THESIS

APPLICATION OF THE FUZZY MAMDANI TO PREDICT THE AMOUNT OF MARBLE PRODUCTION AT PT WUTAMA TRI MAKMUR, SOUTH SULAWESI PROVINCE

Compiled and Submitted by:

MUHRAM SULA IDRIS
D111171503

MINING ENGINEERING STUDY PROGRAM
FACULTY OF ENGINEERING
HASANUDDIN UNIVERSITY
GOWA
2024

LEGALIZATION

APPLICATION OF THE FUZZY MAMDANI TO PREDICT THE AMOUNT OF MARBLE PRODUCTION AT PT WUTAMA TRI MAKMUR, SOUTH SULAWESI PROVINCE

Compiled and Submitted by:

MUHRAM SULA IDRIS
D111171503

Has been defended in front of the Examination Committee which established for the Completion of Mining Engineering Undergraduate Study Program
Faculty of Engineering Hasanuddin University
on June 25th 2024
and declared eligible

Approve,

Supervisor,

Dr. Aryanti Virtanti Anas, S.T., M.T.
NIP.197010052008012026

Co-Supervisor,

Dr. Eng. Rini Novrianti Sutarjo Tui, S.T., M.BA., M.T.
NIP. 198311142014042001

Head of Study Program,

Dr. Aryanti Virtanti Anas, S.T., M.T.
NIP. 197010052008012026

LEMBAR PENGESAHAN SKRIPSI

PENERAPAN METODE FUZZY MAMDANI UNTUK MEMPREDIKSI JUMLAH PRODUKSI MARMER DI PT WUTAMA TRI MAKMUR PROVINSI SULAWESI SELATAN

Disusun dan diajukan oleh:

MUHRAM SULA IDRIS
D111171503

Telah dipertahankan di hadapan Panitia Ujian yang dibentuk dalam rangka Penyelesaian Studi Program Sarjana Program Studi Teknik Pertambangan Fakultas Teknik Universitas Hasanuddin pada tanggal 25 Juni 2024 dan dinyatakan telah memenuhi syarat kelulusan

Menyetujui,

Pembimbing Utama,

Dr. Aryanti Virtanti Anas, S.T., M.T.
NIP.197010052008012026

Pembimbing Pendamping,

Dr. Eng. Rini Novrianti Sutarjo Tui, S.T., M.BA., M.T.
NIP. 198311142014042001

Ketua Program Studi,

Dr. Aryanti Virtanti Anas, S.T., M.T.
NIP. 197010052008012026

STATEMENT OF AUTHENTICITY

The undersigned below:

Name	: Muhram Sula Idris
NIM	: D111171503
Study Program	: Mining Engineering Department
Degree	: Bachelor (S1)

Declare that my bachelor thesis titled,

Application of The Fuzzy Mamdani Method to Predict the Amount of Marble Production at PT Wutama Tri Makmur, South Sulawesi Province

is my own writing and not a claim of others. The Thesis which I wrote is really my own work. If in the future, it is proven or can be proven that a part or a whole of this thesis is the work of others, I am willing to accept any penalty for such act.

Makassar, 25 June 2024

The declarer

Muhram Sula Idris

ABSTRACT

MUHRAM SULA IDRIS. *Application of The Fuzzy Mamdani Method to Predict The Amount of Marble Production at PT Wutama Tri Makmur, South Sulawesi Province* (supervised by Aryanti Virtanti Anas and Rini Novrianti Sutardjo Tui)

Marble can be used in homes for furniture, building components such as floors, tables, bathrooms, windows. Apart from that, marble can also be used as raw material for making trophies, statues, inscriptions, name plates, vandels, etc. Based on marble mining data by PT. Wutama Tri Makmur from 2015 - 2021 experienced excess production, causing the stockpile to be full and unable to accommodate any more marble. Using this research, marble production can be predicted for more efficient mining so as not to exceed stockpile capacity. This research applies the Fuzzy Mamdani method which is calculated using the Python programming language. application of the Mamdani fuzzy method to predict the amount of marble production through several stages, namely fuzzification, implication, rule composition and defuzzification. After several results have been predicted, the accuracy of the application of the fuzzy Mamdani method is then calculated to determine the percentage of error in the calculation of the fuzzy Mamdani method using MAPE. Based on the MAPE results, the calculation error using the fuzzy mamdani method is 11.1% and the calculation accuracy of the fuzzy mamdani method is 88.9%.

Keywords: Supply, Demand, Production, Fuzzy Mamdani, Python, MAPE.

ABSTRAK

MUHRAM SULA IDRIS. *Penerapan Metode Fuzzy Mamdani untuk Memprediksi Jumlah Produksi Marmer di PT Wutama Tri Makmur Provinsi Sulawesi Selatan* (dibimbing oleh Aryanti Virtanti Anas dan Rini Novrianti Sutardjo Tui)

Marmer dapat digunakan pada rumah untuk furniture, komponen bangunan seperti lantai, meja, kamar mandi, jendela. Selain itu marmer juga dapat digunakan sebagai bahan baku pembuatan piala, patung, prasasti, papan nama, vandel, dll. Berdasarkan data penambangan marmer yang dilakukan PT. Wutama Tri Makmur pada tahun 2015 - 2021 mengalami kelebihan produksi sehingga menyebabkan stockpile penuh dan tidak mampu menampung marmer lagi. Dengan penelitian tersebut, produksi marmer dapat diprediksi lebih efisien dalam penambangannya sehingga tidak melebihi kapasitas stockpile. Penelitian ini menerapkan metode Fuzzy Mamdani yang perhitungannya menggunakan bahasa pemrograman Python. penerapan metode fuzzy Mamdani untuk memprediksi jumlah produksi marmer melalui beberapa tahapan yaitu fuzzyfikasi, implikasi, komposisi aturan dan defuzzyfikasi. Setelah beberapa hasil diprediksi, selanjutnya dihitung keakuratan penerapan metode fuzzy Mamdani untuk mengetahui persentase kesalahan dalam perhitungan metode fuzzy Mamdani menggunakan MAPE. Berdasarkan hasil MAPE, kesalahan perhitungan menggunakan metode fuzzy mamdani sebesar 11,1% dan keakuratan perhitungan metode fuzzy mamdani sebesar 88,9%.

Kata Kunci: Penawaran, Permintaan, Produksi, Fuzzy Mamdani, Python, MAPE.

PREFACE

First and fore most my gratefulness to Allah SWT for His blessing, the writer can complete this thesis entitled "Application of The Fuzzy Mamdani to Predict The Amount of Marble Production at PT. Wutama Tri Makmur, South Sulawesi Province ".

Throughout the writing of this research, I have received many supports and assistance. My high gratitude to Mining Engineering Department Head of Hasanuddin University Dr. Aryanti Virtanti Anas, S.T., M.T. and also as my main thesis supervisor and co-thesis supervisor Dr. Eng. Rini Novrianti Sutardjo Tui, S.T., M.BA., M.T. and also I would like to thank all of my examiners Dr. Ir. Irzal Nur, M.T. and Rizki Amalia S.T., M.T. Their immense knowledge and plentiful experiences have helped and encouraged me in my academic year, thesis drafting and daily life.

I would like to express big thank to all members of CONTINUITY especially Yubelium Andrew Patila, Akmal Fauzi, Ryan Pratama and group leader Ibnu Syauqi Ramadhan and special thanks to all of PVT members. Their thoughts, experiences, presence, and stories permeate every year of my academic life.

A big gratitude to my parents who motivate me, give me the passion about future. I would also to thank all of my close friends, especially Sarah Alya Fauzyyah who give me more outlook about passion and consistency that makes me become wiser.

I hope this thesis can participate in development and advancement of science.

