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Reliability Assessment of DP Systems Based on Incidents Data

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Abstract

The DP system consists of various equipment and systems that directly and indirectly affect the ship's position/course keeping. The reliability of the DP system depends directly on various aspects of the system, such as equipment selection, design, architecture, functionality, integration, verification, rules and regulations. The reliability of the DP system depends on the redundancy of the equipment so that a sudden single failure of equipment or an inadvertent action does not result in an unexpected loss of the ship's position and/or course. Furthermore, reliability is indirectly dependent on third party advice on DP design, FMEA, HIL, operational planning and procedures, training of operational personnel, company safety policies, local authorities and government rules and regulations. The present methodologies for assessing the reliability of DP system do not consider the DP incidents database. In the present article a methodology for assessment and improvement of DP system reliability is proposed and analyzed.

Keywords: Dynamic Positioning; Reliability; Methodology; Linear regression; Correlation; Statistical method

Introduction

Gap analysis of traditional reliability assessment reveals many deficiencies, listed below:

i. Lessons learned from the previous casualty database were not considered when performing reliability assessments on new ships.

ii. There is always a discrepancy in the reliability assessments of similar ships carried out by different independent consultants.

iii. The reports produced based on reliability assessments contain too much irrelevant information and only highlight possible failure modes.

iv. There is a lack of clear solutions and guidance on the steps to be taken in the event of failure.

v. Lack of clarity on the interdependency of subsystems.

vi. The relatively short response time for operators to react and prevent accidents is not taken into account.

The above gap analysis clearly highlights the need for a new approach to assessing the reliability of the DP system.

Methodology of the Proposed New Approach for Assessing the Reliability of DP Systems

This article will propose a comprehensive method for assessing the reliability of the DP system that combines qualitative and quantitative analysis. The proposed complex method is based on the assumption that the historical data of the DP incidents and the causes of these incidents are not taken into account when assessing the reliability of the DP system. Furthermore, the human factor, which is essential, is not taken into account. The qualitative analysis includes FMECA, and the quantitative analysis consists of collecting, interpreting, and analyzing data on DP-related incidents between 2010 and 2023. The data analysis is based on regression and correlation analysis from mathematics. The results obtained from the analysis are compared with the results reported in the FMECA, thus further validating the results of the qualitative analysis.

Step 1. Using FMECA Reliability Assessment Analysis

FMEA is one of the most used methods for assessing the reliability of DP systems. However, it does not allow for risk assessment through critical analysis of the consequences of a failure or malfunction in an DP component. Therefore, for the purpose of the proposed methodology, the FMECA method is selected in which a critical analysis is performed. Although the main document dealing with FMECA in DP system is [1], the methodology and FMECA template set out in [2] is used in this methodology. This is because in [2] the largest variety of different failure modes and failures are presented. FMECA can be performed using either a top-down or bottom-up approach. The difference between the two approaches is that the top-down approach is used in the design phase before system finalization and is mostly function-oriented, while the bottom-up approach is used when the system concept has been finalized. In both approaches the criticality analysis can be performed qualitatively and quantitatively. Typically, the quantitative approach is used when component data is available, and alternatively a qualitative approach is used.

Criticality analysis is "a procedure by which each potential failure mode is ranked according to the combined influence of severity and probability of occurrence" [3]. Criticality analysis can be performed to improve reliability, availability, and reduce the consequences of failure [4]. As a procedure, FMECA can be used by identifying and analyzing individual system components and determining their failure modes, and then identifying the effects of these failures on system behavior [5].

Step 2. Data Collection and Interpretation

Data are the facts presented to the researcher by the research setting [6]. There are different methods of data collection, and each researcher collects data using one or more techniques. The researcher selects the method according to its overall appropriateness for the study, along with other practical factors such as: the expected quality of the data collected, the expected level of measurement error, and the length of the data collection period [7].

