

## Using Reliability Block Diagrams and Fault Tree circuits, to develop a Condition Based Maintenance Model for a Vessel's Main Propulsion System and Related Subsystems

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**ABSTRACT:** Merchant shipping has undergone a great transformation over the past three decades. The shipping market is highly competitive, which coupled with high crewing and fuel costs, leads to high operational costs. One of the paramount factor involved in vessel operation is the Maintenance cost and there is a dire need to keep this cost to a minimum. Fortunately the earlier policy of repair only maintenance in commercial shipping has been done away with, and was replaced by the policy of preventive maintenance. Planned Maintenance System was introduced by ship management companies in the early 90's. Planned Maintenance offered benefits over the repair only policy, but has its own demerits. Many a time machinery equipment is opened up for routine maintenance after a specified time interval, irrespective of the need. This could lead to potential failures, which is explained by the fact that preventive maintenance resulted in meddling of a well set piece of machinery equipment, leading to its subsequent failure. This is where Condition based maintenance or CBM steps into prominence. CBM monitors the health of the machinery equipment, analyses the condition and helps you in decision making. The Main Propulsion system forms the heart of a vessel and we need to ensure its reliability, together with the reliability of its associated sub-systems. The entire system can be represented by reliability block diagrams, to show the interdependence of various components comprising the system. This helps in the decision making process of CBM whereby ship's engineer may decide to stop the running machinery equipment, open and overhaul the same, else postpone the overhaul for a later safe date.

### 1 INTRODUCTION TO PLANNED MAINTENANCE

Commercial shipping in the modern world is highly competitive, which coupled with high crewing and fuel costs, leads to high operational costs. One of the paramount factor involved in vessel operation is the Maintenance cost and there is a dire need to keep this cost to a minimum. Fortunately the earlier policy of repair only maintenance in commercial shipping has been done away with, and was replaced by the policy of preventive maintenance. Planned Maintenance

System was introduced by ship management companies in the early 90's.

### 2 WHY CONDITION BASED MAINTENANCE

Planned Maintenance offered benefits over the repair only policy, but has its own demerits. Many a time machinery equipment is opened up for routine maintenance after a specified time interval, irrespective of the need. This could lead to potential failures, which is explained by the fact that preventive

maintenance resulted in meddling of a well set piece of machinery equipment, leading to its (Bhattacharjya and Deleris, 2012) subsequent failure. The author would like to cite an incident experienced during his vast sailing career. A general cargo vessel was on her way from India to Europe. This passage involves the Suez Canal transit where large numbers of vessels go on a convoy. A few days before transiting the Suez canal the No.1 Steering gear motor was opened up for routine overhaul, as specified in the Planned Maintenance Schedule for the vessel. The motor was overhauled and reassembled. The vessel then entered the convoy and all went off well for an hour, under the guidance of the Suez Canal pilot who travels on board the ship during the transit. The pilot then ordered a helm movement and the vessel failed to steer as required. The reason was overload tripping of the overhauled motor, and investigations revealed errors during the reassembly of the motor. The vessel was then tied alongside the canal with the help of tugs, the motor had to be reopened again, and new bearings were fitted. Motor tried out and finally the vessel managed to transit the Suez Canal, though she had to be last on the convoy. resulting in considerable losses in terms of thousands of dollars to the company. This is where Condition Based Maintenance or CBM steps into prominence. CBM monitors the health of the machinery equipment, analyses the condition and helps you in decision making. Accordingly a ship's engineer may decide to stop the running machinery equipment, open and overhaul the same, else postpone the overhaul for a later safe date.

