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*Original Article*

# Criticality Analysis of Electromechanical Equipment Maintenance. A Case Study in Sasol Synfuels Catalyst Preparation Unit

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***Abstract -*** *The subject of maintenance optimization is not new, and many researchers have explored it. However, it is seen that one optimization solution cannot be used in all industries. Each industry and equipment thereof are unique as the product streams differ, layouts and operation variables, to name a few. However, Turnaround management is the most used strategy in petrochemical industries. Equipment downtime remains the biggest challenge; thus, the purpose of the study was to optimize the maintenance practices used on the critical electromechanical equipment in Sasol Synfuels Catalyst Preparation. The data from the Systems Applications and Products (SAP) was collected for each of the 13 electromechanical equipment identified in the catalyst preparation unit from the period of January 2016 to June 2021. An analysis and identification of the critical equipment within the unit were obtained using two different methods, namely the JADERI and AFEFY critical analysis approaches. Both methods include using qualitative and quantitative methods to obtain the results. From the use of the results obtained using both JADERI and AFEFY, the equipment was ranked. According to the JADERI approach, all the equipment was classified as non-critical, yet the AFEFY method classified the Arc furnace and Ball Mill equipment as being the most critical equipment. It is then followed by Kiln, who is categorized as the second most critical. The casting machine and conveyor belts are classified under category C, which dictates that they are the least critical equipment.*

***Keywords*** *- Criticality analysis, Criticality ranking, Electromechanical equipment, Maintenance optimization, Maintenance strategy.*

## 1. Introduction

Petrochemicals refer to the products that are produced from hydrocarbon organic chemicals such as crude oil, natural gas, and natural gas condensates as raw materials. The petrochemical industry uses dome products from oil refineries as raw materials for specific chemical products; thus, it differs from the refinery industry. The products thereof produced include plastic resins, synthetic fibres, synthetic rubbers, surface coating materials and various types of adhesives, as reported in 2006 [5].

The petrochemical industry is divided into three groups. The first is the Upstream Petrochemical industry. This is the baseline and supplier to the further production of the other petrochemical products, of which it aims to produce primary feedstock for the next group of products. Second is the intermediate petrochemical industry, which utilizes the products proceeding from the upstream to provide feedstock to the Downstream production, the last main group. The downstream petrochemical industry utilises products from both the upstream and intermediate to produce the end products, such as synthetic plastic, rubber, etc [18].

A study by MAJOZI [15] explored how the petrochemical industry in South Africa compromises about 55 percent of all chemicals produced, thus requiring high energy consumption. Energy conservation is a factor due to its direct impact on the production cost [5]. MAJOZI's [15] study highlighted that the problems in energy conversion consist of energy management, technology, economy, and human resources. One of the contributing factors is the high cost of machines, technology, and maintenance. In this era of global competition, most of the power, processing and manufacturing sectors are required to reduce their overall cost while maintaining the value and reliability of their sectors [3]. MAJOZI [15] explains in his journal how South Africa's petrochemical industry started in the 1950s after George Williams Stow discovered diesel fuel coal near the Vereeniging on the banks of Vaal River in 1878. The first coal-to-liquids plant was built at Sasolburg.

After that, Sasol built two Petrochemical operations, namely SASOL two and three. The Sasol Advanced process (SAS) was introduced through continuous improvement and development. Seven new SAS reactors were introduced in 1999 [18].

Sasol uses the Fisher-Tropsh process to produce liquids derived from coal, liquids such as synthetic rubber, fertilizers, and secondary chemicals such as ethanol, butanol, ethyl acetate, acrylic acid, and butyl acrylate including diesel [18].

The whole process has a series connection, which means that every unit depends on the other to provide the products needed; however small the unit might be, it is crucial to provide the output product. In other simple terms, it means that the system's successful operation depends on the proper operation of all the components. Hence, if one of these components fails, the system fails.

This type of setup is a disadvantage not only to the operation side of the plant but also to maintenance. Since every unit depends on the other, anytime maintenance activities are rarely used. Most maintenance schedules depend on the unit, plant, or factory shutdown, also known as turnaround maintenance. In terms of survival, the system can be no better than a component with the lowest probability of survival. The catalyst is provided through units 004/204, the catalyst preparation unit.

