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# Failure mode effects and criticality analysis (FMECA) using fuzzy logic for ship dynamic positioning (DP) systems

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## Abstract

Predicting the failure modes effect and criticality analysis (FMECA) of a dynamic positioning (DP) system using fuzzy logic is the aim of this research. The identification of DP systems and subsystems, the classification of failure modes into critical and less-critical levels based on the Risk Priority Number (RPN) to depict the main root causes of failure in the DP system are some critical objectives in support of this goal. The analysis offers details on a number of issues, including the causes of failure modes and their effects on the functionality and dependability of equipment. Based on the information provided, it was determined that a number of failure modes produced identical RPN values, and that the ranking scale was erroneous. A new method was tested but could not really prioritize the failure modes with same RPN because of the few choices in the severity, occurrence and detection template. To compensate for this, excel ranking function was employed putting severity, occurrence and detection as key criteria for ranking. Due to the high severity and occurrence index, the RPN ranking results show that the faulty DP system component identified for the scenario SSTs (F1) is categorized as very critical. SSCs (F12), SSPr (F7), SSTs(F2), and SSPs(F15) are additional critical failures. In the study, data analysis and validation were done using a fuzzy rule system based on MATLAB. From the findings, it can be inferred that the failure modes F1, F2, F5, F6, F7, F8, F10, F11, and F15 have values of a similar type of RPN. According to the initial RPN risk level results; there are 19 failure modes in the medium risk level, 2 in the low risk level and 1 in the high risk level. In the final RPN-based risk level results, there are 18 failure scenarios in the low risk level and 4 in the medium risk level. In contrast, there are 5 failure modes in the fuzzy RPN low risk level and 17 failure scenarios in the medium risk level. Without fuzzy logic, the justification score on traditional FMECA can be given directly. This makes traditional FMECA ABS show greater risk than fuzzy FMECA. The failure modes with the highest RPN values were treated as critical parts, so it was recommended that the highest value of RPN be given special attention by making the necessary repairs or replacements in order to lengthen the equipment's lifespan.

**Keywords:** Failure mode; Fuzzy logic; DP system; Risk; Analysis

## 1. Introduction

The operation of marine vessels in the ocean environment is exposed to environmental load/disturbances such as wave, current and wind. These environmental parameters affect the stability and positioning of the vessels with respect to their dynamic characteristics. Many marine vessels now come with DP systems for efficient vessel positioning during maritime activities. DP can be defined as “a means of holding a vessel in a relatively fixed position with respect to the ocean floor without using anchors [1]. An offshore vessel with a DP system needs fast response to produce thrust to counteract the environmental forces acting on it for the purpose of maintaining its position and heading as close as

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possible to the working position [2]. These DP vessels perform a variety of challenging and unusual tasks. Their level of protection must be increased and classified in order to support these functions. The safety of DP systems has improved over time, thanks to support from many organizational entities and lessons learned from previous DP disasters. A redundancy method is currently used in these DP systems to ensure that a single failure does not result in an accident or overall breakdown.

Conducting 'Failure Modes and Effect Analysis' (FMEA) trials is a common approach to determine how malfunctions in the dynamic positioning system affect a vessel's ability to maintain station. Despite the fact that such trials are conducted on a regular basis, occurrences of loss of status nevertheless occur. It is the responsibility of The International Marine Contractors Association (IMCA) to collect and publish loss of position incident reports, which contain useful information regarding the causes of mishaps as well as details on the sequence of events that led to the incident.

Over time, DP system has developed from being used to maintain position over offshore wells by mobile offshore drilling rigs to being utilized for a wide range of position keeping tasks. Drive off and drift off are two common types of position losses that can occur when the DP system fails [3]. The vessel may veer off course if its thrusters aren't powerful enough or if the DP control system thinks it is maintaining position [4]. As an alternative, if the DP control system finds that the vessel is out of position, the command will be given and the vessel will use its own thrusters to move back into place. Full thrust aimed with the resulting environment pressures is a worst-case scenario for drive off. Because the forces involved in a drive off situation are stronger than those involved in a drift off situation, damages are more likely to occur. The type of Loss of Position (LOP) occurrence is determined by the type of failure. By being aware of the possible consequences of failure, the DP operator will be better equipped to take the necessary steps to avoid likely outcomes.

The downtime of DP vessels in operation can be reduced by using an effective way to identify important components, followed by a practical maintenance strategy and spare part planning for a DP system. When creating a maintenance programme, criticality classification is typically used to specify a common spare part strategy for equipment of equal importance, to assess the quantity and calibre of technical documentation, and to establish the priority of corrective maintenance activities. Consideration of what happens if a particular function fails serves as the basis for criticality classification [5]. To identify DP system failure modes and their effects on personnel, machinery, the surroundings, and operation; new DP vessels undergo FMEA. The predicted risks associated with DP vessels also increase with the variety of possible applications, calling for a higher standard of safety. DP system development has advanced in this direction. DP0 to DP3, a range of classes with various levels of safety are currently available [6].

The main objective of the DP system is to keep the ship in a specific location or on a specific course while staying within reasonable bounds. The system must be capable to withstand transient conditions such as changes in external forces, lost signals from sensors and position-measuring equipment, and hardware failures. The system's additional functions include controlling the vessel to reduce fuel usage and maintain thruster wear to a minimum [7]. Since the installation of the first DP drill ship, Eureka, DP systems have progressed significantly and are presently installed aboard vessels that are utilized for a variety of purposes.

The focus of this research is on the most prevalent technological problems that cause the vessel to lose its intended position. The International Marine Contractors Association (IMCA) provided the information needed to conduct the study, which is based on incidents that were voluntarily reported to them between 2010 and 2019.

## 2. Material and methods

In order to accomplish the research objectives, The DP system's maintenance priorities were decided using the improved FMECA model. The ABS Classification criticality matrix was used by the FMECA model to evaluate the degree of risk associated for each actual failure mode. Utilizing the fuzzy theory simulation method, FMECA results were validated.

The research methodology used in the study is based on historical data and archival analysis. Combining a consequence and likelihood range yields a risk estimate or risk ranking, which aids in decision-making to identify the best ways to lower risk. This is done to improve availability, reliability, and to lessen failure-related consequences [8]. The fuzzy logic method is combined with FMECA to properly and effectively take into account the effects of redundancy.

### 2.1. Development of FMECA based on ABS Classification

Considering the complexity of marine propulsion system and the quest for more energy efficient systems in vessels, this places higher requirements on system design in ships to meet the propulsion system regulations and operations, thus making failure mode analysis imperative [9]. FMECA is the result of combining FMEA and criticality, a bottom-up and structured methodology with which potential effects or known failure modes on subsequent subsystems are visualized [10]. The probability of failure modes versus the severity of their consequences can be plotted by adding criticality to an FMEA process.

