DECISION MAKING SYSTEM IN TANNERY BY USING FUZZY LOGIC

By

MISS Umaphorn TAN

A Thesis Submitted in Partial Fulfillment of the Requirements

for Master of Engineering (ENGINEERING MANAGEMENT)

Department of INDUSTRIAL ENGINEERING AND MANAGEMENT

Graduate School, Silpakorn University

Academic Year 2019

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MISS UMAPHORN TAN : DECISION MAKING SYSTEM IN TANNERY BY USING FUZZY LOGIC THESIS ADVISOR : DOCTOR KANATE PANSAWAT

The aim of this study is to apply a decision support system in the leather industry. According to the unstable quality of raw materials and complicated processes, leather production needs a precise decision from skilled and experienced expert. The decision-making system is needed when the expert is unavailable to prevent producing waste from a wrong decision. Fuzzy logic is a promising method to apply in such a complicated process. In this work focus only wet-end process starting from material selection through drying processes. Defects on the skins, colour from the dyeing process and humidity of the leather are defined as the inputs. The Mamdani max-min in fuzzy inference system is used to operate to get fuzzy output. Maxima method is applied for the defuzzification step to receive the final result. Microsoft Excel is used to perform the membership function graph and operating the inference system in order to achieve the results. Nine case studies are used to test the developed model. The results are shown that the developed model is practical with wet – end process in tannery

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CHAPTER I

INTRODUCTION

1.1. Motivation

High quality finished leather is a key raw material for leather shoes, leather bags and all leather products. Leather production starts from selecting tanned skins called wet - blue that supply from outsource. The selected wet – blue send to retanning, crusting and finishing process to be finished leather. The problems happen all the time during the process due to unstable materials. One of the most common problems is the leather quality does not acceptable as the standard. Only experienced and skilled experts who have the knowledge are in charge to provide their opinions and make the decision to solve the problems.

Therefore, the decision support system is needed to design the process when the experts are unavailable. Fuzzy logic system is the promising way to solve this problem. Due to fuzzy logic system is a system that designed to solve complex problems by using the knowledge base from human experiences to make the decisions. The system has more accuracy repeatability than human. This could help to reduce waste in process that come from unexperienced workers and improve to control the quality of the leather.

In this work, fuzzy logic system is used to develop model to support the decision making of leather making process in tannery. Focus only in wet – end section, the process starts from selecting material to drying process. The developed model will implement by using Microsoft Excel that commonly use in the company. The program is not only simple to use but also has the functions that can perform the complex model.

1.2. Objective of Research

To apply fuzzy logic system to leather making process in quality checking by Microsoft Excel.

1.3. Hypothesis

Leather making process can be design by using fuzzy logic system.

1.4. Scope of Research

Fuzzy logic system will be applied in leather making process focus only in wet-end section. Seven inputs including defects, colour, humidity and quality acceptance as an output are constructed from skilled expert. The developed model will validate by nine case studies.

1.5. Contribution of Research

Apply developed model to leather making process focus on wet-end section.

CHAPTER II

LITERATURE REVIEWS

In this chapter includes literature reviews with the research. The chapter is divided into two parts: the fuzzy logic system and the fuzzy logic with the application.

2.1. Fuzzy logic system

The first idea of fuzzy logic was invented by Professor L. A. Zadeh in 1965. The mathematical theory of fuzzy set is a generalization of the classical set theory by introducing the degree in the condition to be in other state more than only true or false. The following terms were used to implement in fuzzy logic system.

2.1.1. Classical set and Fuzzy set

The fuzzy set is a fundamentally broader set compared with the classical or crisp set. The classical set only considers a limited number of degrees of membership such as '0' or '1'. The fuzzy set considers an infinite number of degrees of membership between 0 and 1.

2.1.2. Membership function

A membership function is used to quantify a linguistic value. Membership function for one input can belong to multiple different types at the same time with different degree of memberships. The shape of membership function depends on the actual applications according to the user experience such as triangular, trapezoidal, piecewise linear, Gaussian, or singleton as shown in figure 1.

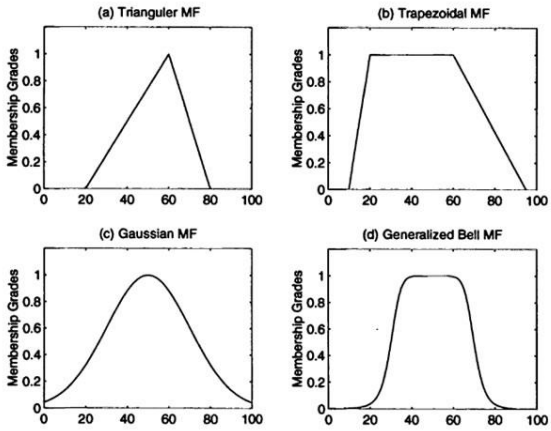


Figure 1 Different types of membership function

(Credit: Fuzzy logic membership function. Accessed March 20,2017. Available from http://researchhubs.com/post/engineering/fuzzy-system/fuzzy-membership-function.htm)

2.1.3. Fuzzy set operations

A fuzzy set operation is an operation on fuzzy sets when there is more than one fuzzy data. There are three operations: fuzzy unions, fuzzy intersections, and fuzzy complements, which corresponding to and, or and not operators for classical set. In fuzzy set, we will use max, min and complement as the operators.

2.1.4. Fuzzy rule/ If-Then rule

Fuzzy rule is constructed to control the output variable. A fuzzy rule is a simple if-then rule with a condition and a conclusion to specify a relationship between the fuzzy input and fuzzy output.

To implement fuzzy logic system to a real process or to solve an actual problem needs three following steps Fuzzification, fuzzy inference and defuzzification as shown in figure 2.

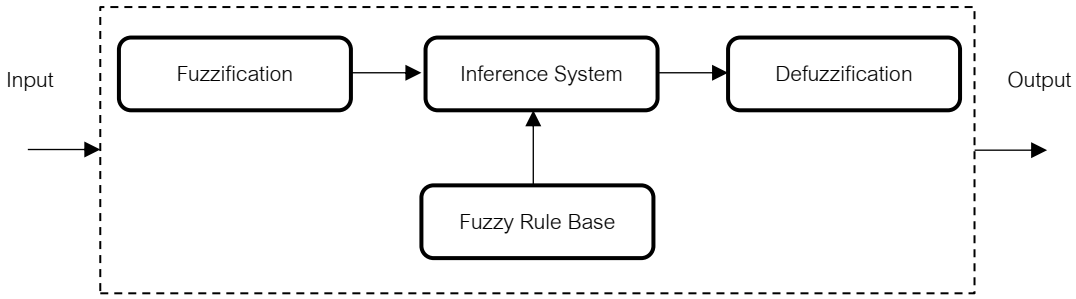


Figure 2 Fuzzy logic system diagram

2.1.5. Fuzzification

Fuzzification is the first step to convert the crisp variables to fuzzy variables by define membership function from input.

2.1.6. Inference system

The fuzzy output sets turn out after using if–then rules that specify a relationship between the fuzzy input and fuzzy output.

2.1.7. Defuzzification

Defuzzification is the step to defuzzify the fuzzy output back to real value.

2.2. Fuzzy logic with the applications

Fuzzy logic implementations have been presented over a hundred year in many different fields. In table 1, the conclusions of some research using fuzzy logic in different way to achieve their purpose are explained as following.

Comparison of Mamdani-Type and Sugeno-Type Fuzzy Inference Systems for Air Conditioning System. Fuzzy inference systems are developed for air conditioning system using Mamdani-type and Sugeno-type fuzzy models. This research presents the comparison of the two fuzzy inference systems (FIS). This paper outlines the basic difference between the Mamdani-type FIS and Sugeno-type FIS. The results also show that which FIS is a better choice for air conditioning system [1].

An expert system for selection wart treatment method. The purpose of this paper is to identify the appropriate treatment for two common types of warts (plantar and common) and to predict the responses of two of the best methods (immunotherapy and cryotherapy) to the treatment by using fuzzy logic rule-based system. The selection of the treatment method was made randomly for 180 patients [2].

A fuzzy logic application for selecting layered manufacturing techniques. This paper is used fuzzy logic to select the best rapid prototyping technique for producing prototypes. The appropriateness of each rapid prototyping technique was translated by fuzzy if- then rules and fuzzy set to each evaluation criterion of the project. The ‘‘Max–Min set’’ method is applied to identify the best rapid proto-typing technique with the highest overall efficiency[3].

Identification of Leather Surface Defects using Fuzzy Logic. This work presents the investigation of an application of fuzzy logic for leather surface defects identification. The objective is to classify the elements and to detect the defective ones by applying a fuzzy logic technique as the application of different rule bases and different numbers of output linguistic terms are investigated [4].

Leather Features Selection for Defects Recognition using Fuzzy Logic. In this work presents 12 investigated histogram and statistical features for analysis of leather surface images. A research of the features suitability for surface defects detection is completed. The quadtree decomposition method was used in the image analysis for partitions an image into homogeneous blocks. This method gave the possibility of investigation the changes of the feature values depending on the area size. It is proposed a scheme for defective regions identification using fuzzy set theory [5].

Assessing the visual quality of sanitary ware by fuzzy logic. This paper presents the significance of visual inspection and assessment of visual quality of industrial products and provide the visual quality assessment of vitreous china ceramic sanitary wares

application by using fuzzy logic method. To improve quality control system, focus on maintaining standards in manufactured products by final users and to detect manufacturing defaults [6].

The use of fuzzy logic in predicting house selling price. Fuzzy logic system was used to develop new grading model to predict the selling price of house-building. The city plans, the nearness to cultural, medical, training and educational buildings, the public transportations systems, the other environmental factors and the increased technological upgrading deals with information about construction, have been considered as the inputs and used to construct the model [7].

Defuzzication: criteria and classification. This paper presents the theory and development of defuzzification techniques by define the core of a fuzzy set and formulate a set of criteria for defuzzification. The most widely used defuzzification techniques were classified into different groups. The prototypes of each group with respect to the defuzzification criteria were examined. The results show that the maxima methods are good with the more basic defuzzification criteria and good candidates for fuzzy reasoning systems. On the other hand, the distribution methods and the area methods are suitable for fuzzy controllers [8].

Prediction of ocean wave energy from meteorological variables by fuzzy logic modeling. The aim of this research is to study the relationship between ocean wave energy and meteorological variables such as wind speed, air temperature, and sea temperature. The relationship between ocean wave energy and meteorological is used in fuzzy logic as the input. The model provides the possible non-linear relationship and consequently the wave energy can be predicted including the possible uncertainties in the system behavior. Takagi – Sugeno (TS) type fuzzy inference system was employed to predict wave energy amount [9].

Fuzzy logic tool for wine quality classification. In this research, fuzzy logic is used to develop a simple in use and reliable tool to classify wine quality based on selected grape attributes. The conditions of berry (total soluble solids, berry volume, grape seed colorization, etc.) were measured at harvest and used as inputs in the tool. The raking of the vineyards, according to the tasting panel, was compared to the raking made by the tool and the results showed high general agreement [10].

Integration of fuzzy logic and computer vision in intelligent quality control of celiac-friendly products. In the present paper, the fuzzy logic and image processing is employed to indicate the optimum formulation of compounds. A sensory evaluation was carried out on one of the main quality attributes as taste and was combined with two others as appearance and texture acquired by computer vision to determine the acceptable level of ingredients of a gluten-free cake (GFC). Analysis of samples using the aforementioned method indicated that acceptable levels of 50% purslane flour (PF) and 1% quince seed gum (QSG). Sensory evaluation indicated that the quality attributes can be ranked in a descending order as texture, taste and color [11].

Approach to prediction of laser cutting quality by employing fuzzy expert system. In this study presents the prediction of the effect of carbon dioxide (CO2) laser cutting quality based on laser cutting parameters onto 1 mm thickness of Incoloy_ alloy 800 was develop by using fuzzy logic model. The predicting fuzzy logic model is implemented on Fuzzy Logic Toolbox of MATLAB using Mamdani technique. A set of training and testing consists of 125 data used in the fuzzy logic model are arranged in a format of three input parameters and two output parameters. The relationships between experimental results, fuzzy logic model and statistical results for both training and testing performance exhibited a good correlation [12].

A fuzzy inference system with application to player selection and team formation in multi-player sports. This research presents a soccer player selection and team formation. The study has divided in two-phase framework. The first phase evaluates the alternative

players with a fuzzy ranking method and selects the top performers for inclusion in the team. The second phase evaluates the alternative combinations of the selected players with a Fuzzy Inference System (FIS) and selects the best combinations for team formation[13].

A fuzzy quality control-decision support system for improving operational reliability of liquid transfer operations in laboratory automation. This paper describes an overall quality metric and failure mode using fuzzy logic as a decision support tool. The work is done by adding real-time quality control capability in liquid transfer operations on a closed-loop controlled MEMS based liquid transfer device. Real-time data acquisition enables the interpretation of system variables. Detection of ordinary fault conditions activate automatic recovery actions without human intervention, leading to 24/7 utilization of an automated laboratory system. Exported quality data can be used for bio-informatics data analysis as well as documentation for regulatory agencies [14].

