BACHELOR THESIS

COAL PRODUCTION FAILURE RISK IDENTIFICATION USING FUZZY FMEA (FAILURE MODE EFFECT ANALYSIS) AT PT SEBUKU TANJUNG COAL SOUTH KALIMANTAN

submitted by

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COAL PRODUCTION FAILURE RISK IDENTIFICATION USING FUZZY FMEA (FAILURE MODE EFFECT ANALYSIS) AT PT SEBUKU TANJUNG COAL SOUTH KALIMANTAN

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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.

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ABSTRAK

Manajemen ekonomi adalah kunci dari peningkatan pendapatan atau penurunan biaya termasuk biaya produksi. Kegagalan produksi membuat perusahaan tambang merugi yang diakibatkan oleh rendahnya manajemen atau penyebab yang tidak terduga/tidak terkendali. PT Sebuku Tanjung Coal adalah perusahaan tambang batubara yang terletak di Kota Baru, Kalimantan Selatan yang telah beroperasi sejak 2019. Kenaikan harga batubara pada Desember 2020 $59,65/ton) ke $75,84/ton pada Januari 2021 membuat perusahaan meningkatkan tingkat produksinya. Untuk menyukseskan produksi, kegagalan harus dihitung dan dikurangi. Peralatan, pengelolaan air tambang, dan desain pit adalah parameter yang diperhitungkan dalam penelitian ini untuk mengidentifikasi risikonya. Penelitian ini menggunakan Failure Mode Effect Analysis *dalam menentukan kepentingan mode kegagalan dengan keluaran berupa* Risk Priority Number *(RPN).* Fuzzy *menggunakan teknik linguistik untuk menetapkan nilai mode kegagalan menggunakan nilai keanggotaan dengan keluaran* Fuzzy Risk Priority Number (FRPN)*. Klasifikasi pentingnya mode kegagalan berdasarkan RPN menunjukkan bahwa sistem drainase yang rendah adalah mode kegagalan yang paling penting dengan RPN 320 dan berdasarkan FRPN masih menunjukkan bahwa sistem drainase yang buruk dengan 915 FRPN. Hasil yang berbeda mungkin terjadi pada FRPN disebabkan oleh* rule *dalam* Fuzzy.

Kata kunci: Harga batubara, mode kegagalan, RPN, FRPN

ABSTRACT

Economical management is mainly responsible for the increase of revenue or decrease cost including cost production. A failure of production makes mining companies losing which is caused by lack of management or unpredicted/ uncontrolled causes. PT Sebuku Tanjung Coal is a coal mining company placed in Kota Baru, South Kalimantan that has produced moderate-rank coal since 2019. The increase of coal price from December 2020 with $56.65/ton to $75.84/ton on January 2021 drives the company to increase its production rate. To ensure it success, failures should be calculated and reduced. Equipment, water, and pit design are parameters which are used in this research to identify and calculate the risk. This research using FMEA to classify the importance of failure mode with Risk Priority Number (RPN) output. Fuzzy use linguistic technique to assign the failure mode values with membership number with Fuzzy Risk Priority Number (FRPN) output. Classification of the importance rank of failure mode based on RPN shows that low drainage system is the most important failure mode with 320 RPN and based on FRPN it still shows that low drainage system is the most important failure mode with 915 FRPN. A different result might be happen on FRPN cause of linguistic technique.

Keywords: Coal Price, failure mode, RPN, FRPN.

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"An investment in knowledge pays the best interest" by Benjamin Franklin. I hope this thesis can participate in development and advancement of science.

Makassar, May 2022

Yubelium Andrew Patila

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CHAPTER I

INTRODUCTION

1.1 Background

PT Sebuku Tanjung Coal is a company which engaged in the extractive industry especially coal production that has been producting since 2019. PT Sebuku Tanjung Coal hired PT Hillcon Jaya Sakti as their single contractor to conduct the overburden and coal production. PT Sebuku Tanjung Coal has planned to open five pits at their location with two pits which have been mined currently, they are Pit T1 and T2. WIUP (Wilayah Izin Usaha Pertambangan) or Legalized Mine Area, PT Sebuku Tanjung Coal is intersected with PT Sebuku Batubai Coal which handle the CPP (Coal Processing Plant). Those companies are in the same group of Sebuku Coal Group.

Mine site is located at Kota Baru District, South Borneo. Monthly plan of coal production of PT Sebuku Tanjung Coal is 250,000 MT. The coal price has increased since December 2020 and reached $75.84/ ton on January 2021 or increased by 27.14% (Dirjen Minerba, 2021) which made the company increase its coal production.

The most significant factor in economical development in the mining industry is production which is proned to failures (Kumar and Kumar, 2018). Production failures can be caused by equipment, environment, and mining method. Many losses happen because of unidentified failures and low control of failures.

There are two coal seams at PT Sebuku Tanjung Coal with three parting layers which has four cm of thickness and 40 cm of average coal thickness. This condition makes a difficult method to mine because of thin parting and coal layer. The quantity and the quality of coal must be controlled to avoid the coal production failure and consument's complain and/ or be rejected.

It is expected that annual production in the mining industry will increase due to increased productivity and the use of larger and more productive equipment, coupled with more comprehensive geological and engineering planning and more accurate measurement of productivity, costs and environmental characteristics (Lien, 2013). FMEA (Failure Mode Effect Analysis) is a systematic technique of identifying, analyzing and preventing product and process problems before they occur (Balaraju et al., 2019; Sharma et al., 2005). The output of this method is RPN (Risk Priority Number). The RPN is a reference to provide recommendations to be used as a focus of maintenance and improvement from the biggest types of risk occurred based on its priorities (Suryoputro et al., 2019).

Fuzzy logic is an appropriate technique which is used to estimate the output response from given input data. FMEA can be compared to fuzzy logic to include the uncertainty. The risk-indexed parametersof Fuzzy FMEA such as Severity (S), Occurrence (O) and Detection (D) are fuzzified with suitable membership functions (Balaraju et al., 2019). Thus this research is focused on coal production risk identification using the FMEA method with a linguistic technique to reduce the probability of losses and/or to increase the coal production rate.

1.2 Research Problem

The way to increase the coal production to meet the market demand is affected by several parameters. Those parameters should be controlled to avoid the coal production failure and to reach the coal production plan. Parameters are classified into five systems which are machine, method, measurement, material and environment. The minimalizing of coal production failure will increase the coal production, thus this research questions are:

1. What factors possibly make coal production failed at PT Sebuku Tanjung Coal?
2. How does the significance of each factor in causing the coal production failure?
3. What is the improvement plan to prevent and/ or detect coal production failure?

1.3 Research Purpose

Based on research problem above, aims of this research are:

1. To identify and determine failure mode that causes coal production failure.
2. To classify failure factors based on their priority with fuzzy linguistical technique.
3. To compose the improvement plan that can prevent and/ or detect the coal production failure.

1.4 Research Advantage

Advantages from this research are research development about risk identification using FMEA method with fuzzy logic and identification of the potential coal production failure from the company.

1.5 Research Stages

In this study, there are several stages performed by the author i.e. collecting and processing data. Data were collected by directly observation and given by the company. Stages have carried out in the research are as follows:

1. Topic determination

   This stage is the initial stage to determine the direction of the research. Predetermined topic becomes guideline in the discussion and problem solving in research.