According to Newman data collection techniques can be grouped into two categories: quantitative and qualitative. According to the type of questions or topic, some techniques are more effective than others. It takes skill, practice, and creativity to match a research question with an appropriate data collection technique [8].

For the purpose of this study, incident data related to DP systems between 2010 and 2023 were collected and analyzed. Incident data over this period has been carefully analyzed and arranged in a way that is necessary for risk analysis and prediction. Although the IMCA collects three different types of DP data (DP Incident, DP Undesired Event, DP Observations), only the DP incident data is considered in this thesis. The IMCA defines a DP incident as the loss of the ability of a DP to maintain position and heading under certain environmental conditions or as a result of human error. The IMCA divides the incident data into two categories -incidents caused by primary causes and incidents caused by secondary causes. The root cause is the overall holistic effect on the ships ability to maintain its position after an initiating(secondary) cause. The secondary cause is the initiating cause, it is the triggering of the event that will cause an effect on the ship and its ability to maintain position and/or course [9].

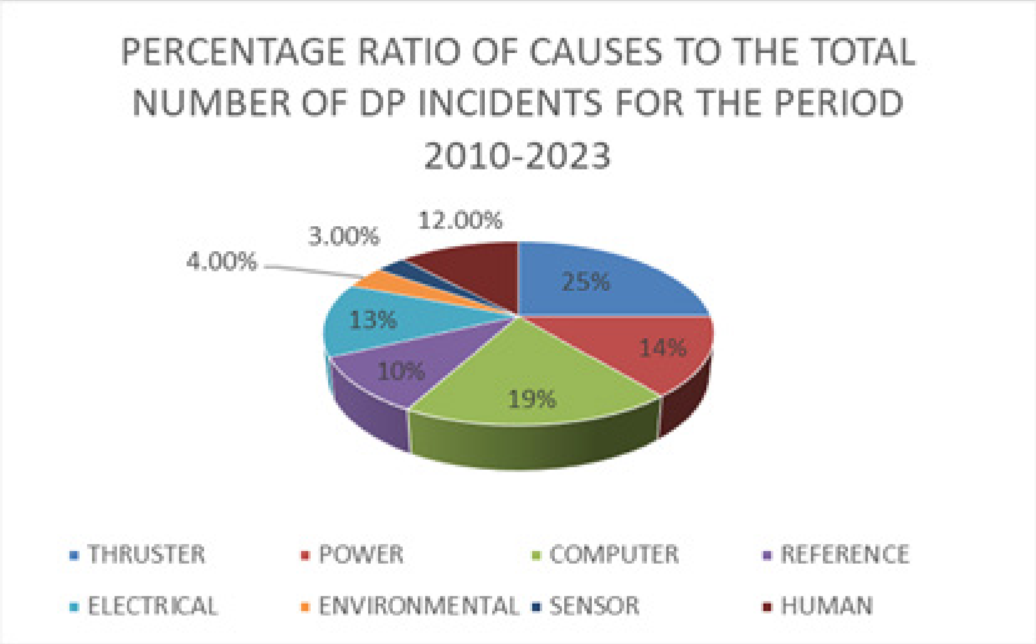

Figure 1: Percentage ratio of causes to the total number of DP incidents in the period 2010-2023.

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In this article, both primary and secondary causes are considered, with the main focus on the primary causes. The data on the secondary causes have been used for correlation analysis and to create some assumptions that have been verified through risk analysis. The total number of incidents reported during the period 2010-2023 was 2016, of which 1224 were caused by primary reasons, and 792 were reported as primary reasons combined with secondary reasons for failure of the DP systems. The overall percentage of different factors contributing to DP incidents is presented in the pie chart (Figure 1) generated using the IMCA thirteen-year data. The pie chart was generated using the overall pattern of incidents without distinguishing between major and minor causes. The pie chart shows that the four major subsystems that contributed to the failure of the DP system were: thrusters-25%, computer system-19%, power system-14%, and electrical system-13%.

