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Modelling Maintenance System of a Fishing Vessel Using Markov Process Method

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ABSTRACT

Reliability analysis on a ship system have developed as the increasing demand on the level of safety and reliability of the ship design. There are some significantly important of ship systems which support the ship operationalization. Failure on one system component can influence the functionality of the respective system and even can damage the whole ship function. If this is happen, the safety of the passengers and cargoes on the ship will be threatened. A comprehensive evaluation on the ship systems must be conducted so that the failure level of the system can be predicted. For the safety of the maintenance action on a system, model of the ship system maintenance must be designed. One common approach to be used on a maintenance modelling of a system is markov approach or markov modelling. The final result of the appoach is an availability index of a system as a consequences of the ship system maintenance. Output from this approach will become input for designing ship system maintenance strategy. This paper discusses the use of markov process approach in modelling maintenance of a ship system. In the final part of the paper, a maintenance modelling case for a ship fresh water cooling system is presented.

Keywords: *Sistem failure; markov process; modelling; maintenance system*

1. INTRODUCTION

In a shipbuilding world, the application of reliability analysis have been progressively developed as the consequences of the increasing demand for safety and reliability of the ship design. In shipbuilding, there are some components in the ship design which requires reliability analysis such as ship structure, machinery and equipments. Those components are play significant roles in terms of safety and reliability of the ship system which support the ship operationalization. Reliable system components or equipments are the ones which fulfill design specification and the performance has no interference in the required environment within a specified time [1].

Failure on one component can affect other failure on different component which can damage the whole ship function. This is in turn will reduce the level of safety, endanger the passengers and cargoes on board and will cost a sum of money.

Most of the systems on a ship are working continuously. This condition will undergo gradual defect on the system components. As a consequence, it will reduce the performance of the system or even the system function will fail.

Event of failure and repair action on a system must be documented. The documents can be used to predict the behaviour of the system in the future including the level of failure or the successful action of the maintenance action. For the successful maintenance action on a system, a maintenance model must be designed to keep the system work as its function [2]. Markov approach or markov modelling can be used for that purpose. Markov approach can be applied on a system in order to identify the system behaviour [3]. The system behaviour can be described as the probability distribution with failure rate or constant repair during certain interval time where both are characterized with exponential distribution. The final result of the approach is an index availability of the respective system as a consequence of the applied maintenance action on the system. Output from this approach will become an input for the system maintenance strategy design.

In order to comprehensively understand the cause of the ship system failure, failure tracking must be conducted according to the level of the system. In specific, the system can be assessed and evaluated to whether a maintenance action is needed to fix system design. Evaluation will be conducted by considering various failure modes on the system components and effect of the failure to the system reliability using failure modes and effect analysis (FMEA) [4]. Then tracing on the failure cause is conducted using fault tree analysis (FTA) tool [4]. Such evaluation must be conducted as the Indonesian classification bureau (BKI) only provide guidance on minimum requirement to a system for enabling the respective system to be normal and safely working instead of stressing on the reliability evaluation. The modelling system maintenance to determine the system availability index on the reviewed system components.

The aim of this paper is to model the ship system maintenance using markov process. In this process, the physical system conditons are being presented in a state space diagram before being put into matemathical model. The level of complexity and the mathematical model solution of the system is relying on the how complex the state space diagram is being represented which being depending on the condition and the number of components in the system.

In this paper, the ship system to be discussed is the fresh water cooling system of a fishing vessel 300 GRT. Exponentional probability distribution is being used for modelling system components failure and system maintenance.

2. METHODOLOGY

A. FMEA and FTA

Failure modes and effect analysis (FMEA) and fault tree analysisi (FTA) are both qualitative methods which commonly used for system reliability evaluation. FMEA is a method for system evaluation by considering various mode of failure of system components as well as analysing the effect of failure on the system reliability [4]. Based on the analysis, repair action can be conducted for fixing the system design and eliminate or reduce the probability of critical failure modes [5]. The severity of component on a system can be categorized [6] into four which are catastrophic which represent component failure that can cause death or system loss, critical which can cause failure or damage to the system, major which can postpone the system mission and minor which reduce the system performance but still under system tolerance. Beside, Ebeling [6] suggested as well the use of the following frases to represent the frequency of the failure mode of the system component which being analysed. They are consist of level A (frequent) for high failure probability, level B (reasonably possible) for moderate level of failure probability, level C (occasional) for small level of failure probability, level D (remote) for rarely level of failure probability and level E (extremely unlikely) for failure which are unlikely to happen. Combination of severity and failure mode frequency for each components in the system can be presented in a failure mode classification matrix.