The catalyst is fed through process lines, which assist in creating hydrocarbons needed in downstream units. The main unique nature of the Catalyst preparation unit is its ability to store products for future use. Thus, unlike most units, this unit can isolate some of the equipment for maintenance for a period without affecting the factory production rate. Hence, it is called a batch plant as it can store catalysts for future use whilst allowing maintenance to be done on the equipment.

## 2. Maintenance Defined

Maintenance is defined by FREDRIKSSON [8] as the combination of all technical, administrative, and managerial actions on an equipment's life cycle. Maintenance intends to retain or restore the equipment to a state where it can perform the required function. In other words, maintenance is an action performed to prevent a device or component from failing either from normal equipment degradation or breakdown. MANICKHAM [16] argues that the maintenance objective is to retain or restore the systems to carry out a perfect production function.

Whilst FREDRIKSSON [8] research work concluded that a maintenance organization’s primary objective is to ensure that all equipment and systems are constantly in good operating condition and online, in other words, to reduce disturbances.

All these arguments have one similar objective: maintenance has two essential objectives, the first being the high availability of production equipment and the second being low maintenance costs [22]. Maintenance is considered support for the production process, whereas the production input is derived into specified production output.

SHAFIEE [19] study further explains how an effective maintenance strategy aims to reduce the frequency of asset downtime and avoid such interruptions. More so, over-maintenance can increase maintenance costs, and subsequently, less maintenance may bring undesirable failures and interruptions.

Maintenance must retain or restore the systems for a perfect production function to avoid losses [16]. Availability and maintainability are the key elements of an effective maintenance practice [8].

Maintenance optimization aims to ensure that machine failure is minimized. Machine failure may cause multiple business-related problems, such as poor product quality, overdue product delivery and loss of business profit. Thus, maintenance activities should be carefully thought of in terms of planning, investment, and control.

## 3. Criticality Analysis

Criticality analysis is a crucial step in the evaluation phase to implement an optimal maintenance solution. According to VISHNU [22], critical analysis is a tool used to systematically evaluate how equipment failures affect organizational performance and rank plant assets for work prioritization and material classification. Furthermore, it assists in scheduling preventative and predictive maintenance development and reliability improvement initiatives. Similarly, the AFEFY [1] study states that criticality analysis is a crucial tool to evaluate how equipment failures impact organizational performance.

This is to systematically rank plant assets for work prioritization, material classification, preventive and predictive maintenance development, and reliability improvement initiatives. Various reliability importance measures are used to determine the criticality of components such as Risk reduction worth and Risk achievement worth. Other measures include sensitivity analysis, time-independent component reliability importance measures, etc., as stated by JADERI [12].

Among the several approaches used for criticality analysis of asset failures, the risk-based maintenance (RBM) approach is the most appropriate risk assessment methodology used in the Petrochemical Industry. Furthermore, JADERI [12] study indicates that Petrochemical companies handle many hazardous materials, and as a result, they can be classified as a high-risk industry.

Moreover, the same study indicated that the consequence of asset failure might lead to major accidents, such as fires, explosions, and toxic gas releases, in chemical industries. Thus, RBM provides tools for maintenance planning and decision-making to decrease the probability of failure of equipment and the consequences thereof [12]

The Risk-based maintenance analysis approach is also being used widely for the optimization of maintenance activities, especially in the Petrochemical industry. This method utilizes risk assessment techniques to prioritize assets and to align maintenance actions to business targets at any time. Thus, maintenance actions are effective, and there is a reduction in indirect and direct maintenance costs. Other benefits include improved safety and environmental risk, reduced production losses and, ultimately, customer dissatisfaction.