The distribution of failures/malfunctions related to major and minor causes is as follows:

Failures in the DP system due to failures in the thrusters made up the largest percentage for the period under review-425 failures due to the thrusters as the primary cause and 76 failures due to the thrusters as a secondary cause. Failures in the DP systems due to computer system failures as the primary cause ranked second with 254 failures, while failures due to computer system failures as a secondary cause were 134. IMCA does not specify whether computer system failures are due to hardware or software failures. The power system as a root cause of the incident is also an issue that needs to be addressed. The reason is that technology is evolving rapidly and the power system on board is increasingly complex, and it can be quite difficult to identify failures. IMCA does not indicate whether incidents involving the ship's power system were the result of open or closed bus operation (Figure 2). The main causes of failure in the reference systems are DGNSS failure due to spoofing or jamming.

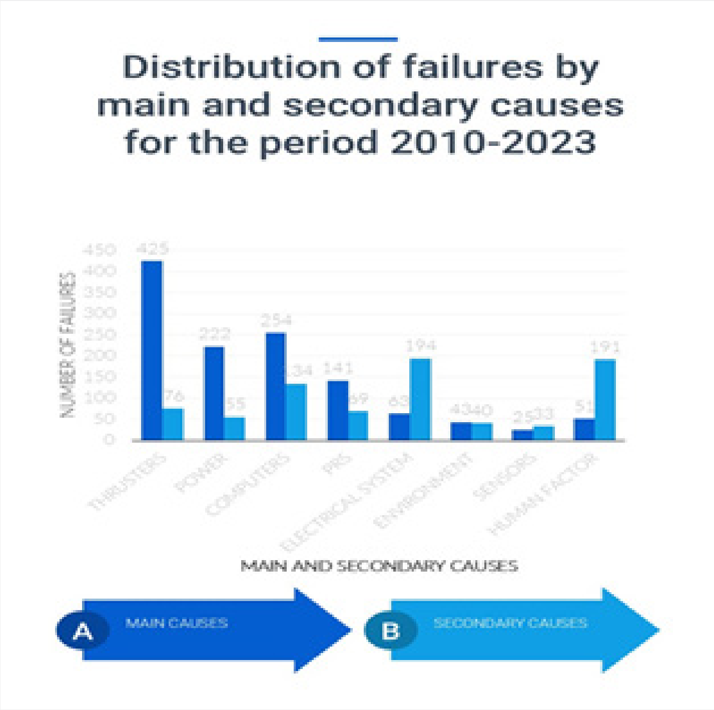

Figure 2: Distribution of failures by main and secondary causes for the period 2010-2023.

Step 3. Analysis of the Collected Data

Data analysis is one of the important steps in the research process. It usually involves inspection, transformation, and modelling of the data to highlight useful information, suggest conclusions, and support decision making [10]. According to [10], data analysis can be divided into two parts: exploratory data analysis (EDA), which focuses on discovering new features in the data, and confirmatory data analysis (CDA), which focuses on confirming or rejecting existing hypotheses. Blaikie divides quantitative data analysis methods into four types: univariate descriptive analyses, bivariate descriptive analyses, explanatory analyses, and deductive analyses [11]. Univariate descriptive analysis examines one variable at a time, whereas bivariate descriptive analysis is concerned with the relationship between two variables. Explanatory analysis can be either a special type of

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bivariate analysis that examines the influence of one variable on another, or a multivariate analysis that examines the relationship or influences between three or more variables.

In this study, a bivariate descriptive data analysis is used in qualitative analysis. In this analysis, the probability and consequence of failure of the DP systems are arranged in a risk matrix according to different classifications. The combination of the consequence range and probability gives a risk score or risk ranking, and then helps the decision maker determine the most cost-effective means of risk reduction. In quantitative analysis, FMECA, multivariate analysis is used according to the three variables including: severity, probability of occurrence and probability of detection. By collecting data, estimating of these variables according to the collected data; the RPN number can be calculated to determine the risk ranking and critical parts of the DP system.

