Analysis and Control of Genset Damage Risk In The Facility Department Using The Hazard and Operability Study (Hazop) And Fault Tree Analysis (FTA) Methods

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Abstract.
A generator set (genset) is an essential supporting facility that ensures the continuity of electrical power supply in manufacturing companies during failures of the main power source. Generator failures may interrupt production activities, increase maintenance costs, and reduce overall operational effectiveness. This study aims to identify potential risks of generator set failures using the Hazard and Operability Study (HAZOP) method, analyze the root causes of failures using Fault Tree Analysis (FTA), and propose appropriate risk control recommendations. The research data were collected through observations, interviews, documentation, and historical maintenance records from the Facility Department. The HAZOP analysis revealed that radiator overheating had the highest Risk Score of 20, categorized as an extreme risk, while battery drop and fuel filter blockage each obtained a Risk Score of 16, categorized as high risk. Furthermore, the FTA results indicated that generator failure was caused by several basic events, including battery drop, fuel filter blockage, radiator overheating, alternator failure, starter motor failure, and oil leakage, with a calculated top event probability of 67.2%. The proposed recommendations include implementing preventive maintenance, conducting routine inspections, replacing components based on service life, and improving generator condition monitoring to enhance equipment reliability and minimize operational failure risks.
Keywords: *Generator Set, HAZOP, Fault Tree Analysis, Risk Analysis and Preventive Maintenance.*

I. INTRODUCTION

The manufacturing industry is a sector that highly depends on the continuity and reliability of production processes to achieve production targets, maintain product quality, and fulfill customer demands within the expected timeframe. The smooth operation of production activities is not only determined by the performance of primary production machinery but also by supporting facilities that ensure the overall operational system functions effectively. One of the critical supporting facilities is the Generator Set (genset), which serves as an emergency power supply when disruptions occur in the main electrical network. The genset plays a vital role in maintaining production continuity by ensuring that production machines, control systems, lighting systems, and other utility equipment remain operational during power outages (Bastuti, 2021).

In manufacturing companies, the Facility Department is responsible for managing, inspecting, maintaining, and improving the reliability of various supporting infrastructures, including electrical systems, generator sets, air compressors, Heating, Ventilation, and Air Conditioning (HVAC) systems, fire protection systems, and other utility facilities. The reliability of generator sets is considered one of the key performance indicators of the Facility Department because failures in genset operation may interrupt production activities, increase downtime, disrupt production schedules, cause defects in work in process products, and generate financial losses due to delayed product delivery to customers (Siswantoro et al., 2022). Therefore, an effective maintenance strategy is required to ensure high equipment availability and operational readiness.

In practice, maintenance activities for generator sets in many manufacturing companies are still dominated by corrective maintenance approaches, where repair actions are carried out only after equipment failure occurs. This approach often leads to increased breakdown frequency, higher repair costs, unplanned spare-part requirements, and reduced component service life (Santoso & Trijeti, 2025). These conditions indicate that conventional maintenance strategies are not yet sufficient to identify critical components with high failure potential. Therefore, a more systematic and reliability-based maintenance approach is needed to improve equipment performance and prevent unexpected failures (Safitri, 2025).

One of the methods commonly used to identify potential hazards and operational risks is the Hazard and Operability Study (HAZOP). HAZOP is a systematic risk assessment technique that identifies deviations from normal operating conditions by applying specific guide words. This method aims to determine potential hazards, causes of deviations, possible consequences, existing control measures, and improvement recommendations to reduce operational risks. In this study, HAZOP is applied to evaluate each subsystem of the generator set in order to comprehensively identify potential failures that may affect operational continuity (Robbi et al., 2025).

However, HAZOP has limitations because it primarily focuses on identifying potential hazards and their consequences without providing a detailed explanation of the logical relationships among failure causes. Therefore, this study integrates Fault Tree Analysis (FTA) to overcome these limitations. FTA is a deductive analytical method used to investigate the root causes of system failures through the development of logical tree diagrams (fault trees) (Muhendra et al., 2026). By applying logical gates, such as AND gates and OR gates, FTA can illustrate the relationship between the top event and various basic events that contribute to system failure. The combination of HAZOP and FTA provides a more comprehensive risk analysis approach, beginning with hazard identification and continuing with the determination of the fundamental causes of failures in the generator set system (Syifa et al., 2026).

