Chapter 11
Risk Assessment of Marine High-Speed Diesel Engine Failures Onboard Naval Vessels Using Failure Mode and Effect Analysis

Muhammad Syafiq Naqiuddin Mohd Zuki, Izuan Ishak, Iwan Mustaffa Kamal, Muhammad Nasuha Mansor, and Yaseen Adnan Ahmed

11.1 Introduction

High-speed diesel engines which run at high crankshaft speed, typically running between 1500 to 2500 rpm (Woodyard 2004; McGeorge 1995; Taylor 1998), are commonly used on board of naval and patrol vessels. In this case, in Malaysia these high-speed diesel engines are used especially in 'Malaysian Marine Enforcement Agencies' fleets such as the Royal Malaysian Navy (RMN) and Malaysian Maritime Enforcement Agency (MMEA) where the naval and patrol vessel are used for daily

M. S. N. M. Zuki
KL Petrogas Sdn. Bhd., B-3A-32 Block B, Merchant Square 1, Jalan Tropicana Selatan 1, PJU 3, Tropicana, 47410 Petaling Jaya, Selangor, Malaysia
e-mail: syafiq@klpetrogas.com

I. Ishak · I. M. Kamal (✉) · M. N. Mansor
Universiti Kuala Lumpur, Malaysian Institute of Marine Engineering Technology, Lumut, Malaysia
e-mail: iwanzamil@unikl.edu.my

I. Ishak
e-mail: izuan.ishak@unikl.edu.my

M. N. Mansor
e-mail: mnasuha@unikl.edu.my

Y. A. Ahmed
Maritime Safety Research Centre, Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, Glasgow, UK
e-mail: yaseen.ahmed@strath.ac.uk

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patrols and surveillances. These aging engines are facing potential breakdowns or in the worst case a total engine failure which at the end will jeopardize their patrol and duty in hand.

MTU engines are commonly used onboard of these RMN and MMEA vessels in maintaining law and order, coordinating search and rescue operations in the country's main sea transportation lines such as the Straits of Malacca, the Straits of Singapore, Malaysian Maritime Zones and on the high seas. But some of the vessels are more than 50 years old and are in an aging state. Most of the aging vessels are powered with MTU 12 V 538 TB81 engines. These MTU engines were popular in the 80s during these vessels design and building phases. MTU derives as *Motoren-und Turbinen-Union* which means "Motor (Engine) and Turbine Union". This company offered high performance and high-speed design with an upper output limit of 9100 kW which was created in 1969 when Daimler-Benz and MAN merged the development and production of relevant engines from MAN and Maybach Mercedes Benz (MTU 1985, 2002, 2009).

Considering these highly likely potential breakdowns, a risk assessment is necessary to prevent or minimize the chances of breakdowns in the future. This risk assessment is crucial to the crew's safety during operation of the ship and this could avoid a catastrophic failure happening to the engine. Risk assessments are used to determine the causes of damage and analysis were carried out to determine the primary failure mode of these high-speed diesel engines. One of the purposes of risk assessment is to know whether the engine is in good condition or not and to identify the potential engine problems that will cause the breakdown of the engine itself. Failure mode and effect analysis (FMEA) is a methodology designed to identify potential failure modes for the high-speed engine, to assess the risk associated with those failure modes, to rank the issues in terms of importance, and to carry out corrective actions to address the most serious failure modes (Patil et al. 2003; Hu-Chen et al. 2013). FMEA is an analysis method determining the causes of damage, where analysis is carried out to determine the primary failure mode. FMEA is also a risk assessment tool that reduces potential failures in systems, processes, designs or services and has been used in a wide range of industries (Hu-Chen et al. 2013). This FMEA was first developed as a formal design methodology in the 1960s by the aerospace industry (Kabir 2017), and has proven to be a useful and powerful tool in assessing potential failures and preventing them from occurring (Faturachman et al. 2013). Initially used by the U.S military after World War II as a process tool, FMEA gradually spread into industry (Saputra et al. 2019). It became widely known within the quality community as a total quality management tool in the 1980s and as a Six Sigma tool in the 1990s (Cicek et al. 2011). FMEA is a living document that should be reviewed and updated whenever the process is changed. To develop the FMEA, initially a survey was done on the functions of each component of the FMEA table which consists of three parts: the first part is the risk identification, the second part is the risk evaluation and the last part is the risk treatment.