As a result, a thorough FMEA analysis of a system frequently covers every level of the hierarchy, from the bottom to the top and the steps of an FMEA are in stages as shown in Figure 1.

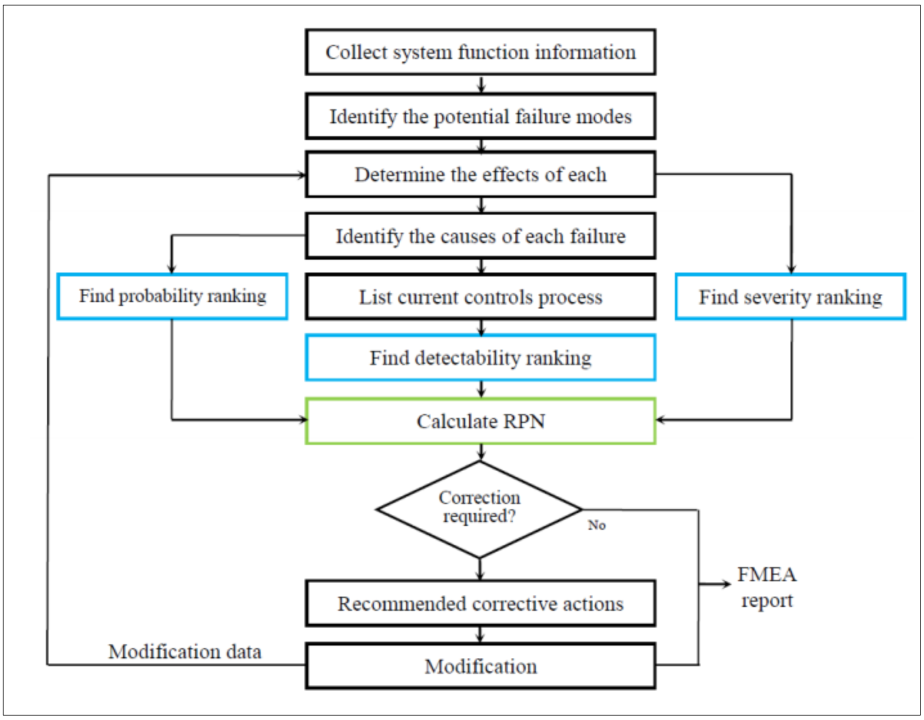


**Figure 1** Steps of an FMEA

### 2.2. Determination of Criticality Model

The criticality model is used as a gauge of risk for each failure mode and effect according on ABS Classification criteria [4]. In this critical model, the likelihood and severity of a loss of protection, safety, as well as operation are all taken into account. The criteria used to assess the severity and likelihood levels are shown in Tables 1 and 2. The risk level is represented by a 4x5 matrix, as seen in Figure 2.

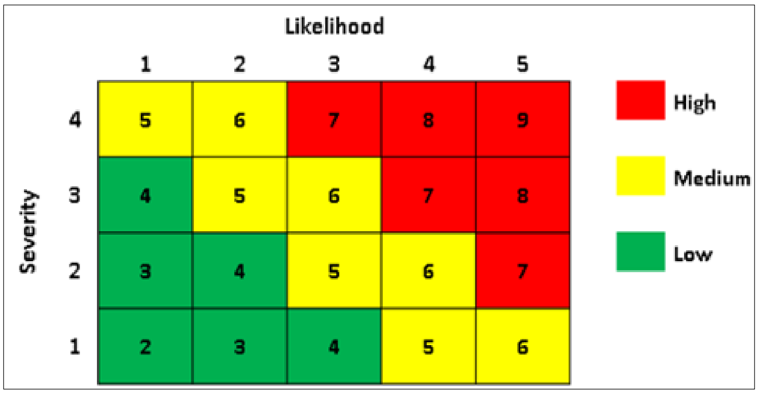


**Figure 2** Risk matrix of ABS classification [4]

**Table 1** Severity Level Based on Loss of Containment(C), Safety(S) and Operation (O) [4]

| Severity level | Descriptions for Severity Level |
|---|---|
| 1 | Minor, Negligible |
| 2 | Major, Marginal, Moderate |
| 3 | Critical, Hazardous, Significant |
| 4 | Catastrophic, Critical |

**Table 2** Likelihood Level [12]

| Likelihood level | Likelihood Descriptor | Description (events/year) |
|---|---|---|
| 1 | Improbable | Fewer than 0.001 |
| 2 | Remote | 0.001 to 0.01 |
| 3 | Occasional | 0.01 to 0.1 |
| 4 | Probable | 0.1 to 1 |
| 5 | Frequent | 1 or more |

### 2.3. Evaluation of FMECA using Fuzzy Logic Simulation

Three elements were used as input factors for the fuzzy system in the study. The MATLAB Fuzzy logic toolbox was used to analyze these using well-defined "If–Then" rules. The fuzzy rules initial foundation was built using the membership function. To access the Membership Function Editor and Rule Editor, open the MATLAB Rule Viewer and leave it open during replication. The list of rules that define the behavior of the framework is editable using the Rule Editor function. The Fuzzy Interface System (FIS) Editor can be used to add input variables and membership functions.

Fuzzy logic simulation can be used to convert the ambiguity of human feeling and recognition into a mathematical formula. Fuzzy logic allows for the measuring of uncertain or ambiguous ideas. The FMECA Fuzzy is a fuzzy rule basis technique that uses "If-Then" rules, according to several literatures [12]. Figure 3 and 4 shows fuzzy rule editor and membership function editor respectively.

