefore, wrong estimation of water and washing powder should be avoided. Smart washing machine helps the proportionate use of water and washing powder for a certain amount of clothes. Improving the efficiency of the washing machine in terms of use of water and washing powder, and reducing the washing time for any amount of cloths is important.

S. Mufozzal *et al.* [1] developed the creative design methodology for meeting ever changing and conflicting demands of various customers. M. Wang *et al.* [2] gave new ideas and fresh design methods for the appearance improvements of the secondary and tertiary market washing machine. Laitala *et al.* [3] reduced laundering frequency, washing and drying processes based on a quantitative wardrobe survey and qualitative laundry diary data from China, Germany, Japan, UK and USA. Cleaning technologies vary worldwide from hard washing to various types of washing machines and dry cleaners.

Pakula *et al.* in [4] compares the energy and water consumption for automatic laundry washing in an average private household with the total energy and water consumption of private households. New dry cleaning methods have been developed to reduce and replace the use of harmful chemicals, such as perchloroethylene by Onasch [5]. Improvement in washing efficiency was made by Sung Min Kim [6].

Waterways are polluted by harmful chemicals such as detergents, solvents and softeners, which is investigated by Gooijer *et al.* [7]. There is an impact of environment for using energy on laundering. A case study on laundry washing in Europeis is given by Shah mohammadi *et al.* [8]. An analysis for cloth cleaning is given by Bain *et al.* [9] and provided a suggestion for saving energy for laundering. The requirement of eco-designing is needed for cleaning technologies, dryers and detergents. Laitala *et al.* [10] worked for the improvement of the product lifetimes.

Automatic washing machine is developed by fuzzy control system. Wash time is output where detergent and dirt are inputs. Islam *et al.* in [11] used various fuzzy numbers such as triangular fuzzy number, trapezoidal fuzzy number and mixed fuzzy number to calculate wash time for washing machine. In fuzzy mathematics, fuzzy inputs are converted from crisp inputs where the membership function represents crisp inputs based on their linguistic terms. By applying fuzzy synthetic evaluation method (FSEM), wash time can also be found where analytic hierarchy process (AHP) method is used to find weight (priorities) of input. Wang *et al.* [12] developed a multi-level FSE model for the long-term safety evaluation system of a tunnel structure. H. Zhang *et al.* [13] developed an effective model for comprehensive fuzzy evaluation and established an index system. Lapevski *et al.* [14] used AHP method to make quality economic offer evaluation and selection of the best bid for purchasing the computer equipment.

In this paper, FSEM has been proposed for washing machine. Mamdani approach is well known in fuzzy control system. In FSEM, we can find wash time which is less than that wash time in Mamdani approach. In this paper, AHP method is also used for choosing weights for inputs. For finding decision matrix, Saaty matrix is also used. Then to reduce the wash time, statistical averaging method is also applied. We can reduce the waste of electricity by the minimum wash time.

2. Control System

A control system is an arrangement of physical components that is defined to control another physical system which will exhibit certain desired characteristics. There are two types of control systems:

1) Open loop control system and

2) Closed loop control system.

2.1. Open Loop Control System

An open loop control system is a system where the input to the control system is independent of the output of the controlled physical system, *i.e.*, there is no feedback from output to the input. An open loop control system can be represented as in "**Figure 1**". An open loop control system is widely used in automatic washing machine, traffic light, refrigerator etc.

2.2. Closed Loop Control System

In a closed loop control system, the new output of the controlled physical system will depend on its previous output. A closed loop control system may have one or more feedback loops between its input and output. The controller in a closed loop control system tries to reduce the error between input and output signals of the system. A closed loop control system can be represented as in "**Figure 2**", where error signal = input signal-output signal. There are vast applications of closed control systems in controlling physical systems, such as air conditioner, heating system, water treatment plants and environment control etc.

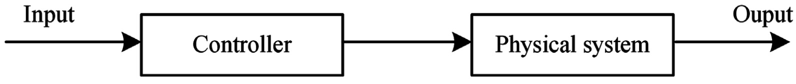

Figure 1. Open loop control system.

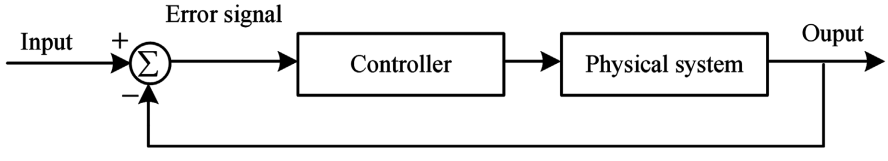

Figure 2. Closed loop control system.