Gowa, June 2024

Muhram Sula Idris

TABLE OF CONTENT

Page

LEGALIZATION ii

LEMBAR PENGESAHAN SKRIPSI iii

STATEMENT OF AUTHENTICITY iv

ABSTRACT v

ABSTRAK vi

PREFACE vii

TABLE OF CONTENT viii

LIST OF PICTURE x

LIST OF TABLE xi

LIST OF APPENDICES xii

CHAPTER I INTRODUCTION 1

1.1 Background 1

1.2 Research Problem 2

1.3 Research Purpose 3

1.4 Research Advantage 3

1.5 Research Stages 3

1.6 Research Location 4

CHAPTER II PRODUCTION QUANTITY PREDICTION USING FUZZY MAMDANI IN PYTHON 5

2.1 Supply 5

2.2 Demand 5

Forecasting 6

Fuzzy Theory 6

Fuzzy Mamdani 8

2.6 Python 11

2.7 Fuzzy in Python 12

2.8 Mean Absolute Percentage Error (MAPE) 28

CHAPTER III RESEARCH METHODS 29

3.1 Data Collection 29

3.2 Data Processing 30

CHAPTER IV APPLICATION OF THE FUZZY MAMDANI TO PREDICT THE AMOUNT OF MARBLE PRODUCTION 34

4.1 Fuzzy Mamdani using The Python Programming 34

4.2 Predicting The Amount of Marble Production Using The Python Programming 44

4.3 Mean Absolute Percentage Error (MAPE) 45

CHAPTER V CONCLUSION 46

5.1 Conclusion 46

5.2 Suggestion 46

REFERENCES 47

LIST OF PICTURE

Page

Figure 2.1 Membership function of triangular fuzzy numbers (Nozari et al., 2019)....................7

Figure 2.2 Hard computing versus soft computing (Himanshu and Yunis, 2020).....................13

Figure 2.3 Simple Venn diagram (Himanshu and Yunis, 2020)...14

Figure 2.4 Difference between crisp set and fuzzy set (Himanshu and Yunis, 2020)................16

Figure 2.5 Triangular membership function (Himanshu and Yunis, 2020). 17

Figure 2.6 Trapezoidal membership function (Himanshu and Yunis, 2020). 18

Figure 2.7 Curve showing all the rating points as specific values (Himanshu and Yunis, 2020). 20

Figure 2.8 Triangular membership of the soccer example (Himanshu and Yunis, 2020)..........23

Figure 2.9 Trapezoidal membership of the soccer example (Himanshu and Yunis, 2020).........25

Figure 2.10 Fuzzy Inference System process (Himanshu and Yunis, 2020)..............................27

Figure 3.1 Flowchart of Research 33

Figure 4.1 Fuzzification using the python programming..37

Figure 4.2 Fuzzification result of supply marble...38

Figure 4.3 Fuzzification result of demand marble...38

Figure 4.4 Fuzzification result of production marble 39

Figure 4.5 Implications using the python programming...42

Figure 4.6 Aggregated result of implications 43

Figure 4.7 Defuzzification using the python programming..43

LIST OF TABLE

Page

Table 1.1 Coordinate Data of PT Wutama Tri Makmur Marble Production Operation IUP Area 4

Table 4.1 Implication result of supply and demand..39

Table 4.2 Mamdani fuzzy calculations based on 2019 PT Wutama Tri Makmur data 44

LIST OF APPENDICES

Page

A. WIUP Map of PT Wutama Tri Makmur....................50

B. Supply, Demand and Production Data....................52

C. Fuzzy Mamdani Coding....................55

CHAPTER I

INTRODUCTION

1.1 Background

Marble is one of the metamorphic rocks with high economic value that can be widely used, starting as a floor, patch stone, or decorative stone, until it is used in carvings and chisels (Haty, 2011). Marble products are a supporting product or component that are closely related to the development sector in Indonesia in general and particularly in projects in housing, buildings, and other buildings (Wibowo, 2016). Recommendations for the use of marble based on thickness are used as floors with a size of ≤10-40 cm. Based on geochemistry it is used as a material for the paper industry, textile coloring, pesticide production, sugar filtering, and cement production, and based on its engineering it is used as a floor with a live load of >250 kg/cm^2, brickwork for deep construction, and light-medium building foundations (Kurniawati and Titisari, 2019).

Companies engaged in the marble industry are faced with a problem, which is the existence of such a competitive level of competition. This requires companies to plan or determine the amount of production, in order to meet market demand in a timely manner and with the appropriate amount. PT Wutama Tri Makmur experienced a decreasing in demand for marble in 2020 with an average decline of 94% from 2019 due to the corona 19 pandemic. It caused the marble stockpile at PT Wutama Tri Makmur in early 2021 to be almost full, based on these problems, this research is conducted to be able to manage the amount of marble stone production according to the amount of marble available in the stockpile and the amount of consumer demand for marble. There are the company's profit is expected to be maximized.

Maximum profit is obtained from maximum sales. Maximum sales indicate that the company can meet existing demands. If the number of products produced by the company is less [illegible] number of requests, the company will lose the opportunity to get maximum profit. [illegible]y, if the number of products produced is much more than the number of requests, the [illegible] will experience a loss (Abrori and Prihamayu, 2015). Therefore, planning the number of products in a company is very important in order to meet market demand appropriately and in the appropriate amount.

In determining the amount of marble production can use the fuzzy Mamdani method. Fuzzy logic is a science that can analyze uncertainty (Abrori and Prihamayu, 2015). Fuzzy logic is a problem-solving control system methodology, which is suitable to be implemented in simple systems, embedded systems, PC networks, multichannel or workstation-based data acquisition, and control systems. This methodology can be applied to hardware, software, or a combination of both. In classical logic it is stated that everything is binary, which means that it has only two possibilities, "Yes or No", "True or False", "Good or Bad", and so on. Therefore, all of these can have a membership value of 0 or 1. However, in fuzzy logic the probability of membership value is between 0 and 1. This means that a situation may have two values "Yes and No", "True and False", "Good and Bad" simultaneously, but the value depends on the fuzzy set operation (Sukandy et al., 2014).

The fuzzy logic of the Mamdani method is applied to manage the amount of marble production of PT Wutama Tri Makmur. The fuzzy logic of the Mamdani method can predict the amount of marble production per month in 2021 by PT Wutama Tri Makmur. Fuzzy Mamdani method is used because at the analysis stage it can be done based on supply and demand data which is the main problem for PT Wutama Tri Makmur. The purpose of this study was to use of the application of fuzzy logic Mamdani method in making decisions about the amount of marble production based on inventory data and the number of requests.

1.2 Research Problem

PT Wutama Tri Makmur experienced a decline in profits due to a lack of consumers during the corona 19 pandemic. The production of PT Wutama Tri Makmur is not proportional nber of consumers which results in the company's inventory being almost full. The oduction process requires careful planning so that the amount of production is not or not too little to maintain stability between sales, supply, and total demand. Planning r of products in a company is very important to meet market demand appropriately and appropriately, thus this research statements is how to predict the production of marble by using the fuzzy logic of the Mamdani method.

1.3 Research Purpose

Based on research problem, the objectives of this research are as follows:

1. to predict the production of marble by using the fuzzy logic of the Mamdani method in making the decision to determine the amount of production based on the supply and demand data of marble.
2. to calculate the accuracy of the Mamdani method by using MAPE based on actual production results and predicted production results.

1.4 Research Advantage

The advantage of this research is provide input for production management at PT Wutama Tri Makmur to maintain between sales, supply, and total demand. Predict the amount of marble production based on supply data and the amount of demand.

1.5 Research Stages

The research activity was carried out at the mining site of PT Wutama Tri Makmur. The data collection process was carried out on January 11, 2021 – April 3, 2021. This study focuses on predicting the amount of marble production using the fuzzy mamdani method. The research is also supported by several literatures, both books and journals related to the title of the proposed research, as well as additional information in the form of experience from expert practitioners in the field. The research stages consist of:

1. Data collection

   The research data collection was obtained directly with the company's permission as ference data for analyzing problems from related research. The data collected in this ıdy were in the form of marble production data for the last five years, as well as ›servations at the PT Wutama Tri Makmur stockpile.

2. Data processing and analysis

   The data collected is processed to calculate the prediction of the amount of marble production using the fuzzy mamdani method in the python 3.9.7 application. The result of the fuzzy mamdani method is the prediction of the amount of marble production that can be mined by PT Wutama Tri Makmur.

1.6 Research Location

Marble production mining permit area of PT Wutama Tri Makmur area of 46 ha. located in Bontoa Village, Minasate'ne District, Pangkep Regency, South Sulawesi Province. Geographically it is limited by 119°35’38,30” east longitude – 119°36’15,10” east longitude and 04°48’20,10” south longitude – 04°48’53,80” south longitude. The research location can be seen in Appendix A.

The coordinate data or the boundary point of the mining business permit area can be seen in Table 1.1 as follows.

Table 1.1 Coordinate Data of PT Wutama Tri Makmur Marble Production Operation IUP Area

Benchmark Number	East Longitude			South Longitude			Description
	Degree (°)	Minute (')	Second (")	Degree (°)	Minute (')	Second (")	
A	119	35	38,30	4	48	20,10	
B	119	35	51,30	4	48	20,10	
C	119	35	51,30	4	48	44,70	
D	119	36	15,10	4	48	44,70	Large =
E	119	36	15,10	4	48	53,80	± 46 Ha
F	119	36	00,10	4	48	53,80	
G	119	36	00,10	4	48	47,30	
H	119	35	30,30	4	48	47,30	

CHAPTER II

PRODUCTION QUANTITY PREDICTION USING FUZZY MAMDANI IN PYTHON

2.1 Supply

The demand for goods and services that are not accompanied by the supply of goods and services cannot carry out transactions in the market. The new demand can be fulfilled if the producer or seller provides the goods or services needed by these consumers. So supply can be interpreted as various quantities of a certain item where a seller is willing to offer his goods or services at various price levels (Akhmad, 2014).