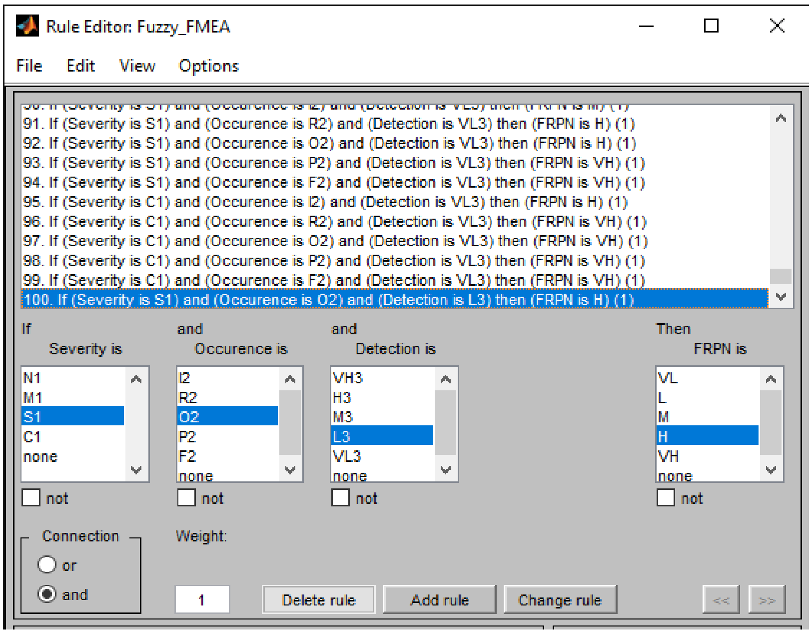


**Figure 3** Fuzzy Rule Editor

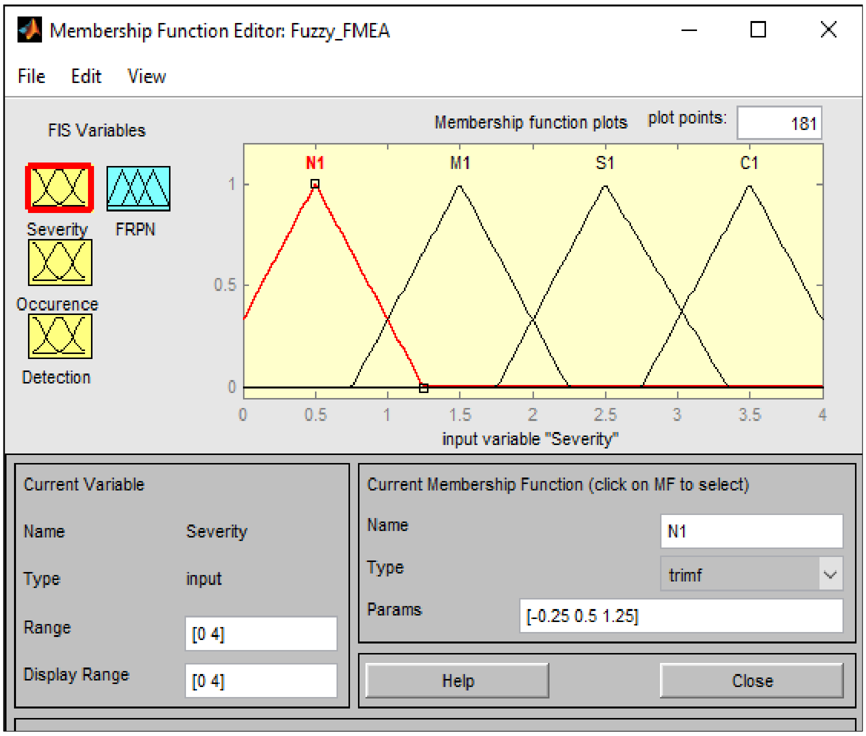


**Figure 4** Membership Function Editor

The FMECA fuzzy steps are as follows [13]:

- The linguistic variables are used in the fuzzification process to create fuzzy representations of the three risk factors S, O, and D. The linguistic variables and their definitions can be used to create a scale for ranking three risk factors. Then, fuzzifying these inputs yields the degree of membership in each input class.
- Fuzzy if-then rules are a representation of expert knowledge about the connections between various failure modes and effects in rule evaluation. The outputs of the fuzzy inference system are known as "riskiness," "critically failure mode," "priority for attention," and "fuzzy RPN" in fuzzy FMEA investigations.
- The defuzzification technique generates a clear ranking from the fuzzy RPN that shows the severity of the failure mode prioritization.

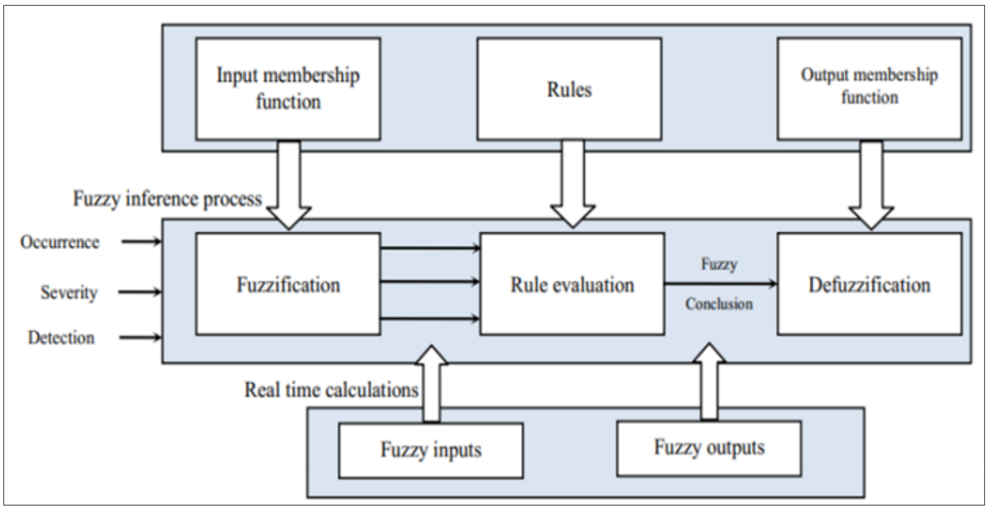


**Figure 5** Fuzzy Rule Base Technique

### 2.4. Step 1

Membership Function Setup and Determine the Score of Fuzzy Numbers. The members of a set of membership values with intervals of [0,1] are represented by the membership function. There are several ways to express the membership function, although analytic representation is the most popular and commonly utilized in fuzzy logic systems. The membership function used in this study represents triangles and trapezoids. The illustration of a triangle and a trapezoidal curve is shown in Figure 6(a) and 6(b).

The input membership functions are severity(S), occurrence (O), and detection (D). The severity and occurrence levels are derived from ABS criteria, whereas the detection level is derived from [14]. Triangle curves are represented by Severity(S), Occurrence (O), and Detection (D).

