FROM SHIP MANOEUVRABILITY, CONTROLLABILITY, CAPTAIN'S MODEL, TRAFFIC MODEL TO ACCIDENT AND TSUNAMI ANALYSIS

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Abstract: This is the recent review of author's researches since last workshop held in Shanghai. The algorithm of automatic collision avoidance system and other functions used in Marine Traffic Simulation System (MTSS) and Imazu problem with sample simulation result using MTSS were introduced in the previous workshop. In this paper some results of free-running experiment and detail behavior or the simulation result of the same Imazu problem treated in the previous paper are introduced. Also as an application of MTSS, the marine traffic simulation of Singapore Straits are shown. Including the applications applied for southward of Tokyo Bay and off Shanghai which was treated in the previous paper, an index to assess the dangerous degree is explained. Further two new researches are introduced. One is the research related to ship accidents. Normally probabilistic approach is common for this, but the new method mainly focuses on human behaviours. The other is related to tsunami. Using AIS data, ships behaviours during the tsunamis at the East Japan Great Earthquake were observed. As for ship manoeuvrability, low speed mathematical model is explained. It will be useful of course for harbour manoeuvring, but also ship motion in current or tsunami can be treated using the model, too. Finally, some new development of automatic berthing using artificial neural network is introduced which was dome more than 10 years before. At that time, the most difficult problem is how to cope with wind disturbances and how to provide consistent teaching data. In this paper, the methods to cope for them are briefly introduced. The paper list is a kind of appendix where detail description of each section is described.

Key words: ship manoeuvrability, ship controllability, ship safety, marine traffic model, captain's model, bridge team simulation, ship motion in tsunami

1. INTRODUCTION

In the previous paper, the author has summarized his 25-year research activities [1] for the next generation marine traffic. It has started from the history of marine traffic simulation to the latest algorithm of collision avoidance. He has also introduced some of his recent researches on estimating ship manoeuvring indices K and T from AIS data acquisition.

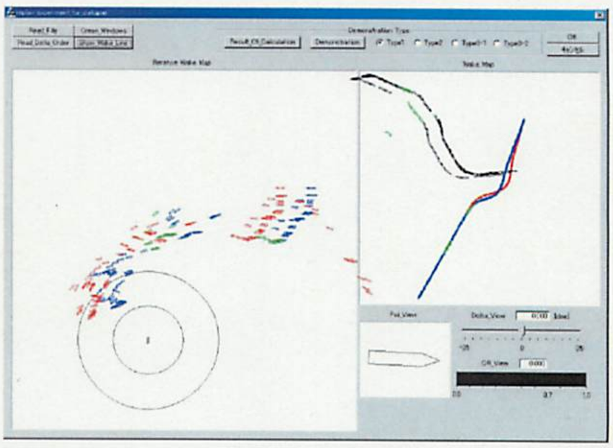
His works are anyway for ship safety in his final goal and in this meaning human recognition or bridge team management play very important role. For this reason, he has also engaged in the development of several ship handling simulators and the intelligent ship handling simulator he has developed with the collaboration with NMRI [2-6] is one of the most unique and promising ship handling simulator in the world. The software of marine traffic simulation system (MTSS) [21-48], including ship dynamics (*K-T* model), autopilot for course and track keeping, collision risk recognition and avoidance manoeuvres, marine traffic generator and data acquisition for result assessment, is now available for public [7-8].

In this paper, he will continuously introduce his latest researches from ship manoeuvrability to accident analysis.