Many things determine the quantity supplied of an item, but when we analyze how the market works, one of the determinants is the price of the good. Since the quantity supplied increases as the price increases, it can be said that the quantity supplied is positively related to the price level. This relationship between price and quantity supplied applies to most types of goods in the economy, so it is called the law of supply (The low of supply). If all things are assumed to be the same, when the price of an item increases, the amount offered will also increase, on the other hand, when the price of the goods decreases, the amount offered will also decrease (Akhmad, 2014).

2.2 Demand

Demand can be defined as the quantity of a particular good that a consumer wants and is able to buy at various price levels. The demand relationship only shows a theoretical relationship between price and quantity purchased per unit of time. The law of demand (The low of demand) is essentially a hypothesis which states: The relationship between the goods demanded and the [illegible]e goods where the relationship is inversely proportional, i.e. when the price increases [illegible]es, the quantity of goods demanded will decrease and vice versa if the price decreases, then the number of goods demanded increases. The amount of demand (quantity demand) of an item is the amount of goods the buyer is willing and able to pay (Akhmad, 2014).

2.3 Forecasting

Prediction is one of the types of data mining if the classification is based on its use. Prediction is essentially the same as classification or estimation but is more directed at values in the future. In prediction, the processed data is historical data which is used as reference data plus simulation data which can be changed according to the possibilities that may occur (Bukhori, 2017).

Prediction is knowing the approximate value of an item in the future. The difference between prediction, forecasting is prediction can be done both qualitatively and quantitatively. Qualitative predictions are predictions based on a party's opinion (judgment forcast) and quantitative predictions are predictions based on past data (historical data) and can be made in the form of numbers which are commonly referred to as time series data. Quantitative predictions are nothing but predictions while qualitative predictions are forecasting, forecasting is seen as a process of predicting future variables based on the data of the relevant variables in the past. Past data are systematically combined through certain methods and processed for future conditions (Jumingan, 2009).

2.4 Fuzzy Theory

Most decisions in the real world are inaccurate due to the inaccuracy of understanding the goals, constraints, and possible actions. In light of a fuzzy environment, when a decision is made the results are highly influenced by personal judgments that can be ambiguous and inaccurate. Inaccurate sources can include non-quantifiable information, incomplete information, inaccessible information, and partial ignorance. In order to find out a way to solve the problem of [illegible]uracy, fuzzy set theory as a mathematical tool was proposed by Zadeh in 1965 to deal [illegible]mation uncertainty in decision making process. Since then, this theory has been well [illegible] and has found many successful applications (Nozari et al., 2019).

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 (Zadeh, 1965). In fuzzy logic, any number between 0 and 1 represents a part of truth, while in definite sets working with binary logic only two values of 0 and 1 are available. Thus, fuzzy logic can express inaccurate and imprecise judgments and act mathematically with them. Utilizing the conventional quantification make it difficult to express reasonably the very complicated situations, so using the linguistic variable concept is necessary in such situations. A linguistic variable is a variable whose value has the form of a phrase or sentence in natural language. Linguistic variables are also very functional in dealing with situations described in quantitative terms because these variables' values are linguistic expressions instead of numbers. In practice, linguistic values can be represented using fuzzy numbers, the most common of which are triangular fuzzy numbers (TFN). A triangular fuzzy number $\tilde{A}$ is defined by [(L, M, U)] where L and U are respectively top and bottom boundary of $\tilde{A}$ as shown in Figure 2.1 (Nozari et al., 2019).

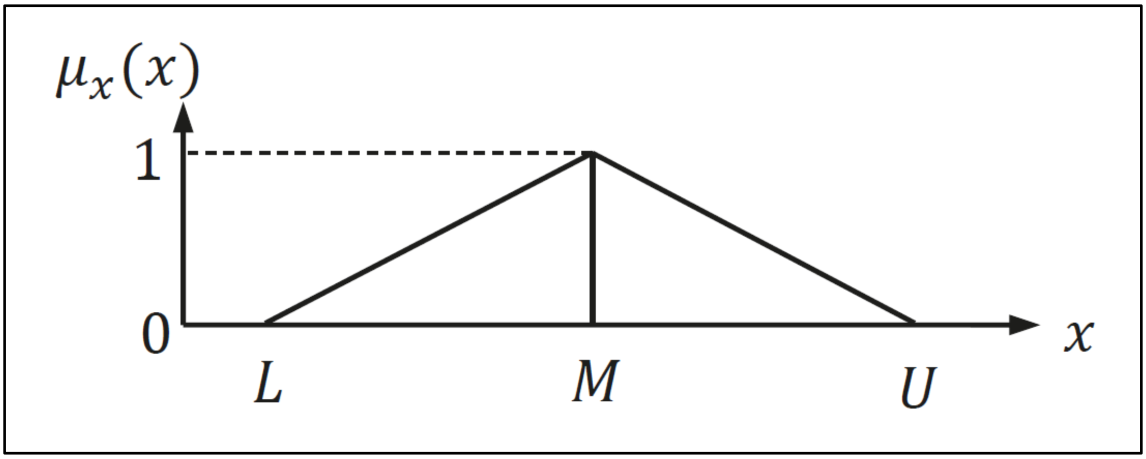


Figure 2.1 Membership function of triangular fuzzy numbers (Nozari et al., 2019).

Fuzzy Inferece System has 3 basic structure that is Rule Base which is used to do selection to fuzzy rule. The database, this component is used to define the membership value of the fuzzy
e reasoning mechanism used to generate the output of the operations performed on the
Basically the input given on the fuzzy inference system is in the form of a firm set and

will produce the output of a fuzzy set depending on the situation where the fuzzy inference system is used (Harliana and Rahim, 2017).

Generally, there are three types of fuzzy inference system, they are Mamdani, Sugeno, and Tsukamoto. All of these three methods can be divided into two processes. The first process is fuzzifying the crisp values of input variables into membership values according to appropriate fuzzy sets, and these three methods are exactly the same in this process. While the differences occur in the second process when the results of all rules are integrated into a single precise value for output. Mamdani is often known as the Max-min method. This method was introduced by Ebrahim Mamdani in 1975. To get the output required 4 stages are the establishment of the fuzzy set: definition of the fuzzy set and the determination of the degree of membership of the input crisp on a fuzzy set, application function implication: evaluation of rules fuzzy to generate output from each rule, composition rule: aggregation or combination of outputs of all rules, defuzzification: calculation of output crisp. The reasoning with the Sugeno method is almost the same as the Mamdani method, only the output system is not a fuzzy set, but rather a constant or a linear equation. Then a weighting mechanism is implemented to work out the final crisp output (Harliana and Rahim, 2017).

2.5 Fuzzy Mamdani

Techniques from the field of artificial intelligence may be usefully employed to control a complex, nonlinear dynamic plant. Although such plants may be difficult to control manually, it may be possible to control them by means of a suitable heuristic program. The effectiveness of such programs has been demonstrated in chess playing and theorem proving etc. These programs may be very complex and hence difficult to construct, and may also take a long time to evaluate decisions. Thus, they have not often been applied to control a dynamic plant, although, in theory, be possible to do so. On the other hand 'learning' controllers have been widely studied, of these have indeed been based on fuzzy set theory. These controllers are similar to cognisers in that their structure is postulated first, and this is then evaluated with respect tion and convergence properties. The purpose of a heuristic program is to implement a 'rule-of-thumb' function of a controller, and, consequently, it may lack structure and generality (Mamdani et al, 1974).

Zadeh's approach, based on fuzzy sets and fuzzy algorithms, provides a general method of expressing linguistic rules so that they may be processed quickly by a computer. At the same time, it is usually possible for an experienced operator to express the strategy or protocol for controlling a plant, using linguistic variables, as a set of rules to be used in the different situations. Thus, a control algorithm may be constructed so that its operation does not depend on the rules being expressed exhaustively, and so that its performance is adequately logged, which may provide clues for subsequent addition to or change of the rules (Mamdani et al, 1974).

Fuzzy Logic utilizes the area between 0 and 1 which is not known in Binary Logic, or in other words 0 and 1 is Binary Logic, while 0 to 1 is fuzzy Logic. Areas between 0 and 1 in the Faint Logic are gray areas, or faint areas, or indistinct areas with a range of 0 percent to 100 percent (Irsan et al., 2019). Fuzzy logic is the study of uncertainty. In fuzzy system theory, a fuzzy system concept is known which is used in the prediction process. One of the methods he uses is the Mamdani method (Rahakbauw et al., 2019). The mamdani method is often known as the max-min method. This method was introduced by Ebrahim Mamdani in 1975 (Kartika et al., 2018).

The Mamdani method is a method that is also often known as the MAX-MIN or MAX-PRODUCT method. The prediction process for the mamdani method has four stages, namely (Rahakbauw et al., 2019):

1. Fuzzy set

   Fuzzy set operations are required for the inference or reasoning process. In this case what is operated is the degree of its membership. There are several things that are the basis for understanding fuzzy logic, including (Sukandy et al., 2014):

   a. Fuzzy variables, namely variables to be discussed in a fuzzy system.

b. Fuzzy set, which is a group that represents a certain condition in a fuzzy variable. The fuzzy set has 2 attributes, namely (Abrori and Prihamayu, 2015):

   a) Linguistics, namely naming a group that represents a certain situation or condition using natural language, such as: Young, Mage, Old.

   b) Numerical, which is a value (number) that indicates the size of a variable such as: 40, 25, 50, and so on.

c. The universe of speech, namely all values that are allowed to be operated in a fuzzy variable.

d. Fuzzy set domain, namely all values allowed in the universe of speech and may be operated in a fuzzy set.