Linear regression analysis and correlation analysis were used in the development of the methodology. Regression analysis is a method for examining the functional relationship between two or more variables. The relationship is usually expressed in the form of a model or equation relating the response variables or predictor variables. In this dissertation, linear regression was used to predict the risk of failure of the DP system.

Step 4. Quantitative analysis

Linear regression analysis: This analysis seeks to model the relationship between two variable factors by fitting a linear equation to the observed data. In this analysis, one variable is the dependent variable, and the other is the independent variable. The number of failures due to primary or secondary causes is the dependent variable and time (years) is the independent variable. Typically, linear regression analysis is given by the following equation (1):

$$Y=a+bX \quad (1)$$

where Y is the dependent variable and X is the independent variable.

In this study, the analysis was performed to quantify the failure rate caused by different root causes and to identify the significant root causes contributing to the failures of the DP system. To this end, linear regression models using the number of failures as the model output were applied. The linear regression results are presented using the Data Analysis→Regression function of Excel.

The results of the regression are presented as a forest tree diagram in (Figure 3). In the flowchart, for each line, the point in the center represents the expected failure rate (number of failures per year contributed by the cause tested), and the error bars on either side represent the confidence intervals (CIs). If the error bars do not cross the central vertical line at zero, then the regression results are statistically significant (P<0.05).

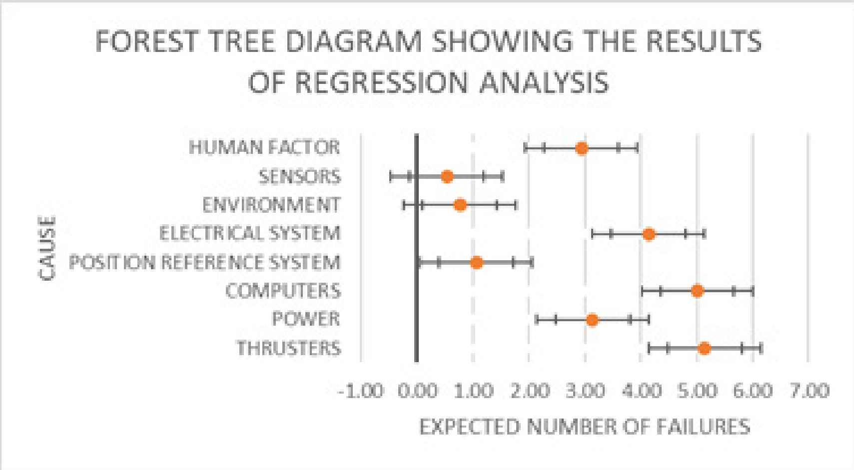

Figure 3: Forest tree diagram.

Correlation Analysis: There are two types of correlation analysis - Pearson correlation and Spearman correlation analysis. Pearson correlation analysis is used in this study. Using this analysis two sets of data are correlated linearly. The result ranges from +1 to -1, where a positive correlation means that the two variables lead to results in the same direction and -1 means the opposite. To determine the contribution of secondary causes to the overall failure rate using the same data, Pearson correlations between 8 primary and secondary causes were calculated.

All correlation values (between causes) are plotted as heatmap using Excel. The heatmap from the Pearson correlation analysis is used to identify the primary cause(s) strongly associated with one or more secondary causes. Since the number of failures due to root causes alone is overwhelmingly higher than failures due to a root cause combined with a secondary cause (1,224 versus 792 failures, respectively), we therefore assume that failures due to a root cause, such as a computer or engine control system failure, has a significant impact on the failure of the DP system compared to the failure of these systems under a secondary cause. A p value <0.05 was used to determine statistically significant results.

