Operation and Maintenance Management of Ship Machinery using System Dynamics

DHIMAS WIDHI HANDANI

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論文内容の要旨

氏　名　Dhimas Widhi Handani

専　攻　Maritime Sciences

論文題目（外国語の場合は，その和訳を併記すること。）

Operation and Maintenance Management of Ship Machinery using System Dynamics

（システムダイナミクスを活用した船舶機関システムの運転・保守管理）

指導教員　Makoto Uchida　内田　誠

（注）2，000字～4，000字でまとめること。

The cost of operation must be considered when analyzing reliable support systems for ship main engines. While respecting the need for safety of ship from machinery risk of failure, the total cost of ship machinery operation (C_T) must also be kept at a minimum. This is an issue that frequently emerges in the operation of merchant ships as ship companies make an effort to gain better profits by reducing the expenses during operation. The determination of minimum C_T is not a simple matter because it includes some particular considerations such as running cost (C_r), maintenance cost (C_m) and downtime cost (C_d).

One is faced with the difficulty to decide the appropriate length of the maintenance interval (I_m) for machinery that yields the minimum C_T but still respects reliability. Along with the running time of machinery, the C_r increases according to the degradation of performance and reliability. Maintenance could reduce the C_r but this would cause a C_m increase. Since maintenance requires a C_m but also has the benefit of reducing the C_r, an optimization process which endeavors to balance the two to find the minimum C_T is needed. The optimization of marine machinery operation is a more complex discussion than for onshore machinery because of its maintenance inflexibility, which sometimes depends on access to shore based facilities or the availability of spare parts onboard.

This study presents an optimization process that minimizes the C_T by considering the minimum reliability requirement and the preference time and place of maintenance. The optimization problem compounds many factors that correlate with each other. The optimization process utilizes the simulation model, system dynamics (SD), which is capable of modeling the interrelationship between components of ship machinery operation e.g. cost component, reliability analysis, and ship voyage pattern. This study also presents a new development model of risk based maintenance (RBM) implemented for ship machinery to prevent high levels of risk during ship operation. Development of RBM resulted in an effective maintenance plan that compared well with the standard of maintenance published by the machinery's manufacturer.

In order to accommodate the matters explained above, this thesis is constructed as follows.

Chapter 1, introduction which contains background information, purposes, and scope of research, including proposed work to be done.

Chapter 2, briefly reviews ship machinery operation and the history of maintenance strategy, risk based maintenance (RBM) and explains the system dynamics (SD) simulation. The modeling process of machinery operation and maintenance in SD simulation is presented in this chapter.

Chapter 3. This chapter proposes new models in system dynamics (SD) simulations to determine the reliability index (RI) degradation of ship machinery which is installed in the main engine support systems of ships. The purpose of this study is to minimize the total operation cost (C_T) of machinery which is comprised of running cost (Cr), maintenance cost (Cm) and downtime cost (Cd). Reliability analysis is taken into account based on data from maintenance records. In this chapter, two kinds of optimization models utilizing SD are compared. Model 1, an optimization model without forecasting, utilizes a value of minimum RI as a decision to obtain the lowest C_T. The minimum RI is the level of reliability of machinery where maintenance actions need to be taken. Model 2, an optimization model with forecasting, constructs the maintenance judgment by forecasting the value of RI to avoid the minimum RI before a ship arrives at a destination port. Sea water and fresh water cooling pumps are analyzed as a case study. Model 1 resulted in minimum C_T, while model 2 reached a C_T lower than the outcome of model 1.

Chapter 4. In this chapter, an SD optimization model is proposed to minimize the C_T by considering the port availability constraint. In this constraint, it is assumed that the maintenance of the machinery is only possible at one particular available port. The purpose is to know how the constraint influences the composition of the cost compared with the results of the study in Chapter 3. In the case study, this chapter discusses the operation of pumps which are installed in the cooling system of a ship's main engine. System dynamics (SD) is used to build two kinds of proposed models of machinery operation, model 1 without forecasting, and model 2 with forecasting of minimum RI. The results were similar to the results in Chapter 3, model 1 results in minimum C_T, while model 2 reaches a C_T lower than that of model 1. Model 2 in this chapter, with forecasting of minimum RI, resulted in the lowest C_T, much better than the other model. This shows that the forecasting model implemented in the problem with port availability constraint has the most significant impact on reducing the cost.

Chapter 5, considers the risk of machinery failure in the management of operation and maintenance of ship machinery. This chapter implements risk based maintenance (RBM) to minimize the frequency and consequences of ship machinery failure. As well as the common steps of RBM, such as identification of problem, risk assessment, risk evaluation, and maintenance planning are conducted, we also propose a new model called ship position estimation. First we look at preliminary identification i.e. identification of failure causes and symptoms as well as the history of failure over time. In the risk assessment, quantification of the consequences of failure (Cof) considers system performance loss, while the probability of failure (Pof) is obtained from the reliability analysis of the failure time history. Risk evaluation compares the result of the risk assessment with the risk acceptance criteria in order to determine the level of risk. The proposed model of ship position estimation recognizes the ship position on the voyage when the analyzed machinery is at a high level of risk. Maintenance planning is then carried out to keep the machinery under the risk acceptance level. This paper utilizes system dynamics simulation (SD) to create each step of the RBM. For our case study, the parts of the pumps in the main engine cooling system are analyzed. The output of the study is a proposed maintenance interval which is suitable when compared with the standard maintenance for the pumps. Additionally, the position, operation hours and distance covered of the ship are included when a pump reaches a high level of risk.