The implementation of HAZOP and FTA is expected to enable companies to identify components with the highest risk levels, understand the factors contributing to equipment failures, and develop more effective risk control strategies. The findings of this research are also expected to provide a practical foundation for the Facility Department in designing preventive maintenance programs, improving generator set reliability, reducing failure frequency, minimizing downtime, and supporting sustainable production operations (A. Putra & Irwan, 2026).

Fig. 1. Generator Observations

Based on initial observations by the Facilities Department, several problems were still found in the generator system, causing suboptimal operation. These problems included starter system failures, decreased battery capacity, fuel system leaks, clogged diesel filters, engine overheating, oil leaks, and alternator problems. These problems resulted in increased repair times, increased maintenance costs, and decreased reliability of the generator as a backup power source. The data on generator failures during the 2025 study is presented in Table 1 below:

Table 1. Generator Failure Data

Month	Battery Drop	Clogged Fuel Filter	Radiator Overheating	Oil Leakage	Damaged Alternator	Damaged Starter Motor	Total Failures
January	1	1	0	1	0	0	3
February	1	0	1	0	1	0	3
March	1	1	1	0	0	1	4
April	0	1	1	1	0	0	3
May	1	1	0	1	1	0	4

Month	Battery Drop	Clogged Fuel Filter	Radiator Overheating	Oil Leakage	Damaged Alternator	Damaged Starter Motor	Total Failures
June	1	1	1	0	0	0	3
July	0	1	1	1	1	0	4
August	1	0	1	0	1	1	4
September	1	1	0	1	0	0	3
October	1	1	1	0	1	0	4
November	0	0	1	1	0	1	3
December	1	1	0	0	1	0	3
Total	**9**	**9**	**8**	**6**	**6**	**3**	**41**

Table 2. Percentage Distribution of Generator Set Failures

No.	Failure Type	Frequency	Percentage (%)
1	Battery Drop	9	21.95
2	Clogged Fuel Filter	9	21.95
3	Radiator Overheating	8	19.51
4	Oil Leakage	6	14.63
5	Damaged Alternator	6	14.63
6	Damaged Starter Motor	3	7.33
	Total	**41**	**100**

Based on the failure records collected during 2025, a total of 41 failure incidents were identified in the generator set system. The most frequent failure modes were battery drop and clogged fuel filter, with each contributing 9 occurrences (21.95%). These findings indicate that the starting electrical system and fuel supply system are the most vulnerable components in the generator set operation. The high frequency of failures in these components suggests that the existing preventive maintenance practices for electrical and fuel system components require further improvement to achieve better equipment reliability.

Furthermore, failures related to radiator overheating and oil leakage also contributed significantly to generator set downtime. These conditions indicate that thermal control systems and lubrication systems require closer monitoring and more effective maintenance strategies. Therefore, an evaluation of the current maintenance approach is necessary to improve generator set reliability, reduce failure occurrence, and minimize the risk of operational interruptions. Based on these findings, further investigation is required to identify potential hazards, analyze operational risks, and determine the root causes of generator set failures as a critical supporting facility in the production process. Therefore, this research focuses on "Analysis And Control Of Genset Damage Risk In The Facility Department Using The Hazard And Operability Study (Hazop) And Fault Tree Analysis (Fta) Methods."

II. METHODS

Research Design

This research employed a descriptive qualitative approach combined with quantitative risk assessment analysis to identify potential failures, evaluate operational risks, and determine the root causes of generator set failures in the Facility Department of a manufacturing company. The research focused on analyzing failure modes of the generator set system using the Hazard and Operability Study (HAZOP) and Fault Tree Analysis (FTA) methods. The integration of HAZOP and FTA was selected because HAZOP is effective in identifying operational deviations and potential hazards, while FTA provides a systematic approach to trace the logical relationship between failure events and their fundamental causes (Mohammadi et al., 2021).

The research was conducted through several stages, including problem identification, data collection, hazard identification using HAZOP, determination of critical failure events, root cause analysis using FTA, and formulation of improvement recommendations. This approach enables a comprehensive evaluation of generator set reliability, starting from failure identification to preventive maintenance strategy development (Mohammadhasani & Pirouzmand, 2021).