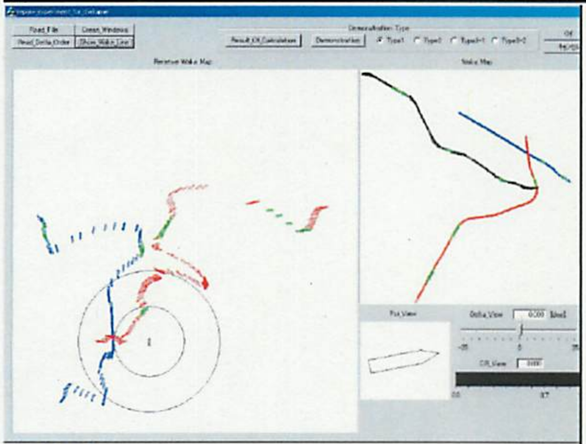
2. SOLVING IMAZU PROBLEM BY MTSS

2.1 Maritime Traffic Simulation System (MTSS)

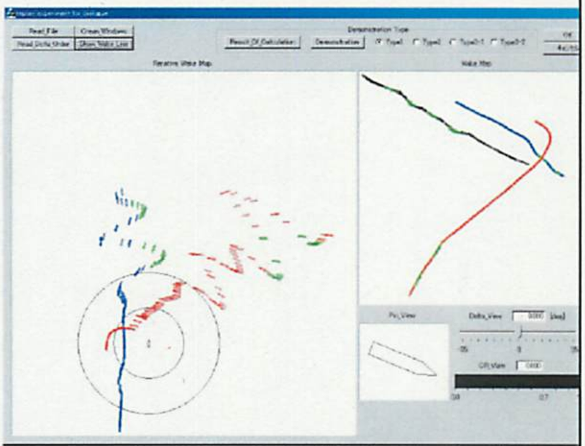
In 2002, free-running experiments of automatic collision avoidance using MTSS (version 2002) with multiple target ships were first done in the world. Fig. 1 is sample results for two-ship (a) and three-ship (b-d) encountering.



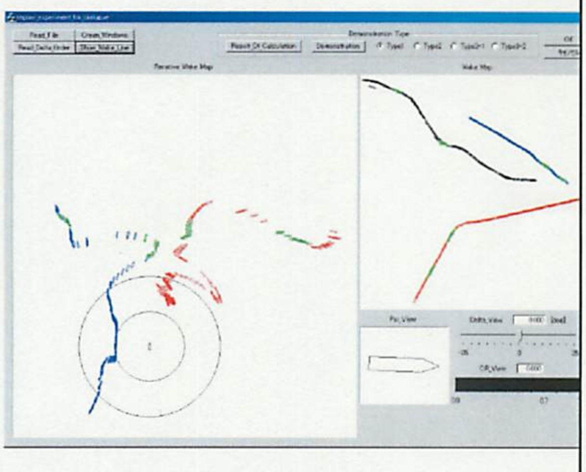
(a) two-ship encounter (crossing)



(b) three-ship encounter meeting and crossing



(c) same with (b) but slight different meeting time



(d) same with (c)

Fig. 1 Result of Free-running Experiments for Multiple Ships (2002) [9, 33].

2.2 An Result of Sophisticated Situations

In the previous paper, the author has introduced Imazu Problem [11]. Fig. 2 is the Phase I of Imazu Problem and the sampled animation of the result of

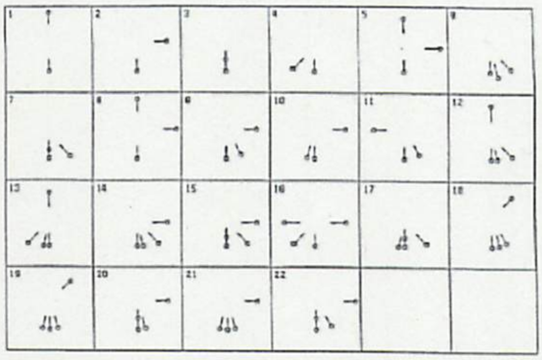


Fig. 2 Imazu problems (Phase I) [11]

case No. 13 by MTSS has showed. In the present paper, the result for case No. 13 in Fig. 2 is shown in Figs. 3-4.