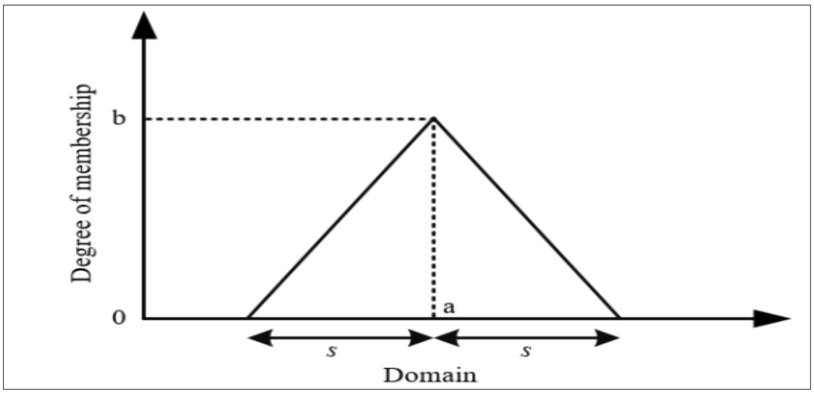


**Figure 6(a)** Triangular Curve Representation of Membership Function

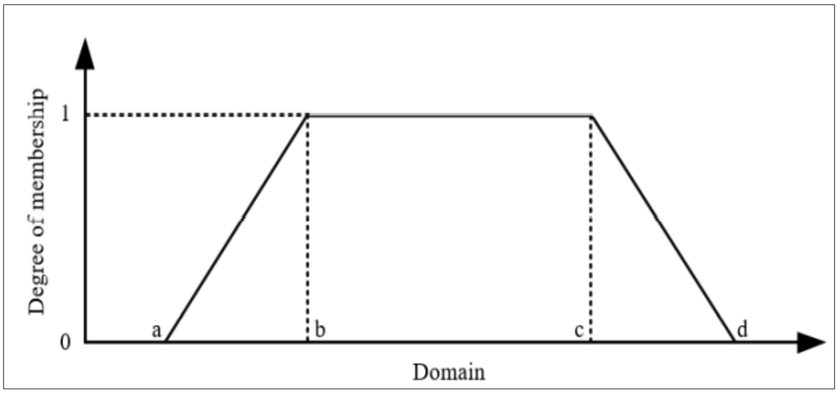


**Figure 6(b)** Trapezoidal Curve Representation of Membership Function

**Table 3** Membership Function of Detection Level

| Detection level | Descriptions for Detection Level | Fuzzy Number |
|---|---|---|
| 5 | Very Low (VL3) | [3.75 4.5 5.25] |
| 4 | Low (L3) | [2.75 3.5 4.25] |
| 3 | Medium (M3) | [1.75 2.5 3.25] |
| 2 | High (H3) | [0.75 1.5 2.25] |
| 1 | Very High (VH3) | [-0.25 0.5 1.25] |

Defining the output membership function as a collection of fuzzy values is crucial as well in addition to the input membership function. The fuzzy value also known as the fuzzy RPN, is used to assess the criticality of FMECA data using the ABS matrix. The FRPN level is transformed using the ABS Matrix shown in Figure 2. The conversion of FRPN level is shown in Table 4.

### 2.5. Step 2

Fuzzy rule setup four input parameters each for severity, five for occurrence, and five for detection levels make up the severity, occurrence, and detection levels equations. As a result, there are 100 rules created. If–then rules are used to put up the rules. By considering the severity value to be the most crucial input for the fuzzy RPN value, the fuzzy ("If - Then") rule is created.

### 2.6. Step 3

Using the FRPN output from the fuzzy analysis, the Mamdani method's fuzzy processing algorithms are applied to the rules.

**Table 4** Membership Function of FRPN Output

| FRPN level | FRPN conversion | Type of Curve | Fuzzy Number |
|---|---|---|---|
| Very Low | Low | Trapezoidal | [00 10 22.5] |
| Low | | Triangle | [17.5 30 42.5] |
| Medium | Medium | Triangle | [37.5 50 62.5] |
| High | High | Triangle | [57.5 70 82.5] |
| Very High | | Trapezoidal | [77.5 90 100 100] |

## 3. Results and Discussion

From IMCA incident results, it was observed that failure within thruster, position reference, computer, and the power systems where a majority which accounts for over 71% of all reported incidents. The study paid attention to incidents caused by four major subsystems that influenced the overall DP failure. Hence, failures within thruster, reference, computer, and power systems formed a base for the study. In total, 482 reported incidents fall under this category.

### 3.1. Thruster System Failure

Analyzing the incident data led to identifying, grouping, recognizing the frequencies of their occurrence, level of severity and rate of detection of possible main cause failures. On this regard, a combination of likelihood and severity score as used to determine the risk score of the equipment which is a standard from ABS risk matrix classification.

The FRPN values were gotten by inputting final values of severity, occurrence and detection into the fuzzy logic rule viewer interphase. Table 5 shows a percentage change between initial and final RPN values whilst Table 6 shows a comparison of criticality level between initial, final and fuzzy FMECA. Figure 7 shows a graphical representation of the criticality level.

**Table 5** Risk Index Estimated Value and RPN Percentage Reduction after Safety Measures

| Sub system | Failure type | Initial OSD and RPN | | | | | | Final OSD and RPN | | | | | | RPN % change |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | O | D | RPN | Risk score | Critical level | S | O | D | RPN | Risk score | Critical level | |
| SSTs | F1 | 4 | 3 | 3 | 36 | 7 | high | 3 | 2 | 2 | 12 | 5 | medium | -66.67 |
| | F2 | 4 | 2 | 3 | 24 | 6 | medium | 3 | 2 | 1 | 16 | 5 | medium | -33.33 |
| | F3 | 3 | 2 | 2 | 12 | 5 | medium | 3 | 2 | 1 | 6 | 5 | medium | -50.00 |
| | F4 | 3 | 2 | 2 | 12 | 5 | medium | 3 | 1 | 1 | 3 | 4 | low | -75.00 |
| | F5 | 3 | 2 | 1 | 6 | 5 | medium | 2 | 1 | 1 | 2 | 3 | low | -66.67 |
| | F6 | 3 | 2 | 1 | 6 | 5 | medium | 2 | 1 | 1 | 2 | 3 | low | -66.67 |

**Table 6** Comparing Critical Level of Initial FMECA ABS, Final FMECA ABS and Fuzzy FMECA

| Failure type | Highest Risk Score of initial FMECA ABS | Highest Risk Score of final FMECA ABS | Highest Risk Score of FMECA Fuzzy | Critical Level of initial FMECA ABS | Critical Level of final FMECA ABS | Critical Level of FMECA fuzzy |
|---|---|---|---|---|---|---|
| F1 | 7 | 5 | 50 | High | medium | Medium |
| F2 | 6 | 5 | 50 | Medium | medium | Medium |
| F3 | 5 | 5 | 50 | Medium | medium | Medium |
| F4 | 5 | 4 | 50 | Medium | low | Medium |
| F5 | 5 | 3 | 30 | Medium | low | Low |
| F6 | 5 | 3 | 30 | Medium | low | Low |

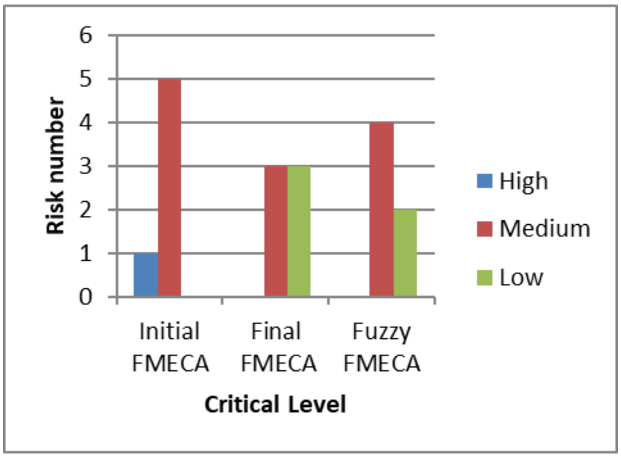


**Figure 7** Graphical Representation of the Criticality Level

### 3.2. Incident Frequency and Types

Upon sorting and analyzing reports from (2010 – 2019), incidents caused by thruster malfunction were 183. ‘Potential LOP’ was used to identify places where actual loss of position did not occur. By adoption of this idea, P-LOP occurred 112 times and A-LOP occurred 71 times. Figure 8 shows a representation of this as the vessel also drove off position 43 times and drifted 28 times.