Research Object and Data Collection

The object of this research was the Generator Set (Genset) system managed by the Facility Department in a manufacturing company. The generator set was selected as the research object because it functions as a backup power supply system that maintains operational continuity during interruptions in the main electrical supply. The data used in this study consisted of primary data and secondary data. Primary data were obtained through direct observation of generator set operating conditions, interviews with Facility Department personnel, and discussions with maintenance technicians involved in equipment management. Secondary data were collected from historical maintenance records, failure reports, inspection documents, and preventive maintenance schedules during the 2025 observation period.

The collected failure data were classified based on failure modes, including battery drop, clogged fuel filter, radiator overheating, oil leakage, alternator failure, and starter motor failure. The failure frequency data were subsequently used to determine dominant failure modes requiring further analysis (Burns et al., 2023).

Research Procedure

The research procedure was carried out through the following stages:

1. Identification of Generator Set Failure Modes

The initial stage involved identifying failure modes that occurred in the generator set system based on historical maintenance data. Each failure mode was categorized according to the affected components, failure frequency, and operational impact. This stage aimed to determine the critical problems affecting generator set reliability.

2. Hazard Identification Using HAZOP Method

The HAZOP method was applied to systematically identify potential hazards and operational deviations within the generator set system. The analysis was performed by dividing the system into several analysis nodes based on major components, including the fuel system, electrical system, cooling system, lubrication system, and starting system.

The HAZOP analysis consisted of identifying:

a. Node, representing the system section being analyzed.
b. Parameter, representing operational variables such as temperature, pressure, voltage, fuel flow, and lubrication conditions.
c. Guide words, used to identify possible deviations from normal conditions.
d. Deviation, describing abnormal operating conditions.
e. Causes, identifying factors that trigger deviations.
f. Consequences, evaluating possible impacts caused by failures.
g. Safeguards and recommendations, determining existing controls and improvement actions.

The HAZOP approach has been widely applied in industrial safety and reliability studies because it provides a structured framework for identifying system weaknesses and operational risks (Zhang et al., 2026).

3. Root Cause Analysis Using Fault Tree Analysis (FTA)

After identifying critical failure events through HAZOP, the FTA method was applied to investigate the root causes of the selected failure events. FTA uses a top down deductive approach by starting from the top event and tracing backward to identify basic events contributing to system failure (Mohammadi et al., 2021).

The stages of FTA analysis included:

a. Determination of Top Event
   The main failure event was selected based on the highest-risk failure mode identified from the HAZOP analysis.
b. Identification of Intermediate Events
   Intermediate events were determined by analyzing direct factors contributing to the top event.
c. Development of Fault Tree Diagram
   Logical relationships between events were constructed using logic gates, including AND Gate and OR Gate.

d. Identification of Basic Events
   Basic events were determined as fundamental causes that directly contribute to system failure.
e. Failure Cause Evaluation
   The identified causes were evaluated to determine appropriate preventive and corrective actions.

FTA has been widely used in reliability engineering because it provides a clear representation of causal relationships and supports decision-making in risk mitigation strategies (Jimenez-Roa et al., 2022).

Data Analysis

The data analysis process was conducted by integrating the results of HAZOP and FTA. The HAZOP results were used to identify potential hazards, operational deviations, and consequences associated with generator set failures. Meanwhile, FTA results were used to determine the root causes and logical relationships among failure factors. The final analysis produced recommendations for improving preventive maintenance strategies, increasing generator set availability, reducing failure frequency, and minimizing production downtime (Khilmy et al., 2021).

III. RESULT AND DISCUSSION

General Description of the Research Object

This research was conducted in the Facility Department, which is responsible for the operation and maintenance of supporting facilities within a manufacturing company. One of the critical facilities investigated in this study was the Generator Set (genset)**,** which functions as a backup electrical power source during interruptions in the main electricity supply from the national grid. The generator set plays an essential role in maintaining production continuity because most production machines and utility systems rely on a stable and continuous electricity supply.

During the period from January to December 2025, the Facility Department recorded several failure incidents involving major generator set components. These historical failure data were used as the basis for hazard identification using the Hazard and Operability Study (HAZOP) method and root cause investigation using the Fault Tree Analysis (FTA) method.

Data Processing

A. Generator Set Failure Data

The generator set failure records indicate that a total of 41 failure incidents occurred during 2025 involving six major components.