2. Literature study

Literature study is the stage of collecting various references according to the topic of the research. References can be obtained from international and national journals, as well as company data and/ or support data that is valid and accountable.

3. Problem identification

This stage aims to identify issues that will be discussed in the research. The problem has a direct relation to the topic of the research.

4. Data collection

Data collection was done to obtain the data needed in the discussion of problems in research. The data is obtained from field observation (primary data) and support data from company or literature (secondary data).

5. Data processing

Data processing was done using several applications e.g. AutoCAD 2020, Microsoft Excel, Mydraw and Microsoft Visio, Python and Matlab. The processed data is reviewed to investigate errors and determine conclusions.

6. Thesis composing

Thesis composing is carried out in accordance with the applicable format in the Manual Book of the Final Assignment of The Mining Engineering Department Student of Hasanuddin University.

7. Thesis seminar

Thesis seminar will be done to present the results and discussion of the thesis.

1.6 Research location

Research loacation took place at PT Sebuku Tanjung Coal which is located at Tanjung District, Kotabaru Regency, South Kalimantan. The research location can be reached by plane from Sultan Hasanuddin airport for 50 minutes, then continued by car for 30 minutes. The average distance between Hasanuddin University and PT Sebuku Tanjung Coal is 413 km. The WIUP map is shown in Appendix A and the reach of research area is shown in Figure 1.1.

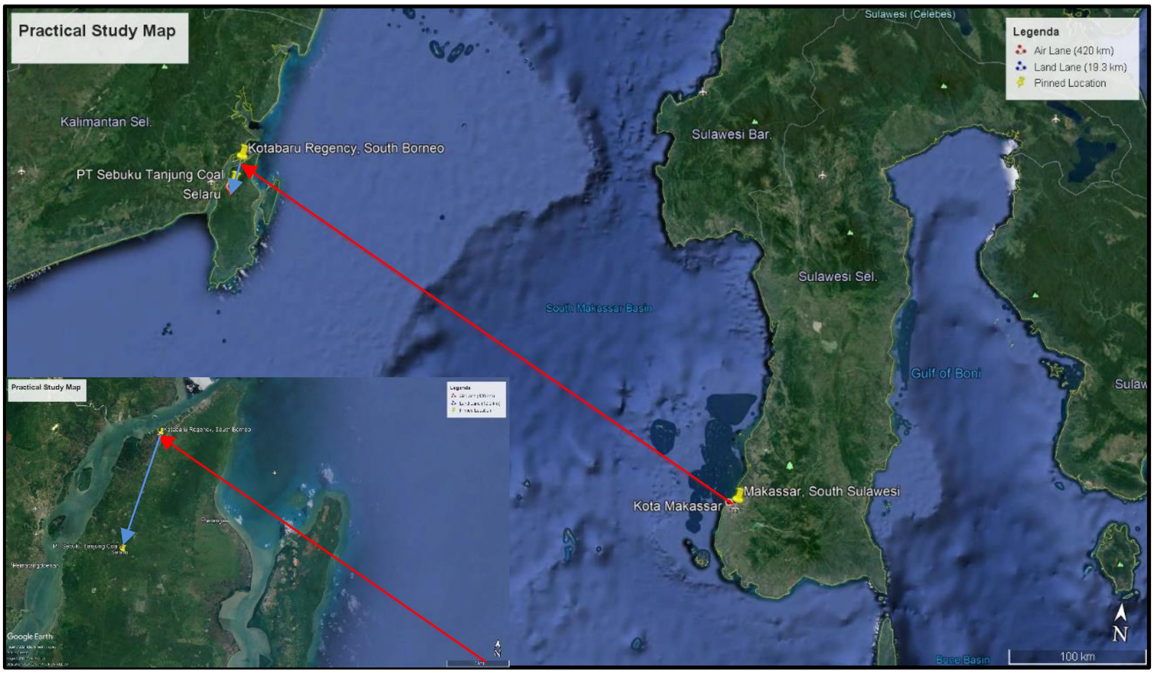

Figure 1.1 Location line view

CHAPTER II

SUSTAINABLE MINING, QUALITY MANAGEMENT AND FUZZY FMEA

2.1 Sustainable Mining

Sustainable mining is an objective as well as a tool for balancing economic, social, and environmental considerations (Masloboev and Pettersson, 2015). Sustainability index of mining management consist of social, economic, environmental and institutional dimension (Anas et al., 2015). Sustainability science has received progressively greater attention worldwide, given the growing environmental concerns and socioeconomic inequity, both largely resulting from a prevailing global economic model that has prioritized profits. It is now widely recognized that mankind needs to adopt measures to change the currently unsustainable production and consumption patterns (Segura-salazar and Tavarez, 2018).

The implementation of sustainable mining should be emphasised that sustainable development is, in any case, an ongoing process, and not a temporary under-taking. It has clearly defined goals and means of achieving them, in all of the above mentioned key areas. It is assumed that these areas are of equal importance. Hence, the emphasis on one area usually leads to a crisis across the entire area of mining activity. Economic growth means achieving long-term sustainability both in regards to planned production volumes, and in meeting the needs of customers, as well as achieving economic efficiency obtained from the sale of the excavated mineral. Protection of natural resources and of the environment means concern for the bed and the protection of its resources by its rational acquisition, which is characterised by savings in its depletion.

This also means taking measures that minimise the negative impact of the different processes related to the extraction of mineral resources on the various forms of the geological environment and natural environment on the surface. Social responsibility, taking into consideration the nature of the mining environment, this means above all ensuring safe working conditions, but also concern the social aspects of mining, including the families of miners, the mining environment, etc (Dubiński, 2013).

Mining can affect both air and water. A fossil fuel that has been mined intensively is coal. Mining, minerals, and metals are important to the economic and social development as they are essentials for modern living. However, supplies of minerals, such as coal, are limited and sustainable management of natural resources requires the maintenance, rational and enhanced use as well as a balanced consideration of ecology, economy, and social justice. Mining industry's recognition and acceptance of its sustainable development is growing. The growth rate for coal consumption is uneven that is shown in Figure 2.1 (Chattopadhyay and Chattopadhyay, 2012).