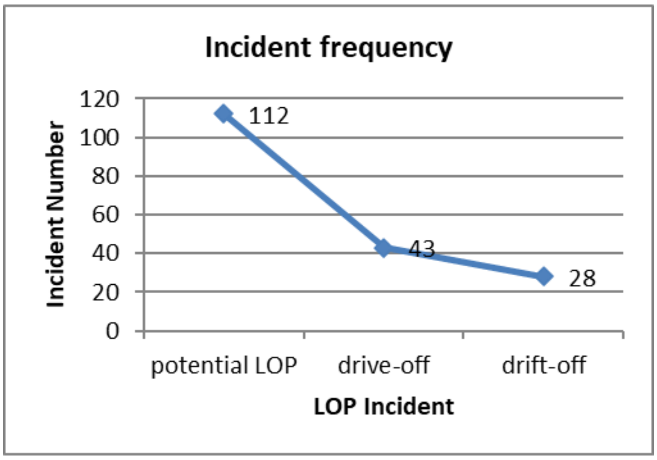


**Figure 8** Propulsion System Failure Frequencies due to LOP Incident

As seen, more drive-off incidents are being influenced by thruster failure rather than drift-off. The potential LOP incidents is on the high side which suggests some level of vulnerability of the thruster system. However, as compared to A-LOP incidents, it becomes clear that the thruster system has a high degree of station-keeping reliability.

### 3.3. Position Reference System Failure

In the study, some environmental sensors were not considered and events influenced by these were excluded. In total, five reference system types (Laser-based/radar-based system, DGNSS, Taut wire, Artemis, and HPR) mentioned in the report were considered in the study: Analyzing the incident data led to identifying, grouping, recognizing the frequencies of their occurrence, level of severity and rate of detection of possible main cause failures.

In the traditional FMECA result on position reference system, there were 4 failure types in medium criticality and 1 failure type on low criticality. After safety measures were taken, it was observed that all 5 failure types in this category fell under low criticality with a substantial percentage change across the 5 failure types. On this regard, a combination of likelihood and severity score was used to determine the risk score of the equipment which is a standard from ABS risk matrix classification. In Table 7, an estimated value of risk index parameters and RPN percentage reduction after safety measures were implemented is shown.

**Table 7** Risk Index Estimated Value and RPN Percentage Reduction after Safety Measures

| Sub system | Failure type | Initial OSD and RPN | | | | | | Final OSD and RPN | | | | | | RPN % change |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | O | D | RPN | Risk score | Critical level | S | O | D | RPN | Risk score | Critical level | |
| SSPr | F7 | 3 | 3 | 3 | 27 | 6 | medium | 3 | 1 | 3 | 9 | 4 | low | -66.67 |
| | F8 | 3 | 2 | 2 | 12 | 5 | medium | 2 | 1 | 2 | 4 | 3 | low | -66.67 |
| | F9 | 2 | 3 | 2 | 12 | 5 | medium | 2 | 2 | 2 | 6 | 4 | low | -50.00 |
| | F10 | 2 | 1 | 3 | 6 | 4 | medium | 2 | 1 | 1 | 2 | 3 | low | -66.67 |
| | F11 | 2 | 1 | 2 | 4 | 4 | low | 2 | 1 | 1 | 2 | 3 | low | -50.00 |

The FRPN values were gotten by inputting final values of severity, occurrence and detection into the fuzzy logic rule viewer interphase. Table 8 shows a comparison of criticality level between initial, final and fuzzy FMECA while Figure 9 shows a graphical representation of the criticality level.

**Table 8** Comparing Critical Level of Initial FMECA ABS, Final FMECA ABS and Fuzzy FMECA

| Failure type | Highest Risk Score of initial FMECA ABS | Highest Risk Score of final FMECA ABS | Highest Risk Score of FMECA Fuzzy | Critical Level of initial FMECA ABS | Critical Level of final FMECA ABS | Critical Level of FMECA fuzzy |
|---|---|---|---|---|---|---|
| F7 | 6 | 4 | 50 | medium | low | medium |
| F8 | 5 | 3 | 40 | medium | low | medium |
| F9 | 5 | 4 | 50 | medium | low | medium |
| F10 | 4 | 3 | 30 | medium | low | low |
| F11 | 4 | 3 | 30 | low | low | low |

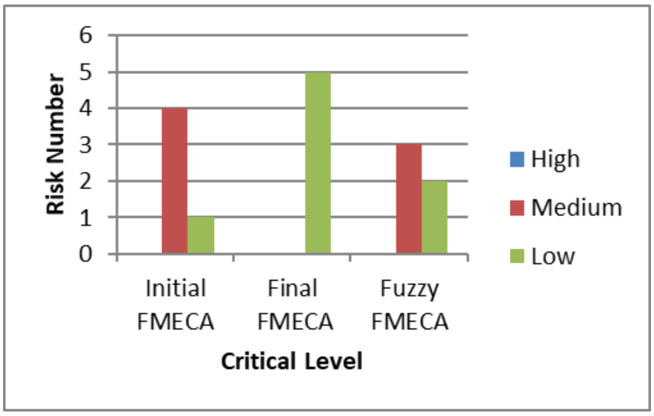


**Figure 9** Graphical Representation of the Criticality Level

### 3.3.1. Incident Frequency and Types

Upon sorting and analyzing reports from (2010 – 2019), incidents caused by position reference malfunction were 117. 'Potential LOP' was used to identify places where actual loss of position did not occur. By adoption of this idea, P-LOP occurred 82 times and A-LOP occurred 35 times. Figure 10 shows a representation of this as the vessel also drove off position 21 times and drifted 14 times.