Table 3. Percentage Distribution of Generator Set Failures

No.	Failure Type	Frequency	Percentage (%)
1	Battery Drop	9	21.95
2	Clogged Fuel Filter	9	21.95
3	Radiator Overheating	8	19.51
4	Oil Leakage	6	14.63
5	Damaged Alternator	6	14.63
6	Damaged Starter Motor	3	7.33
	Total	**41**	**100**

Results of researcher data processing in 2026

Based on Table 3, battery drop and clogged fuel filter were identified as the most frequent failure modes, with each occurring nine times (21.95%). The high occurrence rate of these failures indicates that the starting electrical system and fuel supply system are the most vulnerable parts of the generator set. In addition, radiator related failures also showed a relatively high occurrence rate, indicating that the cooling system requires greater attention in the maintenance program.

B. Downtime Analysis

In addition to failure frequency, an analysis of operational downtime caused by each failure mode was conducted to evaluate the impact of failures on generator set availability.

Table 4. Generator Set Downtime Data

Component	Downtime (Hours)
Battery Drop	16
Fuel Filter	18
Radiator	20
Oil Leakage	10
Alternator	15
Starter Motor	8
Total	**87 Hours**

Results of researcher data processing in 2026

The analysis results show that the radiator failure produced the highest downtime impact, reaching 20 hours**,** even though its failure frequency was lower than battery and fuel filter failures. This finding indicates that failures in the cooling system require a relatively longer repair duration and therefore have a greater impact on generator set operational readiness.

C. Hazard and Operability Study (HAZOP)

The Hazard and Operability Study (HAZOP) method was applied to identify potential hazards, causes of deviations, consequences, existing control measures, and improvement recommendations related to generator set operation.

Table 5. HAZOP Worksheet

Node	Deviation	Cause	Consequence	Existing Safeguard	Recommendation
Battery	Low Voltage	Battery aging	Generator fails to start	Visual inspection	Replace battery according to service life
Fuel System	No Flow	Clogged fuel filter	Engine shutdown	Filter replacement	Implement more frequent replacement schedules
Cooling System	High Temperature	Radiator leakage	Engine overheating	Coolant inspection	Conduct weekly radiator inspection
Lubrication System	Low Oil Level	Oil leakage	Engine component wear	Oil level inspection	Perform leakage monitoring
Alternator	Low Output	Bearing wear	Unstable voltage supply	Voltage checking	Monitor alternator condition
Starter System	No Start	Starter motor failure	Generator unable to operate	Starter inspection	Replace damaged components

Results of researcher data processing in 2026

The HAZOP analysis results indicate that most deviations were caused by component degradation due to operational age, insufficient periodic inspections, and delayed component replacement. These conditions may lead to generator set operational failures if preventive actions are not implemented promptly.

a. Severity (S) Assessment

The Severity (S) rating was determined based on the level of impact caused by each failure mode on generator set performance and its influence on company operational continuity. The assessment scale ranged from 1 to 5, where a higher severity value indicates a greater impact on backup electrical system reliability, production continuity, operational costs, and occupational safety. The highest severity level represents failures that may prevent the generator set from operating, interrupt production activities during electrical outages, and potentially cause secondary damage to other components if corrective actions are delayed. Meanwhile, lower severity values indicate failure impacts that can still be controlled without significantly affecting company operations.

Table 6. Severity Assessment (S)

No.	Failure Type	Impact	Severity (S)	Category
1	Battery Drop	Generator fails during starting process	4	High
2	Clogged Fuel Filter	Engine shutdown due to restricted fuel supply	4	High
3	Radiator Overheating	Engine overheating and potential severe damage	5	Very High

No.	Failure Type	Impact	Severity (S)	Category
4	Oil Leakage	Component wear and reduced engine performance	3	Medium
5	Damaged Alternator	Unstable electrical voltage output	4	High
6	Damaged Starter Motor	Generator cannot be started	5	Very High

Results of researcher data processing in 2026

Based on the severity assessment, radiator overheating and starter motor failure obtained the highest severity score of 5, classified as very high risk**.** These two failure modes have the most significant operational consequences because they can prevent the generator set from functioning properly. Cooling system failure may cause excessive engine temperature that leads to internal component damage, while starter motor failure prevents the generator from initiating the starting process, resulting in the loss of backup power functionality.