2.3. Controlled Washing Cycle in a Washing Machine

As mentioned in subsection 2.1, the washing cycle in a washing machine is controlled following an open loop control system. The entire washing cycle in a washing machine can be divided into the different washing phases as shown in "**Figure 3**".

Based on the type and quantity of laundry and soiling degree of the laundry, the quantity of detergent (powder/liquid) is selected and poured into the washing machine. Then, according to the soiling degree of the laundry, the user may select the washing time (quick wash/standard wash) and start the machine. Before starting the washing of the laundry, the machine heats the washing water to a pre-defined temperature. However, this temperature varies in different types of machines according to the colors of the laundry. In the next phase of washing, the machine chooses whether the laundry needs prewashing or not. After prewashing the washing machine enters into main washing phase. At the end of main washing phase, the enters into rinsing phase when the dirty and soapy water is drained. After rinsing, the machine is refilled with clean water to rewash the laundry. After finishing rinsing and rewashing, the machine enters into spinning phase of washing when the machine spins very fast to drain water

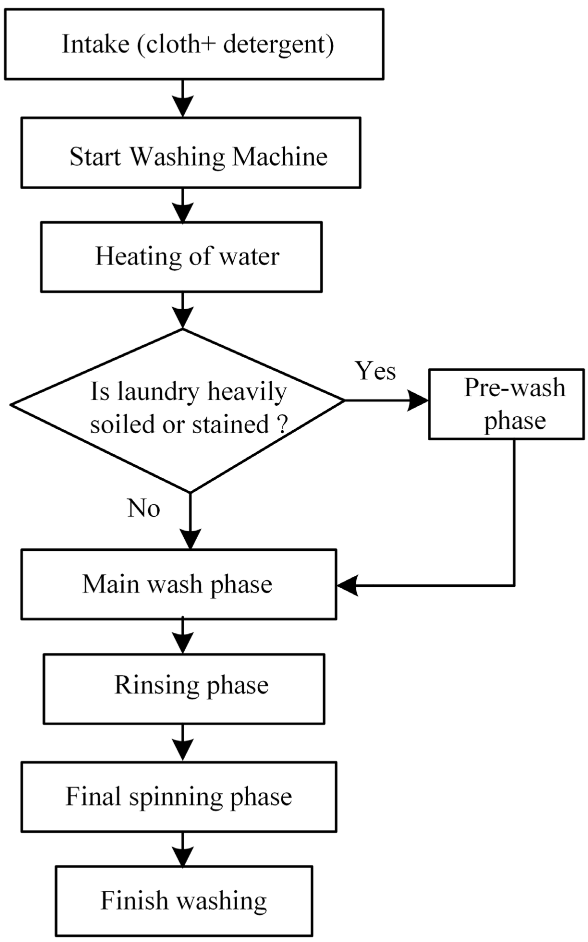

Figure 3. Washing cycle in a washing machine.

completely from clothes, and the machine finishes washing of the laundry.

3. Steps for Designing Fuzzy Logic Controller

A fuzzy logic controller is a fuzzy expert system which uses linguistic variables and fuzzy sets to manipulate uncertainty in a way a human operator does. Actually, the fuzzy logic controller models the knowledge and activity of a human operation in a plant in the fuzzy rule base Abihana *et al.* [15]. In fuzzy logic controller, all the necessary parameters are defined by membership functions. In this paper, the fuzzy logic controller is used to control washing machine. Therefore, the membership functions for each of inputs, e.g., degree of soiling and quantity of detergent (powder/liquid), and output, e.g., wash time, have to be defined. In this paper, triangular membership functions have been used for each of the inputs and outputs.

To design the fuzzy logic controller for washing machine, the following steps are usually used.

Identification of variables: The first step of fuzzy logic controller design for washing machine is to identify the machine variables such as input, output and state variables of the washing machine.

Fuzzy subset configuration: The universe of information spanned by each variable is divided into a number of fuzzy subsets and each subset is assigned as a linguistic variable.

Obtaining membership function: Obtain membership function for each fuzzy subset.

Fuzzy rule base configuration: Formulate fuzzy rule base by assigning relationship between fuzzy input and output.

Normalizing and scaling factors: Appropriate scaling factors for input and output variables must be chosen to normalize variables between [0, 1].

Fuzzification: The fuzzification process is done in this step with the help of fuzzifier.