FTA is a method to identify system failure in terms of the cause of component failure whether is caused by single component failure or some components failure at the same time [4]. In this method, the top failure condition of a system is defined first. Then fault tree of the system can be constructed using top down approach. Based on the definition, cut set then determined using method to obtain cut set (Mocus). The mocus aim is to get cut set and minimum cut set from the constructed fault tree. The cut set can be used to identify the possibility of failure combination on the fault tree which can cause top event failure.

B. Markov Modelling

The result of the analysis using FMEA and FTA is a list of components in the system with the biggest probability severity and mode frequency. Based on the list, the level of failure and successful function of the respective components must be determined using markov modelling method. The purpose of the Markov process is to obtain the index availability of the system. Output from this process is maintenance modelling. This method using stochastic approach [3]. Stochastic process in practice is coming from some random measurements dan events in physical terms.

There are two types of stochastic process. If the state space and time space of the markov process is discrete, it is called Markov Chain [3], while if the time space is continues, it is called continuous markov process [3]. Continues markov processes play significant roles for evaluating engineering systems. Hence, in this paper, this types of maintenance modelling to be discussed.

B.1. Continues Markov Processes

Continuous markov process is a method which discusses the system with discrete characteristic but in continuous time [7].

In this technique, the reviewed system can be expressed as stationary markov process where its conditional failure probability or repair during certain interval time is constant. This is mean that the failure characteristic and repair of the respective components is in exponential distribution.

B.2. General concept of markov modelling

B.2.1. Transition rate concepts

Transition rate can be described as the rate of probability mass from one state to another state. The transition rate concept consider system repairable where its failure rate and repair rate are both constant and characterized with exponential distribution [8].

State space diagram for single component can be shown in Fig.1. below.

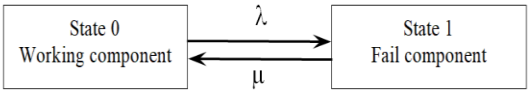

Fig. 1. State-space diagram for single component tunggal

Failure density function for a single component with constant failure rate (λ), can be expressed in equation 1 below [8]:

$$f(t) = \lambda e^{-\lambda t} \quad (1)$$

where:

f(t) = probability failure density function of a component or system.

λ = Failure rate of the component where the number of failures are in hour

By using equation 1, the equation for each state can be expressed in the following equations.

$$f0(t) = \lambda e\text{-}\lambda t \quad (2)$$

$$f1(t) = \mu e\text{-}\mu t \quad (3)$$

where:

μ = Repair rate

B.2.2. Probability equation which time dependent

In a discrete markov chain, transitional from one state to another state is shown by transitional probability. Contrastly, for continuous markov process, the transitional between states can be expressed by transitional rate with parameter λ and μ where each paramater represent transitional rate from working component and transitional rate from failure (Fig. 1.).

Probability that certain component is in a working condition (state 0) at the time (t + dt) can be expressed as [Probability of the component to keep working at time t and not fail at time dt] + [Probability of the component to be fail at time t and can be repaired at time t] [8].

The description can be expressed mathematically as follows:

$$P_0(t) = \frac{\mu}{\lambda+\mu} + \frac{\lambda e e^{-(\lambda+\mu)t}}{\lambda+\mu} \quad (4)$$

$$P_1(t) = \frac{\mu}{\lambda+\mu} - \frac{\lambda e e^{-(\lambda+\mu)t}}{\lambda+\mu} \quad (5)$$

where:

P0(t) = Probability of the component is working at time t

P1(t) = Probability of the component is fail at time t

Equations (4) and (5) each represent the probability of the system to be in a working and fail condition as a function of time where the system start to work at time t = 0.

B.2.3. Probability evaluation for limiting condition

For a single repairable component in Fig. 1. the limiting state probabilities can be evaluated using equations (4) and (5) by taking value t as infinite (∞**).** If the values of limiting state probability can be defined as P_0 and P_1 for working and fail state, then from equations (4) and (5) for infinite value of t, the equations can become:

$$P_0 = P_0(\infty) = \frac{\mu}{\lambda+\mu} \quad (6)$$

$$P_1 = P_1(\infty) = \frac{\mu}{\lambda+\mu} \quad (7)$$

B.2.4. State space diagram for more complex system

Conditioning state space diagram is an important step in solving the problem using markov method. For one single component (Fig. 1.), the evaluation step is as described earlier but for a more complex system, the solution will be more complicated as well in terms of modelling state space diagram and its mathematical model. Hence, the computational process must be helped with computer.

