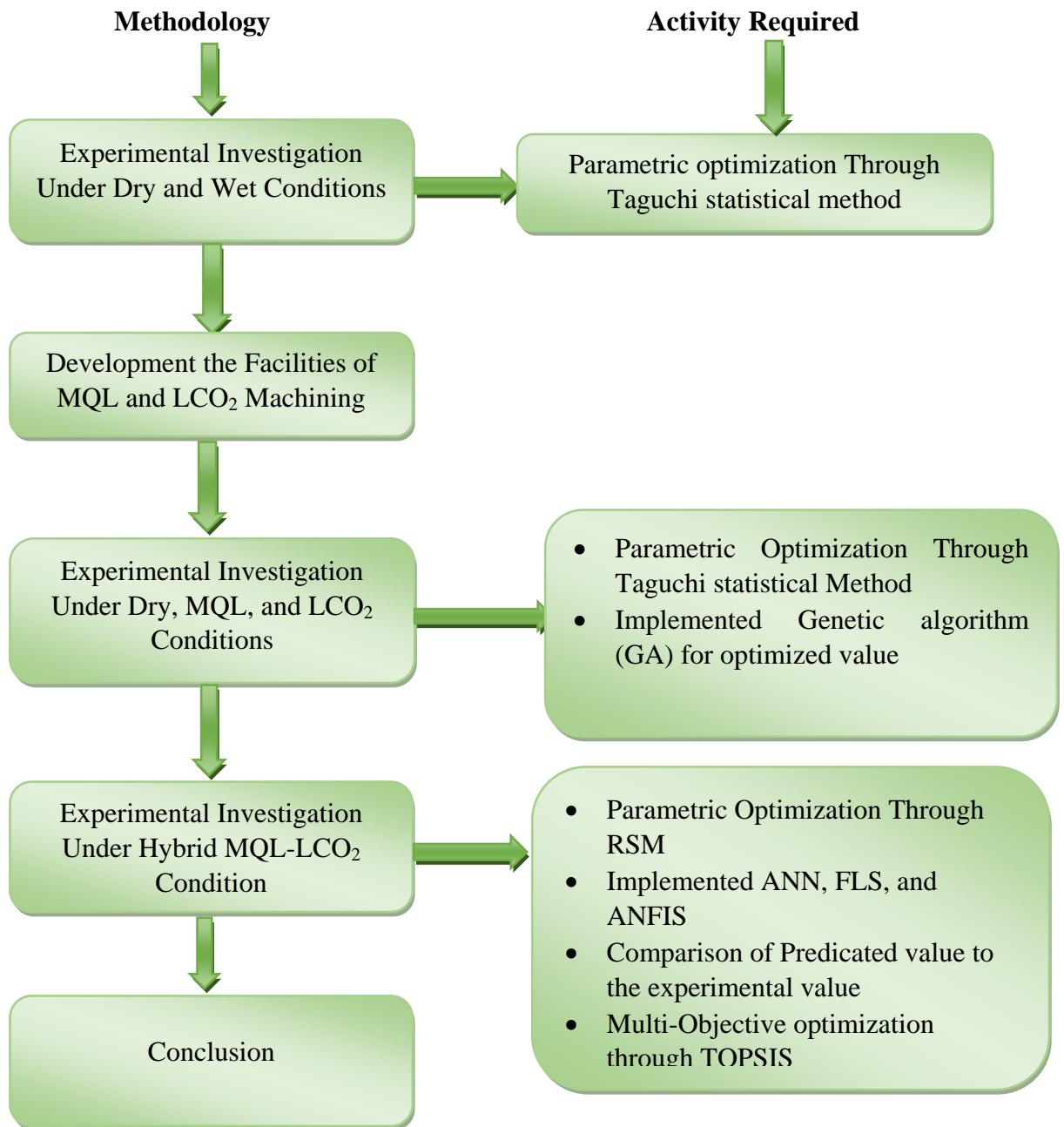




Chapter 3
Research Methodology

CHAPTER-3

RESEARCH METHODOLOGY



3.1 Taguchi Method

3.1.1 Introduction

Dr. Genichi Taguchi developed this Taguchi design methodology in the 20th century. It is effective for creating higher-quality production systems. The Taguchi design method, which was novel in the context of industrial experimentation, is crucial for quality control. The Taguchi technique is a way to plan experiments to look at different factors that affect the variance of performance traits, which describe how well a process performs. The quantity of experiments increases as we raise the process's parameters. Taguchi's approach to experiment design is simple to adopt and apply by users with little background in statistics, it has become very well-liked among scientists and engineers.

The goal of this engineering methodology is to create conditions for the products and processes that deliver high-quality goods at reasonable development and production costs. The technique has been used by numerous businesses throughout the world to save hundreds of millions of dollars in a variety of industries, including automotive, xerography, telecommunications, electronics, software, etc. Taguchi has suggested a methodical strategy for improving any processing technique.

3.1.2 Orthogonal Array (OA)

Orthogonal arrays (OA) are used in Taguchi's design method, to investigate several process variables using a limited number of tests. Orthogonal matrices are symmetric subsets of all treatment combinations in the corresponding complete factorial designs in fractional factorial designs. If the trials are conducted with one level of each parameter at a time, there would be thousands of experiments. The fact that a parameter approach at a time ignores any potential parameter interactions is another significant drawback. When a parameter responds to varying quantities of another parameter, it cannot have the same effect, and this is known as an interaction. The columns of the matrix are mutually orthogonal, as suggested by the name Orthogonal Array. The term "balancing property" refers to this and involves orthogonally. An orthogonal array's number of rows corresponds to the number of