Meanwhile, battery drop, clogged fuel filter, and alternator failure obtained a severity score of 4, categorized as high risk**.** These failures may reduce generator set reliability by causing starting system failure, interrupted fuel supply, and unstable electrical output. Oil leakage received a severity score of 3, categorized as medium risk, because its impact develops gradually and can still be controlled through regular inspection and maintenance activities. Therefore, components with high and very high severity ratings should become the primary focus in developing risk control strategies and maintenance programs within the Facility Department.

b. Likelihood (L) Assessment

The Likelihood (L) value was determined based on the probability and frequency of each generator set failure occurring during the research period. The assessment scale ranged from 1 to 5**,** where a higher likelihood value indicates a greater probability of failure occurrence during operational activities.

This assessment was conducted to identify the most frequently occurring failure modes that should receive priority in developing maintenance strategies and risk control programs. A high likelihood value indicates that a failure occurs frequently and has a high probability of recurring if appropriate preventive measures are not implemented. Conversely, a low likelihood value indicates that the failure occurs less frequently and requires a lower priority level for risk mitigation.

Table 7. Likelihood Assessment

No.	Failure Type	Failure Frequency	Likelihood (L)	Category
1	Battery Drop	9	4	Frequent
2	Clogged Fuel Filter	9	4	Frequent
3	Radiator Overheating	8	4	Frequent
4	Oil Leakage	6	3	Moderate
5	Damaged Alternator	6	3	Moderate
6	Damaged Starter Motor	3	2	Rare

Results of researcher data processing in 2026

Based on the likelihood assessment, battery drop, clogged fuel filter, and radiator overheating obtained a likelihood value of 4, categorized as frequent failures**.** This result indicates that these three failure modes were the dominant problems occurring during the research period. The relatively high failure frequency suggests that the starting electrical system, fuel system, and cooling system require greater attention through improved routine inspections, condition monitoring, and regular preventive maintenance activities.

Meanwhile, oil leakage and alternator failure obtained a likelihood value of 3, classified as moderate**.** This indicates that these failures still occurred with a considerable frequency but were less dominant compared with the previous three failure modes. The starter motor failure obtained a likelihood value of 2, categorized as rare**,** because it had the lowest occurrence frequency during the observation period. However, starter motor failures still require attention because they may prevent the generator set from operating when emergency power is required.

c. Risk Score (RS)

The Risk Score (RS) was determined as a quantitative indicator to establish priorities for controlling generator set failure risks. The risk score was calculated by multiplying two main parameters, namely Severity (S) and Likelihood (L), which represent the impact level of failure consequences and the probability of failure occurrence within the system.

A higher risk score indicates a greater potential failure risk. This means that the failure not only has a significant impact on operational performance and system reliability but also has a high probability of occurrence. Therefore, failure modes with the highest risk scores should become the primary focus for improvement actions, corrective measures, and maintenance planning.

The risk score calculation is expressed as follows:

$$RS = S \, x \, L$$

Note:

S = Severity

L = Likelihood

a. Battery Drop
   RS=4 x 4=16
b. Clogged Fuel Filter
   RS=4x 4= 16
c. Radiator Overheating
   RS=5 x 4 =20
d. Oil Leak
   RS=3 x 3=9
e. Damaged Alternator
   RS=4 x 3=12
f. Motor Starter
   RS=5 x 2=9

Table 8. Risk Score Assessment

No.	Failure Type	Severity (S)	Likelihood (L)	Risk Score	Category
1	Battery Drop	4	4	16	High
2	Clogged Fuel Filter	4	4	16	High
3	Radiator Overheating	5	4	20	Very High
4	Oil Leakage	3	3	9	Moderate
5	Damaged Alternator	4	3	12	High
6	Damaged Starter Motor	5	2	10	High

Results of researcher data processing in 2026

Based on the Risk Score calculation, radiator overheating obtained the highest risk value of 20 and was classified as a very high-risk failure mode. This finding indicates that cooling system failure has a severe impact and occurs frequently, which may lead to generator set shutdown, extensive engine damage, and increased maintenance costs. Furthermore, battery drop and clogged fuel filter obtained a risk score of 16, while alternator failure and starter motor failure obtained scores of 12 and 10, respectively. These four failure modes were classified as high-risk categories, indicating that they have a significant potential to reduce generator set reliability as an emergency power source.

Meanwhile, oil leakage obtained a risk score of 9 and was categorized as moderate risk, because its impact can still be controlled through routine inspections and immediate corrective actions when leakage indicators are detected. Based on these findings, the Facility Department should prioritize preventive maintenance activities on components with the highest risk scores, particularly the cooling system, starting system, and fuel system. Implementing targeted maintenance strategies is expected to reduce operational failure risks, improve generator set availability, and maintain reliable backup power performance.