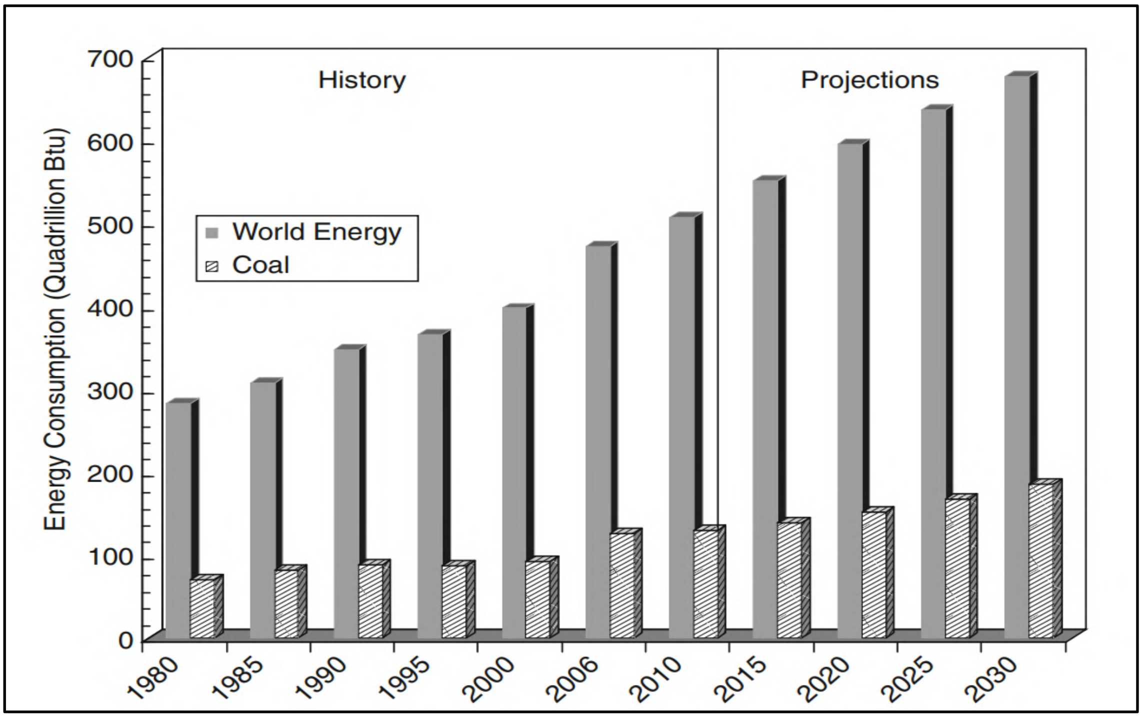

Figure 2.1 Global energy consumption 1980 – 2030 (Chattopadhyay and Chattopadhyay, 2012)

Figure 2.1 shows that averaging 1.1% per year between 2007 and 2020 and 2.0% per year between 2020 and 2035. The slower growth rate for the earlier period is largely from a decline in coal consumption in 2009 during the global economic recession. With economic recovery, world coal consumption rebounded, and it is expected to return to its 2008 level by 2013 (Chattopadhyay and Chattopadhyay, 2012).

The process of coal excavation consists of several cycles, they are: the cycle of excavation, disposal, and recultivation. The first step is reconnaissance of the terrain (preliminary survey of ground) that has been identified for mining. Preparation of the terrain may necessitate demolition of constructions, felling of trees, relocation of watercourses, roads, etc. This is usually followed by excavation of the overburden and then transporting and disposing the material using specialized equipment (mining machinery). In present days, bucket wheel excavators, conveyor belts, and stackers are mainly used. When the coal seam appears, such a seam is excavated and transported to the crushing plant at jetty (Chattopadhyay and Chattopadhyay, 2012).

Sustainability Opportunity and Threat Analysis is another simple operational tool addressing the social, economic, and environmental dimensions of the issues under consideration and it can be applied to evaluate the viability of a mining operation and its ability to contribute to sustainable development objectives. An impact-based model of sustainable mine development is shown in Figure 2.2. This analysis involves constructing inventory of sources of impacts and following key steps including (Chattopadhyay and Chattopadhyay, 2012):

1. Scoping (addressing the reasons for the mining process and the environment, and agreeing to the scope of the exercise).
2. Information gathering (to emphasize the importance of collecting and organizing relevant information into a suitable framework).

3. Identifying risks (systematically reviewing impact areas under consideration, and identifying opportunities or threats).
4. Analyzing and evaluating the risks (qualitative scales of likelihood and consequence can be assigned to identify opportunity or threat to create overall risk rating and prioritized list).
5. Treating risks (control measures to address opportunities or threats considered high priority).
6. Reporting and reviewing to represent a broad, scanning exercise that can be picked up by existing business planning and monitoring processes. It also provides an opportunity for subsequent evaluation of relevant metrics for the issues identified by the process, allowing operations to measure both impacts and progress toward agreed objectives.

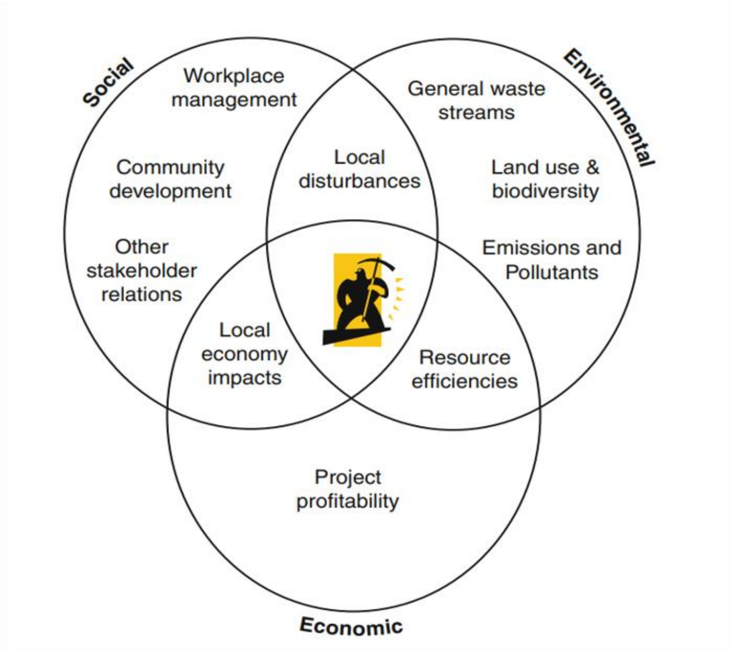

Figure 2.2 Sustainable development model for impact-based mining operations (Chattopadhyay and Chattopadhyay, 2012).

2.2 Mining Productivity

Rising productivity, alongside exploration, is the principal means by which mining can combat resource depletion. Over the past one hundred and fifty years, the mining industry has been remarkably successful in growing its productivity. However, since 2000, there are signs of a slowdown. Some aspects of this are clearly cyclical but there are increasing concerns that some of the underlying, longer term, factors which have kept productivity growing in the past are losing their force (Humphreys, 2020).

Going hand in hand with the increasing size and quality of equipment has been an increase in the size of mines. This permitted the deployment of larger and more productive equipment as well as helping to reduce unit costs of production by helping to spread fixed costs over larger tonnages. Scale in mining is, in effect, the equivalent of mass production in manufacturing (Humphreys, 2020).

Mining productivity is caused by many factors, they are:

1. Physical properties of material

   The physical properties of rock plays significant role in optimization of loading machinery. As the physical properties of rocks are uncontrollable parameters but by knowing them, can design the proper and sustainable method of drilling and blasting in open pit and underground mines (Rezaye, 2019).

2. Front condition

   The dimension and condition of the mining front affect the performance of loading and hauling equipment. Wide mining front dimensions and dry conditions can increase the productivity of loading and hauling equipment.

3. Climate

   Weather is very influential to the working area of mechanical equipment because it will be used to estimate how many days in a year there is rain, so mechanical equipment is not very effective to work when it rains with heavy intensity. This is because the road in the work area becomes muddy and when the dry season causes a lot of dust that makes the work that occurs as a result of direct contact with the outside air in the mining (Arief, 2016).

4. Working efficiency

   The value of a job's success is complicated to determine precisely because it includes several factors such as human factors, machinery and working conditions. The success value of a job is influenced by time efficiency, working efficiency or tool availability to operate and operator efficiency (Arief, 2016).