experiments. The greatest number of factors that can be used for the matrix-based study is represented by the number of columns in an array.

3.1.3 Taguchi Design in Minitab

Static and dynamic response testing was conducted using MINITAB software. The quality function runs during dynamic response testing in a range of values with the aim of enhancing the correspondence between an input signal and an output response.

MINITAB calculates the response tables and generates the main effects and interaction diagrams for:

- Signal-to-noise ratios vs. control factors.
- Static design (Means) or dynamic design (slopes) vs. control factors.
- The Standard deviations vs. control factors.
- The natural log of the standard deviations vs. control factors.

A Taguchi design of an orthogonal array is the method in which they use different types just like two, three, four, five, and mixed levels of designs. Features are shown in this table.

TABLE 3.1: Types of design

Level	2 level design	3 level design	4 level design	5 level design	6 level design
Factor	2 to 31 factors	2 to 13 factors	2 to 5 factors	2 to 6 factors	2 to 26 factors

3.1.4 Analysis of Variance Calculation

The overall variability of the experimental result in variance components, which is how the analysis of variance gauges its significance, is its fundamental premise. Regarding the residues, the significance of the various components connected to the effects of the factors is assessed. When looking at the means of factor levels, the ideal values of this key parameter were discovered Naik, A.B., et al., (2018).

Each of the three quality characteristics described as smaller is better, nominal is better, and larger is better has a different definition of the mean square deviation (MSD).

Nominal Is Better

For the case of a specific target value of the performance characteristic calculated as follows:

$$S/N_i = 10 \log \frac{\bar{y}_i^2}{s_i^2} \quad \text{Naik, A.B., et al., (2018)}$$

Where,

$$\bar{y} = \frac{1}{N_i} \sum_{u=1}^{N_i} y_{i,u}$$

$$s_i^2 = \frac{1}{N_i-1} \sum_{u=1}^{N_i} (y_i - \bar{y}_i)$$

i = Experimental number

u = Trial number

N_i = Number of trials for experiment i

Smaller Is Better

For the case of minimizing the performance of characteristic, the following formula of the S/N ratio should be calculated as:

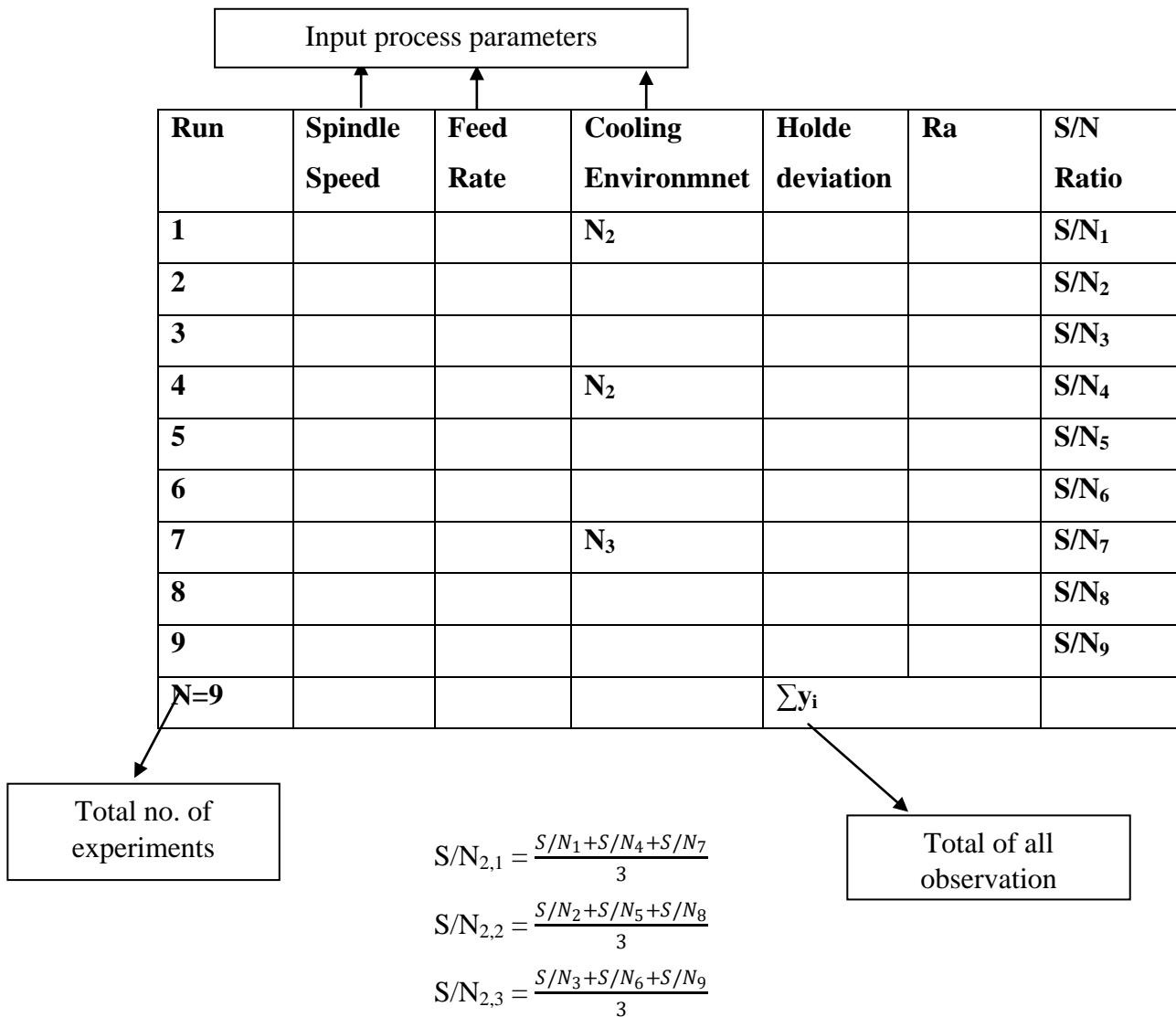
$$S/N_i = -10 \log \sum_{u=1}^{N_i} \frac{y_u^2}{s_i^2} \quad \text{Naik, A.B., et al., (2018)}$$

Larger Is Better

For the case of maximizing the performance of characteristic, the following formula of the S/N ratio should be calculated as:

$$S/N_i = -10 \log \left[\frac{1}{N_i} \sum_{u=1}^{N_i} \frac{1}{\bar{y}_u^2} \right] \quad \text{Naik, A.B., et al., (2018)}$$

Table 3.2:Types of observation



The range R of the S/N for each parameter is calculated and entered into the table after these S/N ratio values are tabulated as shown below for each parameter and level.