The equation for the fuzzy set is (Rahakbauw et al., 2019):

$$\mu_A(x) = \begin{cases} 1, & if\ x\ \in A \\ 0, & if\ x\ \notin\ A\ or\ x\ \in A \end{cases} \qquad (2.1)$$

where μ_A is a function from x (1,0) (Rahakbauw et al., 2019)**.**

2. Implication

   The general form of the rules used in the implication function is (Abrori and Prihamayu, 2015):

$$IF\ \ x\ \ is\ \ A\ \ THEN\ \ y\ \ is\ \ B \qquad (2.2)$$

   Where x and y are scalars, and A and B are fuzzy sets. The proportion that follows IF is referred to as an antecedent, while the proportion that follows THEN is referred to as consequent (Abrori and Prihamayu, 2015).

3. Composition rules

   The composition of the rules is an overall conclusion by taking the minimum membership level from each consequent application of the implication function by combining all the conclusions of each rule (Rahakbauw et al., 2019). The equation for the fuzzy set is (Sukandy 2014):

$$\mu_{A\cap B}\ = min[\mu_A(x), \mu_A(x)] \qquad (2.3)$$

Where A and B are fuzzy sets of x, where shown as the degree of membership of the $A \cap B$ is the result obtained by sharing the award between elements in the sets in question.

4. Defuzzification

Defuzzification or also called the affirmation stage, which is to convert fuzzy sets into real numbers. The input of this affirmation process is a fuzzy set obtained from the composition of fuzzy rules, while the resulting output is a number in the domain of the fuzzy set. The defuzzification used in determining production quantities is using the centroid method. The following is the defuzzification calculation using the centroid method (Rahakbauw et al., 2019):

$$y^* = \frac{\sum \mu_r(y)dy}{\sum \mu_r(y)} \quad \text{.. (2.4)}$$

2.6 Python

Python was developed by Guido van Rossum in 1990 at CWI, Amsterdam as a continuation of the ABC programming language. Python is a multipurpose interpretive programming language with a design philosophy that focuses on code readability. Python is claimed to be a language that combines capabilities, capabilities, with a very clear code syntax, and is equipped with a large and comprehensive standard library functionality. One of the features available in python is as a dynamic programming language that is equipped with automatic memory management. As in other dynamic programming languages, python is generally used as a scripting language although in practice the use of this language includes more contexts of use that are generally not done using scripting languages. Python can be used for various software development purposes and can run on various operating system platforms. Currently, python code can be run on various operating system platforms, including (Supardi, 2020):

1. Linux/Unix

ws

S X

irtual machine

5. OS/2
6. Amiga
7. Palm
8. Symbian (for Nokia products)

2.6.1 The Basic Elements of Python

A Python program, sometimes called a script, is a sequence of definitions and commands. These definitions are evaluated and the commands are executed by the Python interpreter in something called the shell. Typically, a new shell is created whenever execution of a program begins. A command, often called a statement, instructs the interpreter to do something. For example, the statement (Guttag, 2017):

```
print('Yankees rule!')
```

instructs the interpreter to call the function print, which will output the string:

```
Yankees rule!
```

to the window associated with the shell. Another example, the sequence of commands (Guttag, 2017):

```
print('Yankees rule!')
print('But not in Boston!')
print('Yankees rule,', 'but not in Boston!')
```

causes the interpreter to produce the output

```
Yankees rule!
But not in Boston!
Yankees rule, but not in Boston!
```

2.7 Fuzzy in Python

'hen you have crisply defined data that is precise and easy to understand, applying hard ; to it is perfect. Hard computing is based on binary logic, classical sets, crisp (precise) ıd software, basic numerical analysis, etc. But when you try to apply this same approach rld problems that include imprecise data maybe the dataset is partially true, it has a lot of approximations, and so on—hard computing fails. The best way to tackle this situation is to use the soft computing approach (Himanshu and Yunis, 2020).

A very basic example is 2+2. In this scenario, you can use hard computing to arrive at 4. But when you change the equation to 2+x, where x ranges from 0 to 5, soft computing always gives better results. Before you move on to understanding exactly what soft computing is, study the flowchart in Figure 2.2. It depicts the difference between hard and soft computing when it comes to problem solving (Himanshu and Yunis, 2020).

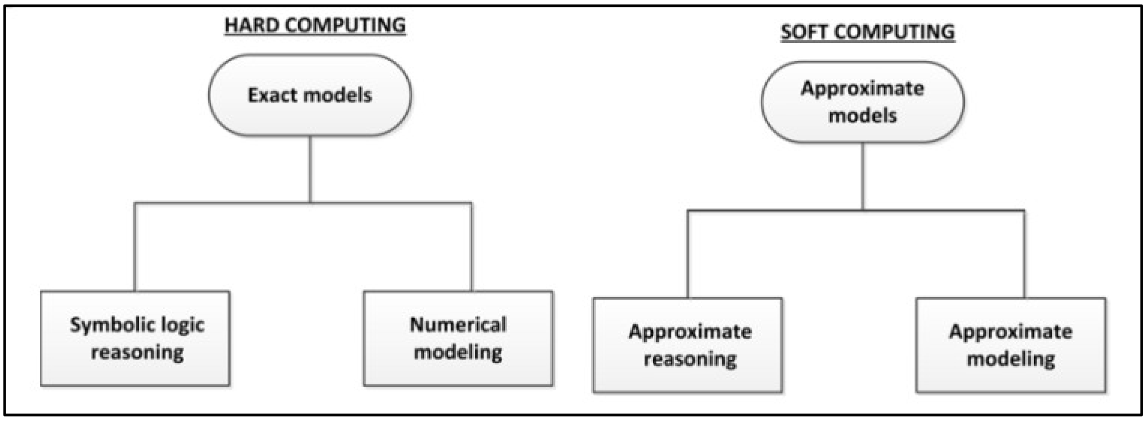


Figure 2.2 Hard computing versus soft computing (Himanshu and Yunis, 2020).

Soft computing tries to imitate the human mind in order to make decisions. These models have cognitive abilities, which include (Himanshu and Yunis, 2020):

1. Ability to think,
2. Ability to reason,
3. Ability to organize,
4. Ability to memorize,
5. Ability to recognize,
6. Ability to process

When your data is imprecise (it has partial truths and is full of approximations), soft [...] is the best approach. The following are features of soft computing-based problem-[...]proaches (Himanshu and Yunis, 2020):

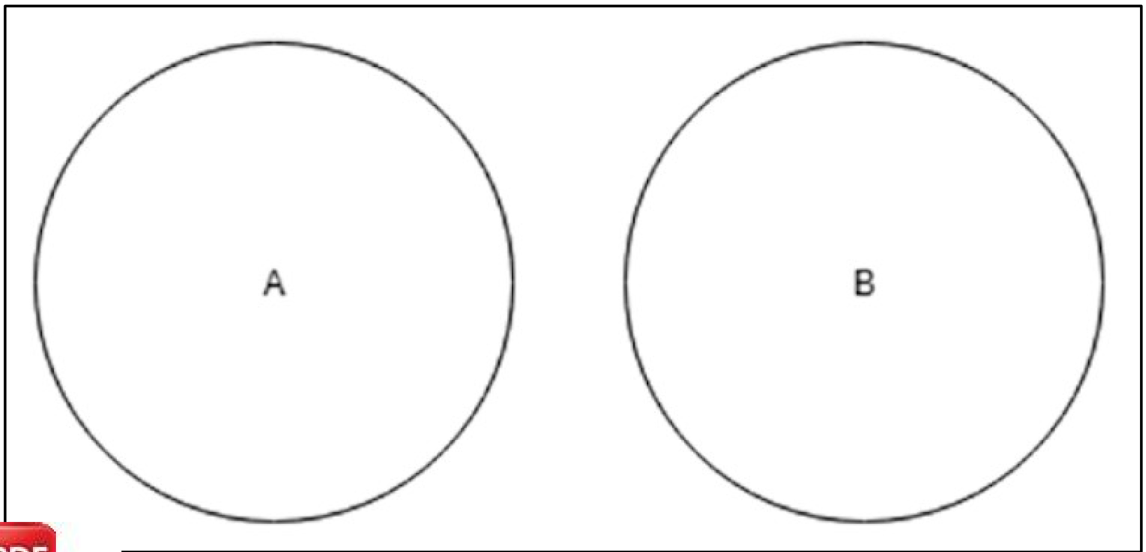
1. Biologically inspired,
2. Fault tolerant,
3. Full of optimizations,
4. Helps make wiser and more intelligent machines,
5. Helps in achieving robustness, tractability, and lower costs,
6. Heavy computation
7. Goal driven

2.7.1 Classical Sets

Classical sets, also called crisp sets, are a collection of objects. Objects can be anything belonging in the real world, and sometimes outside the domain as well. For example (Himanshu and Yunis, 2020):

```
Cars = {Audi, BMW, Mercedes, Porsche}
```

This set shows a list of premium cars. You denote a set by using the curly braces, {}. Once you have effectively defined different sets, you can visualize them as well. A Venn diagram is a visual way to represent sets and their relationships with each other. Figure 2.3 shows a normal Venn diagram (Himanshu and Yunis, 2020).