In general, steps in the continuous markov process modelling can be described as follows: the first step is constructing state space diagram of the system. Then writing the mathematical equations which is based on the system state space diagram. Based on the mathematical equations, the probability of each state can be calculated. After that, the up and down condition of the system is defined and in the final step, index availability and unavailability of the system is determined.

3. RESULTS AND DISCUSSION

Fresh water cooling system is one system in a ship which support the main prime mover system of the ship. The system function is to cooling off the ship main engine in order to help engine to work normally. In this paper, the fresh water cooling system using close loop system. The fresh water colling system in a ship is working in this way. First, the fresh water cooling is supplied from heater tank to the main engine through main pump which is powered by the main engine itself. The water from the main engine before reaching certain temperature will flow back to the main engine through thermostat for temperature controller. When the cooling water have reach certain temperature, the water will flow into the fresh water cooler or heat exhanger to be cooled off. In the mean time, sea water pump is supplying sea water as well in helping to reduce the temperature of the fresh water.

The process will keep going in cycle continuously. When something happen to the main pump or transmission gear, stand by pump which powered by motor electrical will work automatically for the purpose. The diagram of fresh water cooling system of a fishing vessel 300 GRT can be seen in Fig. 2.

List of components which support the fresh water cooling system in Fig. 2. consist of thermostat, sea water cooling system, heat exchanger, centrifugal pump, gear transmission, centrifugal stand by pump, electrical motor, valve, expansion tank/header tank dan pipe.

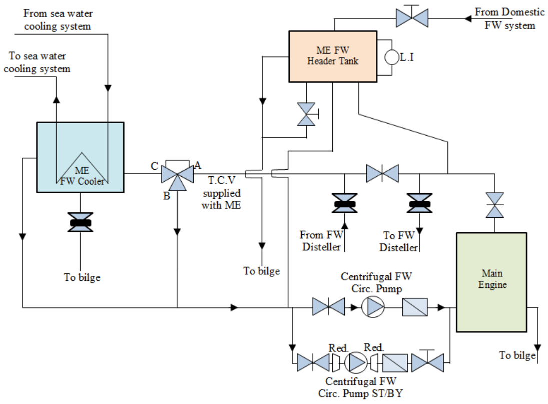

Fig. 2. Fresh water cooling system

A. FMEA analysis

FMEA method can be used to analysed system or component failure. It uses bottom-up approach where analysis is started from the bottom part of the system to the highest level of the system. In this method, review is being conducted to the fresh water cooling system components and the system besides identifying the system failure modes, the cause of the failure and the effect of the failure. Then the qualitative measure to determine criticality of the failure mode of the components can be done by combining severity ranking with probability/ frequency of failure mode [9]. The result then to be put into a failure mode classification matrix as can be seen in Table 1 below.

Table 1. Failure mode classification matrix

Failure rate				
Frequent				
Reasonably Possible	Pipe			
Occasional			Sea Water CoolingPump, Main Centrifugal Pump, Centrifugal Pump	Heat Exhanger
Remote	Valve			Electrical Motor
Extremely unlikely	Expansion Tank	Gear Transmittal	Thermostat	
Severity	Minor	Major	Critical	Catastrophic

From Table 1, komponen in critical and catastrophic column and in remote and occasionally row will be paid into full attention which consist of 5 system components. They are Sea Water CoolingPump, Main Centrifugal Pump, Centrifugal Pump, Heat Exhanger and Electrical Motor.

B. FTA analysis

FTA analysis is being used to identify all the cause of failure in the fresh water cooling system. The top event is failure or not working fresh water cooling system (mechanical failure) if one of the three sub systems under gate G_0 which are heat exchanger system, pumping system or fresh water supply system fail. Failure on heat exchanger sub system is caused by failure on sub sub system thermostat and heat exchanger. The same thing happen on other sub system. (See Fig. 3.).

C. Continous markov process

Construction of the state space diagram is an important step in markov method. Parameter λ and μ represent transitional rate from working component and transitional rate from failure component while probability state can be calculated using expression 2^n where n is the number of the system components. In this paper, there are 5 critical components which can cause failure on the system, hence the number of probability state is 32 states. Based on that result, the state space diagram for all components can be arranged as in Fig. 4. below.