5. Equipment availability

   The availability of equipments is a key management parameter to be predicted and controlled (Modgil and Sharma, 2016). State that the only way to ensure minimum maintenance costs and a minimal probability of failure is to routinely monitor equipment condition and failures, and to make predictions on the basis of current conditions and historical equipment maintenance and operations (Kothamasu et al., 2006).

6. Match Factor

   The match factor itself provides a measure of productivity of the fleet. The ratio is so called because it can be used to match the truck arrival rate to loader service rate. This ratio removes itself from equipment capacities, and in this sense, potential productivity, by also including the loading times in the truck cycle times (Burt and Caccetta, 2018).

7. Haul road

   Haul road greatly affects the productivity of loading equipment and its match with hauling equipment (DT). Speed is authoritative on the cycle time of hauler, therefore the speed has also been designed in accordance with the design of the haul road (Saputra et al., 2017).

2.3 Quality Management

The success of manufacturing relies on engineering power that produces ideas, designs, and methods to realize a tangible product. Manufacturing and engineering share the same fundamental elements to grow and succeed against the competition: cost, productivity, technology, and quality. To develop these elements in a competitive environment requires innovative thinking based on reality and practicality (Lim, 2020).

Quality indicates the capability of all components of an entity to satisfy the stated and implied needs, that a quality item will perform satisfactorily in service, and is suitable for its intended purpose. In any case, to achieve satisfactory quality, we must be concerned with all three stages of the product or service cycle which include (Kiran, 2017):

1. The definition of needs.
2. The product design and conformance.
3. The product support throughout its lifetime.

Quality in fact has been around for quite a long time and has progressed from stages of playing a purely reactive role (inspection) to its present prominence in shaping the competitive strategy of busines (Zairi, 1991).

Quality management like innovation is also a broadly defined topic. Most research, however, agree that the main goal of quality management is to improve and meet stakeholder needs by removing deficiencies including error and rework. While a vast majority of studies view quality management practices as a single variable e.g., quality management on manufacturing capabilities from contries with different cultures (Kull and Wacker, 2010), other more recent studies delineate the various practices into multiple dimensions e.g., hard and soft quality management on quality and innovation peformance (Zeng et al., 2015). The quality management is devided into two different dimensions: social and technical practices. Technical quality management refers to the mechanical methods used by employees of an organization. It is generally defined as practices with a focus on controlling processes and products through tools for the purpose of conforming to and satisfying established requirements. Previous literature defines technical quality management in a variety of ways including process management, preventative maintenance and housekeeping (Schniederjans and Schniederjans, 2015).

2.1.1 Control Chart

Control charts were introduced in 1926 by Walter Shewart who concluded that a distribution can be transformed info a normal shape by estimating its mean and standard deviation. A stable distribution was defined as one where variation does not exceed the set limits more than 0.26% of the time. To arrive at a definition of a stable distribution, Shewart used the central limit theorem (Zairi, 1991).

Control charts are a proven technique for improving productivity, preventing defects and unnecessary process adjustments, and providing diagnostic and process capability information. Control charts are frequently used to monitor the modified process. The project is completed by returning the improved process back to the process owner who now assumes responsibility for the improved process. Control charts provide a clear and visual representation of the status of the process. Often, problems are identified early and corrective action is taken, thus minimizing economic losses (Tofallis et al., 2013).

The control chart consists essentially of symmetrical limits (control limits) placed above and below a central line. The central line in each case indicates the expected or average value of $\bar{X}$ and s,. For samples of n observations each. The control limits used here, referred to as 3-sigma control limits are placed at a distance of three standard deviations from the central line. The standard deviation is defined as the standard deviation of the sampling distribution of the statistical measure in question $\bar{X}$ and s for samples of size *n*. Note that this standard deviation is not the standard deviation computed from the sample values of $\bar{X}$ and *s*. Plotted on the chart but is computed from the variations within the samples, where $\bar{X}$ is average or arithmetic mean and s is sample standard deviation with following formula (ASTM International, 2010):

$$\bar{X} = \frac{X_1 + X_2 + \cdots + X_n}{n} \qquad (2.1)$$

$$s = \sqrt{\frac{(X_1 - \bar{X})^2 + \cdots + (X_n - \bar{X})^2}{n-1}} \qquad (2.2)$$

Where:

$\bar{X}$ = Arithmetic mean

s = Sample standard deviation

X_n = Variable at datum *n*

n = Total frequency

The example of control chart is shown in Figure 2.3.

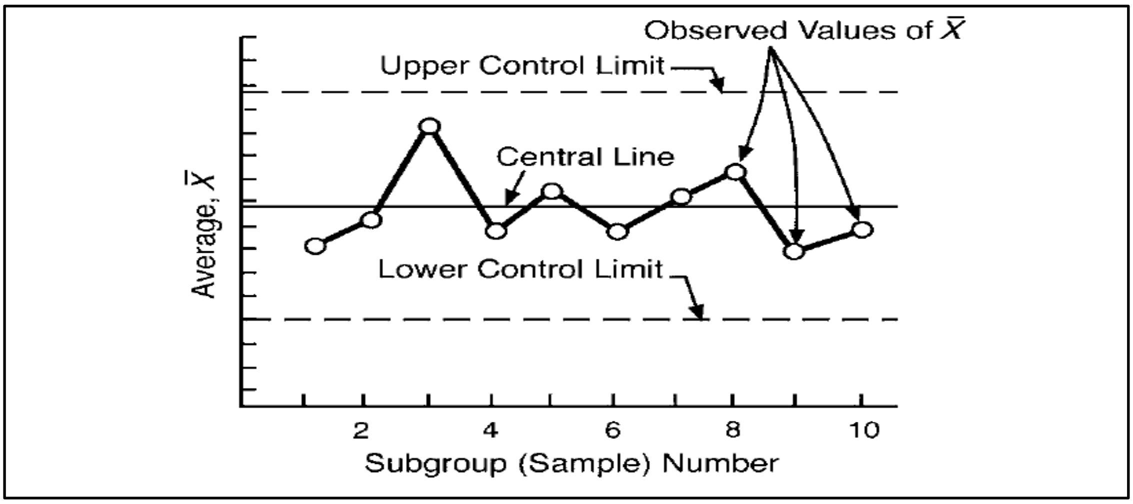

Figure 2.3 Control chart (ASTM International, 2010)

2.1.2 Cause and Effect Diagram (Fishbone Diagram)

Cause and effect diagrams are a problem solving technique developed in 1943 by Ishikawa 'in Japan as a result of workers being confused by the number of factors which influence a process and thus finding it difficult to solve process-related problems. The diagram is developed after brainstorming, by identifying a problem to be solved i.e. effect and the likely causes (Zairi, 1991). This method can be used on any type of problem, and can be tailored by the user to fit the circumstances. Use of this tool has several benefits to process improvement teams (Kiran, 2017):

1. Straightforward and easy to learn visual tool.
2. Involves the workforce in problem resolution—preparation of the fishbone diagram provides an education to the whole team.
3. Organizes discussion to stay focused on the current issues.
4. Promotes "System Thinking" through visual linkages.
5. Prioritizes further analysis and corrective actions.