In this FMEA, effect analysis was done thoroughly in studying the consequences of those failures. FMEA is widely used in the manufacturing industry in the whole life cycle of a product. The FMEA table consists of risk identification, risk effect, risk category, risk treatment and risk evaluation. A risk assessment table was made in this research which consists of system by system of the engine such as the air starting system, fuel system, lubricating oil system, exhaust system and cooling system. The risk assessments using the FMEA method were applied to the MTU 12 V 538 TB81 engines which were still the main engines of some of the old vessels belonging to the RMN and MMEA. Once the analysis was done using the FMEA on the MTU 538 engines, the engine operation checklists were generated according the risk and the remedy identified earlier in the FMEA tables. These operation checklists will help the engine watch keepers in doing their routine daily checks with regards to the engine daily operation. These enhanced daily routine inspections could prevent unexpected breakdown of these high-speed diesel engines.

In general, there are tons of engine failure cases that had occurred, and these incidents indirectly had affected the operation in seas. This research study focused on finding, identifying, and analyzing factors contributing towards the engine failure severity and occurrence especially in the MTU 538 engines. Engine failure of naval vessels is not desirable when the ship‘s crew operates the ship at high speed for manoeuvring or sailing in high seas. This failure could be dangerous to the ship‘s crew while the ship is in operation. Problem that causes failure to high-speed diesel engines could lead to a much more disastrous catastrophic failure. In other words, this catastrophic failure means that the engine cannot sustain the high load and start to destroy itself i.e., crankshaft breaks, crankcase explosions etc. Due to this catastrophic failure, it can contribute to a higher maintenance cost where the whole engine must be substituted with a new engine as a replacement. When ships are at high seas, engine failure could happen as well and this kind of failure will make the ship stranded at high seas. Engine failures while naval ships are at operation such as during war or during sailing on patrol could jeopardize the operation or patrol at sea. Engine failures are unexpected events that can lead to profit loss financially and in regards to properties. Fatality or serious injury can also occur toward crews on-board.

Therefore, considering the problems mentioned in the earlier paragraphs, this research was conducted to help identify the major determinants of engine potential failure occurrence. This research proposed a fault tree diagram according to the potential MTU 538 engine failures and to produce the FMEA tables based on the potential engine failure fault tree diagram. In the end, based on the FMEA tables, this research also generated the engine operation checklists for the MTU 538 engines. This study created risk assessment documents for the MTU engine failure as alternative references to the ship’s crew to carry out maintenance and repair jobs. The scope of this study is limited on the MTU 538 series engine only.

The MTU series 538 engines were established as a high-speed diesel engine for ship’s propulsion purposes. This engine came with 2640 kW per engine of power using the 4 stroke diesel cycle and single acting pistons. The combustion method of this engine is pre-chamber and having an exhaust gas turbocharging with the mode of supercharging. The type of cooling method is water cooling. The arrangement of the cylinders came with a 60° V-engine design configuration, with a total of 16 cylinders, with 8 cylinders in ‘A’ bank and the other 8 cylinders in ‘B’ bank.

