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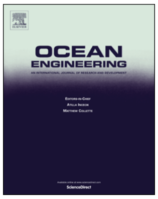

An integrated multicriteria decision making methodology using compromise solution methods for prioritising risk of marine machinery systems

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ABSTRACT

One of the most popular tools used for risk assessment of marine machinery systems is Failure Mode and Effect Analysis (FMEA). With this analysis tool, risk is represented in the form of a risk priority number (RPN) which is computed by multiplying the severity rating (S) by the occurrence probability (O) and the detection rating (D) for all failure modes of the system. This conventional FMEA has been criticised as having several limitations such as inability to aggregate imprecise ratings of multiple experts and inability to incorporate more than three risk criteria. These challenges have been addressed in this paper by developing two novel methodologies for prioritising the risk of failure modes for marine machinery systems. The first methodology integrates an averaging technique with VIKOR (Vlsekriterijumska Optimizacija Ikompromisno Resenje, meaning: Multicriteria Optimisation and Compromise Solution). The second methodology integrates an averaging technique with the Compromise Programming (CP) technique. While the averaging technique is applied as a means of aggregating imprecise risk criteria ratings from multiple experts, VIKOR and CP are used in the ranking of risk of failure modes. The applicability and suitability of these methodologies for risk prioritisation is demonstrated using two case studies.

1. Introduction

Marine machinery systems no matter how well designed will not remain safe and reliable if not properly maintained (Cicek et al., 2010). How to maintain such complex systems is still a challenge in the maritime industry. One of the major problems is the selection of the appropriate maintenance strategy for each piece of equipment/component of the system. Different key players in the maritime industry have adopted various methodologies in overcoming these challenges. One of the most popular methodologies adopted is Reliability Centred Maintenance (RCM). RCM represents a method for preserving functional integrity and is designed to minimise maintenance costs by balancing the higher cost of corrective maintenance against the cost of preventive maintenance (Crocker and Kumar, 2000) and it uses decision logic diagrams in selecting maintenance strategies (Aleksić and Stanojević, 2007; America Bureau of Shipping, 2004; Conachey, 2004, 2005; Conachey and Montgomery, 2003).

However in deciding on the appropriate maintenance strategy, a thorough risk analysis must be carried out because the maintenance decision depends on the assessed risk. Different techniques such as Failure Mode and Effect Analysis (FMEA), Hazard and Operability Analysis (HAZOP) and checklist analysis are available for risk analysis and for the marine industry, American Bureau of Shipping (ABS) requires FMEA to be employed in prioritising risk of failure modes within an RCM framework (Conachey, 2004, 2005; Conachey and Montgomery, 2003).

The development and application of the FMEA methodology dates back to 1949 and the United States Army and in the 1970s its application was extended to aerospace and automotive industries and then to manufacturing industries (Scipioni et al., 2002). Today FMEA is a popular tool used by many maritime industry players for prioritising the risk of failure modes for machinery systems and other hardware prior to maintenance strategy selection in RCM analysis.

FMEA is a risk analysis tool which is used to define, identify, and eliminate known and/or potential failures from the system, design, process, and/or service (Stamatis, 2003). It is one of the most powerful tools for performing risk analysis for marine

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Table 1
Ratings for occurrence (O), severity (S) and Detectability (D) in a marine engine system (Cicek and Celik, 2013; Pillay and Wang, 2003; Yang et al., 2011) revised.

Rating	Linguistic term	Occurrence (O) (failure rate measured in operating days)	Severity (S)	Likelihood of non-detection (D)
10	Very high	>1 in 2	Engine failure resulting in hazardous effects is almost certain	Very high chance control system will not and /or cannot detect a potential cause and subsequent failure mode
9		1 in 3	Engine failure resulting in hazardous effects highly probable	
8	High	1 in 8	Engine inoperable but safe	High chance control system will not detect a potential cause and subsequent failure mode
7		1 in 20	Engine performance severely affected	
6	Moderate	1 in 80	Engine operable and safe but performance degraded	Moderate chance the control system will not detect a potential cause and subsequent failure mode
5		1 in 400	Reduced performance with gradual performance degradation	
4		1 in 2000	Minor effect on engine performance	
3	Low	1 in 15,000	Slight effect on engine performance. Non-vital faults will be noticed most of the time	Low chance the control system will not detect a potential cause and subsequent failure mode
2		1 in 150,000	Negligible effect on engine performance	
1	Remote	<1 in 1,500,000	No effect	Remote chance control system will not detect a potential cause and subsequent failure mode