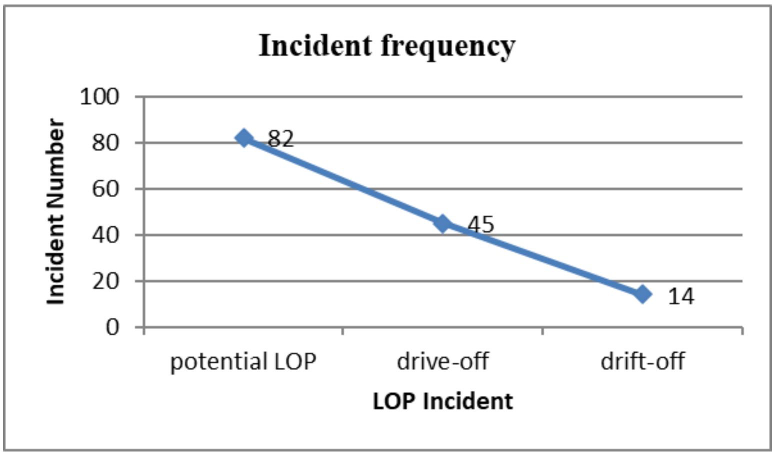


**Figure 10** LOP Incident Frequencies Caused by Position Reference System Failure

As seen, more drive-off incidents are being influenced by position reference failure than drift-off. The potential LOP incidents is on the high side which suggests some level of vulnerability of this system. However, as compared to A-LOP incidents, it becomes clear that the position reference system has a high degree of station-keeping reliability.

## 3.4. DP Computer System Failure

In the study, only DP control computer (controller) and operator control station computer related failures are covered under this section. All unaccountable movements of the vessel were seen to be caused by computer anomaly. Rebooting the computer usually clears up any irregularities. The incident data led to identifying, grouping, recognizing the frequencies of their occurrence, level of severity and rate of detection of possible main cause failures.

In the traditional FMECA result on DP computer system, all 2 failure types are in medium criticality. After safety measures were taken, it was observed that all 2 failure types fell under low criticality with a substantial percentage change across the 2 failure types. A combination of likelihood and severity score was used to determine the risk score of the equipment which is a standard from ABS risk matrix classification. In Table 9, an estimated value of risk index parameters and RPN percentage reduction after safety measures were implemented.

**Table 9** Risk Index Estimated Value and RPN Percentage Reduction after Safety Measures

| Sub system | Failure type | Initial OSD and RPN | | | | | | Final OSD and RPN | | | | | | RPN % change |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | O | D | RPN | Risk score | Critical level | S | O | D | RPN | Risk score | Critical level | |
| SSCs | F12 | 4 | 2 | 4 | 32 | 6 | medium | 3 | 1 | 2 | 6 | 4 | low | -81.25 |
| | F13 | 3 | 3 | 2 | 18 | 6 | medium | 2 | 2 | 1 | 4 | 4 | low | -77.78 |

The FRPN values were gotten by inputting final values of severity, occurrence and detection into the fuzzy logic rule viewer interphase. Table 10 shows a comparison of criticality level between initial, final and fuzzy FMECA. Figure 11 shows a graphical representation of the criticality level.

**Table 10** Comparing Critical Level of Initial FMECA ABS, Final FMECA ABS and Fuzzy FMECA

| Failure type | Highest Risk Score of initial FMECA ABS | Highest Risk Score of final FMECA ABS | Highest Risk Score of FMECA Fuzzy | Critical Level of initial FMECA ABS | Critical Level of final FMECA ABS | Critical Level of FMECA fuzzy |
|---|---|---|---|---|---|---|
| F12 | 6 | 4 | 50 | medium | low | medium |
| F13 | 6 | 4 | 40 | medium | low | medium |

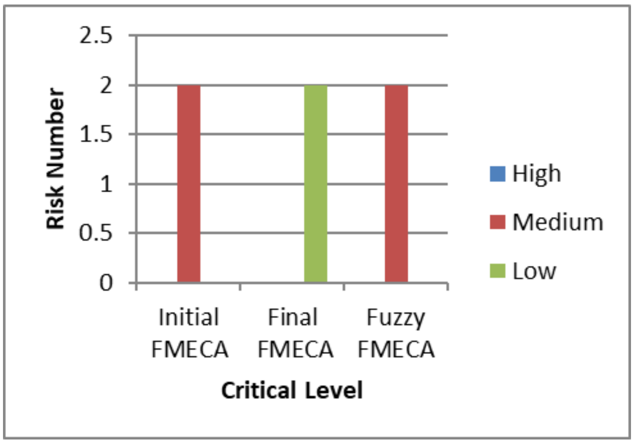


**Figure 11** Graphical Representation of the Criticality Level

### 3.4.1. Incident Frequency and Types

Upon sorting and analyzing reports from (2010 – 2019), incidents caused by computer malfunction were 112. Analyses had shown from Figure 12 that software is causing over three times more failures than hardware within the controllers and operator stations.

This shows the reliability of hardware over software used within the DP computer system due to the easy detectability and correction in the earlier stages. 'Potential LOP' was used to identify places where actual loss of position did not occur. By adoption of this idea, P-LOP occurred 79 times and A-LOP occurred 33 times. Figure 13 shows a representation of this as the vessel also drove off position 18 times and drifted 15 times.

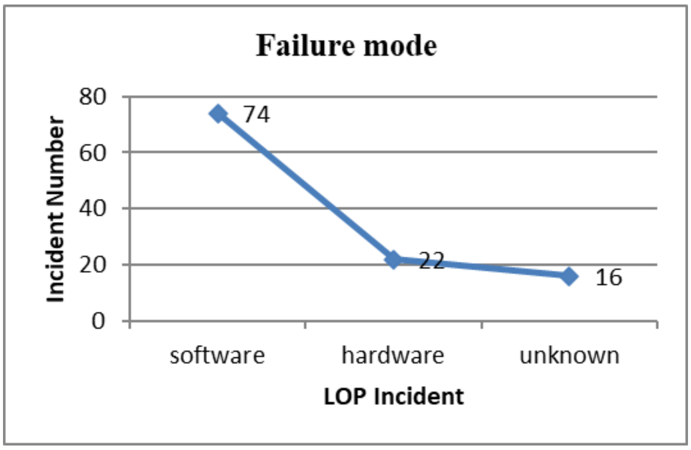


**Figure 12** Failure Mode of Computer System

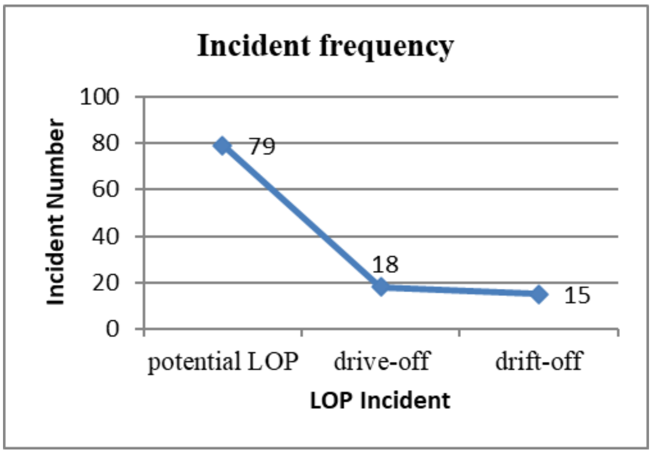


**Figure 13** LOP Incident Frequencies Caused by Computer System Failure

As seen, more drive-off incidents are being influenced by computer failure than drift-off. The potential LOP incidents is on the high side which suggests some level of vulnerability of this system. However, as compared to A-LOP incidents, it becomes clear that the computer system has a high degree of station-keeping reliability.