Table 3.3:Types of response table

Levels	Voltage	Electrolyte	IEG	Flow rate
1	S/N _{1,1}	S/N _{2,1}	S/N _{3,1}	S/N _{4,1}
2	S/N _{1,2}	S/N _{2,2}	S/N _{3,2}	S/N _{4,2}
3	S/N _{1,3}	S/N _{2,3}	S/N _{3,3}	S/N _{4,3}

Δ	R1	R2	R3	R4
Rank

The range R of the S/N for each parameter is calculated and entered into the table after these S/N ratio values are tabulated as shown below for each parameter and level.

3.2 Response Surface Method

The main goal of the response surface method is to determine the correlation between the response and the variables under optimization. It is a collection of mathematical and statistical techniques that are appropriate for modeling and analysis of problems in which the response is partially determined by a number of input parameters. The response surface method has a lot of benefits and has been used successfully to research and refine the process parameters. It provides enormous data from a limited number of experiments. Additionally, the interaction effect of the independent parameters on the response can be distinguished. The model clearly demonstrates the impact of combining the independent process variables in a binary manner. Information is also gathered using the empirical model linked to the response to the independent variables.

RSM has been extensively used to research various processes, plan experiments, create models, assess the effects of various elements, and discover the best conditions to predict desirable outcomes and minimise the number of experiments. After analysing the experimental results, a mathematical model is created to show how the link between the process variable and response works. The Response Surface Methodology (RSM) is a group of mathematical and statistical methods that can be used to create, enhance, and analyse processes. The relationship between different input process parameters and the output Y (response) is as follows.

$$Y = \beta_0 + \sum_{i=1}^k \beta_{ii} X_i + \sum_{i=1}^k \beta_{ii} X_i^2 + \sum_i \cdot \sum_j \beta_{ij} X_i X_j$$

where Y is the anticipated response, β_0 is a constant, and β_{ii} , and β_{ij} are the coefficients for the respective linear, quadratic, and cross-product terms. The coded variables that map to the investigated process parameters are revealed by X .

Keeping this in view, the present work is aimed to investigate the effect of three drilling parameters e.g. drill diameter, spindle speed, feed rate hole deviation, cylindricity error and circularity error during drilling of DSS 2205. The RSM Box-Behnken design is used for experimental planning for this purpose.

3.3 Genetic Algorithm (GA)

The GA method uses the process of spontaneous evolution to find better responses to optimization and search problems. Crossover, mutation, and reproduction are the three primary GA operators. The parameters of the machining process are recorded as genes using binary string encoding in order to apply GA to their optimization. The GA optimization process is shown in Figure 3.1.

In order for the algorithm to operate circumspectly, researchers must select appropriate GA parameters that differ from factors and constraints. We can use the following steps to develop solutions:

Step 1: Across the search space, the initial population of candidate solutions is often created at random. However, it is simple to include more knowledge or domain-specific expertise.

Step 2: After initialization, the fitness values of the potential solutions are constructed for the offspring population.

Step 3: Selection forces the survival of the fittest mechanism on the candidate solutions by allocating more copies of those solutions with better fitness values. Voting for better solutions is the major goal of elections. To implement this concept, numerous selection techniques have been proposed, including stochastic universal selection, roulette wheel selection, ranking selection, tournament selection, etc.