Identification of output: Identify the output from each rule using fuzzy approximate reasoning and combine the fuzzy output obtained from each rule.

Defuzzification: Initiate defuzzification process to form crisp output.

4. Fuzzy Synthetic Evaluation Model

Synthetic evaluation is a multifactor decision making method of giving an evaluation to object. Fuzzy synthetic evaluation method (FSEM) classifies data into several categories according to predetermined quality criteria which eliminates the possible fuzziness. After this FSEM synthesizes and evaluates several individual components of a process as a whole. LI Fachao *et al.* [16]

The fuzzy synthetic evaluation includes three steps:

1) Determining the factor set, the evaluation set, and the weight set;

2) Fuzzy evaluation of single factor;

3) Synthetic evaluation.

These steps of fuzzy synthetic evaluation are described below.

4.1. Determining the Factor Set, The Evaluation Set, and the Weight Set

The fuzzy synthetic evaluation model includes factor set, evaluation set, and weight set. The factor set reflects the terms that affect the object: $U=\left[u_1,u_2,\cdots,u_i\right]$. The assessment results are then categorized into some classes: $V=\left[v_1,v_2,\cdots,v_j\right]$, where v_j reflects the model condition, respectively. Considering the significant degree, the parameter is given a corresponding weight $A=\left[a_1,a_2,\cdots,a_k\right]$, where $a_I \ge 0\left(I=1,2,\cdots,k\right)$ and $\sum_{I=1}^{k} a_I = 1$. The distribution of weights is one of the most important factors that affect the assessment.

4.2. Fuzzy Evaluation of a Single Factor

For describing whether a factor belongs to a fuzzy set, a number between 0 and 1 is used to indicate the membership degree of the factor. Fuzzy evaluation is made from each factor to determine the object membership of the evaluation set. The evaluation result is expressed as:

$$R=\begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1j} \\ r_{21} & r_{22} & \cdots & r_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ r_{i1} & r_{i2} & \cdots & r_{ij} \end{pmatrix} \tag{1}$$

where r_{mn} is the membership of factor u_m to evaluation v_n. Membership function is the constitutional basis of dynamic fuzzy sets. The crucial procedure of fuzzy evaluation depends on the establishment of a realistic membership function. In the process of determining the membership function, the principles respectively take on various roles and functions, determining the effectiveness of the membership function together.

4.3. Synthetic Evaluation

The fuzzy evaluation matrix can be obtained as

$$B=A\cdot R=\begin{pmatrix} a_1 & a_2 & \cdots & a_n \end{pmatrix}\begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1j} \\ r_{21} & r_{22} & \cdots & r_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ r_{i1} & r_{i2} & \cdots & r_{ij} \end{pmatrix} \tag{2}$$

Evaluation matrix R is produced by the membership values. B is the total evaluation conclusion.

5. Analytic Hierarchy Process

Analytic hierarchy process (AHP), proposed by Saaty [17], 1980, is very popular and has been applied in wide variety of areas including planning of works, selecting a best alternative of ingredients, resource allocation and resolving conflict. AHP is a structured technique for organizing and analyzing complex decision, based on mathematics and psychology. It represents an actual approach for quantifying the weights of decision criteria. Individual expert's experiences are utilized to estimate the relative magnitudes of factors through pairwise comparisons. AHP has particular application in group decision making and is used around the world in a wide variety of decision making, in fields such as government, business, industry, healthcare, ship building and education. AHP reduces complex decisions to a series of pairwise comparisons.

5.1. Base Principle of Finding Weights Using Analytic Hierarchy Process

The base principle of finding weights using AHP can be described in steps such as;

1) Developing a model of the system
2) Deriving weights (priorities) for setting the criteria
3) Checking consistency (weights assigned correct or not) and
4) Finalizing decision

Decision making is an important function since, decision making is related to problem, an effective decision making helps to achieve the desired goals or objectives. For multi-criteria decision making AHP is popular widely of areas including planning, selection of best alternatives, resource allocation resolving conflicts. AHP method and fundamental scale were proposed by Saaty in 1980. We can choose the importance of alternatives by using values from the table of fundamental scale given in "**Table 1**".

Form a matrix according to the importance of the elements and calculate the values a, b, c, d, ..., e, f. To find normalized decision matrix, we have to find the sum of each column which divides each elements of every column. Weight can be found from adding row entries and dividing by number of criteria/elements. We can find ratio from weighted sum value. Average of ratio is needed for

Table 1. Fundamental scale (Saaty, 1980) [17].