A fuzzy-logic based decision-making approach for identification of groundwater quality based on groundwater quality indices. In the present study, a Mamdani fuzzy logic was developed to assess groundwater quality based on relevant indices. The proposed approach was evaluated for its ability to assess the drinking water quality of 49 samples collected seasonally from groundwater resources in Iran's Sarab Plain during 2013 - 2014. The developed models' accuracy was assessed, and a comparison of the performance indices demonstrated the Fuzzy Groundwater Quality Index model to be more accurate than both the Fuzzy Water Quality Index and Fuzzy Ground Water Quality Index models [15].

Fuzzy sets. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function which assigns to each object a grade of membership ranging between zero and one. The notions of inclusion, union, intersection, complement, relation, convexity, etc., are extended to such sets, and various properties of these notions in the context of fuzzy sets are established. In particular, a separation theorem for convex fuzzy sets is proved without requiring that the fuzzy sets be disjoint [16].

Table 1 Conclusion of literature review

Authors	Purpose	Method/tools
Kaur & Kaur, 2012, Comparison of Mamdani-Type and Sugeno-Type Fuzzy Inference Systems for Air Conditioning System	To develop the model for air conditioning system using Mamdani-type and Sugeno-type fuzzy models and compare the results from Mamdani-type and Sugeno-type fuzzy models	Mamdani-type and Sugeno-type fuzzy models
Khozeimeh et al., 2017, An expert system for selection wart treatment method	To identify the appropriate treatment for two common types of warts (plantar and common) and to predict the responses of two of the best methods (immunotherapy and cryotherapy) to the treatment	Fuzzy logic rule-based system

Table 1 Conclusion of literature review (Continued)

Authors	Purpose	Method/tools
Khrais, Al-Hawari, & Al-Araidah, 2011, A fuzzy logic application for selecting layered manufacturing techniques	Using fuzzy logic to select the best rapid prototyping technique for producing prototypes.	The ‘‘Max–Min set’’ method is applied to obtain the efficiencies.
Krastev & Georgieva, 2005, Identification of Leather Surface Defects using Fuzzy Logic	To classify the elements and to detect the defective leather surface defects identification.	Image segmentation and fuzzy-based system for defects identification.
Krastev, Georgieva, & Angelov, 2004, Leather Features Selection for Defects Recognition using Fuzzy Logic	To investigate histogram and statistical features for analysis of leather surface images.	The quadtree decomposition method for partitions an image into homogeneous blocks.

Table 1 Conclusion of literature review (Continued)

Authors	Purpose	Method/tools
Kumru, 2013, Assessing the visual quality of sanitary ware by fuzzy logic	To improve quality control system, focus on maintaining standards in manufactured products by final users and to detect manufacturing defaults	Mamdani inference system and center of gravity (COG) as the defuzzification method
Kuşan, Aytekin, & Özdemir, 2010, The use of fuzzy logic in predicting house selling price	To develop new grading model to predict the selling price of house-building.	a questionnaire application has been applied to determine the values of fuzzy training and testing sets
(eekwijck & Kerre, 1999, Defuzzication: criteria and classication	Presents the theory and development of defuzzification techniques	
Özger, 2011, Prediction of ocean wave energy from meteorological variables by fuzzy logic	To investigate the relationship between ocean wave energy and meteorological variables such as wind speed, air temperature, and sea temperature	Multiple inputs to a single output in a non-linear relationship. Takagi–Sugeno (TS) type fuzzy inference system was employed to predict wave energy amount from meteorological variables.

Table 1 Conclusion of literature review (Continued)

Authors	Purpose	Method/tools
Petropoulos et al., 2017, Fuzzy logic tool for wine quality classification	The development of a simple in use and reliable tool to objectively classify wine quality based on selected grape attributes.	Fuzzy logic multi criteria decision making.
Rezagholi & Hesarinejad, 2017, Integration of fuzzy logic and computer vision in intelligent quality control of celiac-friendly products	A sensory evaluation was carried out on one of the main quality attributes as taste and was combined with two others as appearance and texture acquired by computer vision to determine the acceptable level of ingredients of a gluten-free cake (GFC).	the fuzzy logic and image processing is employed to indicate the optimum formulation of compounds. Analysis of samples using the aforementioned method indicated
Syn, Mokhtar, Chin, & Manurung, 2011, Approach to prediction of laser cutting quality by employing fuzzy expert system	the prediction of the effect of carbon dioxide (CO2) laser cutting quality based on laser cutting parameters onto 1 mm thickness of Incoloy_ alloy 800 was develop by using fuzzy logic model	The predicting fuzzy logic model is implemented on Fuzzy Logic Toolbox of MATLAB using Mamdani technique.

Table 1 Conclusion of literature review (Continued)

Authors	Purpose	Method/tools
Tavana 2013, A fuzzy inference system with application to player selection and team formation in multi-player sports	To develop the tools for soccer player selection and team formation	Mamdani's inference system was used to convert the fuzzy outputs into crisp Output values through a defuzzification process.
Unver & Wendel, 2009, A fuzzy quality control-decision support system for improving operational reliability of liquid transfer operations in laboratory automation	This paper describes an overall quality metric and failure mode using fuzzy logic as a decision support tool.	Add real - time quality control capability in liquid transfer operations on a closed-loop controlled MEMS based liquid transfer device

Table 1 Conclusion of literature review (Continued)

Authors	Purpose	Method/tools
Vadiati, Asghari Moghaddam, Nakhaei, Adamowski, & Akbarzadeh, 2016, A fuzzy-logic based decision-making approach for identification of groundwater quality based on groundwater quality indices	The evaluation for its ability to assess the drinking water quality	a Mamdani fuzzy logic was developed to assess groundwater quality based on relevant indices.
Zadeh 1965, ***Fuzzy sets***	Present the theory and definitions of fuzzy sets.	

CHAPTER III

METHODOLOGY

In this chapter, we will describe how to apply fuzzy logic system to a case study. The method has shown in figure 3.

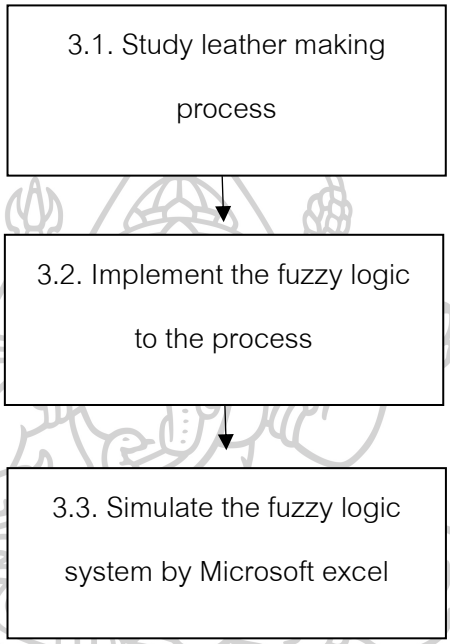


Figure 3 Methodology of research

3.1. Study leather making process

Leather making process has main four steps to describe the whole process as shown in figure 4. In this study, we will focus only three sections; wet blue, retanning and crusting which are also known as wet-end process.

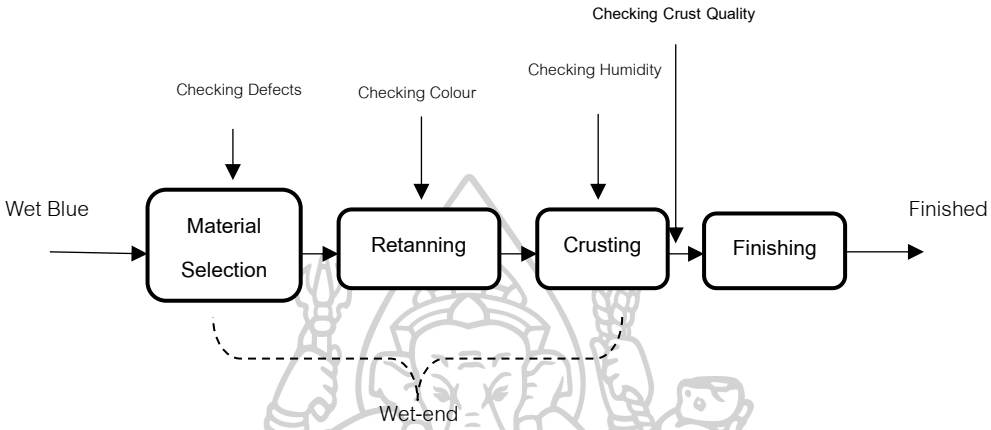


Figure 4 Overall process

3.1.1. Material selection

Wet blue as shown in figure 5 is chrome-tanned wet skin. The raw material is many different types of animal skin such as cow, yak and camel.

Figure 5 Material selection

(Credit: Thomas Stege Bojer. Everything you need to know about how leather is made. Accessed July 21,2019. Available from https://www.denimhunters.com/how-leather-is-made-red-wing-heritage/)

For some products, the customers require high grade of leather to make their product. Wet – blue with defects are considered as the low grade and price. Therefore, we must select wet – blue quality as agree with the customers. For the selection, we consider the defects in table 2.

Table 2 Types of defect

Types of defect	Description
Opened defect Sometimes the animals get their hides caught in barbed wire. This results in a tear in the hide.	
Closed defect These are the result of the animal being scratched in one way or another.	
Brand Mark This will be found on almost every hide. This could be a letter, number or shape and is seen as a natural mark.	
Growth mark Growth mark appear in the neck areas of the hide. They will appear as textured lines in the smooth hide because of their heavy grained effect.	

Table 2 Types of defect (continued)

Types of defect	Description
Vein Vein marks are more evident from older animals and reflective of their climate. In cold weather, veins are smaller. Alternatively, the veins are larger in warmer conditions.	

3.1.2. Retanning

The retanning process (figure 6) is carried out in drums, seeks to minimise this by the introduction of filling materials. Chemicals and dyestuffs are used in retanning process to give the characteristics and colour into the leather structure.

Figure 6 Retaning drums

(Credit: Leather dictionary. Tanning leather. Accessed July 21, 2019. Available from https://www.leather-dictionary.com/index.php/Tanning_leather)

3.1.3. Crusting

After retanning process, the leathers are dried and prepared for the subsequent finishing process. Crusting processes (figure 7) are mostly performed under the action of heat. For efficiency reasons, the drying conditions should be adjusted to the respective tanning method.

Figure 7 Crusting process

(Credit: Leather dictionary. Tanning leather. Accessed July 21, 2019. Available from https://www.leather-dictionary.com/index.php/Tanning_leather)

In this section, we will focus on staking process, staking machine as shown in figure 8, can adjust the level to get the different softness. Humidity after drying process is the key factor to adjust the staking level.

Figure 8 Staking machine

(Credit: Leather dictionary. Tanning leather. Accessed July 21, 2019. Available from https://www.leather-dictionary.com/index.php/Tanning_leather)

3.1.4. Finishing

The final stage of leather production is reached with the finishing process (figure 9). This process has the purpose of making the leather usable and suitable for the manufacture of end products.

Figure 9 Finishing process

(Credit: Leather dictionary. Tanning leather. Accessed July 21, 2019. Available from https://www.leather-dictionary.com/index.php/Tanning_leather)

3.2. Implement the fuzzy logic to the process

To implement fuzzy logic inference to the application the following steps in table 3 are required.

Table 3 Fuzzy logic algorithm

Fuzzy logic system	Algorithm
Fuzzification	1. Define inputs 2. Construct the membership functions 3. Convert crisp input data to fuzzy values using the membership functions
Inference System	4. Construct the rule base 5. Evaluate the rules in the rule base 6. Combine the results of each rule
Defuzzification	7. Convert the fuzzy output data to non-fuzzy values

The overall fuzzy inference system process is shown in figure 10. Starting from fuzzification;

3.2.1. Define the inputs.

3.2.2. Construct the memberships.

3.2.3. Convert crisp input data to fuzzy values using the membership functions.

The eleven rule bases as shown in figure 10 will be explained in 3.2.4.