### 3 ISM CODE AND MAINTENANCE

When it comes to operation of ships, all shipping companies need to abide by the ISM Code which is the International Safety Management Code, the purpose of this Code is to provide an international standard for the safe management and operation of ships and for pollution prevention. The above research will also address section 10.3 of the code which states that, 'The Company should identify equipment and technical systems the sudden operational failure of which may result in hazardous situations. The safety management system should provide for specific measures aimed at promoting the reliability of such equipment or systems. These measures should include the regular testing of stand-by arrangements and equipment or technical systems that are not in continuous use.' (ISM, 2002)

### 4 DIAGNOSIS AND PROGNOSIS

The concept of CBM for ship's machinery is still in its infancy. Reproducing a recent finding which says 'However, according to class records, only about 2% of thw world fleet is operating using CBM'. (MER, 2012). Effective application of CBM techniques will result in large savings to the vessel owner / operator. A ship's machinery space is a large main propulsion system with several subsystems. All these systems have a fairly high degree of correlation;

failure of any one subsystem could result in stoppage of the vessel, which is a highly undesirable event. CBM is a two sided coin with diagnosis on one side and prognosis being the other side. For an efficient vessel operation both the sides of the coin are vital.

Prognosis is an important element of the CBM program as it deals with the predication of failure faults. The above research should be useful to predict the occurrence and timing of a failure in a single subsystem (example ship's main propulsion and power generation system) or in several different subsystems (example ship's main propulsion and power generation system and control air system)

### 5 GROSS MAINTENANCE DEFECIENCIES

A few instances of major shipping disasters on account of gross maintenance deficiencies have been highlighted below. This information was gathered from leading reputable Marine Accident Investigation bodies in the commercial shipping world.

'The scavenge space inspection after the fire in number three unit, shortly after the first turbocharger failure, apparently revealed a high level of scavenge fouling. Similarly the condition of the scavenge spaces after the second turbocharger failure was poor around number two cylinder, albeit as a result of piston cooling oil leaking from the defective O-ring. Whether or not the condition of the scavenges led to a fire, which in turn caused the turbocharger failures, cannot be concluded with any certainty however their condition does indicate that the vessel's main engine maintenance regime in this respect may have been deficient.' (ATSB, 2006).



Figure 1. Condition of scavenge ports on Cylinder no. 1 of Main propulsion Engine Source based on ATSB (2006)



Figure 2. Condition of scavenge ports on Cylinder no. 2 of Main propulsion Engine Source based on ATSB (2006)



Figure 3. Condition of damaged main propulsion turbocharger rotor. Source based on ATSB (2006)

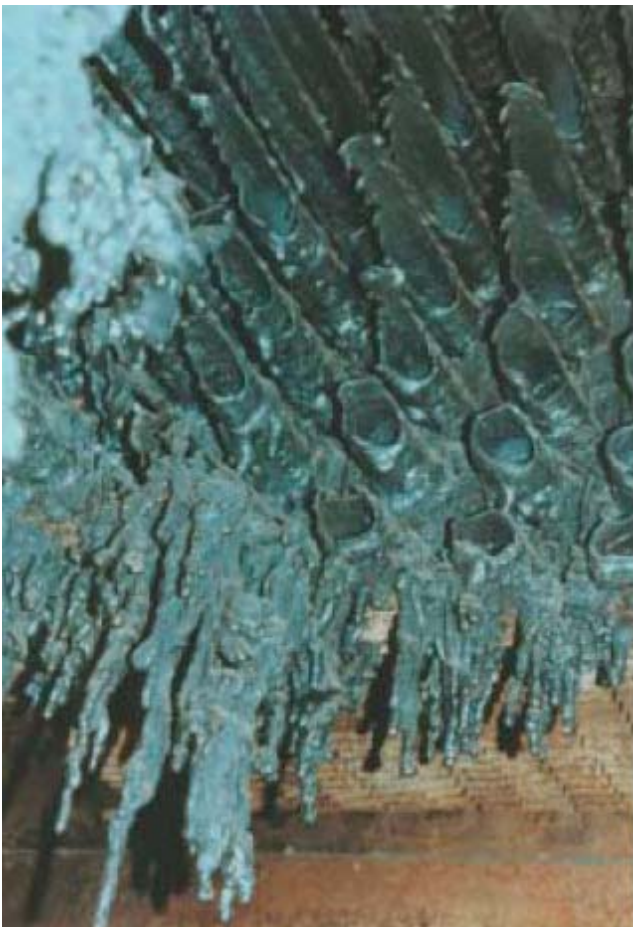


Figure 4. Condition of damaged exhaust gas boiler tubes. Source based on MAIB (2007)

Apart from the failure of the auxiliary boiler, there were other examples where equipment did not work properly that were attributable to ineffective maintenance or equipment checks:

- Standby EGE circulation pump mechanical seal
- Automatic operation of soot blowers
- Fuel tank Quick Closure Valves
- CO<sub>2</sub> drench pilot operating system
- Emergency diesel generator overheating
- Emergency fire pump suction

The maintenance system recorded that checks and planned maintenance were complete on all these items, and that there were no defects. While it is always possible for equipment not to work in an emergency, so many serious defects should not occur

during the same incident. Neither the maintenance system nor any of the technical audits detected these latent defects, so the effectiveness of these systems must be questioned.’(MAIB, 2007)

## 6 RELIABILITY CENTERED MAINTENANCE

CBM leads to improved reliability of the machinery equipment and better inventory control of spares on board the vessel. This approach to maintenance has been advised to ship owners by leading classification societies.’ By applying Reliability-centered maintenance (RCM) principles, maintenance is evaluated and applied in a rational manner that provides the most value to a vessel’s owner/operator. Accordingly improved equipment and system reliability on board ships and other marine structures can be expected by applying this philosophy’. (Robert, 2004)

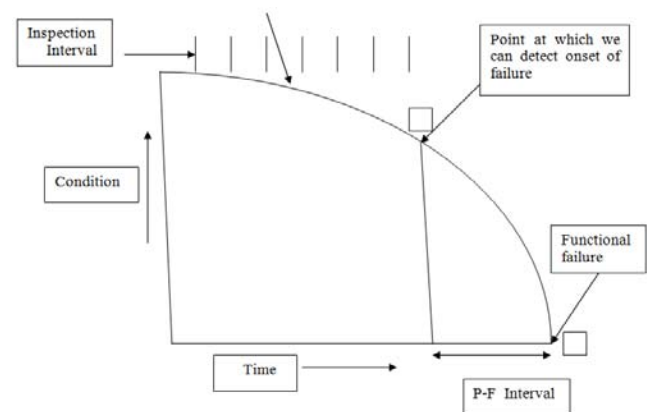


Figure 5. P- F Diagram Source ABS guidance notes 2004

ABS guidance notes on Reliability Centered Maintenance- 2004 highlights the P-F interval. ‘If a potential failure is detected between Point P and Point F, it may be possible to take action to prevent the functional failure (or at least to minimise its effects). Tasks designed to detect potential failure are known as condition-monitoring tasks. See Figure 5 above.

## 7 RESEARCH PROPOSAL

My research proposal is to focus on main propulsion system and related subsystems (Figure 6) on commercial bulk carriers and naval vessels, collect data for these main and subsystems which will then be processed for statistical analysis and produce a reliable maintenance model for the vessel. To begin with, the research will be exploratory in nature, collecting data pertaining to real life examples and case studies published by reputed marine accident investigation bodies in world shipping mentioned above. I shall then start building up my theory developing from the knowledge gained in the exploratory process stage. This should eventually lead to development of a hypothesis which will be tested statically for a large sample size.

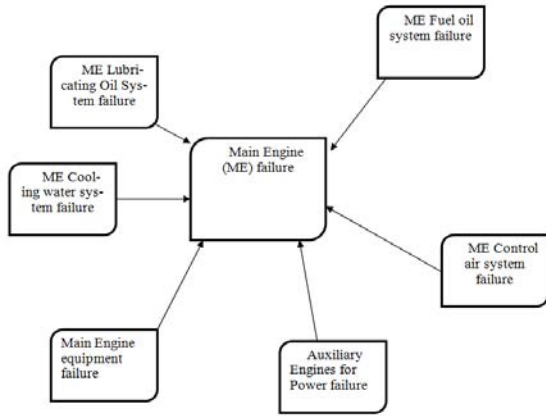


Figure 6. Main propulsion system and related subsystems for large vessels.