Simple Venn diagram (Himanshu and Yunis, 2020).

The circles in Figure 2.3 represent two sets, A and B. All the elements that are part of Set A will be present in Circle A, while all the elements that are part of Set B will be present in Circle B. The circles are called Venn diagrams of Set A and Set B (Himanshu and Yunis, 2020).

2.7.2 Fuzzy Sets

Classical sets involve exactly defined values. This means that the Universe of Discourse is split into two groups—members and non-members. Therefore, you cannot say that any member has a partial membership. For example, if you are pressing brakes or releasing them, these processes can be represented by 1 or 0. With Fuzzy Sets, on the other hand, you can have values in between as well. Therefore, you can say that the Fuzzy Sets have a degree of membership between 0 and 1. For example, you can have values like {0, 0.3, 0.5, 0.7, 1}. The 1 means a full brake, 0.7 means a little less brake, 0.5 means half the pressure, 0.3 means very little pressure, and 0 means no pressure. In the real world, you rarely see classical sets in action. You deal with the values represented by Fuzzy Sets (Himanshu and Yunis, 2020).

2.7.3 Membership Function

In the previous section, you learned that instead of having crisp values of 0 and 1, each element can be mapped to a value between 0 and 1. Each value is called the degree of membership and is represented by a curve, which depicts a function called a membership function. The value is called the membership value. In Figure 2.4, you can see the difference between crisp and Fuzzy Sets (Himanshu and Yunis, 2020).

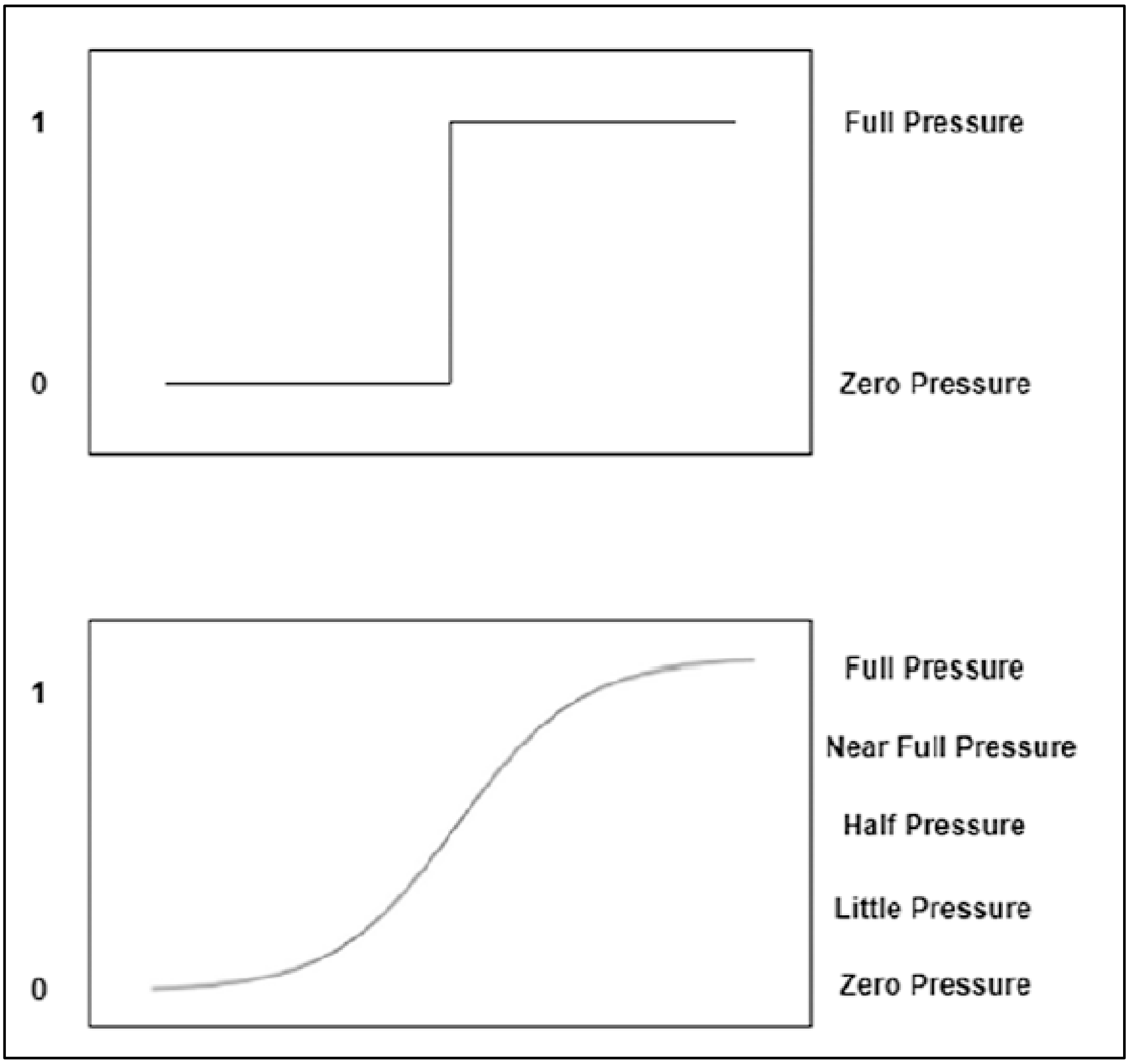


Figure 2.4 Difference between crisp set and fuzzy set (Himanshu and Yunis, 2020).

In a crisp set, you only have two values, represented by 0 and 1, but in a Fuzzy Set, there is a range of values, based on the pressure at which the breaks are applied. The curve representing the range is the membership function curve. With a different pressure, a different membership value will be present, and that can be represented in the membership function curve (Himanshu and Yunis, 2020).

A Fuzzy Set is an extension and gross oversimplification of a classical set. If x is the Universe of Discourse and its elements are denoted by x, then a Fuzzy Set A in x is defined as a [illegible]ered pairs (Himanshu and Yunis, 2020).

$$A = \{x, \mu A(x) | x \varepsilon X\} \qquad (2.5)$$

$\mu A(x)$ is called the membership function of x in A. The membership function maps each element of x to a membership value between 0 and 1. There are different types of membership functions, which are covered in detail in the next chapter. For now, let's list some of them and look at the curves that they represent. This example uses the Scikit Fuzzy package, which has multiple methods and classes, so that you can apply the basic Fuzzy Operations effectively. You can use the following line to install the Scikit Fuzzy package in the Python environment (Himanshu and Yunis, 2020):

```
pip install scikit - fuzzy
```

Figures 1-10 through 1-14 show the different types of membership functions and the curves that they represent (Himanshu and Yunis, 2020).

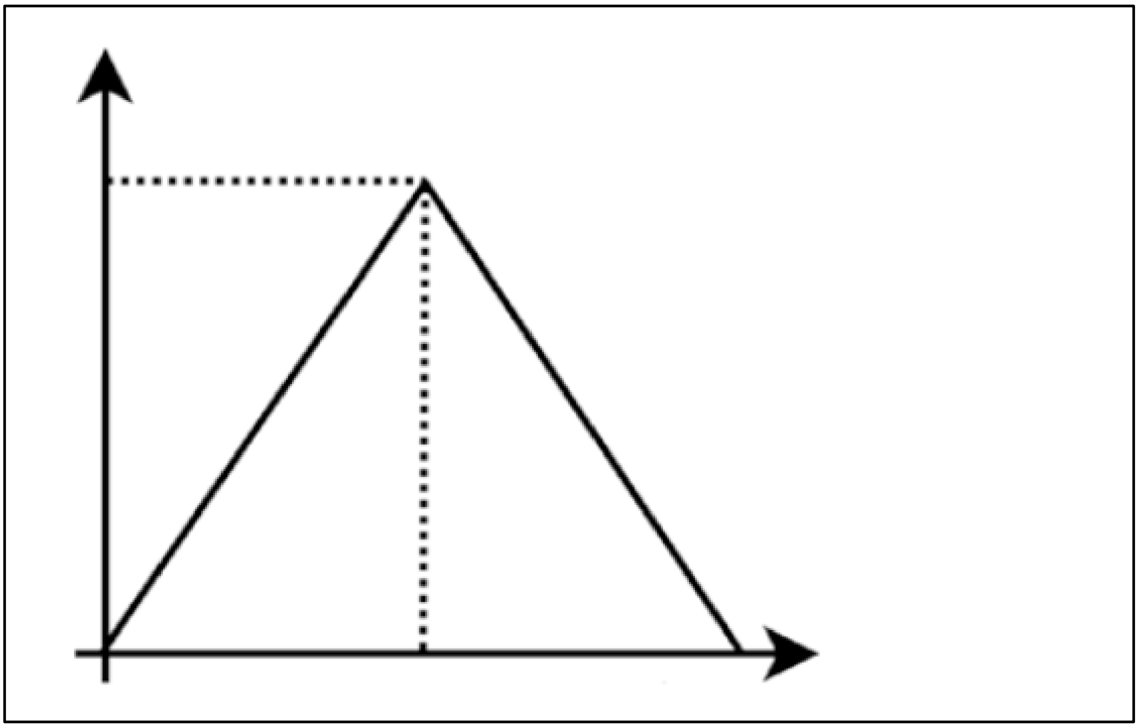


Figure 2.5 Triangular membership function (Himanshu and Yunis, 2020).