Importance	Definition	Explanation
1	Equally important	Both elements have equal contribution in the objective.
3	Moderately important	Moderate advantage of the one element compared to the other
5	Strong important	Strong favoring of one element compared to the other.
7	Very strong and proven importance	One element is strongly favored and has domination in practice, compared to the other element.
9	Extreme importance	One element is favored in comparison with the other, based on strongly proved evidences and facts.
1.5, 1.75, 2, 4, 6, 8		Inter-values

checking consistency whether the weight we calculated is perfect.

Pairwise comparison matrix is $\begin{pmatrix} 1 & a & \cdots & b \\ c & 1 & \cdots & d \\ \vdots & \vdots & \ddots & \vdots \\ e & f & \cdots & 1 \end{pmatrix}$

Normalized decision matrix is $\begin{pmatrix} \frac{1}{x} & \frac{a}{y} & \cdots & \frac{b}{z} \\ \frac{c}{x} & \frac{1}{y} & \cdots & \frac{d}{z} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{e}{x} & \frac{f}{y} & \cdots & \frac{1}{z} \end{pmatrix}$ where

$x = \sum(1 + c + \cdots + e)$, $y = \sum(a + 1 + \cdots + f)$, $z = \sum(b + d + \cdots + 1)$

We can find average of ratio from ratio table "Table 2".

$$\text{Average of Ratios} = \frac{p + q + \cdots + r}{n} = s$$

5.2. Consistency Checking

At first we have to find consistency index.

$\text{consistency index} = \frac{s - n}{n - 1}$, $n = \text{no. of criteria}$

$$\text{consistency ratio} = \frac{\text{consistency index}}{\text{Random index}} < 0.1$$

Random index table is given in "Table 3".

6. Numerical Calculation

To determine the wash time of a domestic washing machine, assume the input as dirt on cloths and grease. Use three descriptors for input variables and five descriptors for output variable. Derive the set of rules for controller action and

Table 2. Ratio table.

				weight of criteria	weighted sum value	$\text{Ratio} = \frac{\text{weighted sum value}}{\text{weight of criteria}}$
$\frac{1}{x}$	$\frac{a}{y}$	$\cdots$	$\frac{b}{z}$	$\frac{\frac{1}{x} + \frac{a}{y} + \cdots + \frac{b}{z}}{n}$	$\frac{1}{x} + \frac{a}{y} + \cdots + \frac{b}{z}$	p
$\frac{c}{x}$	$\frac{1}{y}$	$\cdots$	$\frac{d}{z}$	$\frac{\frac{c}{x} + \frac{1}{y} + \cdots + \frac{d}{z}}{n}$	$\frac{c}{x} + \frac{1}{y} + \cdots + \frac{d}{z}$	q
$\vdots$	$\vdots$	$\vdots$	$\vdots$			$\vdots$
$\frac{e}{x}$	$\frac{f}{y}$	$\cdots$	$\frac{1}{z}$	$\frac{\frac{e}{x} + \frac{f}{y} + \cdots + \frac{1}{z}}{n}$	$\frac{e}{x} + \frac{f}{y} + \cdots + \frac{1}{z}$	r

Table 3. Random index table.

Matrix size	Random index
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

defuzzification. The design should be supported by figure wherever possible. Show that if the cloths are so load to a large degree the wash time will be more and vice versa.

6.1. Mamdani Approach in Fuzzy Control System

In Mamdani approach we have to follow these steps

1) Identify input and output variables and decide descriptor for the same
2) Define membership functions for each input and output variables
3) Form a rule base
4) Rule evaluation
5) Defuzzification

Step 1

Here inputs are dirt and grease. Assume they are in %. Output is "wash time" measured in minutes. Islam *et al.* [11]

Descriptors for input variable		Descriptor for output variable wash time
Dirt	Grease	VS-very short
SD-small dirt	NG-no grease	S-short
MD-medium dirt	MG-medium grease	M-medium
LD-Large dirt	LG-large grease	L-large
{SD, MD, LD}	{NG, MG, LG}	VL-very large
		{VS, S, M, L,VL}

Step 2

Define membership functions for each of input and output variables. Islam *et al.* [11] investigated on triangular, trapezoidal and mixed fuzzy numbers and gave decision that wash time is minimum in both triangular and trapezoidal fuzzy numbers rather than mixed fuzzy numbers. Triangular membership function works on short time period where trapezoidal membership function works on long time period. So here we use triangular membership functions. Numerical ranges for dirt and grease are collected from Islam *et al.* [11]. Membership functions for dirt and grease are