## 8 FAULT TREE ANALYSIS

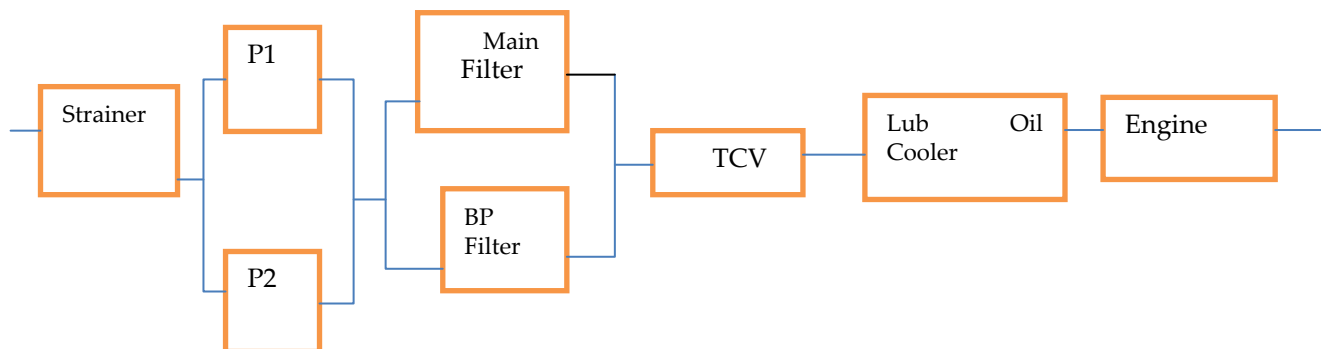
I intend using FTA (Fault Tree Analysis) during development of the CBM (Condition based maintenance) model. FTA is a top down approach, which helps to identify basic event which can lead to the top undesirable event. I have included a few quotes from my earlier research work below: Looking at the fault tree one can easily recognise that a basic event of a distillate pump failure by itself can cause the top undesirable event to happen. Also past sailing experience of the author provides ample cases of Fresh water Generator failure on account of failure of the distillate pump. Hence the emphasis should be to avoid this basic event.’(Anantharamman, 2002)

‘In conclusion the author would like to emphasise that recognising a Fault Tree proves to be a very reliable tool and healthy exercise for a Shipboard Engineer responsible for Operation, Running & Maintenance of ships. The benefits to cost ratio could be tremendous. Hence let us start planting this Tree for all shipboard activities and reap the benefits.’(Anantharaman, 2003).

## 9 RELIABILITY BLOCK DIAGRAM

Another methodology which I find useful is developing Reliability block diagrams (RBD), which

RBD Representation of Series and Redundant Functions for Main Engine Lubricating Oil system



P1:Main Lub Oil Pump , P2 :Standby Lub Oil Pump  
BP; Bypass filter and TCV : Temperature Control Valve

Figure 7. RBD for Main Engine Lubricating Oil System

depict the functional relationships between components comprising a system. Previous researches have shown that RBD’s can be transformed to Bayesian networks (BNs) to represent probabilistic relationships between uncertain variables. Previous research has described how one can transform an RBD into a BN. A fault tree circuit can be constructed directly from an RBD and is more efficient than an arithmetic circuit that is compiled from the BN corresponding to that RBD. We develop several methods for fault tree circuits, highlighting how they can aid the analyst in efficient diagnosis, sensitivity analysis, and decision support for many typical reliability problems. The circuit framework can complement tools that are popular in the reliability analysis community.(Bhattacharjya and Deleris, 2012).

Figure 7 below shows a RBD for a Lubricating oil system for a large Marine Diesel Engine.

## 10 SUMMARY AND CONCLUSION

We have seen in this paper that at times, just following a PMS regime on board vessels could lead to machinery failure, resulting in stoppage of a vessel at a critical juncture. (Anantharaman and Lawrence, 2013)In merchant shipping it is very important that we make a shift from PMS (Planned Maintenance System) to CBM (Condition based maintenance). The main propulsion plant of a vessel should be the focal point of CBM and we can work around the related subsystems. Fault Tree Analysis is one such approach wherein we can identify the basic event, failure of which could lead to a possible catastrophic failure of the plant. We need to look into the probability of failure of the system component using statistical tools for analysis.

A neuro-fuzzy modeling approach for CBM has been effectively utilised by researchers in merchant shipping and other shore based industries.(Kothamasu & Huang, 2007), ( Xu et al, 2010).

This transformation could lead to a huge benefits to cost ratio at the same time ensuring safety and reliability.

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