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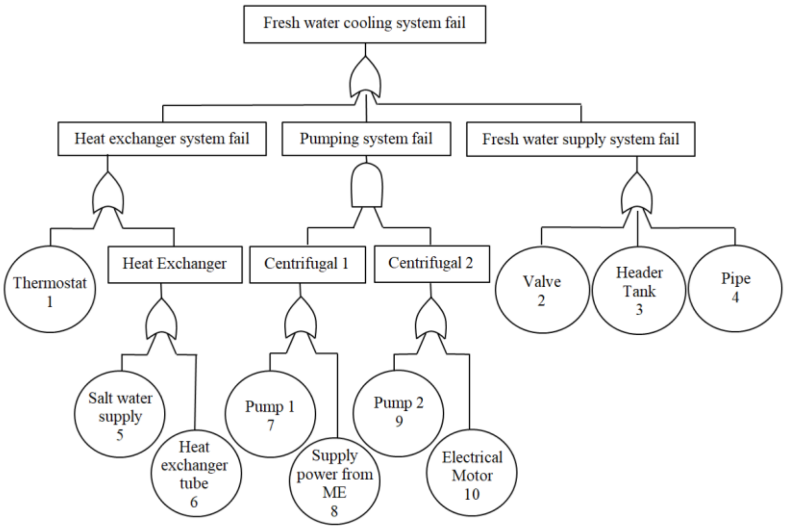

Fig. 3. Fault Tree Diagram

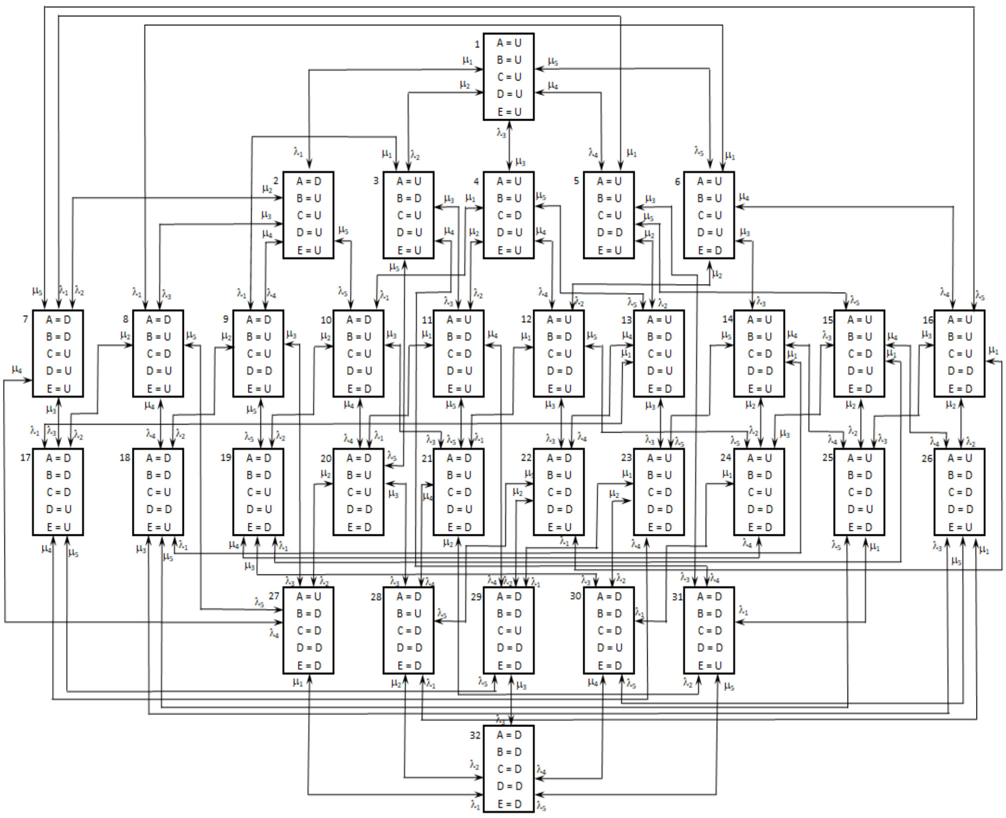

Fig. 4. State space diagram

The next steps in this method is to compose stochastic transitional probability matrix (STP) which is based on the state space diagram in Fig. 4. A STP for continous markov process can be obtained using discrete terminology because probability of a transition at the time interval equal to the transitional rate times interval of time. If the failure rate of a component is λ then the probability of failure at the time Δt is $\lambda\Delta t$ and the probability for working component at this interval is $1 - \lambda\Delta t$. For a single state as shown in Fig. 1, the STP for the respective system is:

$$P = \begin{bmatrix} 1-\lambda\Delta t & \mu\Delta t \\ \mu\Delta t & 1-\lambda\Delta t \end{bmatrix} \quad (8)$$