Turnaround management is the most used strategy in petrochemical industries, yet downtime remains the biggest challenge, especially within the Synfuels catalyst preparation unit. Although maintenance strategies are employed on the equipment, obtaining the right balance of all applied strategies remains a challenge. The main objective of this study is to optimize the maintenance strategies used on the electromechanical equipment in the Sasol Synfuels Catalyst Preparation Unit to increase the equipment's reliability and availability. It is important to note that the criticality rate of the critical equipment affects the plant's performance; hence, this study intends to use criticality analysis to identify the most critical equipment within the unit. This is a crucial step in determining the amount of maintenance to be applied to the equipment for an optimal maintenance strategy solution to be implemented.

## 4. Research Methodology

Sasol Synfuels Catalyst preparation unit is considered a batch plant containing hoppers that store the catalyst. The equipment can be scheduled for downtime for a certain amount of time until the need for more catalysts is met. The analysis contains both east and west units. The eastern unit consists of two Arc Furnaces (AF), Conveyer Belts (CV), Ball Mills (BM) and kilns (CM), all running concurrently, making a total of 8 equipment.

The western unit consists of 5 electromechanical equipment, thus making 13 pieces of equipment. Criticality ranking is crucial to determine the equipment which is most crucial to the plant's overall performance. The key points analysed to determine the critical plant equipment are the availability, maintenance cost, equipment downtime, and safety factors to the people and environment. Two methods were used in this section, namely JADERI [12] and AFEFY [1], to verify the correctness of the results obtained for each equipment.

Risk-based criticality analysis is mainly used to assess the equipment failure rate and consequences (Financial loss, safety, etc.) thereof to formulate an effective maintenance strategy.

Considering the petrochemical industry and how safety is a major factor in the criticality of the equipment, hence, though there are various methods of calculating the criticality of equipment, it is therefore that this study, similar to the JADERI [12] and AFEFY [1] study, uses the same indices as the two methods of criticality analysis were utilised.

### *4.1. Method 1: JADERI Criticality Ranking*

JADERI [12] study measures risk as to the failure frequency coupled with the consequence thereof, as presented in equation 1.

$$R = F \times C = F \times ((OI \times OF) + MC + ISE) \quad (1)$$

The consequence is divided into four factors, namely: Operational Impact (OI), Operational Flexibility (OF), Maintenance Cost (MC) and Impact on Safety and Environment (ISE).

The different scales for each consequence factor are tabulated, and the results are obtained from subject matter experts through the qualitative method. See Appendix A. The following questions were used to assess each factor, with consideration of the Mean Time to Repair (MTTR), Mean Time Between Failure (MTBF), Maintenance downtime and Maintenance cost for each piece of equipment:

- How would you rate the operation impact of this equipment on a scale of 2 to 10, 2 being unavailability resulting in operation cost and 10 being an immediate plant shutdown?
- How would you rate the operational flexibility from high to low using a scale from 4 to 1. 4 being that there are no spares nor alternative operation and 1 meaning there are spares available?
- What is the impact on safety and the environment regarding a breakdown of the equipment? Using a scale from 0 to 8. 0 means there is no impact on human, environmental or operational facilities, and 8 means there is an impact on internal/external human safety requiring notification of public institutions.

The questions were posed to the Mechanical Technician of the plant, the Area Manager, and the production personnel. The outcomes were tabulated in the proceeding results section.

The conclusion was made through a formal meeting with the area manager. Using equation 1, the risk value was calculated and compared to JADERI [12] asset criticality level in Appendix A, and a conclusion was drawn on which equipment is considered critical, semi-critical or non-critical.

### 4.2. Method 2: AFEFY Criticality Ranking

With the AFEFY [1] study, another risk assessment was done using the criticality index, unlike the JADERI [12] study, which used factors to rank the consequence of failure. AFEFY [1] utilises criteria, namely product, safety, availability, and capital cost, to evaluate the critical equipment (EC). Product and Safety impact is weighed as 30%, whilst availability is 25% and capital cost 15%. In summary, the percentages add to 100%, which is then divided by 3 to obtain Equipment Criticality (EC) percentage as in equation 2.

$$EC = ((30 \times P) + (30 \times S) + (25 \times A) + (\frac{15 \times V))}{3}) \qquad (2)$$

Whereby:
EC : is the equipment criticality, %
P : is the product
S : is the safety
A : is the equipment stand by
V : is the capital cost.