This engine also came with specific firing order which is A1-B6-A6-B2-A2-B5-A5-B8-A8-B3-A3-B7-A7-B4-A4-B1. The engine bore and stroke are at 185 mm and 200 mm each, having 5.38 L cylinder displacement and the total displacement is at 86 L. The injection pressure of fuel is at 130.5 bar. The MTU 538 series engines have a combustion pressure final at firing speed of around 24 to 28 bar. The air intake temperature to start the combustion is around 32 °C and the water temperature at the charge air cooler is around 27 °C. The valve clearance is at 0 and the valve of this engine is adjusted automatically. The MTU engine of 16 V 538 TB 91 are used by the RMN in 'Handalan' class ships, which are 'Spica –M2' type with a capacity of three engines per ship. The 'Handalan' class is a heavier derivative of the Swedish Spica II (Norrkoping) rapid attack boat that has been domestically modified. This class succeeded the Perkasa-class squadron, which was built by 'Kalskrona Varvet' and ordered in 1976. One of the 'Handalan' class ships is the 'KD Pendekar' that has three engines of MTU 16 V 538 TB 91 and is delivering 10,865 HP or 8102 kW with three shafts combined together.

11.2 Methodology

In this research, there are three major activities conducted, which are the (1) fault tree diagram analysis, (2) the FMEA analysis and (3) the generation of the operation checklists. In the first step, to accomplish the objectives set for this research the collected data was analyzed by using a fault tree diagram. A tree diagram is simply a way of representing a sequence of events. Tree diagrams are particularly useful in probability since they record all possible outcomes in a clear and uncomplicated manner (Taylor 1998). All these factors which are related were analyzed by referring to the MTU's 538 engine manual operation and maintenance book (MTU 2009, 2002, 1985, 2013, 2018, 2015, 2012). This was done to collect all the information needed to determine the root causes of the engine part components failures.

Then in the second step, after the development of the fault tree diagram for the MTU 538 engine, a detailed risk assessment analysis was done using FMEA tables. Failure mode and effect analysis is widely used in engineering to represent the risk value. The main objective of FMEA is to spot potential failure modes, evaluate the causes and effects of various component failure modes, and determine what could eliminate or reduce the chance of failure. The results of the analysis can help analysts to identify and correct the failure modes that have a critical effect on the system and improve its performance. In this research the focus is on the MTU 538 series engines that are currently used in 'Handalan' class ships of RMN. This is an important step to determine the potential causes for the damage and remedy action can be proposed to prevent its reoccurrence.

FMEA is a systematic evaluation process to identify where and how it might fail and to assess the relative impact of different failures, in order to identify the parts of the process that are most in need of change. "Failure modes" means the ways, or modes, in which something might fail. Failures are any errors or defects, especially

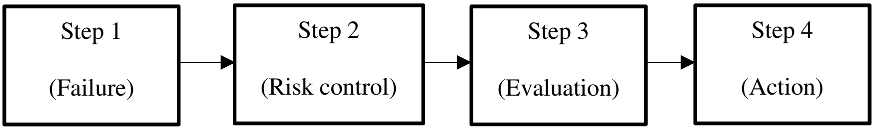

Fig. 11.1 Steps in the risk assessment using FMEA

ones that affect the crew or consumer, and can be potential or actual. "Effects analysis" refers to studying the consequences of those failures. Risk evaluation is important because through evaluation one can know the severity impact of the engine. A FMEA consists of four steps as shown in Fig. 11.1 where:

1. Step 1: Identification of failure (a list of all relevant engine failures with potential causes and risks)
2. Step 2: Risk control options (devising regulatory measures of current risk control)
3. Step 3: How bad and how likely? Assessment of risks (evaluation of risk factors);
4. Step 4: What actions should be taken? Recommendations for decision-making (information about the failure, their associated risks and the cost effectiveness of alternative risk control options is provided).

For example, in the FMEA risk assessments of the turbocharger failure of the MTU 538 engine, the first potential cause of a turbocharger failure is insufficient lubricant to the turbocharger itself. The effect of this insufficient lubricant is that the bearing of the turbocharger will overheat and the consequences of this turbocharger overheating is that the bearing will expand and jammed and finally it will explode. Once the cause, the effect and the consequences were determined, a risk treatment such as how to counter the problem and how to solve that issue is recommended in the FMEA table. In case of the insufficient lubrication to the turbocharger, the risk treatment recommended is that the lubrication oil of the turbocharger must be checked regularly so it will not contribute to the turbocharger failure.