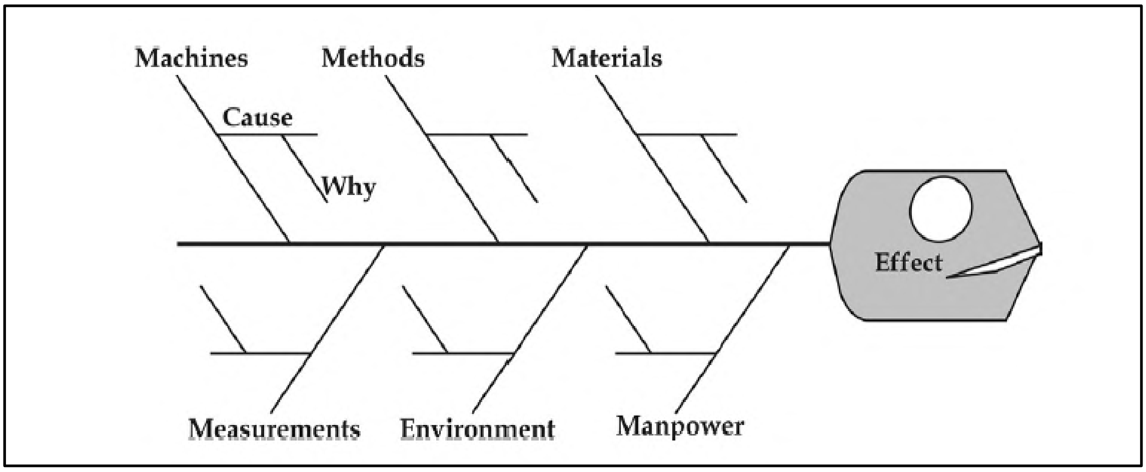

Figure 2.4 Cause and Effect diagram (Kiran, 2017)

The main motive of application of the tool is to disembark the various sources/causes that contribute most extensively toward the problem under examination. These causes are then taken for initiating improvement actions. The method also portrays the interactions among the wide range of potential causes of the effect. Figure 2.4 presents cause and effect analysis. The diagram shows six possible causes, i.e., cause 1, cause 2, cause 3, cause 4, cause 5, cause 6 to a particular event or problem on hand. These causes are connected to a horizontal line which on right-hand side connects to a problem. After identification ofmain causes, the subcauses are added to the bones on the main bone represented by the horizontal line. The fundamental notion in the cause and effect analysis is that the "basic problem" of concern is entered at the right side of the diagram at the end. The major possible causes of the problem (known as the effects) are listed on the horizontal line (Sharma, 2021).

The guidelines to construct Cause and Effect diagram (Sharma, 2021):

1. Define the problem or the effect that needs to be studied or examined.
2. Formulate the team of individuals to carry out the analysis. Often, the teams will discover the probable cause through brainstorming.
3. Draw the effect box on right-hand side and the center line.
4. Identify the probable cause categories and join them as boxes connected to the centre line.
5. Identify the probable cause and classify them into the categories and create new subcategories, if necessary.
6. Ranks order these possible causes in order to recognize those that seem almost certainly to affect the problem.
7. Initiate the remedial actions.

2.4 Failure Mode Effect Analysis (FMEA)

FMEA (Failure Mode and Effect Analysis) is a systematic method of identifying and preventing product and process problems before they occur. FMEAs are focused on preventing defects, enhancing safety, and increasing customer satisfaction. Ideally, FMEAs are conducted in the product design or process development stages, although conducting an FMEA on existing products and processes can also yield substantial benefits (McDermott et al., 2009).

The FMEA process is a way to identify the failures, effects, and risks within a process or product, and then eliminate or reduce them. The relative risk of a failure and its effects is determined by three factors (McDermott et al., 2009):

a. Severity is the consequence of the failure should it occur.
b. Occurrence is the probability or frequency of the failure occurring.
c. Detection is the probability of the failure being detected before the impact of the effect is realized.

Using the data and knowledge of the process or product, each potential failure mode and effect is rated in each of these three factors on a scale ranging from 1 to 10, low to high using Formula 2.3, a risk priority number (RPN) will be determined for each potential failure mode and effect. The risk priority number (which will range from 1 to 1,000 for each failure mode) is used to rank the need for corrective actions to eliminate or reduce the potential failure modes. Those failure modes with the highest RPNs should be attended to first, although special attention should be given when the severity ranking is high (9 or 10) regardless of the RPN factors (McDermott et al., 2009).

$$RPN = severity \times occurence \times detection \text{........................(2.3)}$$

The valuation each severity, occurrence and detection is shown in Table 2.1, 2.2. and 2.3 (Stamatis, 2019).

Table 2.1 Severity valuation of FMEA

Effect	Description	Rate
None	No effect noticed by customer. The failure will not have any effect on the customer.	1

Effect	Description	Rate
Very minor	Very minor disruption to production line. A very small portion of the product may have to be reworked. Defect noticed by discriminating customers.	2
Minor	Minor disruption to production line. A small portion (<5%) of product may have to be reworked online. Process up but minor annoyances	3
Very low	Very low disruption to production line. A moderate portion (<10%) of very low product may have to be reworked online. Process up but minor annoyances.	4
Low	Low disruption to production line. A moderate portion (<15%) of product may have to be reworked online. Process up but some minor annoyances.	5
Moderate	Moderate disruption to production line. A moderate portion (>20%) of product may have to be scrapped. Process up but some inconveniences.	6
High	Major disruption to production line. A portion (>30%) of product may have to be scrapped. Process may be stopped. Customer dissatisfied.	7
Very high	Major disruption to production line. Close to 100% of product may have to be scrapped. Process unreliable. Customer very dissatisfied.	8
Hazard with warning	May endanger operator or equipment. Severely affects safe process operation and/or involves noncompliance with government regulations. Failure will occur *with* warning.	9
Hazard with no warning	May endanger operator or equipment. Severely affects safe process operation and/or involves noncompliance with government regulations. Failure occurs *without* warning.	10

Table 2.2 Occurrence valuation of FMEA

Occurrence	Description	Frequency	Rate
Remote	Failure is very unlikely, no failures associated to similar processes	<1 in 1,500,000	1

Occurrence	Description	Frequency	Rate
Low	Few failures. Isolated failures associated with like processes.	1 in 150,000	2
		1 in 15,000	3
		1 in 2000	4
Moderate	Occasional failures associated with similar processes, but not in major proportions.	1 in 400	5
		1 in 80	6
High	Repeated failures. Similar processes have often failed.	1 in 20	7
		1 in 8	8
Very high	Process failure is almost inevitable.	1 in 3	9
		>1 in 2	10

Table 2.3 Detection valuation of FMEA

Detection	Description	Rate
Almost certain	Process control will almost certainly detect or prevent the potential cause of subsequent failure mode	1
Very high	Very high chance process control will detect or prevent the potential cause of subsequent failure mode	2
High	High chance the process control will detect or prevent the potential cause of subsequent failure mode.	3
Moderate high	Moderately high chance the process control will detect or prevent the potential cause of subsequent failure mode.	4
Moderate	Moderate chance the process control will detect or prevent the potential cause of subsequent failure mode.	5
Low	Low chance the process control will detect or prevent the potential cause of subsequent failure mode.	6
Very low	Very low chance the process control will detect or prevent the potential cause of subsequent failure mode.	7
Remote	Remote chance the process control will detect or prevent the potential cause of subsequent failure mode.	8

Detection	Description	Rate
Very remote	Very remote chance the process control will detect or prevent the potential cause of subsequent failure mode	9
Very uncertain	There is no process control or the control will not or cannot detect the potential cause of subsequent failure mode	10

Improvement of productivity has become an important goal for mining industries in order to meet the expected targets of production and increased price competitiveness. Productivity can be improved in different ways. The effective utilization of men and machinery is one such way. Equipment is prone to numerous unexpected potential failures during its operation. Failure Mode and Effect Analysis (FMEA) is one of the suitable techniques of reliability modeling used to investigate the failure behavior of a complex system (Balaraju et al., 2019).