D. Fault Tree Analysis (FTA) Method

The Fault Tree Analysis (FTA) method is a deductive analytical technique used to investigate the cause-and-effect relationships of a top event by tracing the contributing factors until the fundamental causes **(**basic events**)** responsible for system failure are identified. FTA applies a top-down analysis approach by starting from an undesired event and systematically identifying the intermediate events and basic events that contribute to the occurrence of the failure.

In this study, the selected top event was defined as "Generator Set Fails to Operate When Required." Through the development of a fault tree diagram, the logical relationships between the top event and its underlying causes can be systematically analyzed. This approach enables the company to determine more effective and targeted risk control strategies to prevent generator set failures. Based on the previous failure analysis, the major basic events contributing to generator set failure were identified as follows:

Table 9. Identification of Basic Events

Code	Basic Event	Description
A	Battery Drop	Reduced battery capacity due to aging and prolonged service life
B	Clogged Fuel Filter	Fuel flow obstruction caused by accumulated contaminants
C	Radiator Overheating	Cooling system performance failure resulting in excessive engine temperature
D	Damaged Alternator	Unstable voltage output caused by alternator malfunction
E	Damaged Starter Motor	Starter system failure causing the engine to fail during the starting process
F	Oil Leakage	Reduced engine oil level due to leakage in the lubrication system

The identification of these basic events provides the foundation for constructing the fault tree model. Each basic event represents a potential failure contributor that may lead to the top event, namely the inability of the generator set to provide backup electrical power when required. The FTA analysis enables the determination of critical failure pathways and supports the development of preventive maintenance strategies to improve generator set reliability.

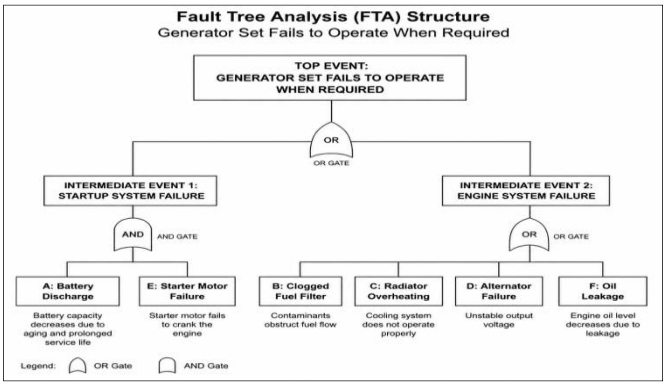

Fig. 1. Fault Tree Analysis (FTA) Diagram

The probability of damage with the highest risk score should be the top priority in system control, repair, and maintenance efforts, including:

$$P = 1 - (1 - A)(1 - B)(1 - C)(1 - D)(1 - E)(1 - F)$$
$$P = 1 - (1 - 0.22)(1 - 0.22)(1 - 0.20)(1 - 0.15)(1 - 0.07)(1 - 0,14$$
$$P = 1 - 0.328$$
$$P = 0.672 = 67.2\%$$

Based on the analysis using the Fault Tree Analysis (FTA) method, the probability of the Top Event, namely the generator set failing to operate when needed, was 67.2%. This value indicates that the generator set system has a fairly high probability of failure if effective control and maintenance measures are not implemented. Therefore, the Facilities Department needs to pay special attention to components that contribute significantly to system failure. The analysis results show that Battery failure and a clogged fuel filter are the basic events with the highest contributing factors, each with a 22% probability of occurrence. This indicates that the starting system and fuel system are the most vulnerable components to failure. Furthermore, radiator overheating, with a 20% probability, also contributes significantly because it can cause engine temperatures to rise, resulting in damage to the generator set's internal components. Meanwhile, alternator failure (15%), oil leaks (14%), and starter motor failure (7%) still contribute to system failure, albeit with lower probabilities.

The FTA results reinforce the HAZOP analysis, which indicates that the components with the highest risk scoresradiator overheating (20), battery failure (16), and clogged fuel filter (16) should be prioritized in the risk control program. Therefore, the company is advised to increase the frequency of cooling system inspections, replace fuel filters according to operating hours, regularly check battery condition, and develop a planned preventive maintenance program. Implementing these recommendations is expected to reduce the probability of generator set failure, reduce downtime, and improve the reliability of the backup electrical system in the Facilities Department.