In the third step, after the fault tree diagram and the risk assessment table using the FMEA method were produced, the engine operation checklists were produced based on the information in the FMEA table and the MTU 538 engine's manual. In these checklists, the information on how specifically the engine component part can be inspected and how to examine the early sign of an engine part failure were determined. These engine checklists are the final step in this research with regards to the risk assessment of these MTU 538 high-speed diesel engine failure. These checklists are important because it will provide the ship's crew an enhanced knowledge on how to carry out the daily inspection job before engine start-up, during engine running and engine stopping detailing any potential sign for engine failures.

11.3 Results and Discussion

In the first step as mentioned in the methodology, fault tree diagrams were constructed for the (1) cooling system (2) lubrication oil system (3) fuel system (4) turbocharger and exhaust system (5) air starting system and (6) governor system. Examples of the fault tree diagrams for the systems mentioned above are shown in Figs. 11.2, 11.3, 11.4, 11.5 and 11.6.

Example Tree Diagram of Potential Engine Failure (Turbocharger Failure)

The example of the fault tree diagram for the turbocharger failure is described here. In general, with reference to Fig. 11.4, the turbocharger failure can be caused by five potential causes which are the (1) lubrication related problem (2) inclusion of foreign object (3) extreme exhaust gas temperature (4) material/workmanship related problem (5) fresh water-cooling related problem.

In case no. (1), a lack of proper lubrication in a turbocharger can ruin a turbocharger within seconds of operation. All bearings must receive a supply of oil that can lubricate and cool as the shaft rotation speeds can easily approach very high rpm where typically it rotates from 10,000 to 12,000 rpm (MTU 1985). In this category, foreign material can also contribute to insufficient lubrication. Foreign material in the oil includes various sizes of abrasive particles and dilution by the coolant or fuel. Foreign material in the engine lubrication system will first damage the bearings. Sludge in the lubrication oil can block the tiny oil passage in the engine block, connecting rods and the piston cooling pipes. Therefore, this block oil passage can also contribute to insufficient lubrication. Extreme exhaust gas temperature can cause problems too. Even premium oil will decompose if the temperatures are forced high enough during operation or shutdown. When these extreme temperatures reach the center housing of the turbocharger, the deposits will form throughout its interior. As deposits accumulate, oil passages become restricted which reduces the oil flow through the unit. Lack