2.5 Failure Mode

Failures are not limited to problems with the product. Because failures also can occur when the user makes a mistake, those types of failures should also be included in the FMEA. Anything that can be done to ensure the product works correctly, regardless of how the user operates it, will move the product closer to 100% total customer satisfaction. Ways in which a product or process can fail are called failure modes. Each failure mode has a potential effect, and some effects are more likely to occur than others. In addition, each potential effect has a relative risk associated with it. The FMEA process is a way to identify the failures, effects, and risks within a process or product, and then eliminate or reduce them (McDermott et al., 2009).

Identifying the failure modes was described as one of the main challenges for conducting an FMEA. Identified problems include a lack of information on the actual or potential asset failure, which in turn lead to difficulties in making detailed distinctions between failure modes and identifying possible causes (Braaksma et al., 2013).

Failure modes are investigated at the system's sub-component level, according to the desired level of depth in the analysis. For each failure mode a severity (S), occurrence (O) and detection (D) rating is defined and rated according to subjectively defined scales, based on available information and supported by expert opinion and evaluation. The rating system involves expert opinion and a level of subjectivity which is typical of rating systems based on a scales defined by the user (Colli, 2015).

2.6 Fuzzy Inference System

Several mathematical disciplines deal with the principles of uncertainty e.g. stochastic uncertainty deals with issues related to the future occurrence of a certain event. The event itself is defined precisely but the uncertainty involved is qualified by a degree of probability that this particular certain event will occur (Friedman and Kandel, 1999).

Another kind of uncertainty is related to lexical uncertainty which deals with the imprecision and ambiguity that is inherent in human languages. Researchers in the field of psycholinguistics investigate the way humans evaluate concepts and derive decisions in these complex structures, usually related to subjective categories. Analysis of this kind of uncertainty usually results in a perceived probability rather than the mathematically defined mobility. The third kind of uncertainty is the theory of fuzzy sets. The main feature of any fuzzy system in the linguistic variable which is closely related to the concept of a fuzzy event; mainly, an event which is not certain but has a grade of membership associated with it. Thus there is a transformation from a linguistic variable to a Linguistic Mathematical Description (LMD) (Friedman and Kandel, 1999).

Fuzzy sets were introduced by L. Zadeh. The definition of a fuzzy set as follows a fuzzy set is a class with a continum of membership grades. 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 (Singh and Lone, 2020). So a fuzzy set A in a referential (universe of discourse) X is characterized by a membership function A which associates with each element $x \in X$ a real number $A(x) \in [0, 1]$, having the interpretation $A(x)$ is the membership grade of x in the fuzzy set A (Zadeh, 1965).

Fuzzy sets are generalizations of the classical sets represented by their characteristic functions $\chi A : X \rightarrow \{0, 1\}$. In our case $A(x) = 1$ means full membership of x in A,while $A(x) = 0$ expresses non-membership, but in contrary to the classical case other membership degrees are allowed. Identify a fuzzy set with its membership function. Other notations that can be used are the following (Bede, 2013):

$$\mu_A(x) = A(x) \qquad (2.4)$$

Every classical set is also a fuzzy set. The set can be defined the membership function of a classical set $A \subseteq X$ as its characteristic function (Bede, 2013):

$$\mu_A(x) = \begin{cases} 1 & if\ x \in A \\ 0 & otherwise \end{cases} \qquad (2.5)$$

Fuzzy sets are able to model linguistic uncertainty (Bede, 2013):

$$A(x) = \begin{cases} 1 & if\ x \in A \\ \frac{max-x}{max-min} & if\ min < x \le max \\ 0 & otherwise \end{cases} \qquad (2.6)$$

In fuzzy set theory these operations are performed on the membership functions which represent the fuzzy sets. The union and intersection connectives on the max and min operations. Detailed informations are described as follows (Bede, 2013):

2.6.1 Inclusion

Let $A, B \in F(X)$. We say that the fuzzy set A is included in B if

$$A(x) \le B(x), \forall x \in X \qquad (2.7)$$

Denote $A \leq B$. The empty (fuzzy) set $\emptyset$ is defined as $\emptyset(x) = 0, \forall x \in X$ and the total set X is $X(x) = 1, \forall x \in X$.

2.6.2 Intersection

Let $A, B \in F(X)$. The intersection of A and B is the fuzzy set C with

$$C(x) = min\{A(x), B(x)\} = A(x) \wedge B(x), \forall x \in X \text{......................(2.8)}$$

Denote $C = A \wedge B$. The graph of intersection is shown in Figure 2.5.

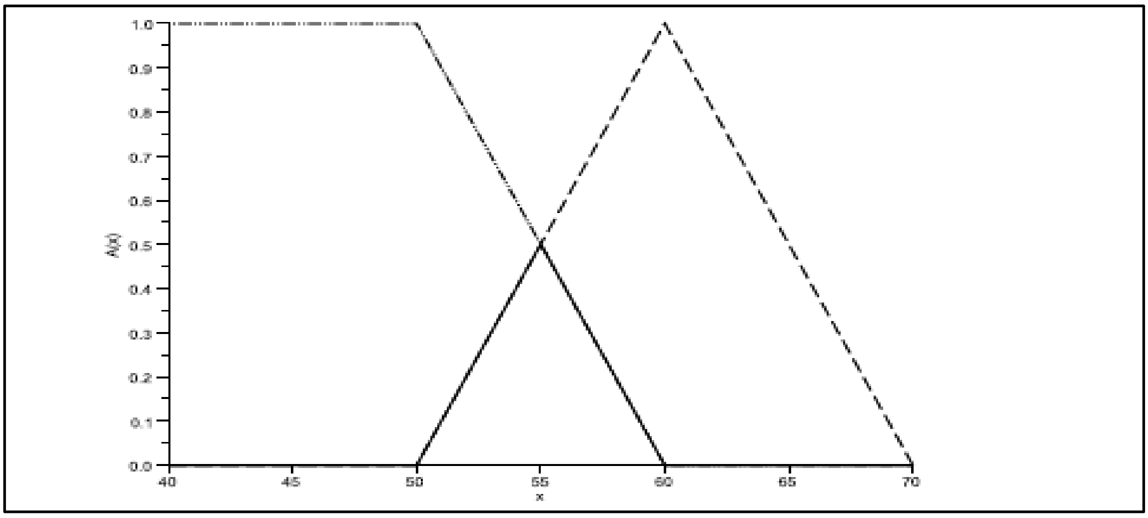

Figure 2.5 Intersection graph (Bede, 2013).

2.6.3 Union

Let $A, B \in F(X)$. The union of A and B is the fuzzy set C, where

$$C(x) = max\{A(x), B(x)\} = A(x) \vee B(x), \forall x \in X \text{....................(2.9)}$$

We denote $C = A \vee B$. The graph of union is shown in Figure 2.6.

