Development of Navigation Safety Analysis for Developing Port Area using Maneuvering Simulation and AIS Data

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論文内容の要旨

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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。）

Development of Navigation Safety Analysis for Developing Port Area using Maneuvering Simulation and AIS Data

(港湾区域開発のための操縦運動シミュレーションと AIS を活用した航行安全性評価法の開発)

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(注) 2,000 字～4,000 字でまとめること。

The number of port throughput in Indonesia increases significantly, in line with the economic growth of the country. Indonesia government has taken a development scheme of main sea-corridor in order to boost the economic growth in the Eastern part of the country. The development of the main sea-corridor is also intended to anticipate the increasing number of ship calls, especially in the port of Western part of Indonesia. The developing ports may lead a new danger area that becomes obstacle for navigators to steer the ships in the port area. Construction of new wharf in the developing port area not only causes the new danger area but also new route of the ships. The new hazards of ship to wharf collision and ship to ship collision in the area should be properly managed. Therefore, the analysis of navigational safety in a developing port area is essential for the port authority to determine and apply new navigational aids and measures in attempt to prevent accident in the port area.

Tanjung Perak Port located in Madura Strait is one of the main sea-corridors of Indonesia. Increasing number of ship calls in the port require the development of new port and canal as well as the improvement of port traffic management. The number of ship calls has been already 38,800 ship calls in 2008 and it is predicted that it will be 58,000 in 2030. On the other hand, the current capacity of the canal is 27,000 ship calls per year. Number of accidents in the area is very high with 11 collisions per year in average for the 18 years of period between 1995 and 2013. Therefore, the navigational safety of ship in the port area is very important to be analyzed in order to propose methods and measures needed to be taken by the port authority. Methods to estimate the width of ship barrier, the optimum safe route, the probability of ship on collision course upon taking crash astern maneuvers, and estimation of collision risk in the bend of new canal are proposed. Maximum safe speed, the optimum safe route, separation of fairways, and installation of new buoys are suggested as measures to avoid collision in the research area.

The application of Automatic Identification System (AIS) data and the Maneuvering Modelling Group (MMG) model for navigational safety analysis in port area of Madura Strait is presented in this research study. These research studies consist of 8 chapters. The introduction including background, purposes, and study area are described in the Chapter 1. The AIS data and MMG model are explored in the Chapter 2 and Chapter 3, respectively. The explanation about AIS data treated in the simulation of maneuvering to calculate the navigational safety in port area by using the MMG model is described in these chapters. Furthermore, the development method to estimate ship barrier for collision avoidance, the development method of navigational safety-indices to evaluate and seek the optimal route, the development method to estimate the probability of ship on collision course, and the method to estimate the probability of collision in the bend of new canal by using AIS data and MMG model are

described in Chapter 4 to Chapter 7, respectively. The discussion and conclusions are presented in Chapter 8.

The AIS data is taken from receiver installed in Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia by the cooperation with Kobe University, Japan. The AIS information is provided by a ship through the transmission includes three types such as the static, dynamic, and voyage-related information. Static information related to a ship's type, identity, dimensions, and other fixed information is programmed into the unit at the time of commissioning. Dynamic information including location, speed, course, heading, rate of turn and the navigational status is derived from a ship's GPS and other sensors connected to the AIS. Voyage-related information including the draught, cargo type, destination and ETA, and route plan are entered manually. The dynamic data of ships' trajectory including the position, course over ground (COG), true heading, and speed over ground (SOG) are analyzed in this study. The maneuvering simulation program of the MMG model is developed using MATLAB program. The MMG model considers the condition of shallow water and the disturbances of wind and current. In Chapter 4, drift angle and yaw rate of an entering ship is analyzed from the COG and true heading using interpolation method and treated in the MMG model to identify and estimate the width of ship barrier treated as a danger area. In Chapter 5, the distribution of yaw rate is analyzed from the trend of yaw angle of a small zig-zag maneuver. The trend of yaw angle is compared to the trend of true heading of a ship from AIS data. The distribution is treated as the initial condition of turning maneuver using the MMG model to estimate probable trajectories and determine the optimal route. A new method of navigational safety index is proposed to determine the optimal route. In Chapter 6, the trend of true heading and SOG as well as the trajectory from AIS data is used as the reference for the subject ship to be followed using the maneuvering simulation. The distribution of yaw rate is estimated from the simulation. The distribution is treated in the simulation of crash astern maneuvers to estimate the probability of ship on collision course.