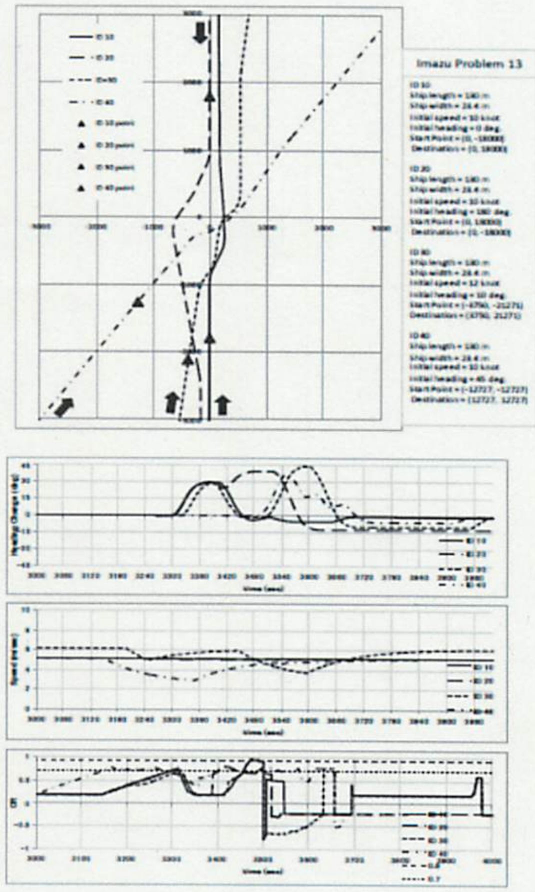


Fig. 3 Automatic Collision Avoidance Manoeuvres for Case No. 13 in Imazu Problem (Phase I) [11] done by MTSS (version 2013) [7-8, 21-48] where the

upper graph shows ship trajectories and the lower graph shows time histories of heading angle, ship speed and collision risk (*CR*) from the top respectively. Give-way ship will take collision avoidance manoeuvre, when if *CR* exceeds 0.7 and even stand-on ship will take collision avoidance manoeuvre, when if *CR* exceeds 0.9 and the point it is called "near-miss". Fig. 4 shows the result of the same case with Fig. 3, but drawn as relative (head-up) trajectories for each ship respectively.

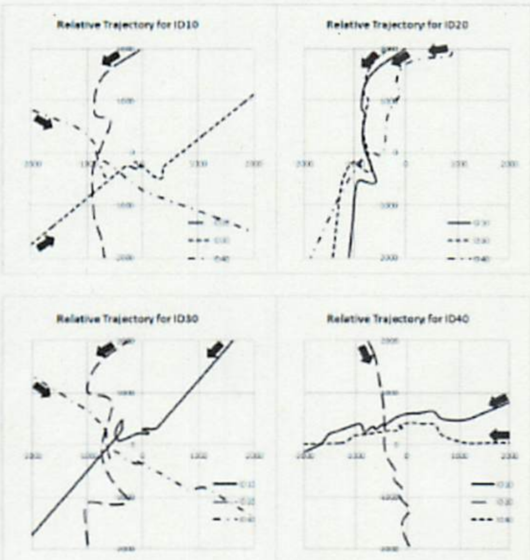


Fig. 4 Automatic Collision Avoidance Manoeuvres for Case No. 13 in Imazu Problem (Phase I) [11] done by MTSS (version 2013) [7-8, 21-48] where relative (head-up) trajectories for each ship respectively

3. QUALITATIVE AND QUANTITATIVE EVALUATION OF CONGESTED WATERWAYS [12]

MTSS can now reproduce a realistic marine traffic flow regarding not only waypoint navigation but also collision avoidance once OD (origin-destination) table is given. OD table creation is a kind of statistical data process and varies based on the area to be simulated. Some statistic database of ports and waterway observation (counting ships passing gate lines) records etc. will be utilized, but now automatic OD table creation and update system based continuous AIS data collection or access to the archive will be under developed.

However, even if the realistic marine traffic is reproduced, how should it be analysed and evaluated? Normally relative evaluation such as comparing an alternative plan with the original plan is done for a given area. It is quite difficult to evaluate objectively beyond the different areas.

Fig. 5 is a sample result of reproduced marine traffic done by MTSS.

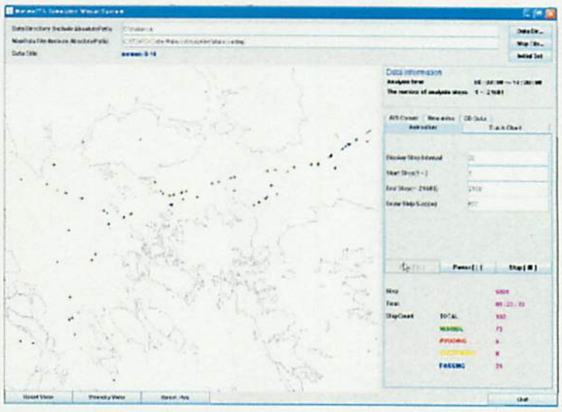


Fig. 5 Maritime Traffic Simulation in Singapore Strait (2008) [10].