machinery systems with risk being quantified through evaluating Risk Priority Number (RPN) which is a product of occurrence (O), severity (S) and likelihood of non-detection (D). Typically values are assigned to O, S and D by a team of experts using an ordinal scale, an example of which is shown in Table 1. The ordinal scales in Table 1 were originally generated by Ford motor Company (Ford Motor Company, 1998) and have since been used by many authors in assigning values to risk criteria in the prioritisation of failure modes of different systems such as; marine diesel engine subsystems specifically fuel oil system and crankcase (Cicek and Celik, 2013; Cicek et al., 2010), aircraft turbine rotor blades (Yang et al., 2011), diesel engine turbocharger (Xu et al., 2002) and the cooling sub-system in an off-shore plant (Sankar and Prabhu, 2000). The FMEA analysis usually involves a series of steps which are diagrammatically represented in Fig. 1.

The classical FMEA employed by the marine industry has been criticised as having some flaws and these flaws limit the effectiveness of the tool in prioritising risk of failure modes of marine machinery systems. Some of the flaws identified in the literature are (1) the inability of the technique to take into account more than three attributes in prioritising risk thereby excluding other important factors such as economic cost, production loss and environmental impact (Liu et al., 2011), (2) the different combinations of the three decision criteria (detection, severity and occurrence) yielding the same RPN value whereas the perceived risk might be totally different (Kutlu and Ekmekçioğlu, 2012) and (3) assumption that decision criteria are the same. These make the classical FMEA that uses RPN in prioritising risk unsuitable especially in the marine environment and as such a more appropriate technique is expedient in the marine world.

In order to eliminate or mitigate the limitations of the classical FMEA and make it suitable for use in the marine environment two Multi-Criteria Decision Making techniques (MCDM); VIKOR and CP are proposed for use in place of the RPN of the FMEA. Utilising these two MCDM techniques which have successfully been applied in solving problems other than risk prioritisation, will allow more decision criteria and flexible decision criteria weights to be use in prioritising risk of failure modes which will therefore result in the risk of failure mode being more effectively prioritised or ranked. In order to enhance the capability of the two MCDM techniques in addressing the limitations of the classical FMEA, an averaging technique has been integrated with the two proposed MCDM techniques. The averaging techniques is a means of aggregating imprecise risk criteria ratings from multiple experts and combining it with the two proposed MCDM compromise solution methods, allows the proposed compromise solution methods to use precise and /or imprecise ratings from experts as input. Thus the use of the averaging technique in the MCDM tools will eliminate the limitation of the classical FMEA of the inability to aggregate imprecise criteria ratings from experts. The suitability and applicability of the proposed methodologies in risk ranking of failure modes of the marine diesel engine which is a sub-system of marine machinery systems are investigated.

The paper is organised as follows: Section 2 presents a review of MCDM tools and Section 3 presents the proposed methodology for risk prioritisation. In Section 4 the case study of the marine diesel engine is presented for illustration of the proposed technique. Finally conclusions are presented in Section 5.

2. Review of MCDM tools and their relevance to the marine industry

As stated in the introduction section, the classical FMEA technique has limitations and in order to enhance its capability and reduced these flaws, various Multi-Criteria Decision Making (MCDM) techniques have been applied in the literature.

Braglia (2000) proposed the Analytical Hierarchical Process (AHP) technique as an alternative to RPN in the FMEA system. With this method, a three-level hierarchy was formed with the top level representing the main objective of fault cause selection, the intermediate level representing the four risk criteria, O, S, D and economic cost and the lowest level representing the alternative causes of failures. With this a series of pairwise comparison matrices was formed and evaluated to obtain the weight of risk criteria and local priorities of possible causes of failure with respect to O, S, D and economic cost. The aggregation technique in AHP was used to synthesise the local priorities of causes of failure into global priorities based on which possible cause of failure was ranked. Carmignani (2009) used a similar approach to that of Braglia (2000) and in the methodology of the former, a new profitability calculation technique was introduced in place of economic cost for risk prioritisation of an electro-injector, a fuel system component. However the use of AHP has been criticised due to its use of an unbalanced scale of judgement and its inadequacy in addressing risk criteria rating that may be uncertain and imprecise in the pairwise comparison process (Deng, 1999; Ilangkumaran and Kumanan, 2009). Furthermore, the use of AHP methodology is performed on problems with 2 to 15 risk criteria and if a problem with more than 15 decision criteria is to be