Step 5: Comparison of the Results of the Qualitative and Quantitative Analysis

Consistent with the FMECA findings where the computer system has a critical influence on the failures of the DP system, our linear regression analysis also confirms a similar trend where the computer system increases the number of failures per year by more than 5 (estimate = 5.01 failures/year) with a statistically significant p-value (P=0.00009). Similarly, the regression analysis further confirms the moderate and strong impact of power from FMECA with a significant regression estimate of 3.14 increased failures/year (P=0.000006). The FMECA analysis found that thrusters have a moderate to high impact on DP system failures, and this impact is also in the direction of increasing in the linear regression analysis, where the calculated estimate is over 5 failures per year (estimate = 5.14; P = 0.0000012) due to thrusters as the main cause of the incident. It is important to note that FMECA does not directly address human and procedural errors, whereas regression analysis quantifies these errors. The regression analysis allows the reliability of the DP system to be examined taking into account the human factor. As is evident from the results, the estimated failure rate caused by human factors is almost 3 failures per year (estimate=2.94). The value is statistically significant with p=0.0005. All other causes increase the number of failures over time, although not significantly, which is consistent with the FMECA analysis where these causes have a moderate to slightly moderate impact on DP system failure. Furthermore, the causes sensors, environmental factors and reference systems are statistically significant.

For the 8(eight) secondary causes, a correlation analysis was performed between the number of incidents to which all 8(eight) primary causes (computer, electrical, combined environmental and external forces, human and procedural errors combined with power, motor and drive, reference system and sensor errors) contributed and the same as a secondary cause of failure. This correlation was calculated to determine if any of these causes were strongly (and significantly) correlated as a primary cause with any other cause as a secondary cause of failure. A total of 64 correlation values were calculated. Using Excel's Conditional formatting function, all 64 correlation values were then plotted as a heat map (Table 1). Lighter shades represent stronger correlations between primary and secondary causes, and darker shades represent the opposite.

Table 1: Heat map showing Pearson correlation between main and secondary causes

	THRUSTER SEC	POWER SEC	COMPUTER SEC	REFERENCE SEC	ELECTRICAL SEC	ENVIRONMENTAL SEC	SENSOR SEC	HUMAN SEC
THRUSTER	-0,0935252191	-0,0311875	0,8382174	0,10456433	0,80375872	0,52409108	0,3203	0,927704
POWER	-0,314409047	-0,3040882	0,64156224	-0,15931234	0,87413695	0,403274587	0,017798	0,880744
COMPUTER	0,036401468	0,10543493	0,95628818	0,4075601	0,78840906	0,773804297	0,553423	0,686335
REFERENCE	-0,227257605	0,04269263	0,41643462	-0,00579526	0,40975629	0,041951642	0,009038	0,68897
ELECTRICAL	0,068793235	-0,2307958	0,03371982	-0,07854182	-0,07600927	-0,19753199	-0,16042	0,496001
ENVIRONMENTAL	-0,02761712	-0,0486633	0,00728162	-0,2335942	0,28408026	0,175496047	-0,20264	0,35513
SENSOR	-0,049225941	0,0112148	0,32451745	0,11334816	0,19255401	0,538484251	0,226416	-0,02193
HUMAN	0,001535309	-0,1570632	-0,5423344	-0,36300315	-0,28878218	-0,334501399	-0,2649	-0,37076

All causes, when considered as primary causes of failure, are represented on the y-axis, and when considered as secondary causes, are plotted on the x-axis. Of the 64, only 18 correlations were statistically significant ($P<0.05$) with correlation values ranging from 0.96 to 0.40. Stronger correlation values are interpreted as indicating that the corresponding secondary causes contributed as an additional reason for the failures along with the primary cause. A stronger correlation in our heatmap may indicate potential main and secondary causes that can be analyzed to reduce future failure incidents in this system. For example, among all 8 main causes, computer errors are significantly correlated with the largest number of secondary causes (n = 6) of failure, including electrical, human, and procedural errors, computer errors, and environmental errors combined with external forces. This finding further confirms that the computer system can have a critical impact (as found by FMECA and regression analysis) on DP system failures either alone or in combination with other highly correlated secondary causes (heatmap Table 1). The other three primary causes showing significantly strong correlation with the secondary causes are power, thrusters and the reference system.