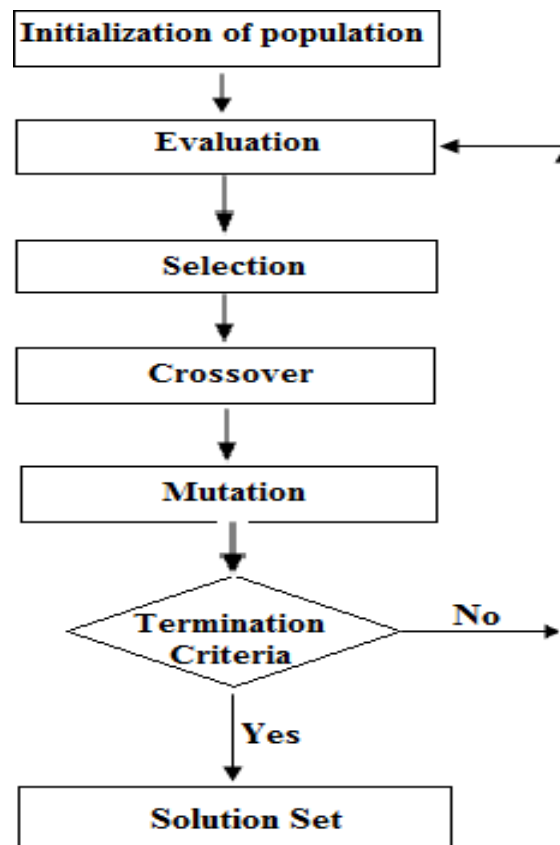


Fig.3.1:FlowChart of GAMethodology (Rooki, 2012)

Step 4: In order to develop a new option for superior solutions, recombination mixes components of two or more parental solutions. Depending on a well-designed recombination process, there are numerous approaches to achieve competent performance. Recombination will produce kids that are not identical to either one of the parents but instead combine parental features in a unique way (Goldberg, 2002).

Step5: Recombination affects two or more paternal chromosomes, whereas mutation alters a situation locally but randomly. Again, there are many different kinds of mutation, but most of the time one or more changes are made to a trait or traits of an individual. In other words, the mutation does a random wander near a potential answer.

Step 6: The initial parental population is replaced by the offspring population produced by selection, recombination, and mutation. GAs employs a variety of replacement strategies, including generation-wise replacement, steady-state

replacement methods, and elitist replacement.

3.4 Artificial Neural Network (ANN)

ANN is a nonlinear mathematical model that can form connections between the parameters of the inputs and outputs. Although they have several benefits, one of the most well-known is that they can really learn from viewing data sets. ANN is a powerful tool that may be used to approximate random functions and forecast machining parameters. When defining computing functions or distributions, these methods can be used to arrive at solutions and approximation response functions. ANN is regarded as merely straightforward mathematical models to improve already-existing data analysis technology. ANN provides the simulation of intricate nonlinear interactions and is possibly more accurate than polynomial regression-based modeling tools. With a distinct number of hidden neurons (nodes) for each, hole deviation, circularity error, and cylindricity error are each independently represented in the current study. Three neurons are predetermined to be the number of neurons in the input layer (drill diameter, spindle speed, feed rate). One neuron in the output layer represents the desired response. Figure 3.2 shows ANN model structure.