With the use of both qualitative and quantitative methods, the proceeding qualitative questionnaire was utilised. The Area Manager of the plant, Mechanical Technician and Production Personnel were questioned using the following questions.

1. How would you rate the impact on the production of the equipment breakdown on a scale of 1 to 3? 1 being normal, meaning no production impact and 3 being very important, meaning a huge loss in production.

2. How would you rate the impact on the safety of the equipment breakdown on a scale of 1 to 3? 1 being normal, meaning less risk to personal and environment and 3 being very important, meaning a huge loss to person and environment.

3. How would you rate the impact on the availability of equipment on a scale of 1 to 3? 1 being with standby and high availability and 3 being without a standby

4. How would you rate the equipment value on a scale of 1 to 3? 1 being low value and can be replaced anytime and 3 being very high value, which will require a project proposal for replacement.

The results were weighted according to the criteria weights in Appendix A, and using Equation 2, the equipment criticality was calculated.

The outputs were classified under four categories: A, B, C, and D. Ranked as A was classified as the most critical, with the subsequent factors following.

If the EC < 45 = D,
EC < 60 = C,
EC < 74 = B,
EC > 74 = A.

Results were tabulated as in the proceeding results section. From the use of the results obtained using both JADERI [12] and AFEFY [1], the equipment was ranked.

Western Unit (004)

**Table 1. Criticality analysis for unit 004**

| Asset Equipment's | Average Failure Rate (F) | OI | OF | MC | ISE | C | R | Priority |
|---|---|---|---|---|---|---|---|---|
| AF-141 | 2 | 2 | 2 | 2 | 8 | 14 | 28 | NC |
| CM-141 | 1 | 2 | 2 | 1 | 2 | 7 | 7 | NC |
| CV-101 | 1 | 2 | 2 | 1 | 2 | 7 | 7 | NC |
| KN-101-R1 | 1 | 2 | 2 | 1 | 4 | 9 | 9 | NC |
| GM-141 | 1 | 4 | 4 | 1 | 6 | 23 | 23 | NC |

Eastern Unit (U204)

**Table 2. Criticality analysis for unit 204**

| Asset | Average Failure Rate (F) | OI | OF | MC | ISE | C | R | Priority |
|---|---|---|---|---|---|---|---|---|
| AF-141A | 1 | 2 | 2 | 2 | 8 | 14 | 14 | NC |
| AF-141B | 1 | 2 | 2 | 2 | 8 | 14 | 14 | NC |
| CM-141 | 1 | 2 | 2 | 2 | 2 | 8 | 8 | NC |
| CV-101 | 1 | 2 | 2 | 1 | 2 | 7 | 7 | NC |
| CV-201 | 1 | 2 | 2 | 1 | 2 | 7 | 7 | NC |
| KN-101A | 1 | 2 | 2 | 2 | 4 | 10 | 10 | NC |
| KN-101B | 1 | 2 | 2 | 2 | 4 | 10 | 10 | NC |

## 5. Results and Discussion

### *5.1. Results 1: JADERI Criticality Ranking*

The first method used was from JADERI [12] study, whereby the following factors were used, namely:

1. Frequency of failure (F)
2. Operational impact (OI)
3. Operational flexibility (OF)
4. Maintenance cost (MC)
5. Impact on Safety and Environment (ISE)

Both qualitative and quantitative methods were used to obtain the results of the Risk value (R) represented in Tables 1 and 2. Whereby the consequence of Failure (c) was also obtained.

With the use of the assets criticality level table in appendix A, the assets equipment was then classified as Critical (C), Semi Critical (SM) or Non-Critical (NC). From the obtained data, all the electromechanical equipment's identified are listed as non-critical.

### *5.2. Results 2: AFEFY Criticality Ranking*

AFEFY [1], study and methodology to critical ranking were used. Similarly to JADERI [12], both qualitative and quantitative methods were used with different 4 weighted factors, namely:

1. Product (P)
2. Safety (S)
3. Availability (A)
4. Capital cost (V)

Unlike JADERI [12], the criticality is ranked as A, classified as the most critical, and D is the least critical, with the subsequent factors following. If the EC < 45 = D, EC < 60 = C, EC < 74 = B, EC > 74 = A.