The graph in Figure 2.5 represents a triangular membership function, and you can use the trimf method from the skfuzzy package to find and plot the points. Here is the sample code. The
er discusses this function in detail. The following code takes an example where a person
a restaurant and tips a waiter. For tipping purposes, the quality of service is rated from

0 to 10. This example looks only at the service quality for now but later it will discuss the actual tipping problem (Himanshu and Yunis, 2020):

```
import numpy as np
import skfuzzy as sk
```

Defining the Numpy array for Tip Quality:

```
x_qual = np.arange(0, 11, 1)
```

Defining the Numpy array for Triangular membership functions:

```
qual_lo = sk.trimf(x_qual, [0, 0, 5])
```

The graph in Figure 2.6 represents a trapezoidal membership function, and you can use the trapmf method from the skfuzzy package to find and plot the points (Himanshu and Yunis, 2020).

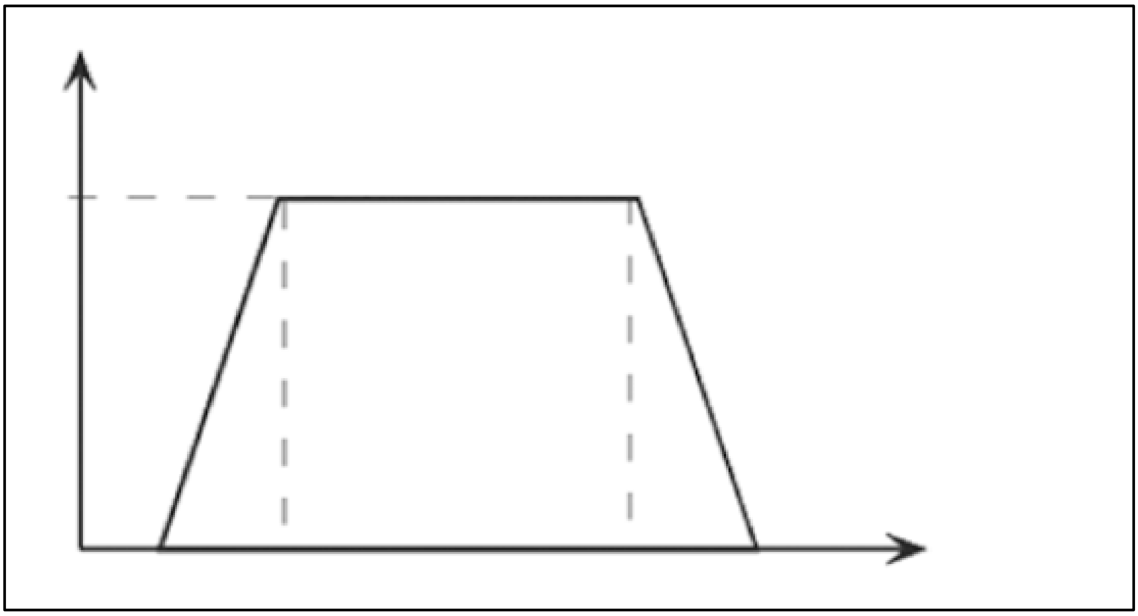


Figure 2.6 Trapezoidal membership function (Himanshu and Yunis, 2020).

Here is the sample code:

```
import numpy as np
import skfuzzy as sk
```

D... the Numpy array for Tip Quality:

```
_qual = np.arange(0, 11, 1)
```

he Numpy array for Trapezoidal membership functions:

```
ual_lo = sk.trapmf(x_qual, [0, 0, 5,5])
```

Membership functions represent the degree of truth of a member in a defined Fuzzy Set. They are curves that define how each point in the input space is mapped to a degree of membership lying between 0 and 1. You may understand this better with the help of an example. Suppose you want to rate the service of a particular restaurant. You might rate the service in the following ways (Himanshu and Yunis, 2020):

```
Awesome
Average
Worst
```

In classical sets, this can be represented as follows:

$$X = \{'Awesome,' Average, 'Worst\} \quad (2.6)$$

This can be coded and represented as X = {}, where 2 represents Awesome, 1 represents Average, and 0 represents Worst. But you might not want to rate the restaurant in only these three ways. You need different ways for customers to express their sentiments. Therefore, you could add these ratings as well (Himanshu and Yunis, 2020):

```
1. Awesome
2. Nice
3. Good
4. Average
5. OK
6. Poor
7. Worst
```

If you again use a classical set, it will contain a lot of code. Instead, you can define a function wherein each rating has a specific value. This function will allow you to go beyond the ratings. This function has an upper limit and a lower limit. Consider, for example, the sigmoid You learn about all the membership functions in detail, later in this chapter.) The unction has an upper limit of 1 and a lower limit of 0. That means that all the rating will have a value that will fall at a point on that curve (see Figure 2.7).

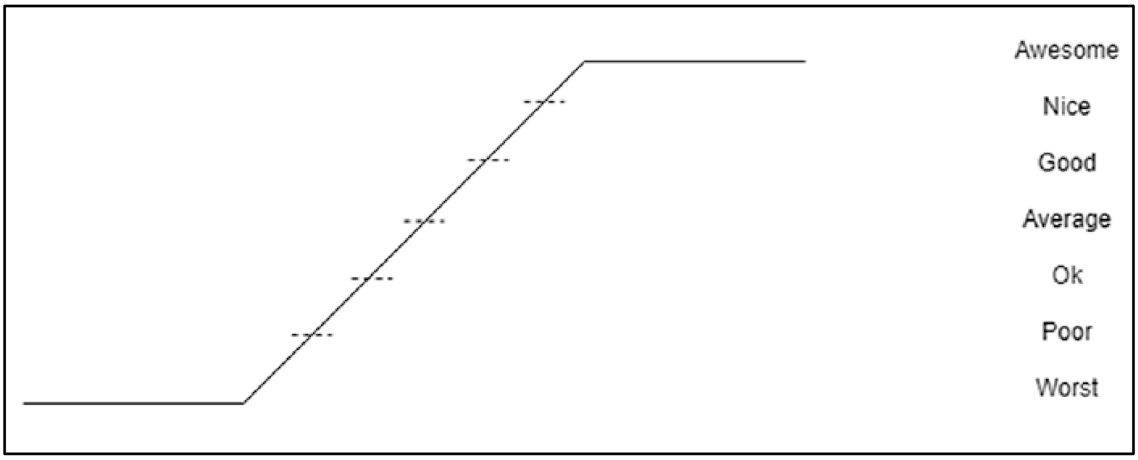


Figure 2.7 Curve showing all the rating points as specific values (Himanshu and Yunis, 2020).

Looking at this curve, you can redefine the crisp set as a Fuzzy Set having values between 0 and 1. Now, if a person gives a rating, the value (membership value) of that rating can be retrieved from the curve. This is what is meant when we say that membership functions represent the degree of truth of a member. You can see in this example that every rating has a value that tells about its degree of truth (Himanshu and Yunis, 2020).

The first chapter covered the different types of membership functions in brief. This section discusses them in detail. A membership function is used to define Fuzziness present in a problem statement. This means that you don't have to represent all the values in a sample space using discrete numbers. Sometimes a member can be a decimal representing its degree of membership (Himanshu and Yunis, 2020).

For example, consider the penalty kick concept in soccer. In discrete terms, the kick can be either 1 (a full kick) or 0 (no kick). In real life, that is not the case. The kick speed depends not only on the mindset of the shooter, but also on the anticipation of where the goalkeeper will move. In this situation, the shooter decides the speed of the kick as well asthe direction in which he aims. Speed also cannot be defined just by two discrete values, 0 and 1. The speed will range from 0 to 1; 0 being no speed and 1 being full speed. Suppose the shooter wants to aim for the top-right he goal post. In this situation, the major decision is finding the most accurate speed that he ball a perfect swing. Too fast and the ball will leave the post, while too slow might oalkeeper anticipate the direction or prevent the ball from swinging properly. Hence, instead of going for 1, the shooter may go for 0.7 from a Fuzzy Set, which according to him is the ideal speed to kick the ball. This concept in a Fuzzy Set is represented by the membership functions (Himanshu and Yunis, 2020).