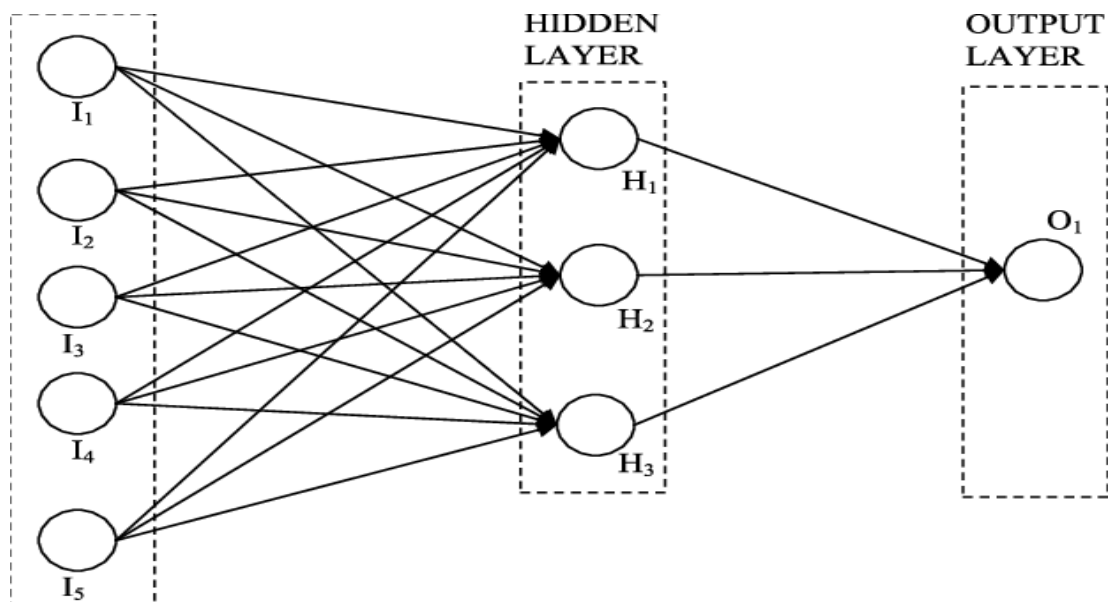


Fig. 3.2: ANN Model structure (Srivastav, 2007)

3.5 Fuzzy Logic System (FLS)

3.5.1 Introduction

For challenges involving system identification, control, and model recognition, fuzzy logic systems are typically used. It is frequently important to carry out a project optimization approach in order to maximize performance, where the variable Fuzzy system parameters are modified to maximize a specific performance condition. A supervised learning challenge is created with some readily accessible impending data. In data approximation, the sum of error squares should typically be minimized.

3.5.2 Operation of Fuzzy Logic Systems

The basic operation of Fuzzy logic is described below

Fuzzification Module –The process of turning sharp values into membership grades for fuzzy set's linguistic concepts is known as "fuzzification." Fuzzification is the process of transforming a crisp input value into a fuzzy value. Each linguistic phrase is given a grade using the membership function.

- **Knowledge Base** - Keep IF-THEN rules provided by experts.
- **Inference Engine** -Simulates the human reasoning process by making a widespread input deduction and IF-THEN rules
- **Defuzzification Module** -Transforms the fuzzy set obtained from the inference engine into a crisp value.

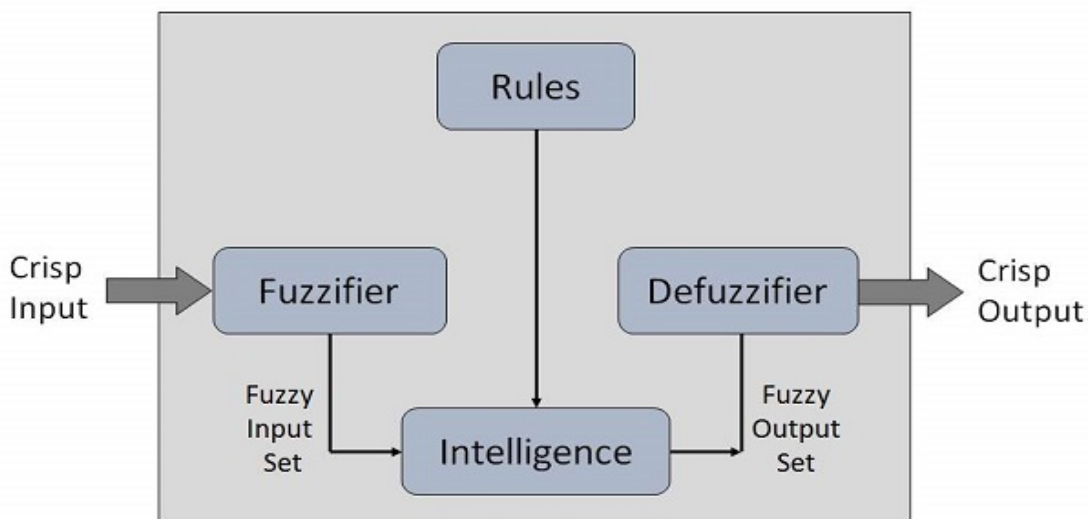


Fig.3.3:Operation of fuzzy logic systems (Tutorials point)