In the western unit, the arc furnace and ball mill were the most critical equipment. This is mainly due to the high safety risk and capital cost. The Kiln has a category B, and lastly, the least critical equipment with category C are both the casting machine and conveyor belt like the eastern unit from Table 3.

Western Unit (U004)

**Table 3. Criticality analysis for Unit 004**

| Asset | P (30) | S (30) | A (25) | V (15) | EC (%) | Category |
|---|---|---|---|---|---|---|
| AF-141 | 1 | 3 | 3 | 3 | 80 | A |
| CM-141 | 1 | 1 | 3 | 1 | 50 | C |
| CV-101 | 1 | 1 | 3 | 1 | 50 | C |
| KN-101-R1 | 1 | 1 | 3 | 2 | 72 | B |
| GM-141 | 2 | 2 | 3 | 3 | 75 | A |

Eastern Unit (U204)

**Table 4. Criticality analysis for Unit 204**

| Asset | P (30) | S (30) | A (25) | V (15) | EC (%) | Category |
|---|---|---|---|---|---|---|
| AF-141A | 1 | 3 | 3 | 3 | 80 | A |
| AF-141B | 1 | 3 | 3 | 3 | 80 | A |
| CM-141 | 1 | 1 | 3 | 1 | 50 | C |
| CV-101 | 1 | 1 | 3 | 1 | 50 | C |
| CV-201 | 1 | 1 | 3 | 1 | 50 | C |
| KN-101A | 1 | 1 | 3 | 2 | 72 | B |
| KN-101B | 1 | 1 | 3 | 2 | 72 | B |
| GM-141 | 2 | 2 | 3 | 3 | 85 | A |

## 6. General Discussion of Results

Two methods for equipment criticality ranking were utilised: JADERI [12] and AFEFY [1] study approach. Based on the discrepancies seen from the JADERI [12] method, as all types of equipment were rated as non-critical.

This is subject to the unit being a batch plant; thus, the operational impact is seen as low since the catalyst is generally stored in hoppers, which act as an emergency plan in case a piece of equipment is shut down. The operational flexibility thus is also reasonably low as a spare function is shared as the catalysts can be fed from one unit to another. However, the ball mall has no spare function, meaning that there is a risk to operations and production when the ball mill is shut down for a longer duration.

According to the rating of the maintenance cost, the arc furnace, casting machine and Kiln in the eastern unit are seen to be high, including the arc furnace on the eastern side. In terms of safety and environmental impact, as this equipment operates at high temperatures, crushing and producing a product which is dangerous to both humans and the environment; thus, the risk of the equipment failure and the effect thereof on the environment and people is high. With all these factors combined, according to JADERI [12] methodology, these equipment were categorized as non-critical. The observations made through the provided equations 1 and 2 were effective in the JADERI [12] study.

Because the formula does not factor in batch plants that have stored products, thus making the operational impact is low. Neither does it factor in the availability of the equipment, which is the main problem area identified for the electromechanical equipment in the catalyst preparation unit.

AFEFY [1] approach is more concise as it factors other variables such as availability and capital cost. The arc furnace and ball mill are considered the most critical due to high safety factors and equipment value. It is noted that the availability is rated as 3 for all equipment as there is no spare equipment available for any of the equipment.

Though on the eastern unit, there are two arc furnaces and conveyor belts, they all run simultaneously. Both types of equipment form part of productivity; thus, if one is shut down, there will be an effect on productivity regardless of whether the plant is a batch plant. The AFEFY [1] method is more direct as the factors considered are diverse and accommodative to the specific catalyst preparation unit as it is a batch plant. Each identified electromechanical equipment within the catalyst preparation unit impacts the production, availability, and safety of the unit. Variables such as the availability thus make the equation concise for this reason. From the qualitative data obtained from the respective maintenance personnel, it is therefore seen that JADERI [12] is rather complex in its derivation and thus not suitable for the batch plant catalyst unit preparation. Thus, according to the AFEFY [1] study, the two pieces of equipment classified as the most critical pieces are the arc furnace and ball mill. The Arc-furnace and Ball Mill are calculated as category A with 80% and 75%, respectively. The Kiln is calculated at 72%, which is category B, resulting in the second most critical equipment. The least critical equipment is, namely, the casting machine and conveyor belt, resulting in 50%, which is classified as category C.