Recommendations for Further Research

In this study, a methodology for assessing the reliability of the DP system was proposed based on a quantitative and qualitative risk analysis of the DP operation and a quantitative risk assessment using statistical methods. Linear regression analysis and correlation analysis of statistical data on DP incidents were used, as well as qualitative DP system reliability analysis based on an FMECA form optimized by the author. Notwithstanding the results achieved using the methodology, further research is needed to more effectively use statistical methods to quantify risk in the DP systems. According to the results of the proposed methodology for assessing the reliability of DP systems, improved maintenance plans can be composed for more reliable and safe DP operations.

IMCA should collect more detailed data on DP incidents when they occurred, such as depth, wind speed, current, wave height, number of thrusters online. These parameters can help quantify risk with greater accuracy and statistical significance, which can help improve DP design and operations. Historical data in terms of number of years and number of factors should be analyzed both qualitatively and quantitatively to predict the risk in the operation of the DP system. Methods such as survival analysis can also be used to predict risk and detect safe and reliable operating limits of the DP system. The possibility of fault tree analysis (FTA) being incorporated into criticality analysis should also be investigated in detail. This would allow us to account for the effect of the FTA collateral in a more correct and efficient way, even more so if the fault tree is used in combination with FMECA.

Conclusions

Based on the analyses carried out, the following conclusions can be drawn:

i. A new methodology is proposed for assessing the reliability of the DP system based on qualitative and quantitative analysis.

ii. Criticality analysis can be considered when assessing the reliability of the DP system

iii. FMECA is useful for the criticality analysis of DP systems. In this study, we propose to use FMECA instead of FMEA and apply RPN number as an effective method to determine the critical components. Furthermore, the format used to evaluate FMECA is optimized by the author.

iv. The risk matrix is used as an effective method for determining risk levels and decision making

v. DP system involves a man-machine system. The methodology proposed also considers the human factor, which was not analyzed in the previous methods. For the safe and reliable operation of the DP system, it is essential to consider all major components of the DP system, including technical system failures and human operational failures, in the risk or safety analysis. The risk analysis in the implementation of the DP system focuses mainly on technical system failures, but little weight is given to human interaction. Incident data show that 12% of incidents are due to a human error, and it is possible that some incidents due to computer failure are also due to human error.

vi. Environmental conditions such as wind speed, wave height and sea current have a direct impact on the performance of the DP vessel. Harsh and severe weather conditions with sudden change in wind speed, current direction can affect the performance of the relevant sensors to provide data to the computer system to counteract the environmental impact. The DP control system and the positioning system have a great influence on the safe and reliable operation of the DP. Other important subsystems of the DP system for safe operation are the computer software, hardware and data network used together with the ship's sensor, which are commonly referred to as the positioning system.

vii. The main causes leading to incidents are thrusters-25%, computer system-19%, power system-14% and electrical system-13%.

viii. The computer system is one of the main components of the control system and contributed to 19% of the total number of incidents in the DP incident data analyzed in this thesis

ix. The proposed methodology is based on the hypothesis that the human factor influence is not taken into account when assessing the reliability of the DP system. The combination of qualitative and quantitative analysis based on statistical data of incidents related to DP system allows to compare the results of both types of analysis, taking into account the causes of incidents and analyzing their trends. This leads to an increase in the reliability of the DP system.

x. Incident statistics are collected annually by IMCA. The low number of ships reporting incidents on board has emerged as a potential problem. For 2023, a total of 177 reports were received, which represents only 0.06% of the total estimated number of ships with DP systems. More motivation is needed for shipowners to report incidents, which would lead to a larger data base when quantified through regression and correlation analysis.

Analytical expertise is required for the proposed methodology to be successfully used on board ship as a means of assessing the reliability of the DP system. The development of procedures and ready-made templates to perform the analysis would greatly facilitate the application of this methodology on board.

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