Risk and Life Cycle Cost based Assessment through Multi-objective Simulation of Ship Machinery Maintenance Policy

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【 学位論文題目 】

Risk and Life Cycle Cost based Assessment through Multi-objective Simulation of Ship Machinery Maintenance Policy（船舶機器保全の多目的要素を考慮したリスクとＬＣＣ評価）

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Ship maintenance scheduling management integrated with risk evaluation and Life Cycle Cost (LCC) assessment approach are developed in this research. It improves upon existing practice arranging an optimal maintenance schedule by modeling operational and economical risks. The maintenance scheduling algorithm will explicitly consider risks associated with some operational problems such as operating schedule, routes, ship position, resources availability, and achievement of reliability-availability-maintainability (RAM) of the system. Modeling of components RAM with failure consequences results risk evaluation. The time value of maintenance cost, replacement cost, earning rate, and penalty cost are also simulated. When the system reaches the lowest level of the lower limit reliability, one or more components should be maintained or replaced. Since maintenance task may interrupt the operation, to minimize time-to-maintain all possible opportunity of maintaining other components at the same time will be evaluated together with resources availability. By researching these possibilities, constraining the risk, and based on LCC calculation result, an optimal maintenance scheduling can then be established.

The main objective of this work is to introduce a method in simulating and arranging multi-objective optimum maintenance schedule by analyzing possible risks, maintenance cost and other costs over a defined period. In this research, decision making criterion utilizes LCC. Several steps in assigning maintenance schedule are proposed by predicting the appropriate time of those activities based on system reliability and LCC. These steps include determining component functions, generating the time predicted and possible component combinations, analyzing alternatives and uncertainties associated. And finally selecting the best alternative by using a criterion LCC.

This thesis is composed in such a way as described below:
Chapter 1 Literature Review. This briefly presents literature review of marine accident, recent maintenance issues including maintenance categories, maintenance factors, maintenance modeling, and criteria on maintenance optimization. This chapter shows the development of related issues of maintenance and how those issues give the idea to

simulate the maintenance activities related to the possible risks and economic factor.

Chapter 2 Basic Theories, contains the basic theories such as reliability and risk Analysis, artificial neural network, System Dynamics and Engineering Economics. In this chapter presents the theory and calculation steps in simulating the problem. Artificial neural network is used for obtaining the best composition of multi-national crew due to the maintenance cost. The reliability theory is to support the modeling and calculation of the system reliability. In this thesis, parallel, series and combination of parallel-series are used. Theory of risk analysis is for evaluating the system risk after the system reliability is formulated and calculated. Since the system reliability and system risk are dynamic, which means they changes over time, then the simulation system to figure the behavior of system during their *live* is needed. The system dynamic simulation system is used. The system dynamic is utilized for a method to relate the parameters or variables and then to simulate them based on some scenarios. After, the system reliability and system risk are figured out for times through simulation, further the economic value of those activities are calculated as present value. For this calculation, the engineering economics is utilized.

Chapter 3 Assessment Simulation Model and Maintenance Policy Model
This chapter presents the flow diagram for modeling of multi-objective maintenance policy simulation. Several steps in arranging the maintenance policy simulation are formulated. The first step is identifying the component data such as the distribution of component failure, time to maintain distribution, cost rate to maintain, initial cost, the effect of doing maintenance to the reliability, and the function of component itself to the system, and also indentify the functional flow diagram. The next step is to build the reliability of the system in order to calculate the system reliability. Based on scenarios of how the simulation system is aimed, the system thinking method is utilized. The system thinking is used to explain easier the system simulation works. Here, the cause and effect are linked for each parameter of system. This step results how the reliability of system or probability of risk calculated, and how the value of consequences as time function is determined. In addition, having the value of consequences, the LCC as time

function is then possibly defined. This new model has been proposed and presented in 25th International Conference on Offshore Mechanics and Arctic Engineering June 4-9, 2006, Hamburg, Germany; The 18th IASTED International Conference on Modelling and Simulation ~MS 2007~ May 30 – June 1, 2007 Montreal, Quebec, Canada; and International Conference on Computational Methods in Marine Engineering - MARINE 2007, Barcelona, 2007. The main systems of ship as the object of simulation are Fuel System, Lubricating oil system, Cooling system, and Starting system

Chapter 4 Modeling and simulating multi objective maintenance policy

Using system dynamics models the life of system that is possibly investigated. *The life of system* is studied thru the history life of each component. Associated components are related as their reliability block diagram presented in Chapter 3. The possible times to operate or to maintain could also be provided in this simulation therefore the user could easily simulate via their own trials. Further, it is shown the modeling of the reliability and risk of single component using SD. There are 3 main parts in the model: the reliability model, maintenance rate and maintenance cost, risk. Each part is related each other. In this chapter is presented a flowchart of how the simulation runs. After the initial data of each component and scenarios of operation and maintenance entered in simulation data fields, the system will calculate the initial system reliability and system risk. While through hours running, it is possible to interrupt the simulation that is if some of variables value required changing. When the hours running, the reliability of component and system change as well as the consequences (if it is set not to be constant by time). The changing of variable during the simulation will directly change the calculation result. For instance, if we decide to maintain a component sometimes, the system will be stop (if component in series configuration) and then the reliability of component updated as well as the operating time of component will be reset or reduced becomes younger. At last, for every hour of simulation, the risk is also calculated based on the possibly consequences and the unreliability of system (the possibility of risk happens). Updating the component failure distribution is also possible. The changing of distribution may be needed for a corrective maintenance of a component. There are two scenarios of simulation. The first it is set as auto-maintenance which mean if a component reach a certain level of reliability, then the maintenance action automatically done. Therefore, the simulation is continuously run without any interruption. The second scenarios, a given maintenance schedule is provided and then using the simulation program is evaluated. In this simulation, we can

interrupt the simulation if some variables need to change by new inputs. This work hase been done and it is published in JIME Journal Vol 41 2006 and JIME Journal Vol 42 No.5 2007.