Simulation of ship maneuvering to estimate the width of ship barrier in order to avoid ship-ship collision has been developed based on the identified danger area and is presented in Chapter 4. In this chapter, a subject ship exiting Lamong Bay Port, a new port in Madura Strait, is simulated to avoid collision with a target ship entering the Tanjung Perak Port area. The estimated ship barrier of ship domain of target ship entering the port area is treated as a danger area. Ship domain is defined as the free area surrounding a ship to avoid collision. The result of the method is compared to other methods. The safest route of subject ship is determined using trial maneuver considering the safety index of Emergency Level (EL). The analysis of ship domain as a danger area as well as the evaluation on the center of passage in the developing port

area is performed. The analysis was developed by using maneuvering simulation and AIS data. The location of danger area and the width of ship domain in the shallow water of the port area were predicted by randomizing the initial conditions of entering ship taking course alteration maneuver at the bend of the passage. The danger area of the entering ship is identified as obstacle which has to be avoided by subject ship exiting the port. The simulation confirms that some of the possible trajectories of target ship were on collision courses with ships anchoring in the anchorage zones. The simulation also shows that avoiding the danger area of anchorage zone will create another danger area in the new port area. The dimension of the danger area is used as the dimension of ship domain which should be free of other ships for avoiding ship-ship collision. The width of ship domain in port area estimated based on the simulation was about 1.12L which is less than that calculated based on Fujii's method, 1.6L. The width of free space between the danger area and port structure was 0.56L and the distance between the passage and anchoring ship is 0.5L. The distances are less than requirement introduced by Inoue which are 0.68L and 0.89L respectively. Furthermore, the route of the exiting ship is determined in order to avoid collision with entering ship in the danger area. The route is determined based on the evaluation of navigation safety which is measured using the method of EL. This chapter has been published in the reference [3] and [7].

A proposed method for the assessment of navigational safety using MMG model and AIS data has been explained in Chapter 5. The method is developed based on Emergency Level (EL) and Environment Stress (ES) methods. The proposed method is intended for seeking the optimal of safety route for developing port area. As a case study, the method is implemented in the existing condition of the passage located between anchorage zones of the port area. The change of route and position of navigation aids can be determined for the developing port area based on result of the method. The EL and ES of subject ship entering the port area between the anchorage zones are evaluated according to the existing condition of the developing port area. The boundary lines of anchorage zones and shallow water of the coast are treated as virtual environment obstacle lines, besides the structure of port jetty. The waterlines of ships anchoring out of the anchorage areas are the representation of traffic obstacle of ship maneuvering in the area. A new method of navigational safety assessment method has been introduced in this chapter. The method is developed based on the existing method of the EL and ES. The existing methods are unable to seek the optimal route. The new methods of Distance Level (DL), Aggregate Distance Level (AgDL) and Average Distance Level (AvDL) are introduced to determine an optimal route in the developing port area. Firstly, distributions of drift angle and yaw rate on a straight passage before taking a turning maneuver are analyzed. The distribution of drift angle on the passage is analyzed from AIS data of ships belong to the same class with a subject ship and the yaw rate distribution of ship on the area is predicted using small zig-zag simulation. The yaw angle time series of subject ship resulted from the simulation is compared to the true heading time series of ship belonging to the same class from AIS data. The distributions are treated in the maneuvering simulation to estimate probable trajectories. The navigational safety indices of all probable trajectories are calculated based on the distances to obstacles and the stopping distances. The stopping distance is calculated based on an estimation equation from IMO. The AvDL of the normal trajectory was 0.2. The proposed method found the optimum trajectory with the AvDL of 0.39. This chapter has been submitted for publication in the Journal of Maritime Affairs.