Membership functions for dirt	Membership functions for grease
$\mu_{SD}(x)=\frac{50-x}{50}, 0\le x\le 50$	$\mu_{SG}(y)=\frac{50-y}{50}, 0\le y\le 50$
$\mu_{MD}(x)=\begin{cases}\frac{x}{50}, 0\le x\le 50\\ \frac{100-x}{50}, 50\le x\le 100\end{cases}$	$\mu_{MG}(y)=\begin{cases}\frac{y}{50}, 0\le y\le 50\\ \frac{100-y}{50}, 50\le y\le 100\end{cases}$
$\mu_{LD}(x)=\frac{x-50}{50}, 50\le x\le 100$	$\mu_{LG}(y)=\frac{y-50}{50}, 50\le y\le 100$

Graphically membership function for dirt is seen in "**Figure 4**" and;

Graphically membership function for grease is seen in "**Figure 5**".

Wash time cannot be higher than 60 minutes, numerical ranges for output or wash time are collected from Islam *et al.* [11]. Membership functions for wash time are

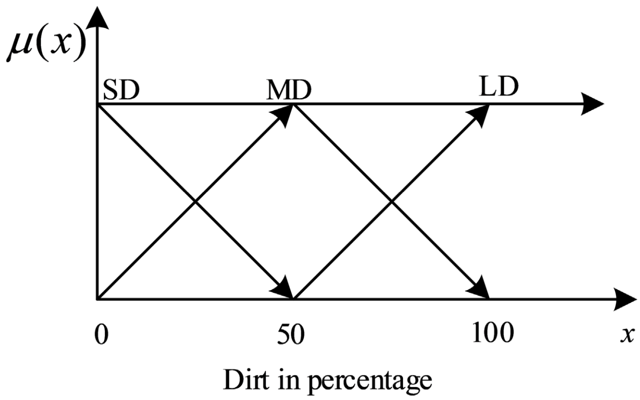

Figure 4. Dirt in percentage.

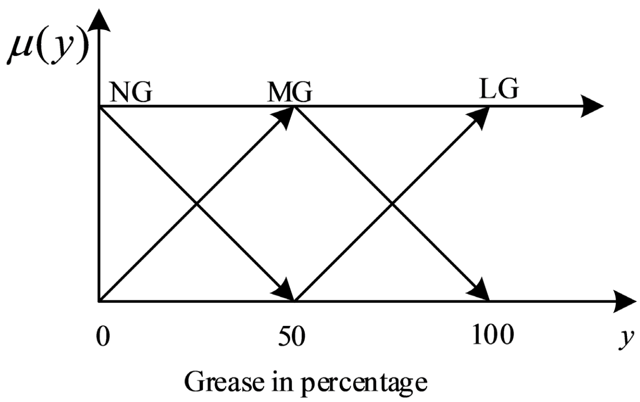

Figure 5. Grease in percentage.

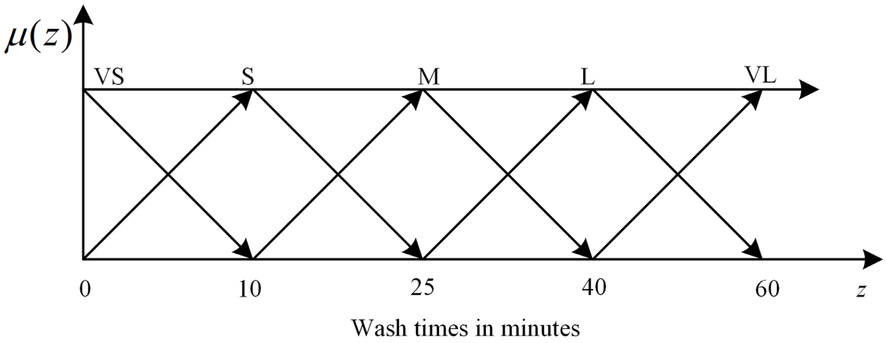

Figure 6. Wash times in minutes.

$$\mu_{VS}(z)=\frac{10-z}{10},0\le z\le 10 \qquad \mu_M(z)=\begin{cases}\frac{z-10}{15},10\le z\le 25\\ \frac{40-z}{15},25\le z\le 40\end{cases}$$

$$\mu_s(z)=\begin{cases}\frac{z}{10},0\le z\le 10\\ \frac{25-z}{15},10\le z\le 25\end{cases} \qquad \mu_L(z)=\begin{cases}\frac{z-25}{15},25\le z\le 40\\ \frac{60-z}{20},40\le z\le 60\end{cases}$$

$$\mu_{VL}(z)=\frac{z-40}{20},40\le z\le 60$$

Graphically membership function for wash time is seen in "**Figure 6**".