Chapter 5 Simulation results and discussion

This chapter shows the results of simulations as given scenarios of doing maintenance and operation schedule. The result of reliability index, availability, risk values, and present values of each activity is presented. In addition, some interesting new findings experienced during programming are also presented.

Chapter 6 Conclusion

It contains summary of this thesis and possible future works.

（別紙１）　　　　　　　　　　論文審査の結果の要旨

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論文題目	Risk and Life Cycle Cost based Assessment through Multi-objective Simulation of Ship Machinery Maintenance Policy （船舶機器保全の多目的要素を考慮したリスクとＬＣＣ評価）

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要　　旨

本論文は６章からなり、英語にて仕上げられている。要旨は以下の通りである。

The main objective of this work is to introduce a method in simulating and arranging multi-objective optimum maintenance schedule by analyzing possible risks, maintenance cost and other costs over a defined period. In this research, decision making criterion utilizes Life Cycle Cost (LCC). Several steps in assigning maintenance schedule are proposed by predicting the appropriate time of those activities based on system reliability and LCC. These steps include determining component functions, generating the time predicted and possible component combinations, analyzing alternatives and uncertainties associated. And finally selecting the best alternative by using a criterion LCC.

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Chapter 2 contains the basic theories such as Reliability and Risk Analysis, Artificial Neural Network (ANN), System Dynamics (SD) and Engineering Economics. In this chapter presents the theory and calculation steps in simulating the problem. Artificial Neural Network is used for obtaining the best composition of multi-national crew due to the maintenance cost. The reliability theory is to support the modeling and calculation of the system reliability. Parallel, series and combination of parallel-series are used. Theory of risk analysis is for evaluating the system risk after the system reliability is formulated and calculated. Since the system reliability and system risk are dynamic, which means they changes over time, then the simulation system to figure the behavior of system during their *live* is needed. The system dynamic simulation system is utilized for a method to relate the parameters or variables and then to simulate them based on some scenarios. After, the system reliability and system risk are figured out for times through simulation, further the economic value of those activities are calculated as present value. For this calculation, the engineering economics is utilized.

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Chapter 4 presents how use SD models the life of system that is possibly investigated. *The life of system* is studied thru the history life of each component. Associated components are related as their reliability block diagram presented in Chapter 3. The possible times to operate or to maintain could also be provided in this simulation therefore the user could easily simulate via their trials. Further, it is shown the modeling of the reliability and risk of single component using SD. There are 3 main parts in the model: the reliability model, maintenance rate and maintenance cost, risk. Each part is related each other. In this chapter is presented a flowchart of how the simulation runs. After the initial data of each component and scenarios of operation and maintenance entered in simulation data fields, the system will calculate the initial system reliability and system risk. While through hours running, it is possible to interrupt the simulation that is if some of variables value required changing. When the hours running, the reliability of component and system change as well as the consequences (if it is set not to be constant by time). The changing of variable during the simulation will directly change the calculation result. For instance, if we decide to maintain a component sometimes, the system will be stop (if component in series configuration) and then the reliability of component updated as well as the operating time of component will be reset or reduced becomes younger. At last, for every hour of simulation, the risk is also calculated based on the possibly consequences and the unreliability of system (the possibility of risk happens). Updating the component failure distribution is also possible. The changing of distribution may be needed for a corrective maintenance of a component. There are two scenarios of simulation. The first it is set as auto-maintenance which mean if a component reach a certain level of reliability, then the maintenance action automatically done. Therefore, the simulation is continuously run without any interruption. The second scenarios, a given maintenance schedule is provided and then using the simulation program is evaluated. In this simulation, we can interrupt the simulation if some variables need to change by new inputs.

Chapter 5 shows the results of simulations as given scenarios of doing maintenance and operation schedule. The result of reliability index, availability, risk values, and present values of each activity is presented. In addition, some interesting new findings experienced during programming are also presented.

Chapter 6　contains summary of this thesis and possible future works

以上。

この研究は、従来の船舶機関保守方策に使われている Reliability and Risk Analysis のみならず、Artificial Neural Network(ANN), System Dynamics(SD),Engineering Economics and Life Cycle Cost に注目して、それらの概念を組み込み船舶機器保全の多目的要素を考慮したリスクとＬＣＣ評価を可能にした研究である。

中でも ANN を使った乗組員国籍比率に関連した保全費用の算出法、SD を使った機関プラントが経年変化に伴って変わる信頼性、プラント全体を考慮した最適保全コスト算出プロセスによって船舶機器保全のリスク評価を行う点は、重要な知見を得たものとして価値ある集積であると認める。

よって、学位申請者の Lahar Baliwangi は、博士（工学）の学位を得る資格あると認める。

本研究に関する公表論文は、審査論文５編（内、第１著者５編、英文論文５編）である。