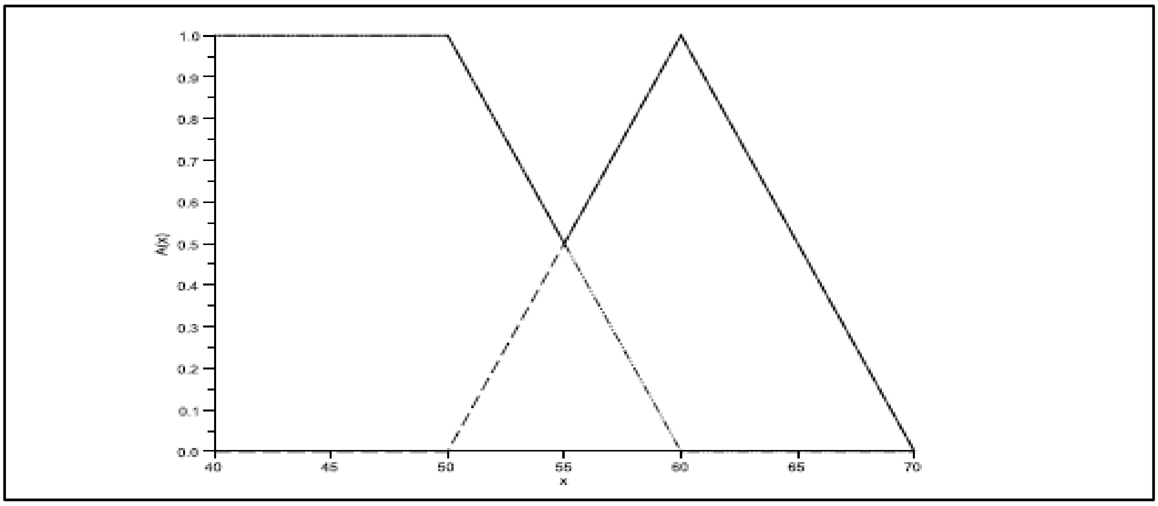

Figure 2.6 Union graph (Bede, 2013).

2.6.4 Complementation

Let $A \in F(X)$ be a fuzzy set. The complement of A is the fuzzy set B where

$$B(x) = 1 - A(x), \forall x \in X \text{...(2.10)}$$

We denote $B = \bar{A}$. The graph of complementation is shown in Figure 2.7.

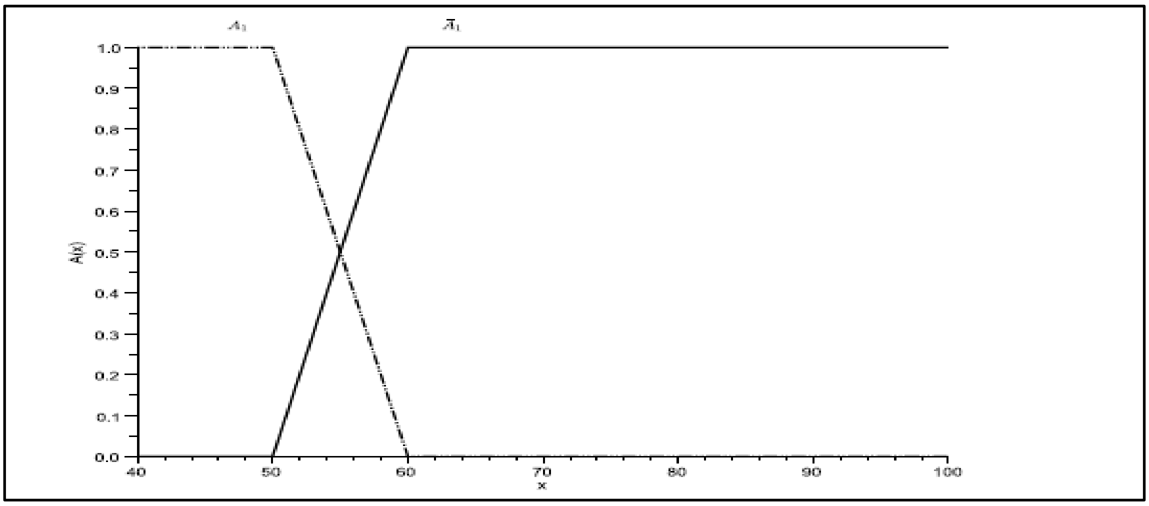

Figure 2.7 Complementation graph (Bede, 2013).

Linguistic fuzzy systems, also known as Mamdani fuzzy systems, possess rules in the form (Nelles, 2021):

$$Ri: IFu1 = Ai1 \ AND \ u2 = Ai2 \ AND \ \ldots up = Aip \ THEN \ y = Bi \text{.........(2.11)}$$

where $u1, \ldots, up$ are the p inputs of the fuzzy system gathered in the input vector u, y is the output, the index $i = 1, \ldots, M$ runs over all M fuzzy rules, Aij denotes the fuzzy set used for input uj in rule i, and Bi is the fuzzy set used for the output in rule i. A comparison with this example illustrates that typically many A*ij* are identical for different rules *i* (the same is valid for the Bi). On first sight, such linguistic fuzzy systems are the most appealing because both the inputs and the output are described by linguistic variables. However, the analysis of the fuzzy inference will show that quite complex computations are necessary for the evaluation of such a linguistic fuzzy system. The following steps must be carried out (Nelles, 2021):

$$\text{Fuzzification} \rightarrow \text{Aggregation} \rightarrow \text{Activation} \rightarrow \text{Accumulation} \rightarrow \text{Defuzzification}.$$

The fuzzification uses the membership functions (MSFs) to map crisp inputs to the degrees of membership. Crisp sets are a collection of objects. In a crisp set, it only has 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 (Singh and Lone, 2020). The aggregation combines the individual linguistic statements to the degree of rule fulfillment. Both steps are identical for all types of fuzzy systems discussed here and have been explained in the previous section. The last three steps depend on the fuzzy system type considered. In the *fuzzification* phase, the degrees of membership for all linguistic statements are calculated. They will be denoted by (Nelles, 2021):

$$\mu ij\ (uj\ ), i = 1, \ldots, M, j = 1, \ldots, p \text{.............................} (2.12)$$

In the *aggregation* phase, these degrees of membership are combined according to the fuzzy operators. When the fuzzy system is in conjunctive form and the product operator is applied as t-norm, the degree of fulfillment of rule *i* becomes (Nelles, 2021):

$$\mu i(\underline{u}) = \mu i1(u1) \cdot \mu i2(u2) \cdot \ldots \cdot \mu ip(up) \text{ ....} (2.13)$$

In the *activation* phase, these degrees of rule fulfillment are utilized to calculate the output activations of the rules. This can, for example, be done by cutting the output MSFs at the degree of rule fulfillment, i.e., (Nelles, 2021)

$$\mu_i^{act}\,(\underline{u}, y) \;=\; min[\mu i(\underline{u}), \mu i(y)] \text{ ....(2.14)}$$

where $\mu i(y)$ is the output MSF belonging to the fuzzy set Bi and $\mu i(u)$ is the degree of fulfillment for rule i.