Step 3

Form a rule base by Islam *et al.* [11]

x	y	NG	MG	LG
SD		VS	S	M
MD		S	M	L
LD		M	L	VL

Step 4

Rule evaluation, assume dirt = 60%, grease = 70%. Dirt 60% maps two membership functions of dirt and grease 70% maps two membership functions of grease

$$\mu_{MD}(x)=\frac{100-x}{50} \qquad \mu_{MD}(60)=\frac{100-60}{50}=4/5$$

$$\mu_{LD}(x)=\frac{x-50}{50} \qquad \mu_{LD}(60)=\frac{60-50}{50}=1/5$$

$$\mu_{MG}(y)=\frac{100-y}{50} \qquad \mu_{MG}(70)=\frac{100-70}{50}=3/5$$

$$\mu_{LG}(y)=\frac{y-50}{50} \qquad \mu_{LG}(70)=\frac{70-50}{50}=2/5$$

The above four equation leads to four rules need to evaluate:

1) Dirt is medium and grease is medium

2) Dirt is medium and grease is large

3) Dirt is large and grease is medium

4) Dirt is large and grease is large

Since the antecedent part of each of the above rule is connected by and operator we use min operator to evaluate strength of each rule.

Stregth of rule 1 DMGM, $S_1 = \min\left(\mu_{MD}(60), \mu_{MG}(70)\right) = \min(4/5, 3/5) = 3/5$

Stregth of rule 2 DMGL, $S_2 = \min\left(\mu_{MD}(60), \mu_{GL}(70)\right) = \min(4/5, 2/5) = 2/5$

Stregth of rule 3 DLGM, $S_3 = \min\left(\mu_{LD}(60), \mu_{MG}(70)\right) = \min(1/5, 3/5) = 1/5$

Stregth of rule 4 DLGL, $S_4 = \min\left(\mu_{LD}(60), \mu_{LG}(70)\right) = \min(1/5, 2/5) = 1/5$

D/G	NG	MG	LG
SD	×	×	×
MD	×	3/5	2/5
LD	×	1/5	1/5

Step 5

Defuzzification

Defuzzification is the process of obtaining a single number from the output of the aggregated fuzzy set. It is used to transfer fuzzy inference results into a crisp output. Islam *et al.* [11] discussed three methods such as mean of maxima method, center of sum method and center of gravity method for defuzzification. Among the three methods mean of maxima method gives minimum wash time for both triangular fuzzy number and trapezoidal fuzzy number. So we want to use mean of maxima defuzzification technique.

Maximum strength=max (S_1, S_2, S_3, S_4) = max (3/5, 2/5, 1/5, 1/5) = 3/5, this corresponds to rule1.

Rule 1: Dirt is medium and grease is Medium has maximum strength (3/5). To find out the defuzzified value, we now take average of $\mu_M(z)$

$$\mu_M(z) = \frac{z-10}{15} \qquad \mu_M(z) = \frac{40-z}{15}$$

$$\Rightarrow \frac{3}{5} = \frac{z-10}{15} \qquad \Rightarrow \frac{3}{5} = \frac{z-10}{15}$$

$$\Rightarrow z = 19 \qquad \Rightarrow z = 31$$

The output wash time is $\frac{19+31}{2} = 25$ minutes

6.2. Fuzzy Synthetic Evaluation Method

By using Mamdani approach in FCS we get wash time 25 minutes. Now we want to apply FSEM method to find the wash time. From inputs we have to decide which components carry significant weight. By applying AHP we will get weight [17].

Saaty matrix is

	Dirt	Grease
Dirt	1	0.571
Grease	1.75	1
sum	2.75	1.571

Normalized decision matrix

	Dirt	Grease
Dirt	1/2.75 = 0.36	0.571/1.571 = 0.3635
Grease	1.75/2.75 = 0.636	1/1.571 = 0.6365
sum	2.75	1.571

For weight

	Dirt	Grease	weight
Dirt	0.36	0.3635	0.36
Grease	0.636	0.6365	0.64

Consistency Check for Weight

	Dirt	Grease	weight	weighted sum value	Ratio	
Dirt	0.36	0.3635	0.362	0.7235	1.998	$n = 1.999$ average of ratios
Grease	0.636	0.6365	0.636	1.2725	2.000	

$$\text{consistency index} = \frac{1.999 - n}{n - 1} = \frac{2 - 2}{2 - 1} = 0$$

$$\text{consistency ratio} = \frac{\text{consistency index}}{\text{Random index}} = 0 < 0.1$$