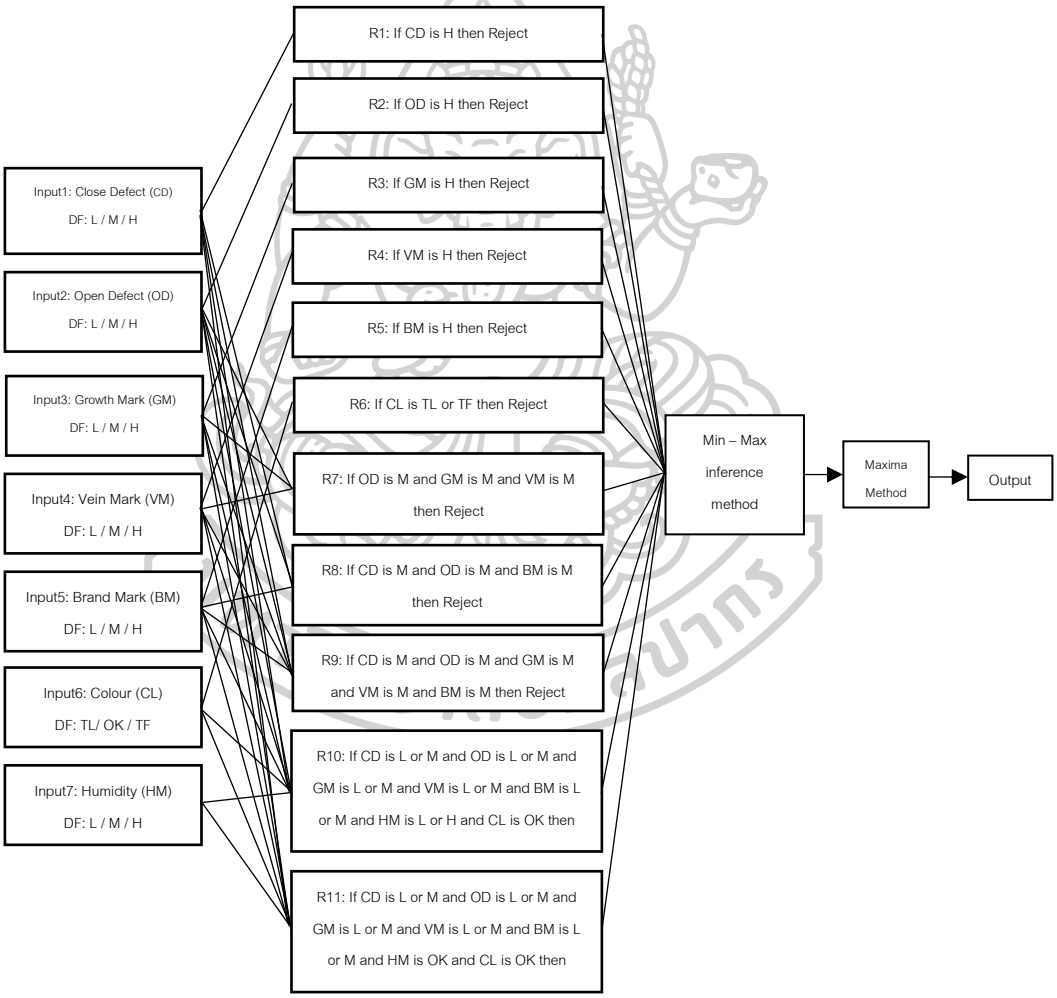


Figure 10 Overall fuzzy Inference system for wet – end process

We define material selection, crust colour, and humidity as the inputs. The shapes of the membership function are usually chosen based on several studies or by the experts. The triangular and trapezoidal shape are the most commonly used.

Triangular curves depend on three parameters and are given by following equation;

$$f(x;a,b,c) = \begin{cases} 0 \quad for\ x < a \\ \dfrac{x-a}{b-a}\ for\ a \le x \le b \\ \dfrac{c-x}{c-b}\ for\ b \le x < c \\ 0\ for\ c > x \end{cases}$$

Trapezoidal curves depend on four parameters and are given by following equation;

$$f(x;a,b,c,d) = \begin{cases} 0 \quad for\ x < a \\ \dfrac{x-a}{b-a}\ for\ a \le x \le b \\ 1 \quad for\ b \le x \le c \\ \dfrac{d-x}{d-c}\ for\ c \le x < d \\ 0\ for\ d \le x \end{cases}$$

3.2.3.1. Material selection.

Suppliers send the wet blue to factory per standard grade that the factory required. The example standard selected wet blue on premium grade are shown in table 4.

Table 4 The standard selected wet blue on premium grade

Type of defects	Allowed defects per hide
1. Close defect	34 blocks
2. Open defect	6 blocks/ maximum 3 blocks per side
3. Growth mark	30 percent
4. Vein mark	30 percent
5. Brand mark	3 brand marks

According to the standard grading on table 4, close defects should not be over than 34 blocks per hide for premium grade. The amounts of defects can be further divided into three sets and turn into linguistic labels, which are 0 to 5 blocks for “Low” in defects, 6 to 10 blocks are “Medium” in defects and more than 11 blocks are defined as “High” in defects. The membership functions of these defects are shown below in figure 11.

Figure 11 The membership functions of close defects that allowed for premium grade in a hide

For open defect, the defects should not be over than 6 blocks per hide or in the other word open defect should be over than 3 blocks per side. The number of defects can be divided into 3 ranges: 0 to 1 belong to “Low” in amount of defect, 2 to 3 belong to “Medium” and more than 4 belong to “High”. The degrees of membership functions are shown in figure 12.

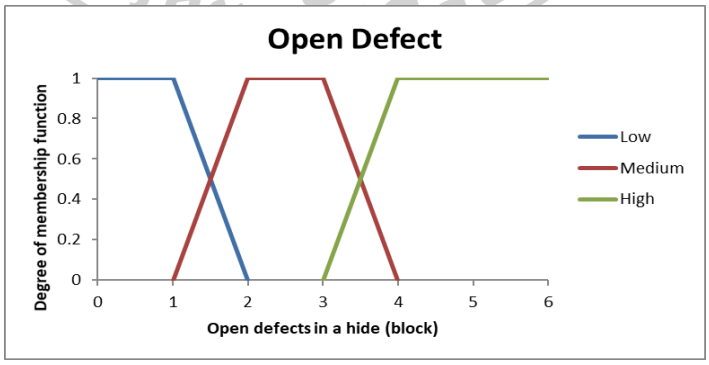


Figure 12 The membership functions of open defects that allowed for premium grade in a hide

For growth mark, the defect should not be over than 30 percent per hide which divided into three sets: 0 to 10 percent belong to “Low” in defect, 11 to 15 belong to “Medium” in defect and more than 16 belong to “High” in defect as shown in figure 13.

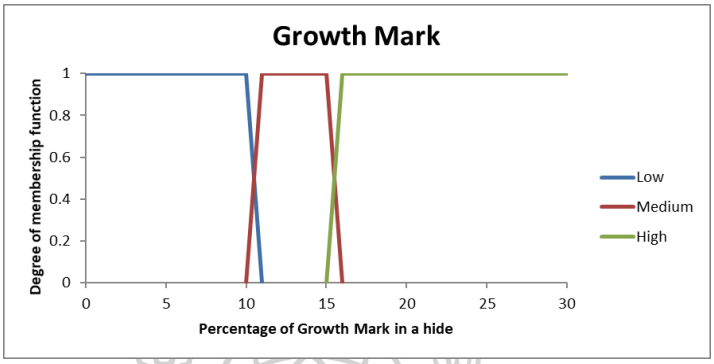


Figure 13 The membership functions of growth marks that allowed for premium grade in a hide

Vein mark should not be over than 30 percent per hide on premium grade. This amount can be divided into three sets like the others, from 0 to 10 percent belong to “Low” amount of defect, 11 to 15 percent belong to “Medium” amount of defect. If vein marks are more than 16 percent, the defects belong to “High” as shown in figure 14.

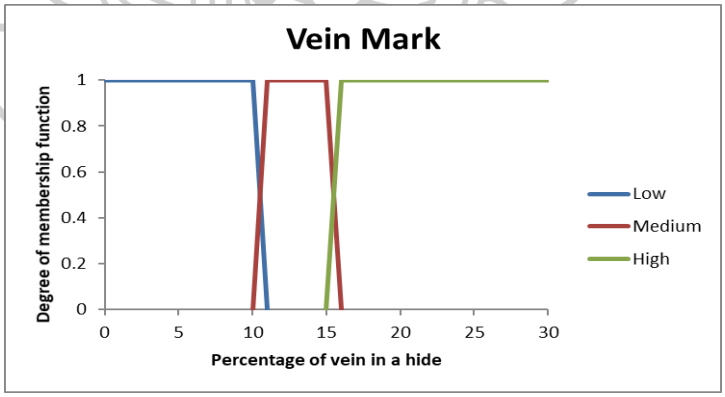


Figure 14 The membership functions of vein that allowed for premium grade in a hide

Likewise, the amount of brand mark on a hide should not be over than 3 marks for p grade of material. This amount of defect can be divided to 3 sets: from 0 to 1 brand mark belongs to “Low”, 2 brand marks belong to “Medium” and more than 3 marks belong to “High” as we can see in figure 15. below;

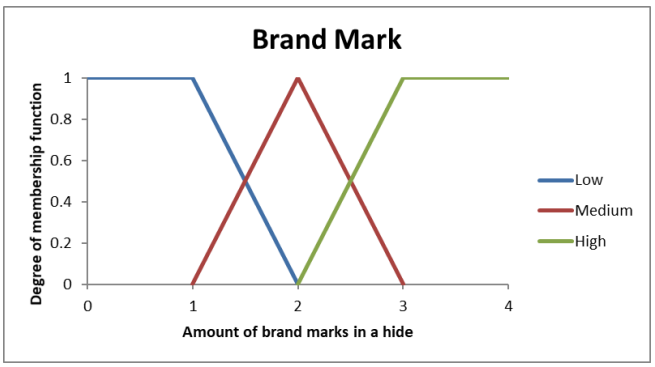


Figure 15 The membership functions of brand marks that allowed for premium grade in a hide

3.2.3.2. Humidity at staking machine

The humidity after drying process is the key to adjust the staking machine. The humidity ranges for standard are shown in table 5.

Table 5 The standard staking level based on humidity

Comments	Humidity in percentage
Low	Less than 12 percent
OK	Between 12 to 14 percent
High	More than 14 percent

From these rules, we define the percentage of the humidity after drying process as the input for this stage. The membership functions on staking process are shown in figure 16. If the humidity of the crust leather is less than 12 percent, the input value will belong to “Low”, 12 to 14 percent belong to “OK” and more than 14 percent belong to “High” humidity. After staking process, crust leather will softer and flatter.

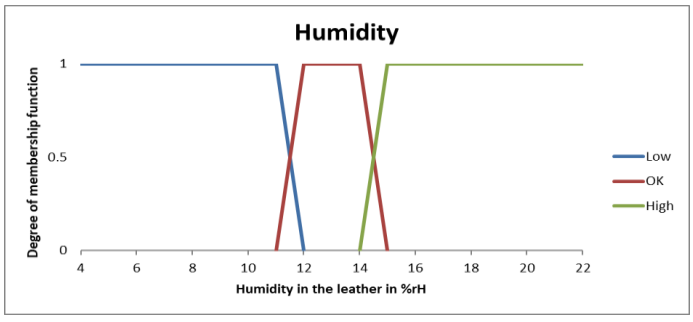


Figure 16 The membership functions of humidity in percentage

3.2.3.3. Crust colour

We will focus on the result of crust colours. The final colour will be receive from customers. The retanning team will design the combination of dye stuff to put in the drum. After drying, we will compare the crust to the master colour. The standard colour compared to master colour in percentage has shown in the table 6.

Table 6 The standard colour compared to master colour in percentage

Comments	How close/far the colour to the master in percentage
Too light	Less than 50 percent
OK	Between 60 to 70 percent
Too full	More than 80 percent

From these rules, we define the percentage of the crust colour after drying process as the input for this stage. These inputs can divide into three sets: less than 50 percent compare to final colour belong to “Too light”, between 60 to 70 percent belong to “OK” and more than 80 percent belong to “Too Full” for crust colour. The membership functions of crust colour are shown in figure 17.

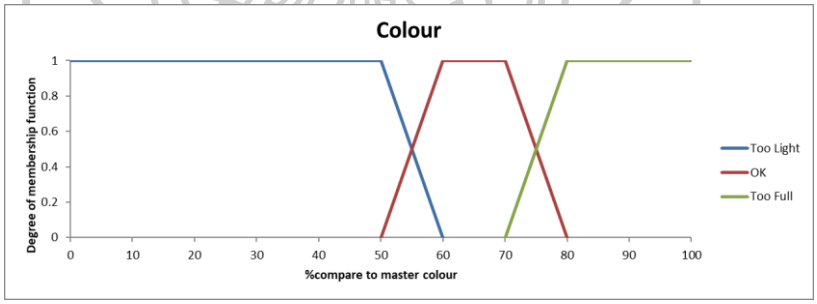


Figure 17 The membership functions of crust colour in percentage compared to the master colour

After wet-end process, the experts from wet-end section and finishing section will discuss if the crust is acceptable per the standard or not. The material selection, crust colour and the softness are used as final input to consider the crust to further section. The

quality acceptable of material selection, crust colour and the softness are considered in percentage, providing the membership functions for fuzzy output.

As shown in figure 18, the quality of the crust leather has divided into three ranges: less than 50 percent, 60 to 70 percent and more than 80 percent belong to “Reject”, “Improve” and “Accept” respectively.

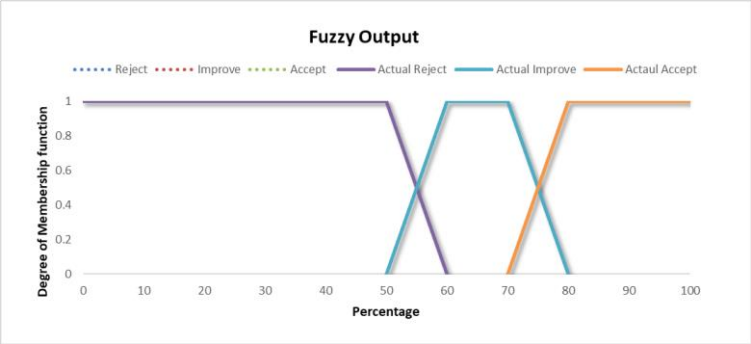


Figure 18 The membership functions of total work in crust in percentage

3.2.4. Construct the rule bases

The membership functions are defined for both input and output. Rule bases are constructed by the expert who have been working in tannery for more than 10 years as the technical specialist to control the output variables. In this study, the implications are;

i. If the quality of the crust leather is low which mean all the defects on the skin are high, the humidity is not ok or the colour is too far from the master colour. Then the quality acceptance should be not accepted. The crust leather will be rejected.

ii. If the quality of the crust leather is medium which mean the defects on the skin are low, the colour is right to the master colour but the humidity is too low or too high. Then the quality acceptance should be not accepted but still not reject. For this case we will add some process to improve the quality of the crust leather.

iii. If the quality of the crust leather is high which mean the all the defects on the skin are in small amount, the humidity is right and the colour is perfect to the further process. Then the quality acceptance should be accepted right away.