2.7.4 Triangular Membership Function

Just as a triangle has three coordinates, a triangular membership function has three parameters (Himanshu and Yunis, 2020):

1. a is the lower boundary
2. b is the center
3. c is the upper boundary

The following equation depicts the triangular membership function (Himanshu and Yunis, 2020):

$$f(x;a,b,c) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{c-x}{c-b}, & b \leq x \leq c \\ 0, & c \leq x \end{cases} \quad \text{.....................................} (2.7)$$

This example uses the triangular membership function with a soccer example. Suppose the shooter can take four kinds of penalty shots (Himanshu and Yunis, 2020):

1. Full speed straight shot
2. Medium powered curvy shot
3. Slow straight shot
4. Medium fast left shot

On average, the top speed at which a shooter takes a penalty kick is 80 mph. Therefore, there is no way we can say that this speed is slow. Hence we assign a 0% membership to 80 mph. Similarly, a speed of 60 mph can be considered 70% fast and 30% medium. Likewise, we can assign different memberships to different speeds (Himanshu and Yunis, 2020).

If we use a triangular membership function, it contains three limits: lower, full, and upper. r and upper bounds have a membership of 0% while the full value is 100%. The values tread linearly. We can assign the following triangular membership functions to gories (Himanshu and Yunis, 2020):

1. Full speed as [60, 80, 80]
2. Medium powered as [40, 50, 70]
3. Slow as [20, 20, 45]
4. Medium fast as [50, 60, 80]

For example, if you defined the triangular membership function for "medium powered" as [40, 50, 70], the membership would be 0% at 40 mph, which linearly increases to 100% at 50 mph, and linearly decreases to 0% at 70 mph. The following Python code shows the execution of these triangular membership functions. Figure 2.8 shows the result (Himanshu and Yunis, 2020).

Importing Necessary Packages:

```
import numpy as np

import skfuzzy as fuzz

import matplotlib.pyplot as plt

%matplotlib inline
```

Defining the Fuzzy Range from a speed of 30 to 90:

```
x = np.arange(30, 80, 0.1)
```

Defining the triangular membership functions:

```
slow = fuzz.trimf(x, [30, 30, 50])

medium = fuzz.trimf(x, [30, 50, 70])

medium_fast = fuzz.trimf(x, [50, 60, 80])

full_speed = fuzz.trimf(x, [60, 80, 80])
```

Plotting the Membership Functions Defined:

```
plt.figure()

plt.plot(x, full_speed, 'b', linewidth=1.5, label='Full Speed')

plt.plot(x, medium_fast, 'k', linewidth=1.5, label='Medium Fast')

t(x, medium, 'm', linewidth=1.5, label='Medium Powered')

t(x, slow, 'r', linewidth=1.5, label='Slow')

le('Penalty Kick Fuzzy')
```

```
plt.ylabel('Membership')

plt.xlabel("Speed (Miles Per Hour)")

plt.legend(loc='center right', bbox_to_anchor=(1.25, 0.5),

ncol=1, fancybox=True, shadow=True)
```

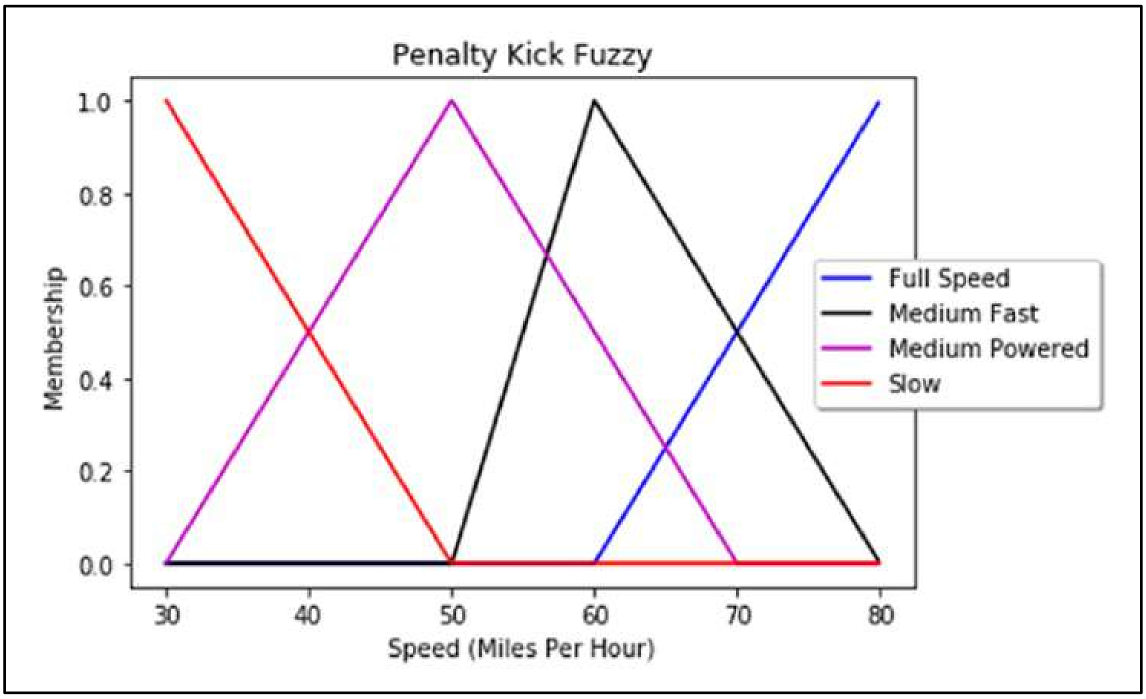


Figure 2.8 Triangular membership of the soccer example (Himanshu and Yunis, 2020).

2.7.5 Trapezoidal Membership Function

A trapezoid has four coordinates, so the membership function also has four coordinates values: a, b, c, and d, for a crisp value x. This equation can be expanded with multiple cut-points (Himanshu and Yunis, 2020):

$$f(x;a,b,c,d) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ 1, & b \leq x \leq c \\ \frac{d-x}{d-c}, & c \leq x \leq d \\ 0, & d \leq x \end{cases} \quad \text{.................................. (2.8)}$$

In trapezoidal membership functions, we need to provide four points. With the soccer we have to provide a range based on a specific class. In this membership function, the ip reaches 100% from 0% in the center, and then again drops to 0%. Instead of three with the triangular membership function, we have four points. This applies the soccer example to the trapezoidal membership function, whose classes are defined as follows (Himanshu and Yunis, 2020):

1. Full speed as [60, 80, 80, 90]
2. Medium powered as [30, 50, 50, 70]
3. Slow as [20, 30, 30, 50]
4. Medium fast as [50, 60, 60, 80])

Here is the Python implementation, the result is shown in Figure 2.9 (Himanshu and Yunis, 2020):

Importing Necessary Packages

```
import numpy as np
import skfuzzy as fuzz
import matplotlib.pyplot as plt
%matplotlib inline
```

Defining the Fuzzy Range from a speed of 30 to 90

```
x = np.arange(30, #Defining the trapezoidal membership functions
slow = fuzz.trapmf(x, [20, 30, 30, 50])
medium = fuzz.trapmf(x, [30, 50, 50, 70])
medium_fast = fuzz.trapmf(x, [50, 60, 60, 80])
full_speed = fuzz.trapmf(x, [60, 80, 80, 90])
#Plotting the Membership Functions Defined
plt.figure()
plt.plot(x, full_speed, 'b', linewidth=1.5, label='Full Speed')
plt.plot(x, medium_fast, 'k', linewidth=1.5, label='Medium Fast')
plt.plot(x, medium, 'm', linewidth=1.5, label='Medium Powered')
t(x, slow, 'r', linewidth=1.5, label='Slow')
le('Penalty Kick Fuzzy')
bel('Membership')
```

```
plt.xlabel("Speed (Miles Per Hour)")

plt.legend(loc='center right', bbox_to_anchor=(1.25, 0.5),

ncol=1, fancybox=True, shadow=True) 90, 0.1)
```