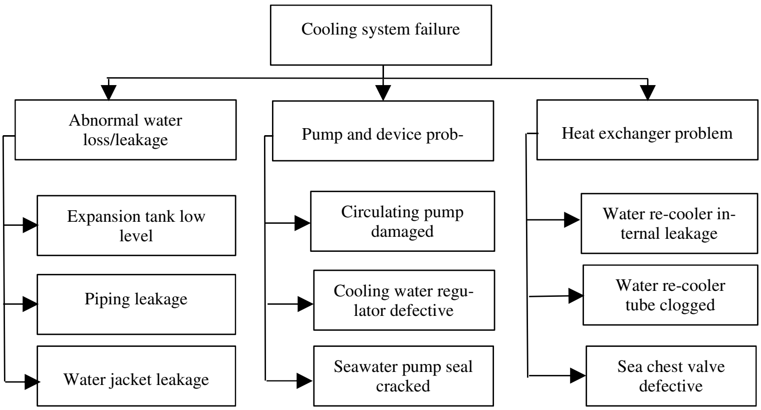

Fig. 11.2 Fault tree diagram for cooling system failure

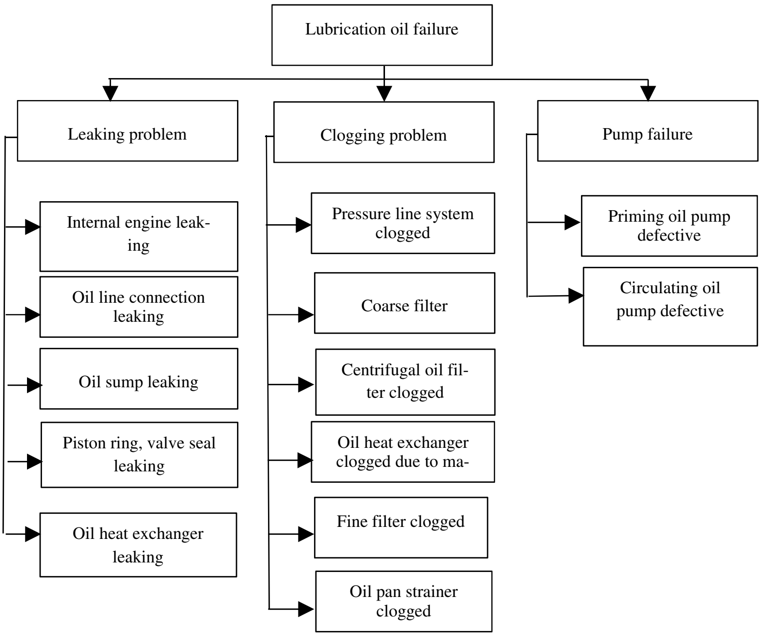

Fig. 11.3 Fault tree diagram for lubrication oil system failure

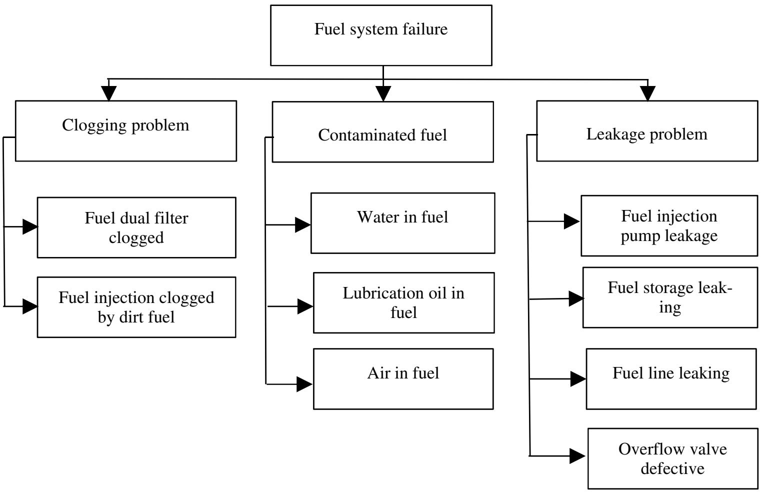

Fig. 11.4 Fault tree diagram for fuel system failure

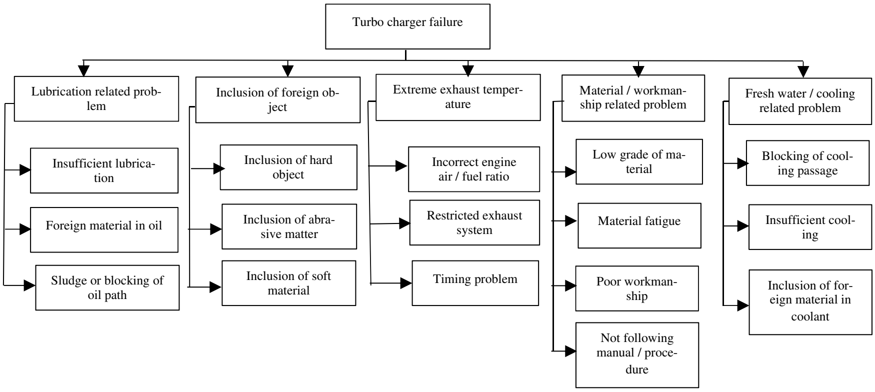

Fig. 11.5 Fault tree diagram for turbocharger system failure

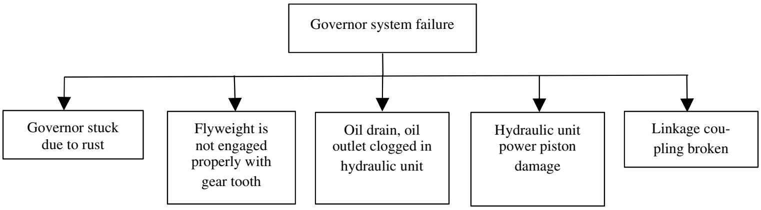

Fig. 11.6 Fault tree diagram for governor system failure

of proper cooling also brings similar symptoms as poor lubrication. These symptoms will cause the casing to discolorate first than the heat will move towards the compressor wheel which than later causes the bearing to seize-up. When a damaged turbo charger is replaced or needs to be dismantled, with a little or no thought given to the cause of the damage, therefore there is a high likelihood of recurrence of the failure resulting in extra downtime and expenses.

Example Risk Assessment Table of FMEA for Turbocharger Failure

In the second step as mentioned in the methodology, FMEA tables were constructed for the (1) cooling system (2) lubrication oil system (3) fuel system (4) turbocharger and exhaust system (5) air starting system and (6) governor system. In the FMEA table, there are three main columns which are the (1) risk identification (2) risk analysis and evaluation and (3) risk treatment. All the information from the fault tree diagrams were transferred to the first column: Risk Identification. In this risk identification, the risks and effects are identified. Then in the second column, i.e., risk analysis and evaluation, scores were given to all issues mentioned in the first column. Scores were given for the severity and the likelihood. The severity number is the impact of the failure which might be low, moderate, high and extreme. The likelihood is the probability number of potential the engine failure might occur. The likelihood scores were also given in either low, moderate, high and extreme. As a guidance in giving scores to each of the issues, a severity index matrix was used as shown in Table 11.1. In the risk analysis and evaluation column, the risk index was calculated by multiplying the severity with the likelihood i.e., Risk Index = Severity × Likelihood. The risk level than can be identified using the severity index matrix as in Table 11.1. Finally, in the third column, i.e., risk treatment, a treatment category and the recommended action/additional control was proposed. A treatment can be proposed in order to reduce the risk level, either by (1) avoiding (2) transfer (3) reduce or (4) accept. As a guidance for the risk treatment, Table 11.2 which was taken from Faturachman et al. (2013) was used to propose the risk treatment in this research.