In the Chapter 6, development of collision candidate frequency method using MMG model and AIS data has been analyzed and discussed. The method is developed for predicting the probability of ship on collision course upon taking crash astern maneuvers. Probable trajectories of crash astern maneuvers are predicted based on distributions of initial conditions for the maneuver. Originally, the concept of PAW is developed based on the positions when the emergency actions are ordered. A new Potential Area of Water (PAW) for maneuvering has been introduced in this chapter, which not only based on the positions of ordering crash astern maneuvers but also the distributions of yaw rate in the area of the positions. Crash astern maneuvers with random initial condition based on the distribution of yaw rate are treated to develop the new PAW. Probability of ship on collision courses upon taking crash-astern maneuvers was estimated using the new PAW.

The normal entering trajectory of ship is plotted based on AIS data. A subject ship is simulated using MMG model to take the same trajectory and yaw angle trend with the AIS data of a ship belong to the same class. The yaw rate time series of ship on the trajectory is taken from the simulation. The trajectory is divided into 6 areas including 3 areas of course keeping and 3 areas of course changing. Crash astern maneuvers are taken at 4 initial positions for each area. The simulation confirmed that the maximum safety speed of ship in the research area of the port area in Madura Strait is 6 knots. Based on the distribution of ship speed in the port area it is estimated that the probability of ships on collision courses upon taking a slow crash astern maneuver is 50%. A largest lateral deviation is found at area D, area of long turning located in front of the position of new Lamong Bay Port. The distribution of lateral deviation at the area fits with normal distribution with the mean of -5.894B and standard deviation of 0.342B. The large distribution of lateral deviation in this area is in line with to distribution of yaw rate in the area. This chapter has been published in the reference [1] and [8].

In Chapter 7, the collision risk estimation of ship during maneuvering in the transition part of bend of new two-lane canal located at the gate of the research area has been described. A method to estimate the probability of collision in the new canal is proposed. The method is developed based on Friss-Hansen method and the collision estimation resulted using the method is compared with that proposed by Kristiansen. The consequence of collision is estimated using collision energy loss. This chapter is developed based on a contribution in OMAE conference which has been published in the reference [4] and [6].

In the Chapter 8, discussions and conclusions were presented. The chapter is developed from discussion and conclusion parts of the previous chapters.

（別紙１）　　　　　　　　　　論文審査の結果の要旨

氏名	I Putu Sindhu Asmara	
論文題目	Development of Navigation Safety Analysis for Developing Port Area using Maneuvering Simulation and AIS Data （港湾区域開発のための操縦運動シミュレーションと AIS を活用した航行安全性評価法の開発）	

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要旨

概要

本研究は、実際に開発がすすめられている港湾について、そこに入出港する船舶の航行安全性を評価する手法の開発に関するもので以下の構成となっている。

第一章では、インドネシアの特に西域で、近年の著しい経済成長と連動して、船舶貨物取扱量の増加を背景に港湾水域での船舶の輻輳と事故の増加が課題でありそれを評価し解決するための取り組みについての本研究の視点をまず述べている。すなわち、本研究にかかる具体的な運航ルートの紹介や当該海域における具体的な荷物取扱量の推移などを示しつつ、海上交通の課題が、船舶同士の衝突事故の増加が危機的状況であること、特に現在開発整備中の港での航行管制の必要性、航行ルート整備の重要性、衝突事故の確率予測が港の整備状況の急激な変化もあり難しい点、そしてそのような状況下であるがゆえに何らかの航行安全性評価手法の導入が必要であると研究背景の説明を行い、本研究の骨子と目的を次のように設定している。

(1) 船舶の航行可能性エリアを予測する手法の開発および既往研究提案手法との比較
(2) 最適航行ルートを本研究で新たに示す EL(Emergency Level)値を用いて評価する
(3) 衝突リスクを本研究で新たに導入する PAW(Potential Water Area)手法で評価する
(4) 2 レーンの対向航路での衝突リスクにかかる新たな手法の提案と評価