In the *accumulation* phase, the output activations of all rules are joined together. This can be done by computing the maximum of all output activations, that is (Nelles, 2021),

$$\mu^{acc}\,(\underline{u}, y) \;=\; max_i[\mu_{\,i}^{\,act}(u, y)] \text{ ....(2.15)}$$

The accumulation yields one fuzzy set, which is the fuzzy output of the fuzzy system. If no crisp output is required, the inference mechanism stops here.

Otherwise, a crisp output value can be calculated by a final *defuzzification* step. The most common strategy for extraction of a crisp value from a fuzzy set is the *center of gravity* method, that is (Nelles, 2021),

$$\hat{y} = \frac{\int_{ymin}^{ymax} y\; \mu^{acc}(\underline{u}{,}y)dy}{\int_{ymin}^{ymax} \mu^{acc}(\underline{u}{,}y)dy} \text{ ....(2.16)}$$

where $\mu acc(u, y)$ is the fuzzy output set, i.e., the accumulated output activation. Other defuzzification methods can yield substantially different results.

Figure 2.8 summarizes the complete inference procedure for linguistic fuzzy systems with min and max operators for conjunction and disjunction, max operator for the accumulation, and center of gravity defuzzification (Nelles, 2021).

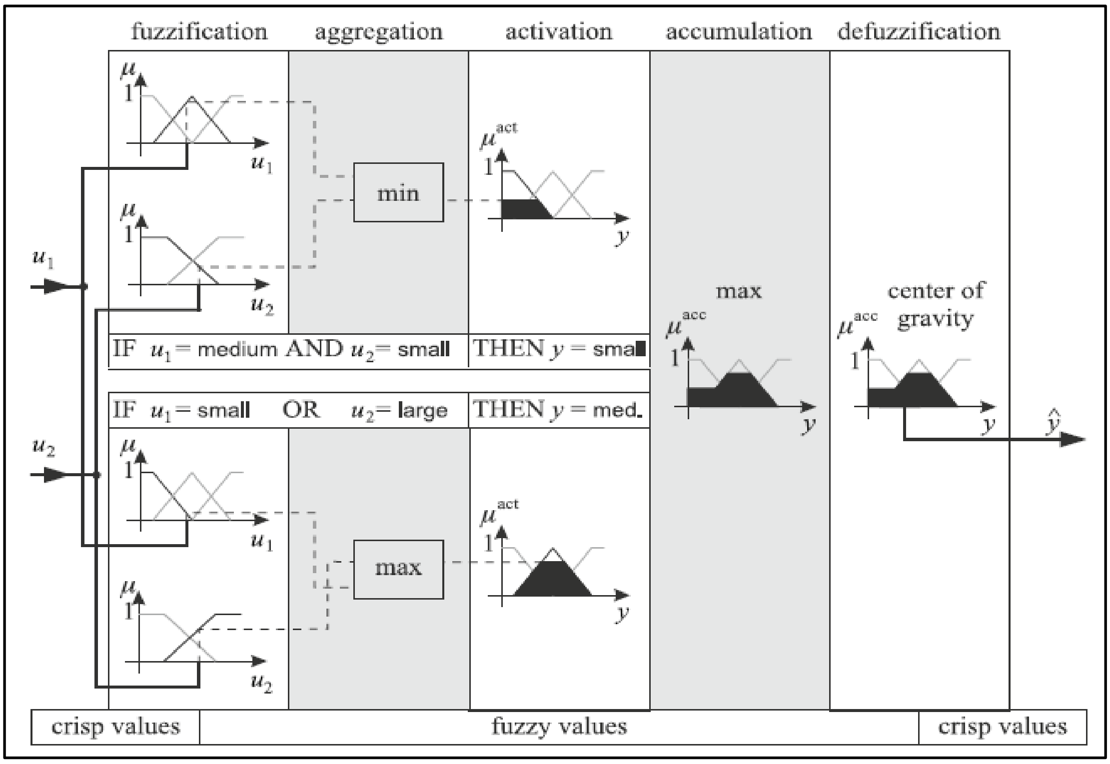

Figure 2.8 Inference for a linguistic fuzzy (Nelles, 2021).

2.7 Fuzzy Failure Mode Effect Analysis

Fuzzy logic is an appropriate technique which is used to estimate the output response from given input data. There are a wide variety of reasons why business commentators use a fuzzy logic system, these being, among others (Balaraju et al., 2019):

1. The Fuzzy logic concept is very easy to understand. The fundamentals of the mathematics are also uncomplicated in the Fuzzy Interface System.
2. This is flexible and can tolerate the data if any inappropricy exists in the datasets.
3. This technique is able to model complex non-linear functions in a short period of time.
4. This approach can also build up the experience of specialists with out of the need of additional training.
5. This technique will work on the basis of simple natural language.

FMEA is widely used method during the risk management and reliability analysis in manufacturing and service sector. By ranking the failures according to the failure's risk priority number, the corrective actions could take rightly and quickly for reducing or eliminating. However, FMEA parameters are determined by linguistic term of FMEA's members. These linguistic terms include subjective and qualitative description. The fuzzy set theory is a useful tool for overcoming these vagueness as a new risk assessment system. While only the membership function is considered in type-1 fuzzy set theory (Ayber and Erginel, 2019).

The fuzzy risk assessment methodology based on fuzzy sets theory provides a more flexible and meaningful way to assess risk associated with component/item failure modes. The parameters, i.e. severity, occurence and detection which are used in FMEA are fuzzified using appropriate membership functions to determine degree of membership in each input class. The resulting fuzzy inputs are evaluated in fuzzy inference engine, which makes use of well-defined rule base consisting of If-Then rules and fuzzy logic operations to determine criticality/riskiness level of the failure. The fuzzy conclusion is then defuzzified to get risk priority number (Braglia et al., 2003).

Higher the value of RPN, greater will be the risk and lower the value of RPN, lesser will be the risk (Sharma et al., 2005). The propose a reduction of the "degrees of freedom" inherent to the membership functions selection. In particular, cover the intervals of existence [1,10] of the three input criteria and of the output by using the simpler triangular shape for each possible fuzzy set. In fuzzy control field, these functions are the most used in fuzzy applications since more complex functions (trapezoidal, Gaussian, etc.) cause a greater computational complexity, often without remarkable advantages (Braglia et al., 2003).

2.8 Python

Python is a high-level and general-purpose computer language that lends itself to many applications (Kong et al., 2021). 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. Usually a window is associated with the shell. A command, often called a statement, instructs the interpreter to do something (Guttag, 2016).

Objects are the core things that Python programs manipulate. Every object has a type that defines the kinds of things that programs can do with that object. Types are either scalar or non-scalar. Scalar objects are indivisible. Think of them as the atoms of the language. Non-scalar objects, for example strings, have internal structure. Many types of objects can be denoted by literals in the text of a program. For example, the text '2' is a literal representing a number and the text 'abc' a literal representing a string. Python has four types of scalar objects (Guttag, 2016):

1. int is used to represent integers. Literals of type int are written in the typically denote integers (e.g., -3 or 5 or 10002).
2. float is used to represent real numbers. Literals of type float always include a decimal point (e.g., 3.0 or 3.17 or -28.72). (It is also possible to write literals of type float using scientific notation. For example, the literal $1.6 * E^3$ stands for 1.6×10^3, i.e., it is the same as 1600) this type is not called real. Within the computer, values of type float are stored in the computer as floating point numbers. This representation, which is used by all modern programming languages, has many advantages. However, under some situations it causes