To make this fuzzy model works, eleven if-then rules are applied in this study as shown below;

Rule 1 If close defect is high, then crust leather is “Reject”.

Rule 2 If open defect is high, then crust leather is “Reject”.

Rule 3 If growth mark is high, then crust leather is “Reject”.

Rule 4 If vein mark is high, then crust leather is “Reject”.

Rule 5 If brand mark is high, then crust leather is “Reject”.

Rule 6 If colour is too light *or* too full, then crust leather is “Reject”.

Rule 7 If close defect is medium *and* open defect is medium *and* growth mark is medium *and* vein mark is medium *and* brand mark is medium, then crust leather is “Reject”.

Rule 8 If close defect is medium *and* open defect is medium *and* growth mark is medium *and* vein mark is medium *and* brand mark is medium, then crust leather is “Reject”.

Rule 9 If close defect is medium *and* open defect is medium *and* growth mark is medium *and* vein mark is medium *and* brand mark is medium, then crust leather is “Reject”.

Rule 10 If close defect is low *or* medium *and* open defect is low *or* medium *and* growth mark is low *or* medium *and* vein mark is low *or* medium *and* brand mark is low *or* medium *and* humidity is low *or* high *and* colour is okay, then crust leather is “Improve”.

Rule 11 If close defect is low or medium *and* open defect is low or medium *and* growth mark is low or medium *and* vein mark is low *or* medium *and* brand mark is low *or* medium *and* humidity is okay *and* colour is okay, then crust leather is “Accept”.

3.2.5. Evaluate the rules in the rule base

The evaluations of the fuzzy rules and the combination of the results of the individual rules are performed by using fuzzy set operations. The operations on fuzzy sets are different than the operations on non-fuzzy sets fuzzy operations for *or* and *and* operators on these sets. The mostly used operations for *or* and *and* operators are *max* and *min*, respectively.

3.2.6. Combine the results of each rule

After evaluating the result of each rule, these results should be combined to obtain a result. This process is called inference. The results of individual rules can be combined in different ways. The maximum algorithm is used in this study.

3.2.7. Convert the fuzzy output data to non-fuzzy values

Defuzzification is the step to defuzzify the fuzzy output back to real value. In this work, maxima method is applied. The output with the highest value of membership function is considered as the result in each case. If there is no highest value of membership function. Center of maxima method will use to indicate the result.

3.3. Simulate the fuzzy logic system

The fuzzy logic model for wet - end process will be simulated by Microsoft excel. The following figures will show how to perform fuzzy system with Microsoft excel. We defined the fuzzy input and its membership function, then convert the crisp inputs into fuzzy inputs as degrees of membership functions by using the trapezoidal and triangle graph. The input inference form is shown in table 7. The first column is the inputs, the second column is input value that was measured from the leather skin and the last column is fuzzy input converting from input value.

Table 7 Input inference form

Check point	Input Value	Degree of membership functior		
Close Defect (Blocks)		Low	Medium	High
Open Defect (Blocks)		Low	Medium	High
Growth Mark (% in hide)		Low	Medium	High
Vein Mark (% in hide)		Low	Medium	High
Brand Mark (Marks)		Low	Medium	High
Humidity(%rH)		Low	OK	High
Colour (% compare to final colour)		Too light	OK	Too Full

For instance, close defect has three sets of membership functions. At each set has its own conditions. As shown in figure 19, the input set for "Low" state. The condition for this set is if the input value is between 0 to 4 ,the degree of membership function is 1 ,but if the input value is more than 4 but not over than 5, the degree of membership function is slowly change from 1 to 0 base on its formulation.

The Equation of a Straight Line is used to calculate the degree of membership function.

Equations of straight lines are in the form: $y = mx + c$

Where, m is the gradient of the line and c is the intercept.

Here, we consider x as the inputs and y is the degree of membership function.

Thus, *Degree of membership function = slope(input) + intercept*

In figure 19, A15 is the input value from input form, column B is the formulation that we get from the equation.

Where, the slope is calculated by following formulation.

= SLOPE (INPUT SET, DEGREE OF MEMBERSHIP FUNCTION SET)

The intercept is calculated by following formulation.

= INTERCEPT (INPUT SET, DEGREE OF MEMBERSHIP FUNCTION SET)

Syntax = IF (logical_test, [value_if_true], [value_if_false])

= IF (the input value in A15 is less than or equal 4, return to “1”. Otherwise, IF (the input value in A15 is greater than or equal to 5, return to “0”. Otherwise, return to “slope value multiply by input then plus intercept value))

	A	B
5	Low	
6	Input range	MF range
7	0	1
8	4	1
9	5	0
10		
11	slope1=	=SLOPE(B8:B9,A8:A9)
12	intercept1=	=INTERCEPT(B8:B9,A8:A9)
13		
14		
15		=IF(A15<=4,1,IF(5<=A15,0,A15*$B$11+$B$12))

Figure 19 The formulation of degree of membership function for low state in MS Excel

In figure 20, C15 is the input value from input form, column B is the formulation that we get from the above equation. If the input is higher than 4, the degree of membership function will be calculated by equation of straight line.

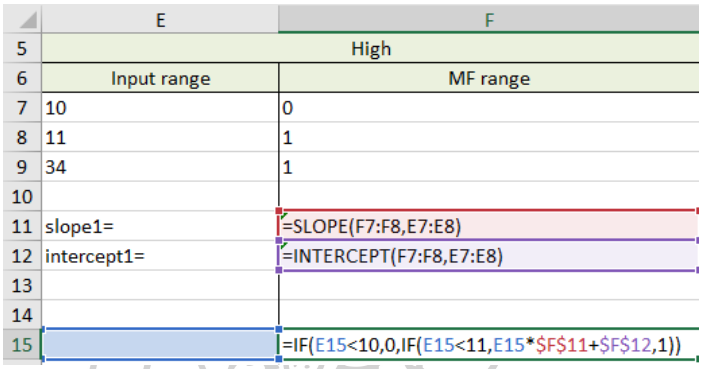
= IF (the input value in A15 is less than or equal 4, return to “1”. Otherwise, IF (the input value in A15 is greater than or equal to 5, return to “0”. Otherwise, return to “slope value multiply by input then plus intercept value))

	C	D
5	Medium	
6	Input range	MF range
7	4	0
8	5	1
9	10	1
10	11	0
11	slope1=	=SLOPE(D7:D8,C7:C8)
12	intercept1=	=INTERCEPT(D7:D8,C7:C8)
13	slope2=	=SLOPE(D9:D10,C9:C10)
14	intercept2=	=INTERCEPT(D9:D10,C9:C10)
15		=IF(C15<=4,0,IF(C15<5,C15*$D$11+$D$12,IF(C15<=10,1,IF(C15>11,0,C15*D13+D14))))

Figure 20 The formulation of degree of membership function for medium state in MS Excel

In figure 21, E15 is the input value, column B is the formulation that we get from the straight - line equation. If the input is lower than 10, the degree of membership function will be calculated by equation of straight line. From the formulation in F15,

= IF (the input value in A15 is less than or equal 4, return to “1”. Otherwise, IF (the input value in A15 is greater than or equal to 5, return to “0”. Otherwise, return to “slope value multiply by input then plus intercept value))



	E	F
5	High	
6	Input range	MF range
7	10	0
8	11	1
9	34	1
10		
11	slope1=	=SLOPE(F7:F8,E7:E8)
12	intercept1=	=INTERCEPT(F7:F8,E7:E8)
13		
14		
15		=IF(E15<10,0,IF(E15<11,E15*$F$11+$F$12,1))

Figure 21 The formulation of degree of membership function for high state in MS Excel

After we received the fuzzy inputs, the if – then rules are applied to aggregate the fuzzy output. As shown in figure 22, column C1 to C7 refers to the fuzzy inputs as we defined, column S1 refers to the result including “Reject”, “Improve” and “Accept”. Row R1 to R11 refer to eleven if – then rules.

The formulations as shown below are the calculation for if - then rules bases;

(S1, R1) = MIN (C1, R1)

(S1, R2) = MIN (C2, R2)

(S1, R3) = MIN (C3, R3)

(S1, R4) = MIN (C4, R4)

(S1, R5) = MIN (C5, R5)

(S1, R6) = MIN (C7, R6)

(S1, R7) = MIN ((C2, R7), (C3, R7), (C4, R7))

(S1, R8) = MIN ((C1, R8), (C2, R8), (C5, R8))

(S1, R9) = MIN ((C1, R9), (C2, R9), (C3, R9), (C4, R9), (C5, R9))

(S1, R10) = MIN ((C1, R10), (C2, R10), (C3, R10), (C4, R10), (C5, R10), (C6, R10), (C7, R10))

(S1, R11) = MIN ((C1, R11), (C2, R11), (C3, R11), (C4, R11), (C5, R11), (C6, R11), (C7, R11))

The degree of membership function of each input will show in inference table as shown in figure 22.

	C1		C2		C3		C4		C5		C6		C7		S1	
	Close Defect (Blocks)		Open Defect (Blocks)		Growth Mark (% in hide)		Vein Mark (% in hide)		Brand Mark (Marks)		Humidity(%rH)		Colour (% compare to final colour)		Result	
R1	High		Any		Any		Any		Any		Any		Any		Reject	
R2	Any		High		Any		Any		Any		Any		Any		Reject	
R3	Any		Any		High		Any		Any		Any		Any		Reject	
R4	Any		Any		Any		High		Any		Any		Any		Reject	
R5	Any		Any		Any		Any		High		Any		Any		Reject	
R6	Any		Any		Any		Any		Any		Any		Too Light or Too Full		Reject	
R7	Any		Medium		Medium		Medium		Any		Any		Any		Reject	
R8	Medium		Medium		Any		Any		Medium		Any		Any		Reject	
R9	Medium		Medium		Medium		Medium		Medium		Any		Any		Reject	
R10	Low or Medium		Low or Medium		Low or Medium		Low or Medium		Low or Medium		Low or High		Ok		Improve	
R11	Low or Medium		Low or Medium		Low or Medium		Low or Medium		Low or Medium		Ok		Ok		Accept	

Figure 22 Fuzzy Inference System for wet-end process perform via MS Excel

CHAPTER IV
RESULTS AND DISCUSSION

4.1. Results

This chapter presents the developed fuzzy logic model for wet – end section in leather making process. Nine following case studies are used to illustrate the performance of the developed model. Case studies have been introduced at different levels of detail and divided to three groups as shown in figure 23. First group, the inputs and the results are simple. Second group, moderate cases have more complex the inputs than the first simple group and have more than one answer. The last group, complex cases have complex inputs and have the most complex results.

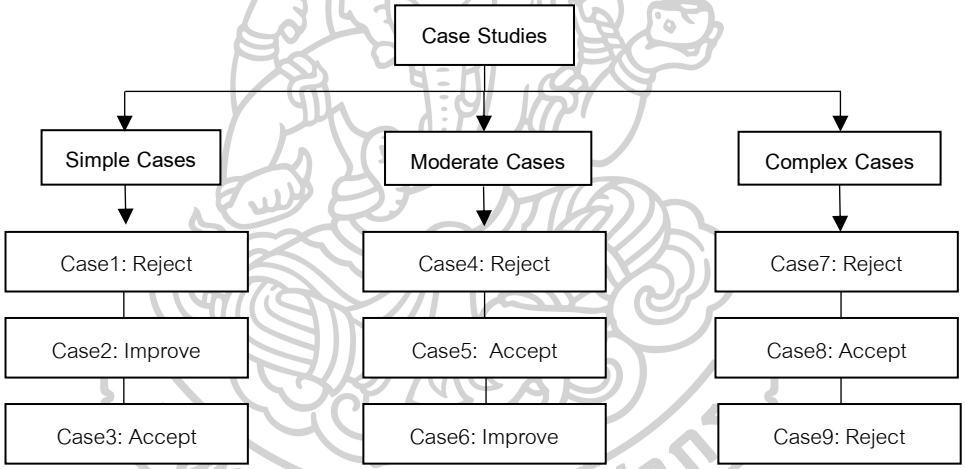


Figure 23 Three groups of case study

First group, three simple cases present the input values that indicate the degree of membership function strongly into the core value. The degree of membership function belongs to only one region for every case. The maxima method is used to defuzzify the output.

4.1.1 Case 1

After fuzzification, the input values convert to fuzzy inputs as show in table 8. The degree of membership functions for all the material defects are only in one linguistic term.