An example is shown for turbocharger failures in Table 11.3. With reference to the issue no. 1, insufficient lubrication to turbocharger, the risk and the effect were

Table 11.1 Risk severity matrix

Almost certain	5	Moderate	High	Extreme	Extreme	Extreme
Likely	4	Moderate	Moderate	High	Extreme	Extreme
Possible	3	Low	Moderate	Moderate	High	Extreme
Unkikely	2	Low	Low	Moderate	High	High
Rare	1	Low	Low	Low	Moderate	Moderate
		1	2	3	4	5
		Insignificant	Minor	Moderate	Major	Critical

Table 11.2 Risk treatment category and action to be proposed

Risk treatment		
Treatment category	Description	Action
Avoid	1. This can be done by not taking or continuing activities 2. When a risk is both of high likelihood and high consequences, the organization will wish to avoid or eliminate the risk	Eliminate the process flow
Transfer	1. This involves another party to share in whole or in part through contracts, insurance, MoU 2. When the likelihood of a risk is low but the consequences is high, the organization will wish to transfer that risk	Pass over risk to 3rd party
Reduce	1. This can be done with training, testing, control, improve the management system 2. When the level of risk exposure (likelihood) is high but potential loss (impact) associated with it is low, the organization will wish to treat to reduce the risk	Action required
Accept	1. Where identified risks cannot be eliminated or avoided or no treatment process that can be done 2. When the risk considered to be within the risk appetite of the organization, the organization will accept the risk	No need action plan

identified as bearing overheating and bearing jamming respectively. The current risk control was identified as periodically checking of lubrication oil using an oil sump dipstick. The scores for the severity and the like hood were given as 4 and 2, making the risk index to be at 8. With the risk index at 8, the risk level for this issue was identified as high using the severity index matrix. The treatment category was proposed to be ‘reduce’. An additional control was proposed to reduce the risk level by checking the lubrication oil level periodically and give sufficient amount of lubrication oil.