### 3.5. Rule Viewer and Surface Viewer

The Surface viewer simplifies it to see how certain inputs, like severity and detection affect the output. In the study, a three-dimensional mapping view with severity, detection, and FRPN serves as the surface viewer. The plot revealed that the severity (4) and detection (1) risk indices had the highest levels of FRPN reliance (60). Where any two of the inputs vary slightly, the Surface Viewer can create a three-dimensional output surface. In the case of two (or more) inputs and one output, the Surface Viewer has a unique feature that is very useful. The 100 rules that took into account factors such as severity, occurrence, and detection generated the plots. On the other hand, the fuzzy logic system is predicated on a few statements of good judgement. Without having to reverse what was already done, additional rules can be added to the list that will influence how the final product is characterized. The use of more than one influencing input factors can be accurately predict the FRPN value as compared to a single input factor. Figure 14 and 15 shows how two input factors influenced and reduced the FRPN value as compared to Figure 16 with a single input factor.

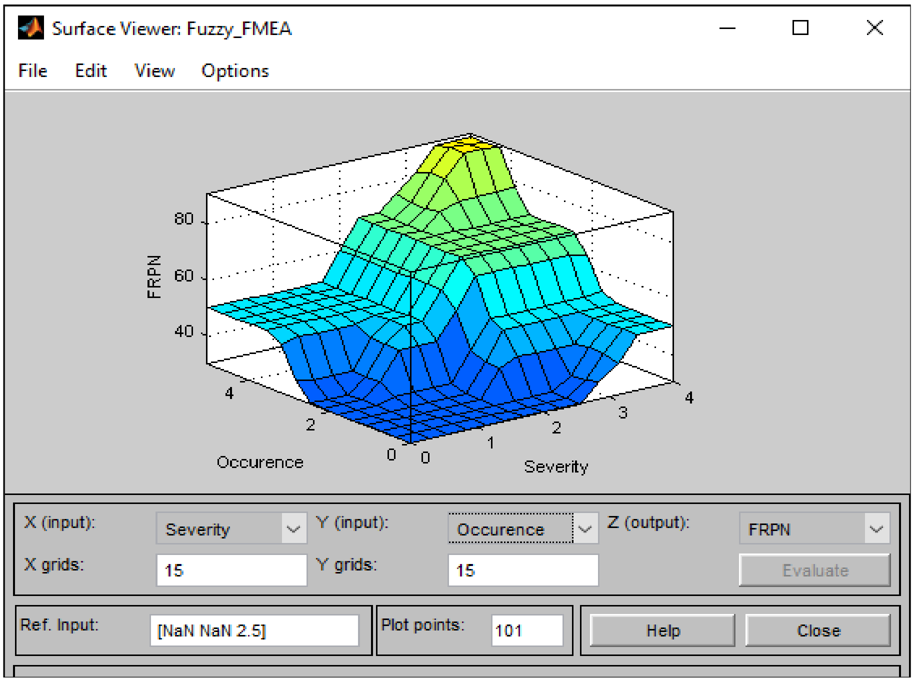


**Figure 14** A Plot of Severity on X-axis, Occurrence on Y-axis and FRPN on Z-axis

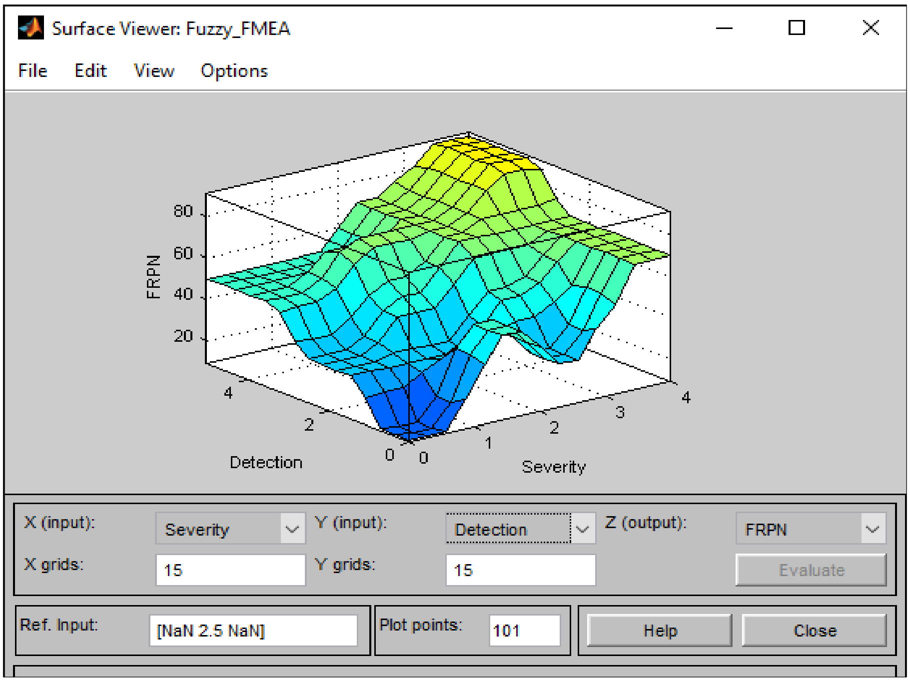


**Figure 15** A Plot of Severity on X-axis, Detection on Y-axis and FRPN on Z-axis

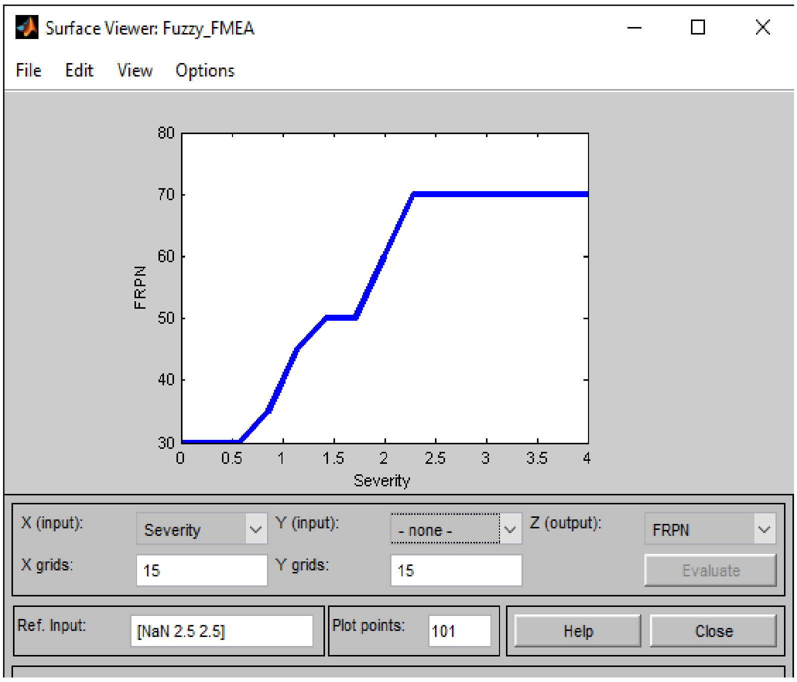


**Figure 16** A Single Plot of Severity on X-axis and FRPN on Z-axis

## 4. Conclusion

Breakdown is a big proof of unreliability of equipment over time. When capital intensive equipment breakdown unexpectedly, there is an overall drop in performance of operation. There are many potential causes of these failures, including poor management practices and inefficient maintenance. As a result, analyzing a system's failure is useful in discovering the primary influencing elements on the performance of equipment. Failure behaviors of DP subsystems were investigated within each individual probable failure mode in the study. The development of a successful risk categorization approach to enhance the conventional FMEA process was achieved. The said analysis offers details on a number of topics, including the causes of failure modes, how they affect equipment performance and reliability, and more.

A modified risk prioritization methodology was proposed after analysis was done to address the subjective and qualitative source of the issue in the design FMEA and excel ranking function was employed putting severity, occurrence and detection as key criteria for ranking. Results of the calculations and analysis are explained as follows:

- Due to high severity, the RPN ranking presented reveals that the faulty DP system component identified for the scenarios SSTs(F1) is categorized as very critical. This denotes the effect these components have on DP system operation. Other major errors (with highest RPN values) include SSCs(F12), SSPr(F7), SSTs(F2), SSPs(F15). In order to reduce the severity level and occurrence of failure modes, RPN value can be used as guidance for failure mode prioritization. Additionally, it will be beneficial when outlining the necessary corrective steps to be taken in attempt to improve a design or procedure. A significant degree of severity and the highest likelihood of potential breakdowns occurring were found to be the causes of higher levels of RPN value. The DP system's overall efficiency and component life are both reduced by this effect. Preventive Maintenance (PM) at regular intervals and by and DP operator training and retraining to gain knowledge of each component.