This crust is low quality with high defects. The crust colour is too light when compare to master colour which could design to reject the crust.

Table 8 Input values and degree of membership functions for case 1

Check point	Input Value	Degree of membership function		
Close Defect (Blocks)	12	Low	Medium	High
		0	0	1
Open Defect (Blocks)	2	Low	Medium	High
		0	1	0
Growth Mark (% in hide)	14	Low	Medium	High
		0	1	0
Vein Mark (% in hide)	12	Low	Medium	High
		0	1	0
Brand Mark (Marks)	1	Low	Medium	High
		1	0	0
Humidity(%rH)	13	Low	OK	High
		0	1	0
Colour (% compare to final colour)	50	Too light	OK	Too Full
		1	0	0

As shown in table 9, the evaluation from the inference system using max and min inference method provide us the degrees of membership functions for output. Three strength rules are fired as following;

1. If close defect is high, then crust leather is “Reject”.

(S1, R1) = MIN (C1, R1)

(S1, R1) = MIN (1) = 1

6. If colour is too light *or* too full, then crust leather is “Reject”.

(S1, R6) = MIN (C7, R6)

(S1, R6) = MIN (1) = 1

7. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R7) = MIN (1,1,1) = 1

Table 9 The evaluation for case 1

Close Defect (Blocks)		Open Defect (Blocks)		Growth Mark (% in hide)		Vein Mark (% in hide)		Brand Mark (Marks)		Humidity(%rH)		Colour (% compare to final colour)		Result	
High	1	Any		Any		Any		Any		Any		Any		Reject	1
Any		High	0	Any		Any		Any		Any		Any		Reject	0
Any		Any		High	0	Any		Any		Any		Any		Reject	0
Any		Any		Any		High	0	Any		Any		Any		Reject	0
Any		Any		Any		Any		High	0	Any		Any		Reject	0
Any		Any		Any		Any		Any		Any		Too Light or Too Full	1	Reject	1
Any		Medium	1	Medium	1	Medium	1	Any		Any		Any		Reject	1
Medium	0	Medium	1	Any		Any		Medium	0	Any		Any		Reject	0
Medium	0	Medium	1	Medium	1	Medium	1	Medium	0	Any		Any		Reject	0
Low or Medium	0	Low or Medium	1	Low or Medium	1	Low or Medium	1	Low or Medium	1	Low or High	0	Ok	0	Improve	0
Low or Medium	0	Low or Medium	1	Low or Medium	1	Low or Medium	1	Low or Medium	1	Ok	1	Ok	0	Accept	0

The fuzzy output graph for case 1 has shown in figure 24. As we can see, the result is marked as “Reject”.

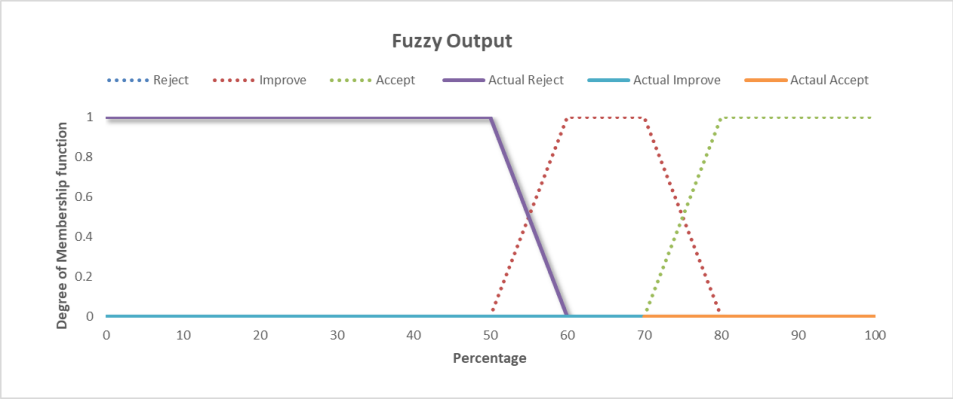


Figure 24 Fuzzy output for case 1

4.1.2 Case 2

For case 2, the idea is similar to case one. We concern at the humidity which is lower than the standard. The degrees of membership functions bring us to clearly output graph shape. The input values and degrees of membership functions for each input has shown in table 10.

Table 10 Input values and degree of membership functions for case 2

Check point	Input Value	Degree of membership function		
Close Defect (Blocks)	4	Low 1	Medium 0	High 0
Open Defect (Blocks)	2	Low 0	Medium 1	High 0
Growth Mark (% in hide)	15	Low 0	Medium 1	High 0
Vein Mark (% in hide)	10	Low 1	Medium 0	High 0
Brand Mark (Marks)	1	Low 1	Medium 0	High 0
Humidity(%rH)	10	Low 1	OK 0	High 0
Colour (% compare to final colour)	65	Too light 0	OK 1	Too Full 0

After the evaluation from the inference system that shows in table 11, we have one firing strength rule as following;

10. If close defect is low or medium and open defect is low or medium and growth mark is low or medium and vein mark is low or medium and brand mark is low or medium and humidity is low or high and colour is okay, then crust leather is “Improve”.

(S1, R10) = MIN ((C1, R10), (C2, R10), (C3, R10), (C4, R10), (C5, R10), (C6, R10), (C7, R10))

(S1, R10) = MIN (1, 1, 1, 1, 1, 1, 1) = 1

Table 11 The evaluation for case 2

Close Defect (Blocks)		Open Defect (Blocks)		Growth Mark (% in hide)		Vein Mark (% in hide)		Brand Mark (Marks)		Humidity(%rH)		Colour (% compare to final colour)		Result	
High	0	Any		Any		Any		Any		Any		Any		Reject	0
Any		High	0	Any		Any		Any		Any		Any		Reject	0
Any		Any		High	0	Any		Any		Any		Any		Reject	0
Any		Any		Any		High	0	Any		Any		Any		Reject	0
Any		Any		Any		Any		High	0	Any		Any		Reject	0
Any		Any		Any		Any		Any		Any		Too Light or Too Full	0	Reject	0
Any		Medium	1	Medium	1	Medium	0	Any		Any		Any		Reject	0
Medium	0	Medium	1	Any		Any		Medium	0	Any		Any		Reject	0
Medium	0	Medium	1	Medium	1	Medium	0	Medium	0	Any		Any		Reject	0
Low or Medium	1	Low or Medium	1	Low or Medium	1	Low or Medium	1	Low or Medium	1	Low or High	1	Ok	1	Improve	1
Low or Medium	1	Low or Medium	1	Low or Medium	1	Low or Medium	1	Low or Medium	1	Ok	0	Ok	1	Accept	0

The fuzzy output for case 2 has shown in figure 25. As we can see from the fuzzy output graph, the result for this case is “Improve”.

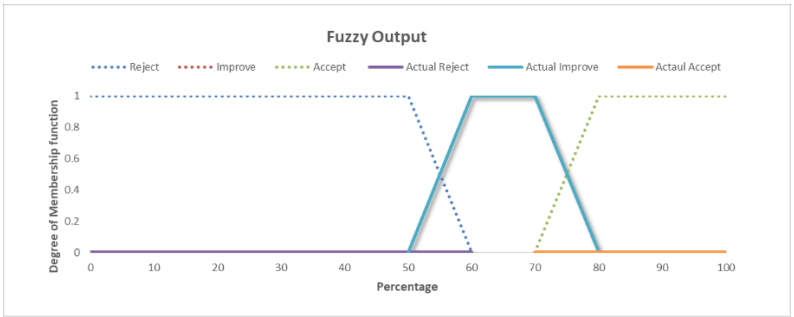


Figure 25 Fuzzy output for case 2

4.1.3. Case 3

In case 3, most of the degree of membership functions for the defects on the skin are strongly in medium level. We could consider this crust as a low-grade selection. There is a possibility to reject this crust. However, the humidity on the crust and the colour when compare to master colour are ok to accept this crust as the standard. The input values and degree of membership functions for each input has shown in table 12.

Table 12 Input values and degree of membership functions for case3

Check point	Input Value	Degree of membership function		
Close Defect (Blocks)	6	Low 0	Medium 1	High 0
Open Defect (Blocks)	3	Low 0	Medium 1	High 0
Growth Mark (% in hide)	15	Low 0	Medium 1	High 0
Vein Mark (% in hide)	15	Low 0	Medium 1	High 0
Brand Mark (Marks)	1	Low 1	Medium 0	High 0
Humidity(%rH)	12	Low 0	OK 1	High 0
Colour (% compare to final colour)	65	Too light 0	OK 1	Too Full 0

After the evaluation from the inference system that shown in table 13, we have one firing strength rule as following;

11. If close defect is low or medium and open defect is low or medium and growth mark is low or medium and vein mark is low or medium and brand mark is low or medium and humidity is okay and colour is okay, then crust leather is “Accept”.

(S1, R11) = MIN ((C1, R11), (C2, R11), (C3, R11), (C4, R11), (C5, R11), (C6, R11), (C7, R11))

(S1, R11) = MIN (1, 1, 1, 1, 1, 1, 1) = 1

Table 13 The evaluation for case 3

Close Defect (Blocks)		Open Defect (Blocks)		Growth Mark (% in hide)		Vein Mark (% in hide)		Brand Mark (Marks)		Humidity(%rH)		Colour (% compare to final colour)		Result	
High	0	Any		Any		Any		Any		Any		Any		Reject	0
Any		High	0	Any		Any		Any		Any		Any		Reject	0
Any		Any		High	0	Any		Any		Any		Any		Reject	0
Any		Any		Any		High	0	Any		Any		Any		Reject	0
Any		Any		Any		Any		High	0	Any		Any		Reject	0
Any		Any		Any		Any		Any		Any		Too Light or Too Full	0	Reject	0
Any		Medium	1	Medium	0	Medium	1	Any		Any		Any		Reject	0
Medium	1	Medium	1	Any		Any		Medium	0	Any		Any		Reject	0
Medium	1	Medium	1	Medium	0	Medium	1	Medium	0	Any		Any		Reject	0
Low or Medium	1	Low or Medium	1	Low or Medium	1	Low or Medium	1	Low or Medium	1	Low or High	0	Ok	1	Improve	0
Low or Medium	1	Low or Medium	1	Low or Medium	1	Low or Medium	1	Low or Medium	1	Ok	1	Ok	1	Accept	1

The fuzzy output for case 3 has shown in figure 26. As we can see from the fuzzy output graph, the result for this case is “Accept”.

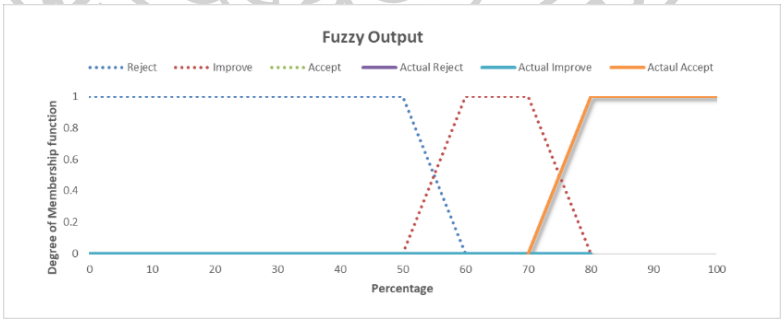


Figure 26 Fuzzy output for case 3

Second group presents the cases with some of the degree of membership functions belong to more than 1 range. More than 1 rule base has fired. The maxima method is used to defuzzify the output.

4.1.4. Case 4

The input values and degree of membership functions for each input has shown in table 14. The degree of membership functions of most of the inputs belong to more than on range. The crust has a possibility to reject.

Table 14 Input values and degree of membership function for case 4

Check point	Input Value	Degree of membership function		
Close Defect (Blocks)	7	Low	Medium	High
		0	1	0
Open Defect (Blocks)	3.2	Low	Medium	High
		0	0.8	0.2
Growth Mark (% in hide)	15.5	Low	Medium	High
		0	0.5	0.5
Vein Mark (% in hide)	15.4	Low	Medium	High
		0	0.6	0.4
Brand Mark (Marks)	2	Low	Medium	High
		0	1	0
Humidity(%rH)	14.7	Low	OK	High
		0	0.3	0.7
Colour (% compare to final colour)	78	Too light	OK	Too Full
		0	0.2	0.8

After the evaluation from the inference system that show in table 15, we have nine firing strength rules as following;

2. If open defect is high, then crust leather is “Reject”.

(S1, R2) = MIN (C2, R2)

(S1, R2) = MIN (0.2) = 0.2

3. If growth mark is high, then crust leather is “Reject”.

(S1, R3) = MIN (C3, R3)

(S1, R3) = MIN (0.5) = 0.5

4. If vein mark is high, then crust leather is “Reject”.

(S1, R4) = MIN (C4, R4)

(S1, R4) = MIN (0.4) = 0.4

6. If colour is too light *or* too full, then crust leather is “Reject”.

(S1, R6) = MIN (C7, R6)

(S1, R6) = MIN (0.8) = 0.8

7. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R7) = MIN ((C2, R7), (C3, R7), (C4, R7))

(S1, R7) = MIN (0.8, 0.5, 0.6) = 0.5

8. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R8) = MIN ((C1, R8), (C2, R8), (C5, R8))

(S1, R8) = MIN (1, 0.2, 1) = 0.2

9. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R9) = MIN ((C1, R9), (C2, R9), (C3, R9), (C4, R9), (C5, R9))

(S1, R9) = MIN (1, 0.8, 0.5, 0.6, 1) = 0.5

10. If close defect is low *or* medium *and* open defect is low *or* medium *and* growth mark is low *or* medium *and* vein mark is low *or* medium *and* brand mark is low *or* medium *and* humidity is low *or* high *and* colour is okay, then crust leather is “Improve”.