Thus the weight of dirt is 0.36 and weight of grease is 0.64. The weight matrix is $\begin{pmatrix} 0.36 & 0.64 \end{pmatrix}$ Evaluation matrix is $\begin{pmatrix} 4/5 & 1/5 \\ 3/5 & 2/5 \end{pmatrix}$. From the Matrix multiplication of 1 × 2 weight matrix and 2 × 2 evaluation matrix we get the 1 × 2 fuzzy evaluation matrix $\begin{pmatrix} 0.672 & 0.328 \end{pmatrix}$

$$\begin{pmatrix} 0.36 & 0.64 \end{pmatrix} \begin{pmatrix} 4/5 & 1/5 \\ 3/5 & 2/5 \end{pmatrix} = \begin{pmatrix} 0.672 & 0.328 \end{pmatrix}$$

Here we use "mean of Max" defuzzification technique $\text{Max}\begin{pmatrix} 0.67 & 0.33 \end{pmatrix} = 0.67$. To find out the defuzzified value, we now take average of $\mu_M(z)$

$$\begin{aligned} 0.67 &= \frac{z-10}{15} & 0.67 &= \frac{40-z}{15} \\ &\Rightarrow z - 10 = 10.05 & &\Rightarrow 40 - z = 10.05 \\ &\Rightarrow z = 20.05 & &\Rightarrow z = 29.5 \end{aligned}$$

The output wash time is $\frac{20.05+29.5}{2} = 24.775$ minutes.

6.3. Comparison between Mamdani Approach and Fuzzy Synthetic Evaluation Method

By using statistical averaging method wash time can be reduced in both Mamdani approach and FSEM. The table compared between Mamdani approach and FSEM is given in "Table 4".

Wash time in Mamdani approach and FSEM is given "Figure 7".

6.4. Statistical Averaging Method for Mamdani Approach

By applying the statistical averaging method we can reduce the wash time in Mamdani approach. Geometric mean gives less wash time than arithmetic mean and harmonic mean gives less wash time than geometric mean.

$$\text{Arithmetic mean} = \frac{19+31}{2} = 25 \text{ minutes}$$

$$\text{Geometric mean} = \sqrt{19 \times 31} = \sqrt{589} = 24.269 \text{ minutes}$$

$$\text{Harmonic mean} = \frac{2}{\frac{1}{19}+\frac{1}{31}} = \frac{2}{0.0526+0.0322} = \frac{2}{0.0848} = 23.584 \text{ minutes}$$

Wash time in Mamdani approach by using statistical averaging method is given in "Table 5".

Wash time in Mamdani approach by using statistical averaging method is given in "Figure 8".

Table 4. Comparison table between Mamdani approach and FSEM.

wash time in Mamdani approach (minutes)	wash time in FSE method (minutes)
25	24.775

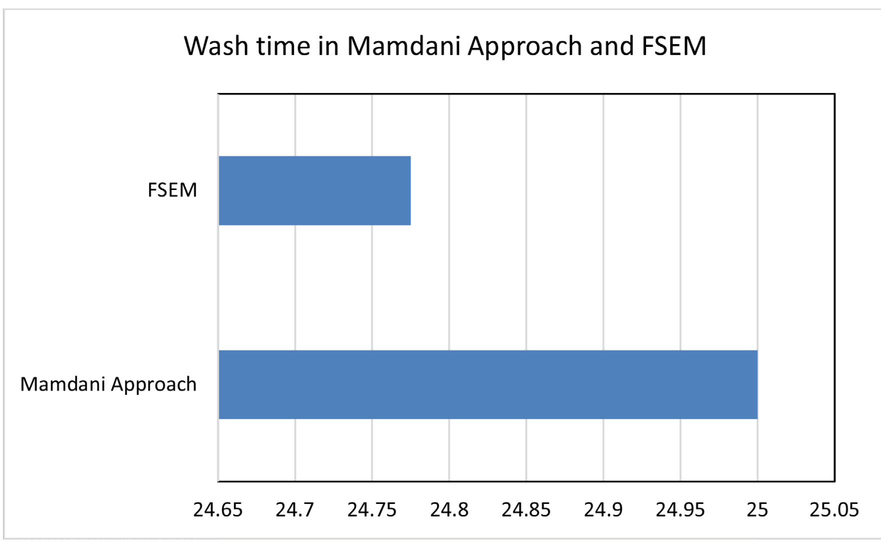

Figure 7. Wash time in Mamdani Approach and FSEM.