After analysing such simulation results, we can evaluate the waterway by certain indices such as near-miss, collision or any other one, if it is considered appropriate. Fig. 4 is an example using near-miss and it is compared between southern area approaching to Tokyo Bay, Singapore Strait and off Shanghai. It is obvious the difference, but it is hard to compare. Is Singapore Strait nearly 18 times dangerous that Southward of Tokyo Bay and is off Shanghai 7 times dangerous than Singapore Strait?

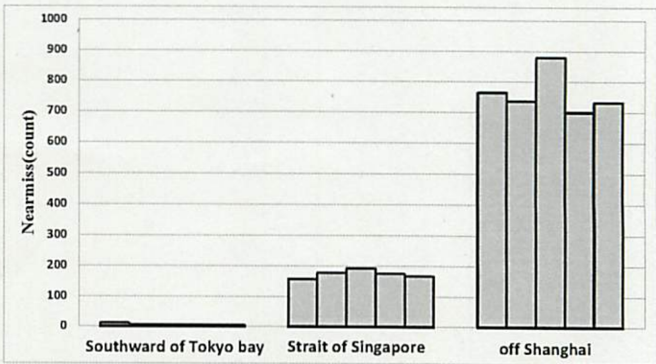


Fig. 4 The number of near-misses by simulation [12]

To answer this question, Fig. 5 is made. It is evaluated in logarithm scale against logarithm scale of traffic density defined by number-of-ship per unit area and unit time [12].

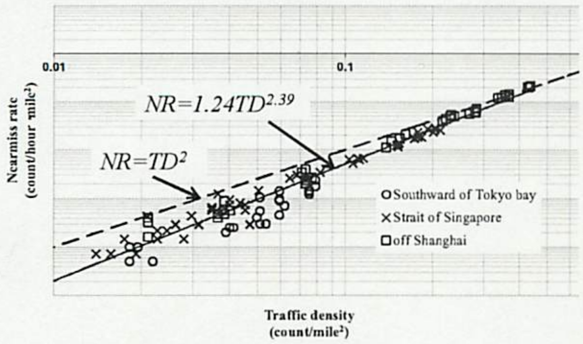


Fig. 5 The traffic volume allowance degree [12]

4. ACCIDENT ANALYSIS

4.1 Bridge Resource Simulation System [18]

Bridge Resource Simulation System is newly developed tool to analyse accidents which have occurred by some miss judgement of crew members [18]. The model is applied for the stranding of *Costa Concordia*. Fig. 6 is the incident overview, and Table 1 is the scenario of the accident. A software is developed using Prolog to simulate the scenario automatically following Table 1. It is still concept stage, there is a possibility to use this kind of accident simulation system treating human conception or communication.

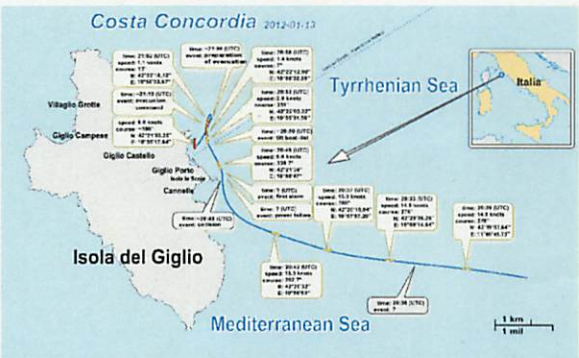


Fig. 6 Timeline representation of the accident of Costa Concordia [19]

Table. 1 Variable parameters of the Prolog code explaining the decisions, agreements and tasks of crew of the ship [19]