(S1, R10) = MIN ((C1, R10), (C2, R10), (C3, R10), (C4, R10), (C5, R10), (C6, R10), (C7, R10))

(S1, R10) = MIN (1, 0.8, 0.5, 0.6, 1, 0.3, 0.2) = 0.2

11. If close defect is low or medium *and* open defect is low or medium *and* growth mark is low or medium *and* vein mark is low *or* medium *and* brand mark is low *or* medium *and* humidity is okay *and* colour is okay, then crust leather is “Accept”.

(S1, R11) = MIN ((C1, R11), (C2, R11), (C3, R11), (C4, R11), (C5, R11), (C6, R11), (C7, R11))

(S1, R11) = MIN (1, 0.8, 0.5, 0.6, 1, 0.7, 0.2) = 0.2

Table 15 The evaluation for case 4

Close Defect (Blocks)		Open Defect (Blocks)		Growth Mark (% in hide)		Vein Mark (% in hide)		Brand Mark (Marks)		Humidity(%rH)		Colour (% compare to final colour)		Result	
High	0	Any		Any		Any		Any		Any		Any		Reject	0
Any		High	0.2	Any		Any		Any		Any		Any		Reject	0.2
Any		Any		High	0.5	Any		Any		Any		Any		Reject	0.5
Any		Any		Any		High	0.4	Any		Any		Any		Reject	0.4
Any		Any		Any		Any		High	0	Any		Any		Reject	0
Any		Any		Any		Any		Any		Any		Too Light or Too Full	0.8	Reject	0.8
Any		Medium	0.8	Medium	0.5	Medium	0.6	Any		Any		Any		Reject	0.5
Medium	1	Medium	0.2	Any		Any		Medium	1	Any		Any		Reject	0.2
Medium	1	Medium	0.8	Medium	0.5	Medium	0.6	Medium	1	Any		Any		Reject	0.5
Low or Medium	1	Low or Medium	0.8	Low or Medium	0.5	Low or Medium	0.6	Low or Medium	1	Low or High	0.3	Ok	0.2	Improve	0.2
Low or Medium	1	Low or Medium	0.8	Low or Medium	0.5	Low or Medium	0.6	Low or Medium	1	Ok	0.7	Ok	0.2	Accept	0.2

The fuzzy output for case 4 has shown in figure 27. As we can see from the fuzzy output graph. The fuzzy output values for each result are 0.8 in “Reject”, 0.2 in “Improve” and 0.2 in “Accept”. The maxima method has applied; MAX (0.8 ,0.2, 0.2), (Reject, Improve, Accept) = 0.8 in “Reject”. Therefore, the result for this case is “Reject”.

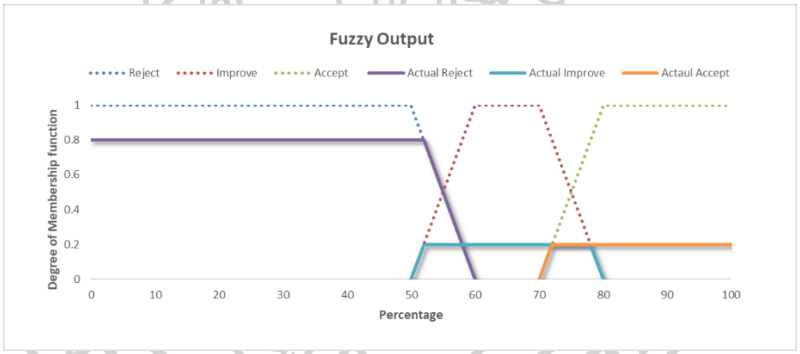


Figure 27 Fuzzy output for case 4

4.1.5 Case 5

In case 5, most of the degree of membership functions for defects are in low state. This crust has a good grade on material selection. The decision points are considering at humidity and colour. The humidity is 0.7 belong to “OK” and 0.3 belong to “High” which could have a possibility to design to improve. The colour when compare to master colour is 0.7 belong to “OK” and 0.3 belong to “Too Full” which indicate to reject the crust. The input values and degrees of membership functions for each input are shown in table 16.

Table 16 Input values and degree of membership function for case 5

Check point	Input Value	Degree of membership function		
Close Defect (Blocks)	4.1	Low	Medium	High
		0.9	0.1	0
Open Defect (Blocks)	1	Low	Medium	High
		1	0	0
Growth Mark (% in hide)	10.1	Low	Medium	High
		0.9	0.1	0
Vein Mark (% in hide)	5	Low	Medium	High
		1	0	0
Brand Mark (Marks)	1.1	Low	Medium	High
		0.9	0.1	0
Humidity(%rH)	14.3	Low	OK	High
		0	0.7	0.3
Colour (% compare to final colour)	73	Too light	OK	Too Full
		0	0.7	0.3

After the evaluation from the inference system that show in table 17, we have six firing strength rules as following;

1. If close defect is high, then crust leather is “Reject”.

(S1, R1) = MIN (C1, R1)

(S1, R1) = MIN (0.1) = 0.1

3. If growth mark is high, then crust leather is “Reject”.

(S1, R3) = MIN (C3, R3)

(S1, R3) = MIN (0.1) = 0.1

5. If brand mark is high, then crust leather is “Reject”.

(S1, R5) = MIN (C5, R5)

(S1, R5) = MIN (0.1) = 0.1

6. If colour is too light *or* too full, then crust leather is “Reject”.

(S1, R6) = MIN (C7, R6)

(S1, R6) = MIN (0.3) = 0.3

10. If close defect is low *or* medium *and* open defect is low *or* medium *and* growth mark is low *or* medium *and* vein mark is low *or* medium *and* brand mark is low *or* medium *and* humidity is low *or* high *and* colour is okay, then crust leather is “Improve”.

(S1, R10) = MIN ((C1, R10), (C2, R10), (C3, R10), (C4, R10, (C5, R10), (C6, R10), (C7, R10))

(S1, R10) = MIN (0.9, 1, 0.9, 1, 0.9, 0.3, 0.7) = 0.3

11. If close defect is low or medium *and* open defect is low or medium *and* growth mark is low or medium *and* vein mark is low *or* medium *and* brand mark is low *or* medium *and* humidity is okay *and* colour is okay, then crust leather is “Accept”.

(S1, R11) = MIN ((C1, R11), (C2, R11), (C3, R11), (C4, R11), (C5, R11), (C6, R11), (C7, R11))

(S1, R11) = MIN (0.9, 1, 0.9, 1, 0.9, 0.7, 0.7) = 0.7

Table 17 The evaluation for case 5

Close Defect (Blocks)		Open Defect (Blocks)		Growth Mark (% in hide)		Vein Mark (% in hide)		Brand Mark (Marks)		Humidity(%rH)		Colour (% compare to final colour)		Result	
High	0.1	Any		Any		Any		Any		Any		Any		Reject	0.1
Any		High	0	Any		Any		Any		Any		Any		Reject	0
Any		Any		High	0.1	Any		Any		Any		Any		Reject	0.1
Any		Any		Any		High	0	Any		Any		Any		Reject	0
Any		Any		Any		Any		High	0.1	Any		Any		Reject	0.1
Any		Any		Any		Any		Any		Any		Too Light or Too Full	0.3	Reject	0.3
Any		Medium	0	Medium	0	Medium	0	Any		Any		Any		Reject	0
Medium	0	Medium	0	Any		Any		Medium	0	Any		Any		Reject	0
Medium	0	Medium	0	Medium	0	Medium	0	Medium	0	Any		Any		Reject	0
Low or Medium	0.9	Low or Medium	1	Low or Medium	0.9	Low or Medium	1	Low or Medium	0.9	Low or High	0.3	Ok	0.7	Improve	0.3
Low or Medium	0.9	Low or Medium	1	Low or Medium	0.9	Low or Medium	1	Low or Medium	0.9	Ok	0.7	Ok	0.7	Accept	0.7

The fuzzy output for case 5 has shown in figure 28. As we can see from the fuzzy output graph. There are three values occur 0.3 in “Reject”, 0.3 in “Improve” and 0.7 in “Accept”. The maxima method has applied, the highest value is in “Accept”. Therefore, the result for this case is “Accept”.

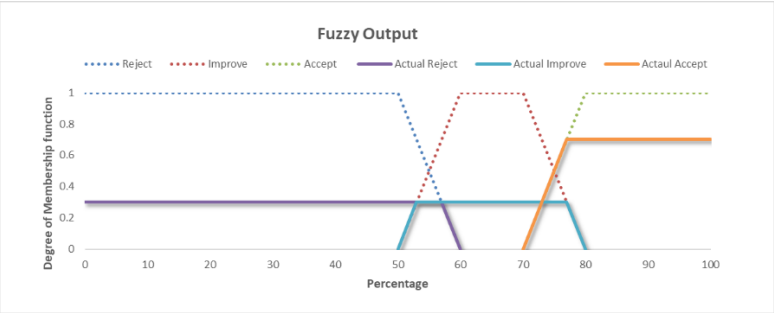


Figure 28 Fuzzy output for case 5

4.1.6. Case 6

In this case, most of the defects are strongly in medium level. This could make the crust rejected because of low selection. However, open defects and brand marks are not only belonging to medium but also in "Low". These make the crust still can be accepted. The humidity is 0.3 belong to "OK" and 0.7 belong to "High" which highly indicate to improve. The colour is 0.3 belong to "Too light" and 0.7 belong to "OK", make this crust possibly rejected due to the colour not per standard. The input values and degree of membership functions for each input has shown in table 18.

Table 18 Input values and degree of membership function for case 6

Check point	Input Value	Degree of membership function		
Close Defect (Blocks)	5	Low	Medium	High
		0	1	0
Open Defect (Blocks)	3.2	Low	Medium	High
		0	0.8	0.2
Growth Mark (% in hide)	12	Low	Medium	High
		0	1	0
Vein Mark (% in hide)	12	Low	Medium	High
		0	1	0
Brand Mark (Marks)	1.5	Low	Medium	High
		0.5	0.5	0
Humidity(%rH)	14.7	Low	OK	High
		0	0.3	0.7
Colour (% compare to final colour)	57	Too light	OK	Too Full
		0.3	0.7	0

After the evaluation from the inference system that show in table 19, we have six firing strength rules as following;

6. If colour is too light *or* too full, then crust leather is “Reject”.

(S1, R6) = MIN (C7, R6)

(S1, R6) = MIN (0.3) = 0.3

7. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R7) = MIN ((C2, R7), (C3, R7), (C4, R7))

(S1, R7) = MIN (0.2, 1, 1) = 0.2

8. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R8) = MIN ((C1, R8), (C2, R8), (C5, R8))

(S1, R8) = MIN (1, 0.2, 0.5) = 0.5

9. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R9) = MIN ((C1, R9), (C2, R9), (C3, R9), (C4, R9), (C5, R9))

(S1, R9) = MIN (1, 0.2, 1, 1, 0.5) = 0.2

10. If close defect is low *or* medium *and* open defect is low *or* medium *and* growth mark is low *or* medium *and* vein mark is low *or* medium *and* brand mark is low *or* medium *and* humidity is low *or* high *and* colour is okay, then crust leather is “Improve”.

(S1, R10) = MIN ((C1, R10), (C2, R10), (C3, R10), (C4, R10, (C5, R10), (C6, R10), (C7, R10))

(S1, R10) = MIN (1, 0.8, 1, 1, 0.5, 0.7, 0.7) = 0.5

11. If close defect is low or medium *and* open defect is low or medium *and* growth mark is low or medium *and* vein mark is low *or* medium *and* brand mark is low *or* medium *and* humidity is okay *and* colour is okay, then crust leather is “Accept”.

(S1, R11) = MIN ((C1, R11), (C2, R11), (C3, R11), (C4, R11), (C5, R11), (C6, R11), (C7, R11))

(S1, R11) = MIN (1, 0.8, 1, 1, 0.5, 0.3, 0.7) = 0.3

Table 19 The evaluation for case 6

Close Defect (Blocks)		Open Defect (Blocks)		Growth Mark (% in hide)		Vein Mark (% in hide)		Brand Mark (Marks)		Humidity(%rH)		Colour (% compare to final colour)		Result	
High	0	Any		Any		Any		Any		Any		Any		Reject	0
Any		High	0	Any		Any		Any		Any		Any		Reject	0
Any		Any		High	0	Any		Any		Any		Any		Reject	0
Any		Any		Any		High	0	Any		Any		Any		Reject	0
Any		Any		Any		Any		High	0	Any		Any		Reject	0
Any		Any		Any		Any		Any		Any		Too Light or Too Full	0.3	Reject	0.3
Any		Medium	0.2	Medium	1	Medium	1	Any		Any		Any		Reject	0.2
Medium	1	Medium	0.2	Any		Any		Medium	0.5	Any		Any		Reject	0.2
Medium	1	Medium	0.2	Medium	1	Medium	1	Medium	0.5	Any		Any		Reject	0.2
Low or Medium	1	Low or Medium	0.8	Low or Medium	1	Low or Medium	1	Low or Medium	0.5	Low or High	0.7	Ok	0.7	Improve	0.5
Low or Medium	1	Low or Medium	0.8	Low or Medium	1	Low or Medium	1	Low or Medium	0.5	Ok	0.3	Ok	0.7	Accept	0.3

The fuzzy output for case 6 has shown in figure 29. As we can see from the fuzzy output graph. There are three values occur: 0.3 in “Reject”, 0.5 in “Improve” and 0.3 in “Accept”. The maxima method is applied, the highest value is in “Improve”. Therefore, the result for this case is “Improve”.