Example Engine Checklist for Turbocharger

In the final step, the engine operation checklists were produced based on the information in the FMEA table. In these checklists, the information on how specifically the engine component part can be inspected and how to examine the early sign of an engine part failure were determined. An example for the checklist for the turbocharger is described here. In the turbocharger checklist as shown in Table 11.4, there are three main rows which are the (1) item to be check (2) remedy and (3) check box. In the first row, all the issues as in the fault tree diagram and the FMEA table were transferred here in the first row. For example, in the first row for ‘Insufficient Lubrication’, the remedy was transferred or taken from the proposed additional control in the FMEA table, where the remedy is ‘Check lubrication oil level periodically and give sufficient amount of lube oil’. In the third row, a check box is provided for the ship’s crew or the engine watch keeper to tick either ‘pass’ or ‘fail’. Symptoms for insufficient lubrication were also provided in the checklist for the crew or watch keeper to look for during the engine operation. Here in this example symptoms for insufficient lubrication are mentioned such as (1) engine lacks power (2) black exhaust smoke (3) blue exhaust smoke and (4) turbocharger noisy.

11.4 Conclusion

A risk assessment using the FMEA method for MTU 538 engines used by the Malaysian Marine Enforcement Agencies such as the RMN and MMEA was proposed. This risk assessment was associated with an enhanced engine operation checklist for the usage of the ship’s crew or the engine watch keeper. These operation checklists were generated so that it could be used for the engine crews for daily routine inspections. These enhanced daily routine inspections could prevent unexpected breakdown of these high-speed diesel engines. In this research, all engine system such as the fuel system, lubrication oil system, cooling system, air starting system and governor system have a separate risk assessment FMEA tables. From the FMEA tables, all the risks, effects, and the additional controls were transferred into the engine operation checklists. In addition, it is hoped that this operation checklist for every system could play a vital role in a better and a safer ship operation.

Table 11.3 Example FMEA risk assessment table of turbocharger

No	Risk identification			Risk analysis and evaluation					Risk treatment	
	Issue	Risk	Effect	Current risk control	Severity (impact)	Occ. (likelihood)	Risk index	Risk level	Treatment category	Recommended action/ additional control
1	Insufficient lubrication to turbocharger	Bearing overheated	Bearing jammed and failure	Periodically checking of lubrication oil using oil sump dipstick	4	2	8	High	Reduce	Check lubrication oil level periodically and give sufficient amount of lube oil
2	Clogged air filter	Filter body damaged and compressor wheel fractured	Engine lacks power, black exhaust smoke, excessive engine oil consumption, blue exhaust smoke and oil leak from compressor seal	Replace air filter periodically	4	2	8	High	Reduce	Replace air filter periodically
3	Obstructed air intake to turbocharger	Compressor wheel damaged	Turbocharger failed to run	Check air intake before engine start and remove any obstruction	4	1	4	Moderate	Reduce	Check air intake before engine start and remove any obstruction

(continued)

Table 11.3 (continued)

No	Risk identification			Risk analysis and evaluation					Risk treatment	
	Issue	Risk	Effect	Current risk control	Severity (impact)	Occ. (likelihood)	Risk index	Risk level	Treatment category	Recommended action/ additional control
4	Obstructed air outlet duct from compressor to intake manifold	Intake hood overheated	Engine lacks power, black exhaust smoke, turbo noisy	Engine lacks power, black exhaust smoke, turbo noisy	4	2	8	High	Reduce	Remove any obstruction and check regularly before running turbocharger
5	Air leak in duct from air cleaner to compressor	Compressor wheel cracked	Turbo noisy	Replace seals periodically as needed	3	1	3	Low	Reduce	Replace seals or tightened fasteners