3.5.3 Membership Function

We can quantify the language and visually depict a large set using membership functions. In the world of speech X, a function that belongs to a diffuse set A is defined as $A: X [0,1]$. In this case, a value between 0 and 1 is given to each element of X. It's referred to as a membership value. The membership function's X and Y axes display the subject matter under debate. and the levels of inclusion in the range [0, 1]. The following is a list of all affiliate features for LP, MP, S, MN, and LN:

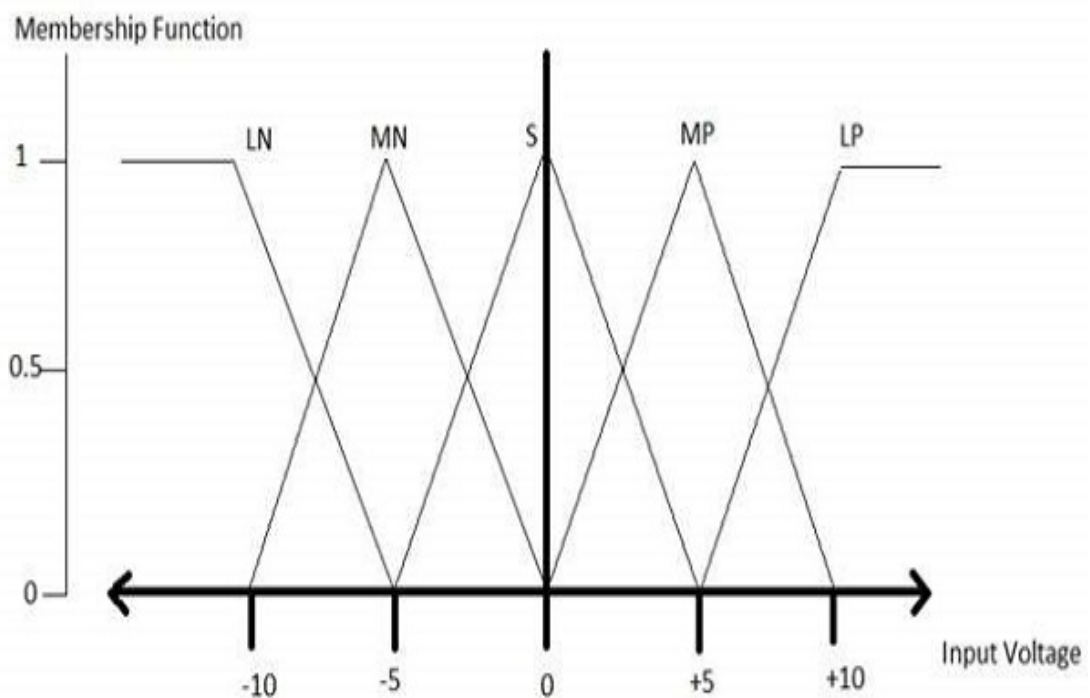


Fig. 3.4: Membership Function (Tutorials point)

Where-

LP	In this X is Large but Positive
MP	In this X is Medium but Positive
S	In this X is Small
MN	In this X is Medium but Negative
LN	In this X is Large but Negative

The triangular forms of membership function are more common among other forms of adhesion function, such as trapezoidal, singleton, and Gaussian.