Chapter 6. Summarizes the studies of the previous chapters and discusses the result obtained. In this study, the optimum management of operation and maintenance for ship machinery is clearly presented. This is shown as the optimization of C_T by endeavoring to find the value of the minimum RI. The optimization utilizes SD simulation to build two models, model 1 without forecasting and model 2 with forecasting of the minimum RI. Model 2 shows the greatest impact on the reduction of C_T, much better than model 1, especially in the case study on the ship operated under the port availability constraint. Considering risk management, this study presents a new development in the RBM method. The beneficial outputs achieved are an improved maintenance plan and the addition of ship position estimation for ship machinery operation at a high level of risk. Further, this chapter draws conclusions and discusses other improvements that may be possible for future research.

（別紙１）　　論文審査の結果の要旨

氏名	DHIMAS WIDHI HANDANI　（ディマス　ウィディ　ハンダニ）		
論文題目	Operation and Maintenance Management of Ship Machinery using System Dynamics （システムダイナミクスを活用した船舶機関システムの運転・保守管理）		
審査委員	区　分	職　名	氏　　名
	主　査	教　授	内田　誠
	副　査	教　授	小林　英一
	副　査	教　授	段　智久
	副　査		
	副　査		印

要　　旨

本申請論文は船舶機関システムの運転・保守管理における最適化の一方策を提案し試算結果に基づき最適化手法の発展可能性が示されたものである。本論文における最適化の考え方は，要求される信頼性を最小限確保しつつ，３要素からなるコスト全体を最少化するものである。本論文では，船舶機関システムの内，主機冷却水系ポンプ３種を対象に検証されている。運転・保守管理に関する指標算出のモデル構築および試算に用いられる環境は，複雑系システムの課題をシステム全体および構成要素の詳細の双方が視覚的にも解り易く表現出来る特徴がある“System Dynamics”(SD)が活用されている。本論文で提案されている最適化システムが実務活用される場合，システムの解りやすさは重要である。

本申請論文の構成は以下の通りである。

【第１章】序章として，研究着手の背景，研究目標および研究計画の全体像が簡潔にまとめられている。

【第２章】運転・保守管理最適化の基盤となる Risk Based Maintenance (RBM)およびシステム構築環境である SD の概要と要点が解説され，主機冷却水系ポンプを対象にモデル構築の典型例が示されている。

【第３章】第１段階としてコスト３要素（Running cost：Cr, Maintenance cost：Cm, Downtime cost：Cd）の計算モデルが構築されている。Cr, Cm および Cd の相関算出に必要な機器信頼性及び故障発現可能性に関する情報は，先行研究の成果が活用されている。最適化試算の結果，運用実績に比較して３割弱，先行研究の最適化手法に比較して 1.5 ポイント程度の削減の可能性が示されている。

【第４章】第３章のモデルを基本として，重大な故障対応を想定し，保守（故障機器修理）実行が母港入港中に限定される制約条件を追加した計算モデルが構築されている。最適化試算の結果，機器信頼性指標が就航中に許容最低値（Minimum RI）を下回るか否か予測する場合としない場合で，コスト削減効果の差が保守実行制約条件下では大きくなることが示されている。

【第５章】本論文で対象とする主機冷却水系ポンプについて，実船の運用・保守データを基に，ポンプ構成要素及び故障・異状・保守の内容に注目し，SD を活用した RBM 手法の提案と試算結果が示され，構成要素のメーカー推奨値との対比によって計算モデルの有用性が検証されている。

【第６章】終章として，第３章から第５章の全体概要及び各々の章で得られた結果が総括されている。

氏名	DHIMAS WIDHI HANDANI　（ディマス　ウィディ　ハンダニ）

本申請論文では，船舶機関システムの運転・保守管理において必要最小限の信頼性を維持しつつ運転・保守費用を最少化する最適化手法が提案され，主機冷却水系統のポンプ類に焦点を当てて実船データに基づく検証により有用性が示された。船舶動力機関プラント全体に本研究で示された最適化モデルを適用するためには，プラント全体に関わる膨大な運用実績，保守データ，構成機器情報と各要素の信頼性指標に関する検討が必要となるが，それらの共通項となる最適化システム骨格部が構築され，その有用性が主機冷却水系統を対象に確認されたことは，船舶機関管理分野において大きな成果であると共に今後のさらなる発展が期待できる。

本申請論文を構成する研究成果の公表について，下記リストの通り学術雑誌に研究論文２件が掲載され，学術雑誌研究論文掲載審査中が１件，国際会議等口述講演報告が４件，内１件で“Honorable Mention Paper Award”が授けられた。

以上，論文審査の結果，本論文は博士（工学）＜海事科学分野＞の学位授与に相当すると認める。

【学術雑誌掲載研究論文】

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以上