Organizational Decisions	Work Place or External Influences/Decisions	Captain Decisions	SOOW Decisions	JOOW Decisions	Helmsman Decisions
Organizations have specific guidelines for changing voyage plan and requires prior approval. ~~O1. allow_change_in_voyage_plan~~ O2. do_not_allow_change_in_voyage_plan ~~O3. allow_without_prior_approval~~ O4. do_not_allow_without_prior_approval	The mentor of the captain was in the Giglio Island. Also the hotel manager requested the captain to make a change in the voyage plan. W1. tribute_to_mentor W2. change_in_voyage_plan	Captain may make the following decisions: C1. change_in_voyage_plan C2. no_prior_approval C3. informal_procedure C4. no_ins C5. rudder_orders C6. danger_observed C7. no_danger	SOOW thinks this is an informal voyage so he may decide the following: ~~S1. plan_on_small_scale_charts~~ S2. plan_on_large_scale_charts S3. use_ins S4. ins_alarm_furthest_point_from_echo ~~S5. ins_alarm_10m_line~~ S6. no_crew_challenge S7. danger_observed S8. no_danger	JOOW thinks this is also an informal voyage so he may decide the following: ~~J1. crew_challenge~~ J2. no_crew_challenge J3. danger_observed J4. no_danger	Not considered.
		Captain Agrees	**SOOW Agrees**	**JOOW Agrees**	
		CA1. Captain agrees whatever SOOW decides regarding voyage plan/charting *(CA1 = S1 or S2)*	SA1. SOOW agrees to whatever captain decides as it is an informal voyage.	JA1. JOOW Agrees whatever the Captain/SOOW orders him.	
				JOOW Task	**Helmsman Task**
				JT1. Help SOOW fixing ship position on paper chart. JT2. Assist helmsman in translating the conning orders.	HT1. Execute whatever Captain/SOOW commands for navigating the ship

Table. 2 Errors Table (Errors are based on the study of reference [20]).

	First Error	Second Error	Third Error		Fourth Error	Fifth Error	Sixth Error	
Description	The captain decides to change the original voyage plan just few hours before the voyage. This is because his mentor was in Giglio island and he was influenced by the Hotel manager.	Limited time and informal practice resulted in incomplete route planning on large-scale paper charts.	The route monitoring on paper chart was done by JOOW. Firstly, she didn't have "planned larger charts" to fix ships position and detect any danger. Secondly, she left route monitoring and went to assist Helmsman as there was language barrier.		Route monitoring on INS had a fundamental flaw. Chart alarm was set to go on if the radar distance is 2000m or less. The alarm was not set for crossing 10m bathymetric line.	At the final stage of the approach the Captain took over command form SOOW. But SOOW didn't challenge. Captain's intentions and expected outcomes were not clear. Because of the presence of guests and hotel manager his role as a team leader was not fulfilled. Nobody thus challenged captain's decision.	When the Captain took over the control from SOOW, valuable time was lost. Within that very short span of time the ship crossed safety contour from 0.5 Nautical mile to 0.28 nautical mile. The captain was relying on eyesight and until he sees the first rock his rudder order was very little.	Accident
Logical Relations	*(W1, W2) = C1* *(O2, O4, C1, C2) = C3*	*(Limited Time, C3, CA1) = S2* *CA1 = S1 or S2*	When JT1 *S2 = J3 Or J4* *J4, C3 = J2*	When JT2 *JA3, C3 = J2*	*S4, JA1*	*S3 = S7 or S8* *~~S3~~, C4 = C7*	*C7 = C5*	

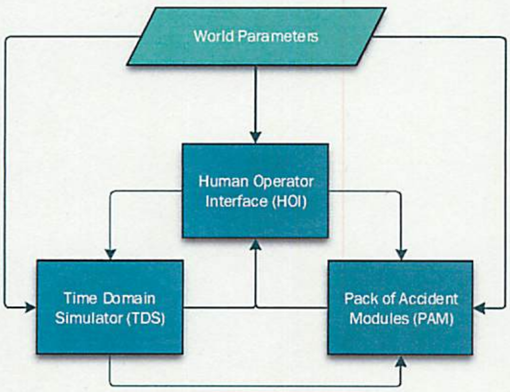


Fig. 7 Basic composition of the model [19]

5. SHIP MOTION IN TSUNAMI [16]

Marine traffic simulation system will be a key issue when we consider next generation marine traffic model. It will be a powerful tool to plan and evaluate the system.