6.5. Statistical Averaging Method for FSEM

FSEM gives minimum wash time than Mamdani approach. We can reduce wash time again by applying statistical averaging method such as arithmetic mean, geometric mean and harmonic mean. Harmonic mean gives minimum wash time.

$$\text{Arithmetic mean} = \frac{20.05 + 29.5}{2} = 24.775 \text{ minutes}$$

$$\text{Geometric mean} = \sqrt{20.05 \times 29.5} = \sqrt{591.475} = 24.320 \text{ minutes}$$

$$\text{Harmonic mean} = \frac{2}{\frac{1}{20.05} + \frac{1}{29.5}} = \frac{2}{0.04987 + 0.03389}$$

$$= \frac{2}{0.08376} = 23.8777 \text{ minutes}$$

Wash time in FSEM by using statistical averaging method is given in "**Table 6**".

Wash time in FSEM by using statistical averaging method is given in "**Figure 9**".

7. Conclusion

In this paper, FSEM has been proposed for finding wash time in washing machine.

Table 5. Wash time in Mamdani approach and statistical averaging method.

wash time in Mamdani approach (minutes)	wash time in statistical averaging method (minutes)		
	Arithmetic mean	Geometric mean	Harmonic mean
25	25	24.269	23.584

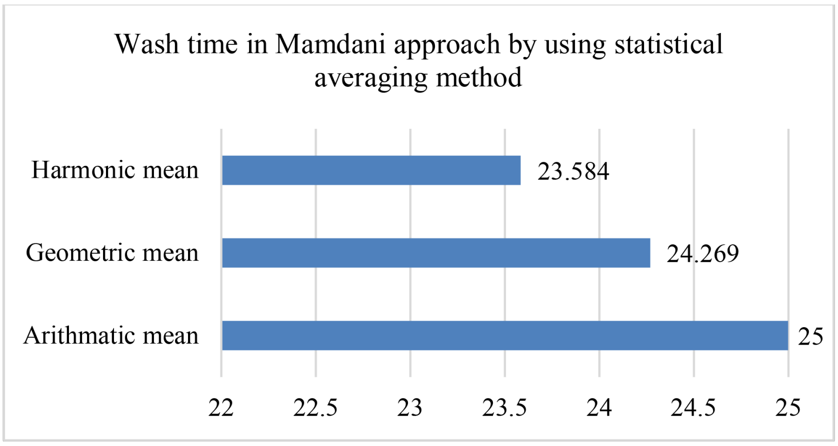

Figure 8. Wash time in Mamdani approach by using statistical averaging method.

Table 6. Wash time in FSEM and statistical averaging method.

wash time in FSE method (minutes)	wash time in statistical averaging method (minutes)		
	Arithmetic mean	Geometric mean	Harmonic mean
24.775	24.775	24.320	23.8777

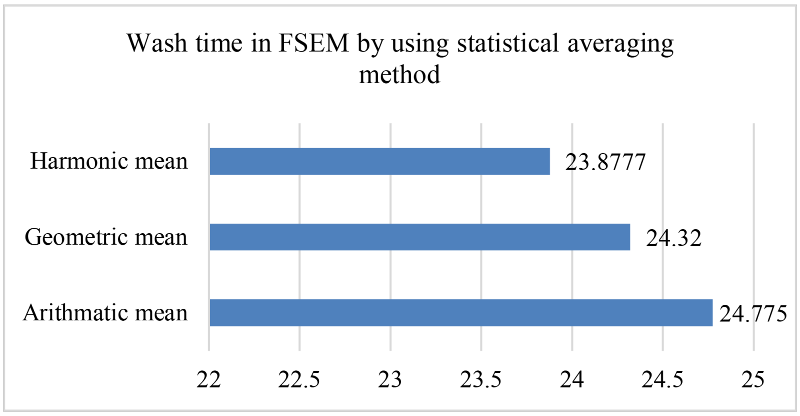

Figure 9. Wash time in FSEM by using statistical averaging method.

FSEM is compared to the Mamdani approach. FSEM gives less wash time than Mamdani approach. To further reduce the wash time, statistical averaging method is also applied to both Mamdani approach and FSEM. Decision makers for the washing machine can use statistical averaging method to reduce more time which can minimize the cost significantly.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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