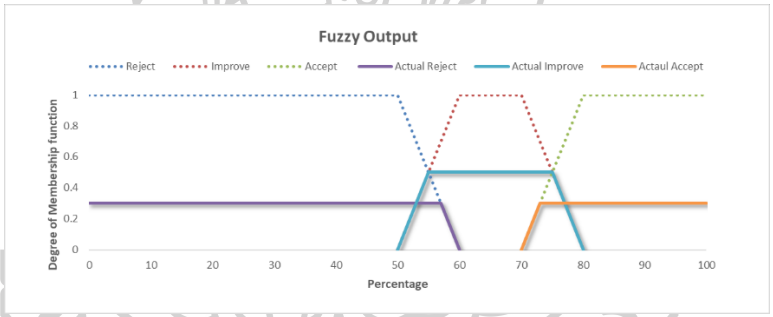


Figure 29 Fuzzy output for case 6

Last group presents the cases with the degree of membership functions belong to more than one ranges and have equal value. For defuzzification, the maxima method cannot be used. The center of maxima is applied to defuzzify the output.

4.1.7 Case 7

All the degrees of membership functions belong to two range. All the defects are strongly in medium level. The humidity is quite ok make this crust has possibility to improve. The input values and degree of membership functions for each input has shown in table 20.

Table 20 Input values and degree of membership function for case 7

Check point	Input Value	Degree of membership function		
Close Defect (Blocks)	10.2	Low	Medium	High
		0	0.8	0.2
Open Defect (Blocks)	3.2	Low	Medium	High
		0	0.8	0.2
Growth Mark (% in hide)	15.2	Low	Medium	High
		0	0.8	0.2
Vein Mark (% in hide)	15.2	Low	Medium	High
		0	0.8	0.2
Brand Mark (Marks)	2.2	Low	Medium	High
		0	0.8	0.2
Humidity(%rH)	14.2	Low	OK	High
		0	0.8	0.2
Colour (% compare to final colour)	78	Too light	OK	Too Full
		0	0.2	0.8

After the evaluation from the inference system that show in table 21, all the rule bases are fired as following;

1. If close defect is high, then crust leather is “Reject”.

(S1, R1) = MIN (C1, R1)

(S1, R1) = MIN (0.2) = 0.2

2. If open defect is high, then crust leather is “Reject”.

(S1, R2) = MIN (C2, R2)

(S1, R2) = MIN (0.2) = 0.2

3. If growth mark is high, then crust leather is “Reject”.

(S1, R3) = MIN (C3, R3)

(S1, R3) = MIN (0.2) = 0.2

4. If vein mark is high, then crust leather is “Reject”.

(S1, R4) = MIN (C4, R4)

(S1, R4) = MIN (0.2) = 0.2

5. If brand mark is high, then crust leather is “Reject”.

(S1, R5) = MIN (C5, R5)

(S1, R5) = MIN (0.2) = 0.2

6. If colour is too light or too full, then crust leather is “Reject”.

(S1, R6) = MIN (C7, R6)

(S1, R6) = MIN (0.2) = 0.2

7. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R7) = MIN ((C2, R7), (C3, R7), (C4, R7))

(S1, R7) = MIN (0.8, 0.8, 0.8) = 0.8

8. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R8) = MIN ((C1, R8), (C2, R8), (C5, R8))

(S1, R8) = MIN (0.8, 0.8, 0.8) = 0.8

9. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R9) = MIN ((C1, R9), (C2, R9), (C3, R9), (C4, R9), (C5, R9))

(S1, R9) = MIN (0.8, 0.8, 0.8, 0.8, 0.8) = 0.8

10. If close defect is low *or* medium *and* open defect is low *or* medium *and* growth mark is low *or* medium *and* vein mark is low *or* medium *and* brand mark is low *or* medium *and* humidity is low *or* high *and* colour is okay, then crust leather is “Improve”.

(S1, R10) = MIN ((C1, R10), (C2, R10), (C3, R10), (C4, R10, (C5, R10), (C6, R10), (C7, R10))

(S1, R10) = MIN (0.8, 0.8, 0.8, 0.8, 0.8, 0.8, 0.8) = 0.8

11. If close defect is low or medium *and* open defect is low or medium *and* growth mark is low or medium *and* vein mark is low *or* medium *and* brand mark is low *or* medium *and* humidity is okay *and* colour is okay, then crust leather is “Accept”.

(S1, R11) = MIN ((C1, R11), (C2, R11), (C3, R11), (C4, R11), (C5, R11), (C6, R11), (C7, R11))

(S1, R11) = MIN (0.8, 0.8, 0.8, 0.8, 0.8, 0.2, 0.8) = 0.8

Table 21 The evaluation for case 7

Close Defect (Blocks)		Open Defect (Blocks)		Growth Mark (% in hide)		Vein Mark (% in hide)		Brand Mark (Marks)		Humidity(%rH)		Colour (% compare to final colour)		Result	
High	0.2	Any		Any		Any		Any		Any		Any		Reject	0.2
Any		High	0.2	Any		Any		Any		Any		Any		Reject	0.2
Any		Any		High	0.2	Any		Any		Any		Any		Reject	0.2
Any		Any		Any		High	0.2	Any		Any		Any		Reject	0.2
Any		Any		Any		Any		High	0.2	Any		Any		Reject	0.2
Any		Any		Any		Any		Any		Any		Too Light or Too Full	0.2	Reject	0.2
Any		Medium	0.8	Medium	0.8	Medium	0.8	Any		Any		Any		Reject	0.8
Medium	0.8	Medium	0.8	Any		Any		Medium	0.8	Any		Any		Reject	0.8
Medium	0.8	Medium	0.8	Medium	0.8	Medium	0.8	Medium	0.8	Any		Any		Reject	0.8
Low or Medium	0.8	Low or Medium	0.8	Low or Medium	0.8	Low or Medium	0.8	Low or Medium	0.8	Low or High	0.8	Ok	0.8	Improve	0.8
Low or Medium	0.8	Low or Medium	0.8	Low or Medium	0.8	Low or Medium	0.8	Low or Medium	0.8	Ok	0.2	Ok	0.8	Accept	0.2

The fuzzy output for case 7 has shown in figure 30. As we can see from the fuzzy output graph. There are two values occur 0.8 in “Reject” and 0.8 in “Improve”. For this case there is no highest value, we cannot use the maxima method like the previously cases. The center of maxima method is applied, the middle value between 0 and 72 is 36 which is close to “Reject”. Therefore, the result for this case is “Reject”

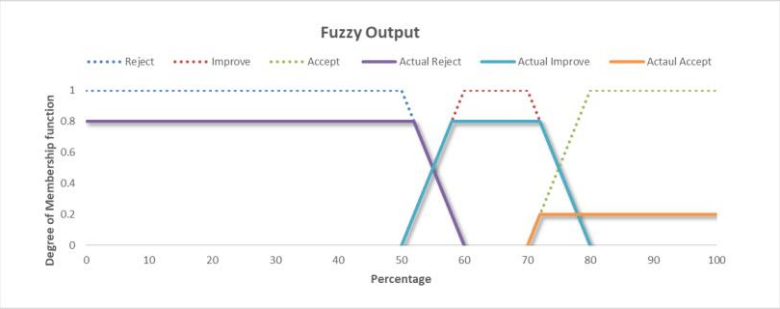


Figure 30 Fuzzy output for case 7

4.1.8. Case 8

In case 8, all the defects belong to more than one range. Most of defects are in low level, only growth mark is strongly in medium. The colour is good with 0.9 in “OK” make this crust still can be accepted. The input values and degree of membership functions for each input has shown in table 22.

Table 22 Input values and degree of membership function for case 8.

Check point	Input Value	Degree of membership function		
Close Defect (Blocks)	4.2	Low	Medium	High
		0.8	0.2	0
Open Defect (Blocks)	1.4	Low	Medium	High
		0.6	0.4	0
Growth Mark (% in hide)	15.3	Low	Medium	High
		0	0.7	0.3
Vein Mark (% in hide)	10.2	Low	Medium	High
		0.8	0.2	0
Brand Mark (Marks)	1.5	Low	Medium	High
		0.5	0.5	0
Humidity(%rH)	11.5	Low	OK	High
		0.5	0.5	0
Colour (% compare to final colour)	59	Too light	OK	Too Full
		0.1	0.9	0

After the evaluation from the inference system that show in table 23, we have seven firing strength rules as following;

3. If growth mark is high, then crust leather is “Reject”.

(S1, R3) = MIN (C3, R3)

(S1, R3) = MIN (0.3) = 0.3

6. If colour is too light *or* too full, then crust leather is “Reject”.

(S1, R6) = MIN (C7, R6)

(S1, R6) = MIN (0.1) = 0.1

7. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R7) = MIN ((C2, R7), (C3, R7), (C4, R7))

(S1, R7) = MIN (0.4, 0.7, 0.2) = 0.2

8. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R8) = MIN ((C1, R8), (C2, R8), (C5, R8))

(S1, R8) = MIN (0.2, 0.4, 0.5) = 0.2

9. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R9) = MIN ((C1, R9), (C2, R9), (C3, R9), (C4, R9), (C5, R9))

(S1, R9) = MIN (0.2, 0.4, 0.7, 0.2, 0.5) = 0.2

10. If close defect is low *or* medium *and* open defect is low *or* medium *and* growth mark is low *or* medium *and* vein mark is low *or* medium *and* brand mark is low *or* medium *and* humidity is low *or* high *and* colour is okay, then crust leather is “Improve”.

(S1, R10) = MIN ((C1, R10), (C2, R10), (C3, R10), (C4, R10, (C5, R10), (C6, R10), (C7, R10))

(S1, R10) = MIN (0.8, 0.6, 0.7, 0.8, 0.5, 0.5, 0.9) = 0.5

11. If close defect is low or medium and open defect is low or medium and growth mark is low or medium and vein mark is low or medium and brand mark is low or medium and humidity is okay and colour is okay, then crust leather is “Accept”.

(S1, R11) = MIN ((C1, R11), (C2, R11), (C3, R11), (C4, R11), (C5, R11), (C6, R11), (C7, R11))

(S1, R11) = MIN (0.8, 0.6, 0.7, 0.8, 0.5, 0.5, 0.9) = 0.5

Table 23 The evaluation for case 8

Close Defect (Blocks)		Open Defect (Blocks)		Growth Mark (% in hide)		Vein Mark (% in hide)		Brand Mark (Marks)		Humidity(%rH)		Colour (% compare to final colour)		Result	
High	0	Any		Any		Any		Any		Any		Any		Reject	0
Any		High	0	Any		Any		Any		Any		Any		Reject	0
Any		Any		High	0.3	Any		Any		Any		Any		Reject	0.3
Any		Any		Any		High	0	Any		Any		Any		Reject	0
Any		Any		Any		Any		High	0	Any		Any		Reject	0
Any		Any		Any		Any		Any		Any		Too Light or Too Full	0.1	Reject	0.1
Any		Medium	0.4	Medium	0.7	Medium	0.2	Any		Any		Any		Reject	0.2
Medium	0.2	Medium	0.4	Any		Any		Medium	0.5	Any		Any		Reject	0.2
Medium	0.2	Medium	0.4	Medium	0.7	Medium	0.2	Medium	0.5	Any		Any		Reject	0.2
Low or Medium	0.8	Low or Medium	0.6	Low or Medium	0.7	Low or Medium	0.8	Low or Medium	0.5	Low or High	0.5	Ok	0.9	Improve	0.5
Low or Medium	0.8	Low or Medium	0.6	Low or Medium	0.7	Low or Medium	0.8	Low or Medium	0.5	Ok	0.5	Ok	0.9	Accept	0.5

The fuzzy output for case 8 has shown in figure 31. As we can see from the fuzzy output graph. There is two value occur 0.5 in “Improve” and 0.5 in “Accept”. For this case there is no highest value like the previously cases. The center of maxima method is

applied. The middle value between 55 and 100 is 77.5 which belong to “Accept”. Therefore, the result for this case is “Accept”.