- In the study, collected data and verification were carried out using a fuzzy rule system built on MATLAB. If two or more failure modes have an equal ranking, the fuzzy-FMEA technique will aid in accurately prioritizing the failure modes. A similar kind of RPN value was found for the failure modes of F1, F2, F5, F6, F7, F8, F10, F11, and F15. It was suggested to use the fuzzy-FMEA technique to rank the potential failure mode rankings. This technique can also assess the criticality and hazards of DP system components by characterizing the MATLAB database of Fuzzy IF-THEN guidelines. This technique considers vague and ambiguous data in the assessment procedure. This analysis not only determined the restrictions connected with the traditional FMEA approach for RPN, it also estimated the reasons for the occurrence of potential failure modes in a complex repairable system. In addition, the fuzzy rule base should also be amended or updated when more failure information exist. It was concluded that a rule-based Fuzzy-FMEA analysis provides strong evidence that the proposed

methodology is logically useful for prioritizing RPN values. Also, to assure a longer lifespan of DP system in general, attention should be given to the failure modes with highest RPN values.

## Compliance with ethical standards

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*Disclosure of conflict of interest*

All authors declare that they have no conflicts of interest.

## References

[1] Holvik, J. Basics of Dynamic Positioning. MTS Dynamic Positioning Conference. 1998. Available at: http:// dynamic-positioning.com/proceedings/dp1998/BHol-vik.PDF

[2] Inegiyemiema. M and Odokwo, V. E. Preliminary Design of Dynamic Positioning System for A Drillship. American Journal of Engineering Research *(AJER).* 2021. 10 (02), 52-60

[3] Hansen, E & Oke, S. DP Dependability - Proceedings of the Dynamic Positioning Conference, Houston, USA. 2011.

[4] American Bureau of Shipping. Guide for Surveys Based on Machinery Reliability and Maintenance Techniques. - 2016 edition (ABS Classification).

[5] Singh, P., Rajesh, K. & Tore, M. Development of Maintenance Strategies for Offshore Production Facilities. The Proceedings of the 3rd World Congress on Engineering Asset Management and Intelligent Maintenance Systems. Beijing, China. 2012.

[6] DNV. Recommended Practices DNV-RP-D102: Failure Mode and Effect Analysis (FMEA) of Redundant Systems. 2012.

[7] Alstom. Guide to Dynamic Positioning of Vessels, Alstom DP manual. 2000.

[8] Ebrahimi, A. Effect Analysis of Reliability, Availability, Maintainability and Safety (RAMS) Parameters in Design and Operation of Dynamic Positioning (DP) Systems in Floating Offshore Structures. [Master Thesis]. KTH. Royal Institute of Technology. 2010.

[9] Odokwo, V. E., Ogbonnaya, E. A. & Barinyima, N. Modeling and Simulation of Ship Propulsive Efficiencies Related Characteristics with Energy Efficiency Design Index in Focus. American Journal of Science, Engineering and Technology. 2022, 7(2), 50-56. doi: 10.11648/j.ajset.20220702.14

[10] Sharma, R.K.; Kumar, D. & Kumar, P. Systematic Failure Mode Effect Analysis (FMEA) using Fuzzy Linguistic Modeling. Int. J. Qual. Reliab. Manag. 2005. 22, 986–1004.

[11] [Harli, M. & Ilja, P. Causes of Dynamic Positioning System Failures and Their Effect On Dp Vessel Station Keeping [Master thesis]. 2018.

[12] Yang, Z., Bonsall, S., and Wang, J. Fuzzy Rule-based Bayesian Reasoning Approach for Prioritization of Failures in FMEA IEEE Transactions on Reliability. 2008. 57 (3). 517–28

[13] Dinmohammadi F. & Shafiee, M. A Fuzzy-FMEA Risk Assessment Approach for Offshore Wind Turbines. International Journal of Prognostics and Health Management, 2013, 1(2), 1-10.

[14] Wang, Y. M., Chin, K. S., Poon, G. K. K. and Yang, J. B. Risk Evaluation in Failure Mode and Effects Analysis using Fuzzy Weighted Geometric Mean Expert Systems with Applications, 2009. 36 1195-1207