IV. DISCUSSION

Based on the data processing results, it was found that generator set failures in the Facilities Department were dominated by several types of failures: battery failure (21.95%), clogged fuel filters (21.95%), radiator overheating (19.51%), oil leaks (14.63%), alternator failure (14.63%), and starter motor failure (7.33%). Based on the Likelihood (L) and Severity (S) assessments using the Hazard and Operability Study (HAZOP) method, most failures were classified as high to very high risk. Radiator overheating achieved the highest risk score, at 20, making it a very high risk and a top priority for control efforts.

The HAZOP analysis results indicated that the primary risks to generator sets stem from the cooling system, fuel system, and starter system. Radiator overheating has the potential to significantly increase engine temperature, which can lead to damage to internal components and even shutdown of the generator set. Meanwhile, battery drop and clogged fuel filters were the types of failures with the highest frequency of occurrence, indicating that the starter and fuel systems remain the most vulnerable components to disruption. Through the HAZOP approach, each potential hazard can be identified based on operational deviations, causes, consequences, and necessary control measures, thus establishing a priority order of risks that must be addressed immediately by the Facilities Department.

Next, the Fault Tree Analysis (FTA) method was used to analyze the cause-and-effect relationships of each risk identified through the HAZOP. Based on the FTA diagram, it was discovered that the top event, namely generator set failure to operate when needed, was influenced by several basic events, including battery drop, clogged fuel filter, radiator overheating, alternator failure, starter motor failure, and oil leaks. The probability analysis results showed that the probability of the top event occurring was approximately 67.2%, indicating that the system still has a fairly high probability of failure if effective control measures are not implemented. Of all the basic events, battery drop, clogged fuel filter, and radiator overheating contributed the most to system failure due to their high frequency of occurrence and high risk level.

Furthermore, based on the results of the HAZOP and FTA analyses, several risk control recommendations can be implemented, including:

1. Conducting regular battery condition checks, including voltage measurements, terminal cleaning, and battery replacement according to their service life to prevent starter system failure.
2. Establishing a fuel filter replacement schedule based on generator operating hours and maintaining fuel quality to prevent fuel system blockages.
3. Improving cooling system maintenance by checking coolant levels, cleaning radiators, inspecting for leaks, and replacing coolant according to manufacturer recommendations to prevent overheating.
4. Conducting routine inspections of alternators, electrical systems, and starter motors to ensure all components are operating optimally and to avoid disruptions during starting and during generator operation.
5. Developing and implementing a scheduled preventive maintenance program, including maintenance records and periodic evaluations, as a basis for improving generator set reliability.

V. CONCLUSION

Based on the results of the risk analysis of generator set failures in the Facility Department using the Hazard and Operability Study (HAZOP) and Fault Tree Analysis (FTA) methods, several conclusions can be drawn. The HAZOP analysis identified six major failure modes affecting generator set reliability, namely battery drop (21.95%), clogged fuel filter (21.95%), radiator overheating (19.51%), oil leakage (14.63%), alternator failure (14.63%), and starter motor failure (7.33%). The risk assessment based on Severity (S) and Likelihood (L) parameters showed that radiator overheating obtained the highest Risk Score of 20, classified as a very high risk, while battery drop and clogged fuel filter obtained a Risk Score of 16, categorized as high risk. These findings indicate that the cooling system, starting system, and fuel system are the most critical components requiring priority attention in the maintenance strategy.

The FTA analysis revealed that the top event, defined as "Generator Set Fails to Operate When Required," was influenced by several basic events, including battery drop, clogged fuel filter, radiator overheating, alternator failure, starter motor failure, and oil leakage. The analysis indicated that the probability of the top event occurrence reached 67.2%, demonstrating that the generator set still has a considerable failure risk if appropriate control measures are not implemented. The fault tree model also confirmed that failures in the cooling system, starting system, and fuel supply system represent the dominant pathways contributing to generator set operational failure.

Based on the integration of HAZOP and FTA results, several risk mitigation strategies are recommended for the Facility Department, including periodic battery condition monitoring, scheduled fuel filter replacement based on operating hours, routine inspection and maintenance of the cooling system, evaluation of alternator and starter motor conditions, and implementation of a structured preventive maintenance program supported by maintenance history documentation. These improvement actions are expected to reduce failure probability, minimize operational downtime, improve generator set availability, and strengthen the reliability of backup power systems in supporting continuous manufacturing operations.

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