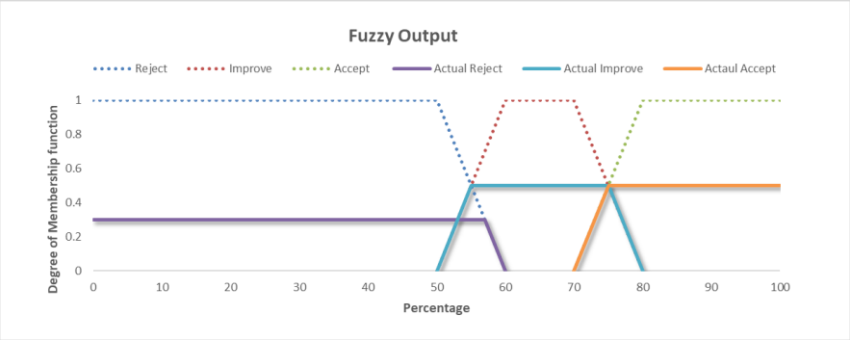


Figure 31 Fuzzy output for case 8

4.1.9 Case 9

In case 9, all of defects on this crust are strongly in low level which mean the material is in a good grade. The points that we concern are at humidity and colour. The humidity is 0.5 belong to “OK” and “High”. The colour is 0.5 belong to “OK” and “Too Full” which make this crust could have a possibility to improve and reject, respectively. The input values and degree of membership functions for each input have shown in table 24.

Table 24 Input values and degree of membership function for case 9

Check point	Input Value	Degree of membership function		
Close Defect (Blocks)	4.5	Low 0.5	Medium 0.5	High 0
Open Defect (Blocks)	1.4	Low 0.6	Medium 0.4	High 0
Growth Mark (% in hide)	15.5	Low 0	Medium 0.5	High 0.5
Vein Mark (% in hide)	10.1	Low 0.9	Medium 0.1	High 0
Brand Mark (Marks)	2.5	Low 0	Medium 0.5	High 0.5
Humidity(%rH)	14.5	Low 0	OK 0.5	High 0.5
Colour (% compare to final colour)	75	Too light 0	OK 0.5	Too Full 0.5

After the evaluation from the inference system that show in table 25, we have nine firing strength rules as following;

1. If close defect is high, then crust leather is “Reject”.

(S1, R1) = MIN (C1, R1)

(S1, R1) = MIN (0.5) = 0.5

3. If growth mark is high, then crust leather is “Reject”.

(S1, R3) = MIN (C3, R3)

(S1, R3) = MIN (0.5) = 0.5

5. If brand mark is high, then crust leather is “Reject”.

(S1, R5) = MIN (C5, R5)

(S1, R5) = MIN (0.5) = 0.5

6. If colour is too light *or* too full, then crust leather is “Reject”.

(S1, R6) = MIN (C7, R6)

(S1, R6) = MIN (0.5) = 0.5

7. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R7) = MIN ((C2, R7), (C3, R7), (C4, R7))

(S1, R7) = MIN (0.4, 0.5, 0.1) = 0.1

8. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R8) = MIN ((C1, R8), (C2, R8), (C5, R8))

(S1, R8) = MIN (0.5, 0.4, 0.5) = 0.4

9. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R9) = MIN ((C1, R9), (C2, R9), (C3, R9), (C4, R9), (C5, R9))

(S1, R9) = MIN (0.5, 0.4, 0.5, 0.1, 0.5) = 0.1

10. If close defect is low *or* medium *and* open defect is low *or* medium *and* growth mark is low *or* medium *and* vein mark is low *or* medium *and* brand mark is low *or* medium *and* humidity is low *or* high *and* colour is okay, then crust leather is “Improve”.

(S1, R10) = MIN ((C1, R10), (C2, R10), (C3, R10), (C4, R10, (C5, R10), (C6, R10), (C7, R10))

(S1, R10) = MIN (0.5, 0.6, 0.5, 0.9, 0.5, 0.5, 0.5) = 0.5

11. If close defect is low or medium *and* open defect is low or medium *and* growth mark is low or medium *and* vein mark is low *or* medium *and* brand mark is low *or* medium *and* humidity is okay *and* colour is okay, then crust leather is “Accept”.

(S1, R11) = MIN ((C1, R11), (C2, R11), (C3, R11), (C4, R11), (C5, R11), (C6, R11), (C7, R11))

(S1, R11) = MIN (0.5, 0.6, 0.5, 0.9, 0.5, 0.5, 0.5) = 0.5

Table 25 The evaluation for case 9

Close Defect (Blocks)		Open Defect (Blocks)		Growth Mark (% in hide)		Vein Mark (% in hide)		Brand Mark (Marks)		Humidity(%rH)		Colour (% compare to final colour)		Result	
High	0.5	Any		Any		Any		Any		Any		Any		Reject	0.5
Any		High	0	Any		Any		Any		Any		Any		Reject	0
Any		Any		High	0.5	Any		Any		Any		Any		Reject	0.5
Any		Any		Any		High	0	Any		Any		Any		Reject	0
Any		Any		Any		Any		High	0.5	Any		Any		Reject	0.5
Any		Any		Any		Any		Any		Any		Too Light or Too Full	0.5	Reject	0.5
Any		Medium	0.4	Medium	0.5	Medium	0.1	Any		Any		Any		Reject	0.1
Medium	0.5	Medium	0.4	Any		Any		Medium	0.5	Any		Any		Reject	0.4
Medium	0.5	Medium	0.4	Medium	0.5	Medium	0.1	Medium	0.5	Any		Any		Reject	0.1
Low or Medium	0.5	Low or Medium	0.6	Low or Medium	0.5	Low or Medium	0.9	Low or Medium	0.5	Low or High	0.5	Ok	0.5	Improve	0.5
Low or Medium	0.5	Low or Medium	0.6	Low or Medium	0.5	Low or Medium	0.9	Low or Medium	0.5	Ok	0.5	Ok	0.5	Accept	0.5

The fuzzy output for case 9 has shown in figure 32. As we can see from the fuzzy output graph. There is three values occur 0.5 in “Reject”, 0.5 in “Improve” and 0.5 in “Accept”., the middle value between 0 and 100 is 50 percentage which is belong to “Reject”. Therefore, the result for this case is “Reject”.

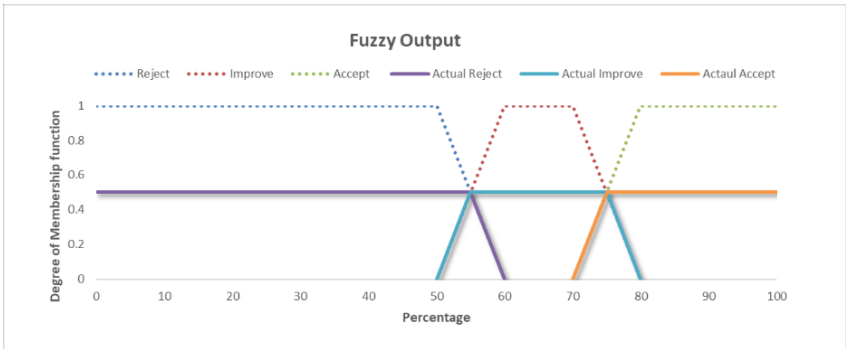


Figure 32 Fuzzy output for case 9

4.2. Discussion

From the simulation results in nine case studies, the developed model provided us the accuracy results compared to the results providing from the expert. The case studies which had the different results including reject, improve and accept have proved the model. However, computer programing with the limit of data still not like human knowledge. The limitation of this developed model was the fuzzy output was in reject and accept equally. The membership function graphs were at the boundary and not connected. The model provided an error to calculate the output (shown in Appendix B)

CHAPTER V
CONCLUSION

In leather making production, one of the most common problems is the leather quality does not acceptable as a standard during the process. Decision support tool is needed when experts are unavailable, to reduce waste from inexperienced worker's decision.

In this research, fuzzy logic is used to develop the model by using data and knowledge from skilled experts to decision support tool for applying in leather making process focus only in wet – end section. The developed model was starting from fuzzification. Firstly, the seven inputs were constructed from the check points at each process. The quality acceptance of the crust leather has defined as the output. The membership functions were constructed to convert crisp input to fuzzy input. Secondly, the inference systems, the eleven rule bases from skilled experts were constructed to convert the fuzzy input to fuzzy output. Lastly, defuzzification, the maxima method and center of maxima were used to defuzzify the results. The developed model is implemented in three groups of case studies with different details and conditions including simple group, moderate group and complex group. The developed model was implemented by using the formulation in Microsoft Excel.

According to the results in chapter 4, nine case studies with different conditions have proved that the developed model was practical the accuracy results compared to the results providing from the experts.

Moreover, this model only develops for one of various products. The model can be improved to apply on different products, different materials by adjust and add more process. The results could perform in percentage from different shape of output graph by apply different defuzzification methods.

APPENDIX A

LIST OF ABBREVIATIONS

Abbreviations	Descriptions
CD	Close Defect
OD	Open Defect
GM	Growth Mark
BM	Brand Mark
VM	Vein Mark
CL	Colour
HM	Humidity
L	Low
M	Medium
H	High
TL	Too Light
TF	Too Full
RJ	Reject
IMP	Improve
ACPT	Accept

APPENDIX B

Error case

The input values and the degree of membership functions for this case are shown in table 26.

Table 26 Input values and degree of membership functions for error case

Check point	Input Value	Degree of membership function		
Close Defect (Blocks)	4	Low	Medium	High
		1	0	0
Open Defect (Blocks)	1.1	Low	Medium	High
		0.9	0.1	0
Growth Mark (% in hide)	10.5	Low	Medium	High
		0.5	0.5	0
Vein Mark (% in hide)	10.5	Low	Medium	High
		0.5	0.5	0
Brand Mark (Marks)	1.5	Low	Medium	High
		0.5	0.5	0
Humidity(%rH)	12	Low	OK	High
		0	1	0
Colour (% compare to final colour)	75	Too light	OK	Too Full
		0	0.5	0.5

After the evaluation from the inference system that show in table 27, we have three firing strength rules as following;

6. If colour is too light *or* too full, then crust leather is “Reject”.

(S1, R6) = MIN (C7, R6)

(S1, R6) = MIN (0.5) = 0.5

7. If close defect is medium and open defect is medium and growth mark is medium and vein mark is medium and brand mark is medium, then crust leather is “Reject”.

(S1, R7) = MIN ((C2, R7), (C3, R7), (C4, R7))

(S1, R7) = MIN (0.1, 0.5, 0.5) = 0.1

11. If close defect is low or medium *and* open defect is low or medium *and* growth mark is low or medium *and* vein mark is low *or* medium *and* brand mark is low *or* medium *and* humidity is okay *and* colour is okay, then crust leather is “Accept”.

(S1, R11) = MIN ((C1, R11), (C2, R11), (C3, R11), (C4, R11), (C5, R11), (C6, R11), (C7, R11))

(S1, R11) = MIN (1, 0.9, 0.5, 0.5, 0.5,1 ,0.5) = 0.5

Table 27 The evaluation for error case

Close Defect (Blocks)		Open Defect (Blocks)		Growth Mark (% in hide)		Vein Mark (% in hide)		Brand Mark (Marks)		Humidity(%rH)		Colour (% compare to final colour)		Result	
High	0	Any		Any		Any		Any		Any		Any		Reject	0
Any		High	0	Any		Any		Any		Any		Any		Reject	0
Any		Any		High	0	Any		Any		Any		Any		Reject	0
Any		Any		Any		High	0	Any		Any		Any		Reject	0
Any		Any		Any		Any		High	0	Any		Any		Reject	0
Any		Any		Any		Any		Any		Any		Too Light or Too Full	0.5	Reject	0.5
Any		Medium	0.1	Medium	0.5	Medium	0.5	Any		Any		Any		Reject	0.1
Medium	0	Medium	0.1	Any		Any		Medium	0.5	Any		Any		Reject	0
Medium	0	Medium	0.1	Medium	0.5	Medium	0.5	Medium	0.5	Any		Any		Reject	0
Low or Medium	1	Low or Medium	0.9	Low or Medium	0.5	Low or Medium	0.5	Low or Medium	0.5	Low or High	0	Ok	0.5	Improve	0
Low or Medium	1	Low or Medium	0.9	Low or Medium	0.5	Low or Medium	0.5	Low or Medium	0.5	Ok	1	Ok	0.5	Accept	0.5

The fuzzy output for this case has shown in figure 33. As we can see from the fuzzy output graph, there is two values occur 0.5 in “Reject” and 0.5 in “Accept” equally. The maxima method can apply only when there is the highest value and center of maxima can apply in the connected function graph. The developed model could not provide the results in such a case.

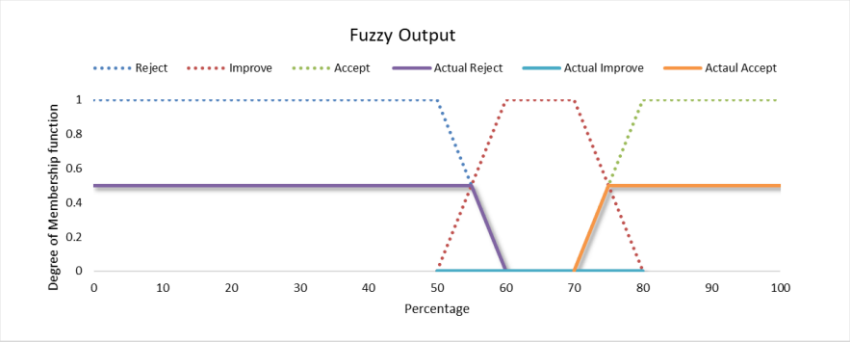


Figure 33 Fuzzy output for error case

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