3.6 Adaptive Neural Fuzzy Interface System (ANFIS)

For a variety of applications, such as system identification, parameter prediction, and energy load forecasting, ANFIS is a hybrid intelligent computing approach that combines artificial neural networks with a fuzzy system. ANN, a soft computing technique that simulates the functioning of the human brain, is characterized by linked layers made up of processing neurons or nodes. An output layer, hidden interconnected layers, and input layers make up an ANN. By applying simple calculations, such as weight multiplication and bias addition at each node, ANN may learn the pattern of the data. A control strategy based on fuzzy logic is known as a fuzzy system. Fuzzy logic uses a set of if-then rules based on human experiences to translate nonlinear input data into scalar outputs. A fuzzy inference engine, defuzzification, and fuzzification are some of the operations that make up fuzzy systems. To feed a fuzzy inference engine, this technique converts crisp values into a corresponding linguistic fuzzy variable. The Takagi-Sugeno fuzzy system model and the Mamdani fuzzy system model are the two system models for fuzzy systems. The fuzzy inference engine uses implication operations to apply the fuzzy rules to the fuzzy variables. The defuzzification procedure is then fed to the outputs. where the outputs are made sharp again after being blurry. As long as appropriate fuzzy rules that are based on human experiences are designed, fuzzy systems are model-free and can be presented for a variety of applications. Fuzzy systems also exhibit robust stability despite model uncertainties and are resilient to perturbations. In this study, the Takagi-Sugeno fuzzy system model was employed. Figure 3.5 demonstrates the ANFIS structure.

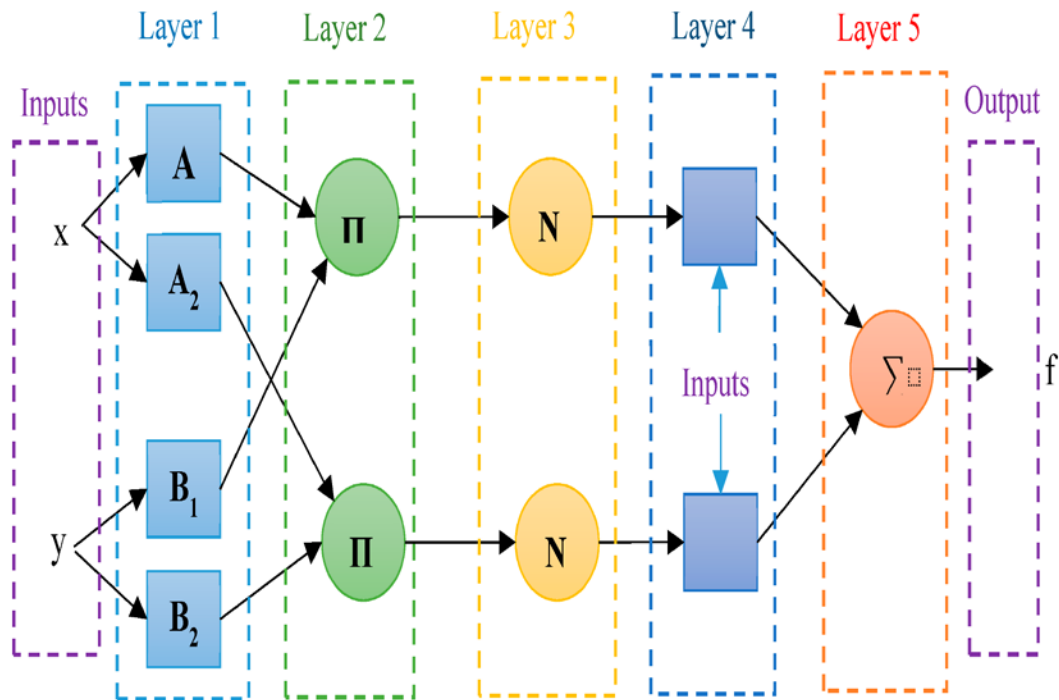


Fig. 3.5: ANFIS Model structure (AlRassas et al., 2021)

3.7 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

In the year 1981, Hwang and Yoon created the TOPSIS method. The TOPSIS technique, which is straightforward and more trustworthy for producing noticeable results, was employed to enhance the multi-response drilling procedures. The alternative was selected in this process based on the distance between it and the ideal solution, and the degree of similarity to the perfect solution was then determined. The TOPSIS method reduces the multi-objective responses into a single response in order to find the best process parameters.