For evaluating limiting state probability, the approach to be applied is by defining matrix α as a free condition vector which stay constant if multiply by STP or $\alpha.P = \alpha$. If α is $[P_0\ P_1]$ for single repairable component, the equation will become:

$$[P_0 - P_1] \begin{bmatrix} 1-\lambda\Delta t & \lambda\Delta t \\ \mu\Delta t & 1-\mu\Delta t \end{bmatrix} = [P_0 - P_1] \quad (9)$$

The equation can be expressed in an explicit form as the following equations.

$$(1 - \lambda\Delta t)\, P_0 + \mu\Delta t\, P_1 = P_0 \quad (10)$$

$$\lambda\Delta t P_0 + (1 - \mu\Delta t)\, P_1 = P_1 \quad (11)$$

These equations can be simplified to become:

$$-(\lambda\Delta t\, P_0 + \mu\Delta t\, P_1) = 0 \quad (12)$$

$$\lambda\Delta t\, P_0 - \mu\Delta t\, P_1 = 0 \quad (13)$$

Hence, the solution of the equations is by solving the equations at the same time to find one variable. The other variable then can be figured out using the equation $P_1 + P_2 = 1$. For the case of fresh water cooling system, matrix with the probability state 2^n can described as follow:

$$\begin{bmatrix} 0.998784 & 0.000298121 & 0.000298121 & . & . & . & 0 \\ 0.008219 & 0.990863275 & 0 & . & . & . & 0 \\ 0.008219 & 0 & 0.990863276 & . & . & . & 0 \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ 0 & 0 & 0 & . & . & . & 0.96644 \end{bmatrix}$$

$$\begin{bmatrix} 1-5\lambda_1 & \lambda_1 & \lambda_2 & \dots & - \\ \mu_1 & 1-(\mu_1+4\lambda_1) & - & \dots & - \\ \mu_2 & - & 1-(\mu_2+4\lambda_1) & \dots & - \\ . & . & . & \dots & - \\ . & . & . & \dots & - \\ . & . & . & \dots & - \\ - & - & - & \dots & 1-(\mu_1+\mu_2+\mu_3+\mu_4+\lambda_1) \end{bmatrix}$$

Data needed for analysis can be seen in Table 2.

Tabel 2. Value of λ and μ for each components

Code	Komponen	λ	μ
A	Pompa utama	$298.1209 \cdot 10^{-6}$	0.008219
B	Pompa stand by	$298.1208 \cdot 10^{-6}$	0.008219
C	Sea water pump	$298.1209 \cdot 10^{-6}$	0.008219
D	Heat exchanger	$249.9991 \cdot 10^{-6}$	0.0027397
E	Electric motor	$71.486 \cdot 10^{-6}$	0.0061644

The value of the availability system (A) is obtained from the result of the calculation which is:

Availability system (A) = $P_1 + P_2 + P_3 + P_6 + P_{13} = 0.7858$

While the value of unavailability system (U) can be obtained from the following equation:

Unavailability system (U) = 1 – A = 0.2142

The value 0.7858 represent that the probability of the five components to be working is 78.58% and serious attention should be given to this five components as they affect the system to work. Failure on one components of the five will fail the whole system.

4. CONCLUSION

The aim of the markov proses analysis in maintenance modelling is to present the physical condition of the system into a space state diagram before modelling mathematically. The level of complexity and the solution of the mathematical model of the system is highly dependent on the complexity of the state space diagram. Further the complexity of the state space diagram is depend on the condition and the number of the system component which can cause the system to be fail. The number of possible state is 2^n, where n is the number of component. For the reviewed system (fresh water cooling system), n is 5 so that the number of state become 32. This 32 states then defined in matrix [32 x 32]. The result of this matrix shows that the availability system (A) to be obtained is 0.7858. This number means that the system will work (with the big roles of the five components) for about 78.58% of the total operational time. Hence, the five components must be paid full attention considering that they contribute significantly for the system to work.

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