## 7. Conclusion and Recommendation

From the use of the results obtained using both JADERI [12] and AFEFY [1], the equipment was ranked. According to JADERI [12], all the equipment was classified as non-critical, yet the AFEFY [1] method classified the Arc furnace and Ball Mill equipment as being the most critical equipment. Kiln then follows it categorized as B.

The casting machine and conveyor belts are classified under category C, which dictates that they are the least critical equipment. Due to the different criteria weights used on both methods and the consistent scaling of questionaries in the AFEFY [1] method. It is, therefore, observed that the AFEFY [1] qualitative approach was more consistent compared to the JADERI [12] approach. In conclusion, the aim of the study was met as the equipment was ranked according to different criteria weights. However, the unit is categorized as a batch plant. The equipment availability is also seen to be a high-risk factor as they do not have any spare equipment. Thus, downtime is a challenge. This was proven through AFEFY [1] results. Qualitative approaches were utilised for the criticality analysis that required detailed information on the frequency of the failures and the consequences thereof. These types of information are normally uncertain and imprecise; thus, uncertainty may result from lack of information, incompleteness, and inaccuracy of derived measurement. Thus, it is recommended that the quantitative criticality approach should be further researched with methods that can accommodate batch plant operations thereof.

## Data Availability

The data used to support the findings of this study are included in the article.

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## Appendix

**Table A. Frequency of failure measurement [12]**

| Failure frequency (F) | Failure per year | Model Value |
|---|---|---|
| Poor | > 4 | 4 |
| Average | 3-4 | 3 |
| Good | 1-2 | 2 |
| Excellent | <1 | 1 |

**Table B. Operation impact factor (OI) [12]**

| Operational impact factor (OI) | Consequence | Model scale |
|---|---|---|
| Extremely high | Immediate plant shutdown | 10 |
| Very high | Partial plant shutdown | 6 |
| High | Impact production levels or quality | 4 |
| Average | Operational costs associated with unavailability | 2 |

**Table C. Operational flexibility (OF) [12]**

| Operational flexibility (OF) | Consequence | Model scale |
|---|---|---|
| high | No spare or alternative operation | 4 |
| average | Spare function shared | 2 |
| low | Spare function available | 1 |

**Table D. Maintenance Cost (MC) [12]**

| Maintenance cost (MC) | Consequence | Model Scale |
|---|---|---|
| high | $C \geq$ R 70 000 | 2 |
| medium | R 30 000 < C < R 70 000 | 1.5 |
| low | $C \leq$ R30 000 | 1 |

**Table E. Impact on safety and environment (ISE) [12]**

| (ISE) | Consequence | Scale |
|---|---|---|
| Extremely high | Impact on internal and external human safety requires notification of public institutions | 8 |
| Very high | Irreversible environmental impacts | 6 |
| High | Impact on operations facilities causing severe damage | 4 |
| Average | Minor accidents and incidents | 2 |
| low | Environmental effects without violation of law | 1 |
| Very low | No impact(s) on human, environmental, or operational facilities | 0 |

**Table F. Asset criticality level [12]**

| Asset criticality level | Risk value |
|---|---|
| Critical | R >100 |
| Semi- Critical | 40 < R < 100 |
| Non- Critical | R < 40 |

**Table G. Criteria weights [1]**

| Criteria | Weight | Levels |
|---|---|---|
| Impact on production (P) | 30% | (3) Very important<br>(2) Important<br>(1) normal |
| Impact on safety (S) | 30% | (3) Very important<br>(2) Important<br>(1) normal |
| Availability of standby (A) | 25% | (3) Without standby<br>(2) With standby and medium availability, and<br>(1) With standby and high availability |
| Equipment value (V) | 15% | (3) High value<br>(2) normal, and<br>(1) Low value |