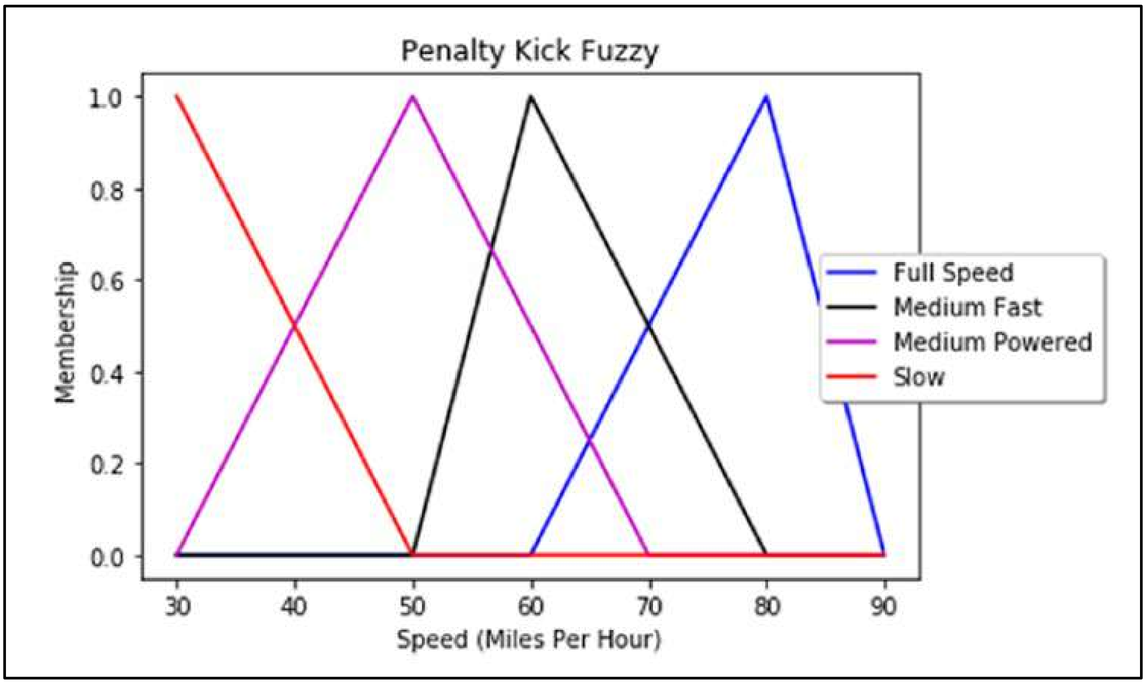


Figure 2.9 Trapezoidal membership of the soccer example (Himanshu and Yunis, 2020).

2.7.6 Fuzzy Rules

The most important thing to understand is the Fuzzy If-Then Rules. A single sample Fuzzy Rule looks like this:

$$If\ x\ is\ A\ then\ y\ is\ B \quad \text{..} (2.9)$$

In this statement, A and B are called linguistic values. These are the values that assume that it has been derived from statistical research, a mathematical model, etc. For example, it can take categorical values (good, average, or best), probabilistic values (0.1, 0.3, or 0.9), or any other part of an experiment. These values can be part of a Fuzzy Set, which can be a member of the Universe of Discourse X and Y. If you break the previous statement into two halves (Himanshu and Yunis, 2020):

is A

is B

The first part is called an antecedent or premise, while the second part is called the consequent or conclusion (Himanshu and Yunis, 2020).

2.7.7 Aggregation in Fuzzy System Modeling

Before look at aggregation, you must know the steps required for any Fuzzy Inference Process (Himanshu and Yunis, 2020):

1. Whatever the input is, you must match every rule with it.
2. Determine the output of every rule as a Fuzzy Set.
3. Aggregate all the rule outputs to get the overall Fuzzy System output Fuzzy Set.
4. Perform an action based on the output Fuzzy Set.

The consideration in this section is the third point: aggregation of the output rules. You can represent this operation as follows (Himanshu and Yunis, 2020):

$$F(y) = Agg\ (R_1(y), R_2(y) \ldots R_n\ (y)) \quad (2.10)$$

In the previous equation, Agg represented the aggregation operator. All the parameters present inside the operator are the membership grades of the output rules for every value of y present in Fuzzy Set Y (Himanshu and Yunis, 2020).

2.7.8 Fuzzy Inference Systems

The previous two chapters explained the core concepts related to Fuzzy Logic. They discussed Fuzzy Sets and how they are different from the classical/crisp sets. You also learned about various operations that can be done on them and their properties. Then you learned about membership functions, which define the membership values of each element present in a Fuzzy Set. You learned about the different types of membership functions. Later, you learned about the Fuzzy Rules and reasoning approaches that utilize the concepts of membership functions to give various Fuzzy Solutions (Himanshu and Yunis, 2020).

This chapter looks at real applications of all the concepts that you have learned so far. er covers different types of Fuzzy Inference Systems, through which various real-life are solved in the industry. To understand these systems, you first need to understand sses of Fuzzification and Defuzzification. You have already seen the Fuzzification process in the previous chapter, when you found the membership function values of each element of a set to make it a member of a Fuzzy Set. This chapter starts with the concept of Defuzzification and then moves on to different Fuzzy Inference Systems (Himanshu and Yunis, 2020).

When you have to design a system that is quite uncertain, one of the best approaches is using Fuzzy Inference Systems. Fuzzy Logic is used when you have a fixed set of rules and need to create systems based on that. But, when you add uncertainties inside the process, it requires some kind of inference of the process from the existing data. Using a Fuzzy Inference System is the way to infer those processes (Himanshu and Yunis, 2020).

A Fuzzy Inference System (FIS) provides a way of mapping an input space to an output space with Fuzzy Logic. FIS tries to mimic the process with which humans solve any problem statement using reasoning. FIS does that by using Fuzzy Logic, especially Fuzzy If-Then rules. Figure 2.10 represents the Fuzzy Inference System structure (Himanshu and Yunis, 2020).

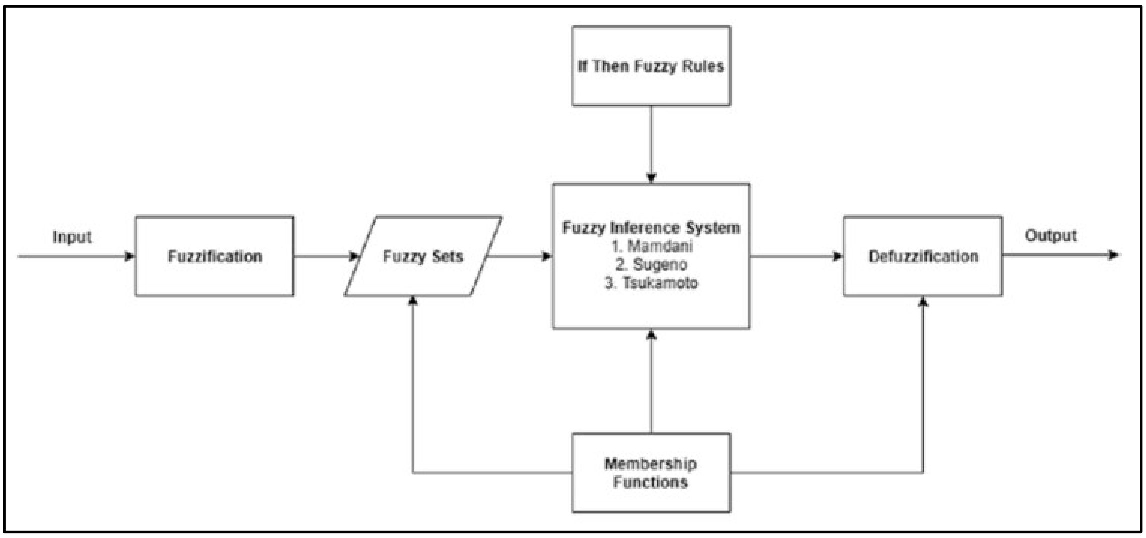


Figure 2.10 Fuzzy Inference System process (Himanshu and Yunis, 2020)

All the blocks in the diagram in Figure 2.10 are explained here (Himanshu and Yunis, 2020):

1 ^ database of all the Fuzzy If-Then Rules describing a system

atabase of membership functions

ference operations on Fuzzy Rules

efuzzification of Fuzzy Results into crisp outputs

When we combine all the rules and the membership functions database, it is called a knowledge base (Himanshu and Yunis, 2020).

2.7.9 Defuzzification

Defuzzification is the process of converting a Fuzzy Set into a crisp set. You know that in most applications you have to use Fuzzy Sets, as people's opinions are never crisp. But when you incorporate these Fuzzy values and have to make a decision, you must convert the Fuzzy output into crisp values. Therefore, Defuzzification helps convert output given in a Fuzzy Set to crisp values. If control system functioning depends on input, the process of Defuzzification determines what exactly needs to be done once that input is provided (Himanshu and Yunis, 2020).

2.8 Mean Absolute Percentage Error (MAPE)

Mean Absolute Percentage Error (MAPE) is one of the most popular measures of forecast accuracy. This is recommended in most textbooks (Bowerman et al., 2004). Let At and Ft represent the actual and estimated values at the data point t. Then, MAPE is defined as (Kim and Kim, 2016):

$$MAPE = \frac{1}{N}\sum_{t=1}^{N}\left|\frac{A_t - F_t}{A_t}\right| \qquad (2.11)$$

Where N is the number of data points. This approach is useful when the size or magnitude of the forecast variable is important in evaluating the accuracy of the forecast. MAPE indicates how big the forecast error is compared to the real value in the series. MAPE is scale-independent and easy to interpret, which has made it popular among industry practitioners (Kim and Kim, 2016).