次に、本研究が対象とする水域(Madura Straits)や研究の範囲について示し、最後に本学位論文の構成を述べている。

第二章ではまず、スラバヤ工科大学に設置した AIS(船舶自動識別装置)の説明を行っている。次にそのデータによる研究対象水域(Madura Straits)での船舶航行データの解析に基づき、本研究での解析対象とするスラバヤ近くの Tanjyung Perak 港に入港する代表的な航路の設定を行った。また合わせて、今後の解析のためのゾーン分けや、AIS データに含まれる方位角データから、船舶の回頭角速度の振れ幅の計算も示している。次に次章で説明する船舶の操縦運動モデルにより、その航路に沿って入港する船舶の軌跡の再現計算についても示している。

第三章では、次章以降での解析のために使用する操縦運動を表わす数学モデルとそこに含まれるパラメターの説明を行っている。この数学モデルとしては、当該操縦運動解析分野で標準的な MMG モデルを採用しているが、その基本的な原理の説明と今回の船舶に合わせて特に考慮したり、また拡張した部分について詳述している。特に本研究で最も重要な項目の一つであるプロペラ逆転時の有効推力と船体に作用する横力や回答モーメントの導出方法については、既往研究事例なども参考に考察を加え設定している。また今回の研究の対象船型として設定した PCC について、MMG モデルを構成する流体力微係数の導出についての解説も行っている。このほか、風圧力影響、潮流影響、浅水影響についても本研究での取り扱いについて説明がなされている。

第四章では、本研究で解析の対象とする Madura Strait の中に位置する現在建設中の Lamong Bay 港の概要についてまず示している。次に 解析手法とし新たに導入する PAW(Potential Area of Water)について既往類似研究との違いや特長について概説した後、計算条件と必要な風や潮流の外乱条件の設定方法について示している。さらに、そのような外乱下で入港操船中に、不測の事態でプロペラを逆転させ停止するときに指定航路から逸れる程度をシミュレーション計算で示している。合わせて、その逸れる範囲の外側に出港のための航路の設定が可能であることも論じている。加えてそのような緊急時停止を想定した場合の EL(Emergency Level) についても解析を行い、初期設定の計画航路の変更が必要であることも合わせ示している。

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第五章では既往研究で提唱されてきた EL や ES などの航行にかかる安全性の指標の限界なども考察しつつ、これら従来の二つの指標をベースとして、前述の検討対象水域における航行安全性の評価に用いることのできる AgDL (Aggregate Distance Level) および AvDL (Average Distance Level) という新たな航行安全指数(Navigation Safety Index)の導入について論じている。これは先に述べた PAW という概念に依るものである。

第六章では緊急事態に遭遇した時に主機を逆転させ船体を停止させる操船を行った時の操船性について論じている。一般的にはプロペラ逆転停止操船時には舵がほとんど効かず、その逆転操作直前のわずかな運動が積分されていくため、初期航路から大きく外れることが多い。この現象を予め予想することは難しいが、事前にその程度の範囲を把握することができるのでこれをシミュレーション計算で評価している。

第七章では既往研究で実績のある船舶同士の衝突確率推算方法をこの水域に応用し、船舶航行 AIS データと照らし合わせリスク想定を試みている。

最後に第八章では本研究の結論および将来に向けた課題の整理とその解決方法の提示を行っている。

なお、本論文を構成する主な投稿論文は査読付学会論文 2 編、国際学会プロシーディング 3 編にまとめられ公表されている。

以上述べてきたように、本論文は、インドネシアスマトラ島のマドゥラ海峡の奥部で新たに計画が進められている港湾建設に関連して、そこの入出港する船舶の航行安全性をどう評価し、またどう必要な対策を講じるかについて纏めたものである。この海域では航行船舶の数が増加しており船舶の衝突が増加する傾向であるなかの安全性確保のための学際的な研究が求められる中で、精緻な数学モデルを用いた船舶緊急停止時の停止性能予測や、危険度指標の導入など多面的な視点からのアプローチを試みており、その意義は大きい。この研究成果は主として査読付学会論文 2 編、国際学会プロシーディング 3 編にまとめられ公表されている。よって本論文は，学位に値するものと認める。