Table 11.4 Example of turbocharger checklist

Turbocharger checklist										
DATE :										
Item to be check		Insufficient lubrication to turbocharger	Clogged air filter	Obstructed air intake to turbo	Obstructed air outlet duct from compressor to intake manifold	Obstructed intake	Air leak in duct from air cleaner to compressor	Air leak in duct from compressor to intake manifold	Air leak at intake manifold to engine joint	Obstruction in exhaust manifold
Remedy		Check lubrication oil level periodically and give sufficient amount of lube oil	Replace air filter	Remove obstruction	Remove obstruction	Remove obstruction	Replace seals or tightened fasteners	Replace seals or tightened fasteners	Replace seals or tightened fasteners	Remove obstruction
Check box		Pass ☐ Fail ☐	Pass ☐ Fail ☐	Pass ☐ Fail ☐	Pass ☐ Fail ☐	Pass ☐ Fail ☐	Pass ☐ Fail ☐	Pass ☐ Fail ☐	Pass ☐ Fail ☐	Pass ☐ Fail ☐
SYMPTOMS	Engine lacks power	■	■		■	■		■	■	■
	Black exhaust smoke	■	■	■	■	■		■	■	■
	Excessive engine oil consumption			■				■	■	■
	Blue exhaust smoke	■	■	■				■	■	■
	Turbo noisy	■	■	■	■	■	■	■	■	■
	Cylic sound from turbo			■						
	Oil leak from compressor seal		■	■						■

References

Cicek K, Turan HH, Topcu YI, Searslan MN (2011) Risk-based preventive maintenance planning using failure mode and effect analysis (FMEA) for marine engine systems. In: Second international conference on engineering system management and applications, pp 1–6

Faturachman D, Mustafa S, Octaviany F, Theresia DN (2013) Failure mode and effects analysis (FMEA) of diesel engine maritime transportation for ship navigation system improvement. In: International conference on business innovation, entrepreneurship and engineering

Hu-Chen L, Long L, Nan L (2013) Risk evaluation approaches in failure mode and effects analysis: a literature review. Expert Syst Appl 40(2):828–838

Kabir S (2017) An overview of fault tree analysis and its application in model based dependability analysis. Expert Sys. Appl. 77:114–135

McGeorge HD (1995) Marine auxiliary machinery, 7th edn. Butterworth-Heinemann, Oxford

MTU (1985) MTU 12V 538 TB81 manual maintenance plan book, description and services instruction. MTU, Friedrichshafen

MTU (2002) Technical publication diesel engine 8V 4000 G 12V 4000 G 16V 4000 G tolerances and wear limits list. MTU, Friedrichshafen

MTU (2009) MTU value service technical documentation. MTU, Friedrichshafen
MTU (2012) Maintenance schedule of 4000 series engine. MTU, Friedrichshafen
MTU (2013) Operating instruction of 4000 series engine. MTU, Friedrichshafen
MTU (2015) MTU-12V4000M53 spare parts catalog. MTU, Friedrichshafen
MTU (2018) MTU diesel engine 12V 4000 Gx0/Gx1 16V 4000 Gx0/Gx1 maintenance manual. MTU, Friedrichshafen
Patil R, Waghmode LY, Chikali PB, Mulla TS (2003) An overview of fault tree analysis (FTA) method for reliability analysis and life cycle cost management. IOSR J Mech Civ Eng 4–18
Saputra RSH, Priharanto YE, Abrori MZL (2019) Failure mode and effect analysis (FMEA) applied for risk assessment of fuel oil system on diesel engine of fishing vessel. J Eng Appl Sci 13(20):14–20
Taylor DA (1998) Introduction to marine engineering, 2nd edn. Elsevier Butterworth-Heinemann, Oxford
Woodyard D (2004) Pounder's marine diesel engines and gas turbines, 8th edn. Elsevier Butterworth-Heinemann, Oxford