Fig. 8 Port Onahama

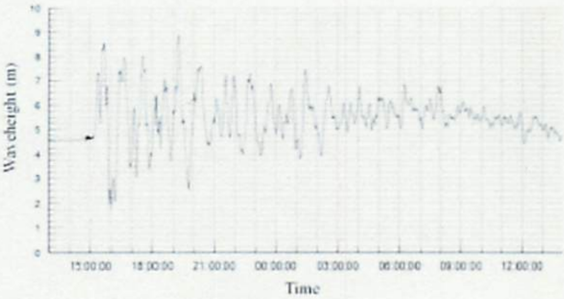


Fig. 9 Tsunami Height Observation at Port Onahama by Japanese Meteorology Agency

Fig. 10 Ship Positions and Trajectories After 30 min. of Tsunami Warning Measured by AIS [19]

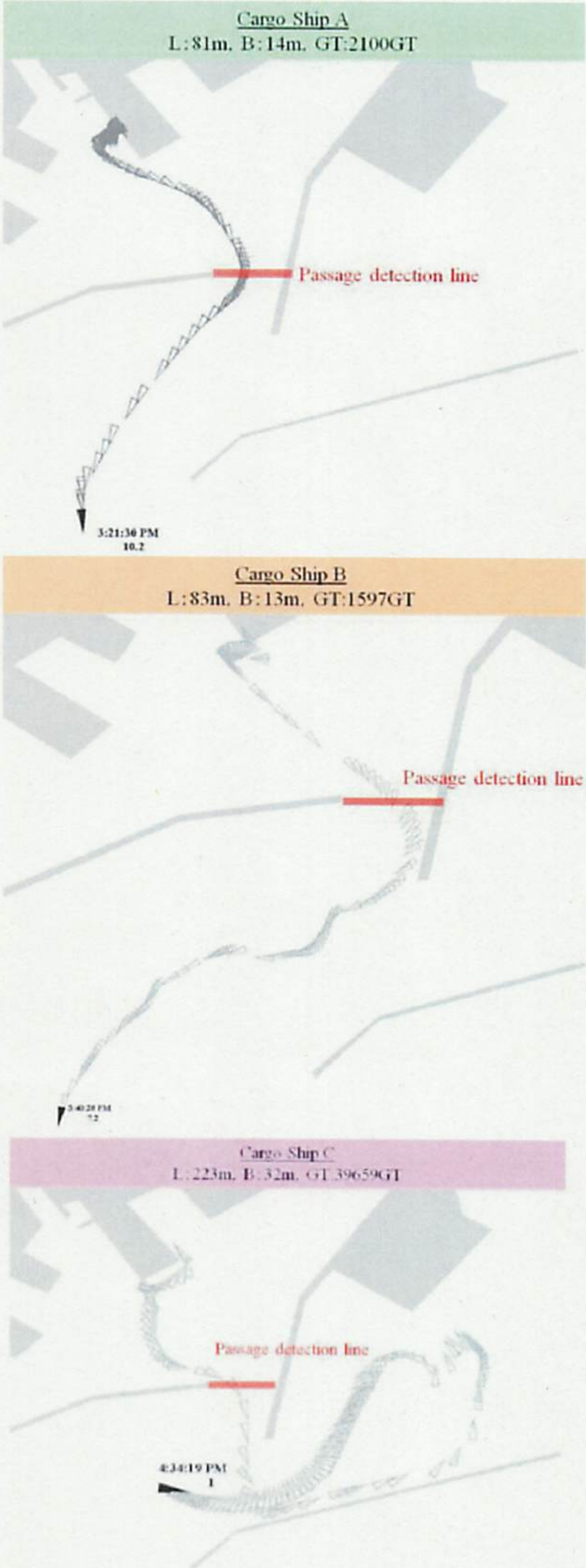


Fig. 11 Three Ships' Trajectories with Different Evacuated Time After The Tsunami Warning [19]

6. LOW SPEED MANOEUVRABILITY AND ITS MATHEMATICAL MODELS [13-15]

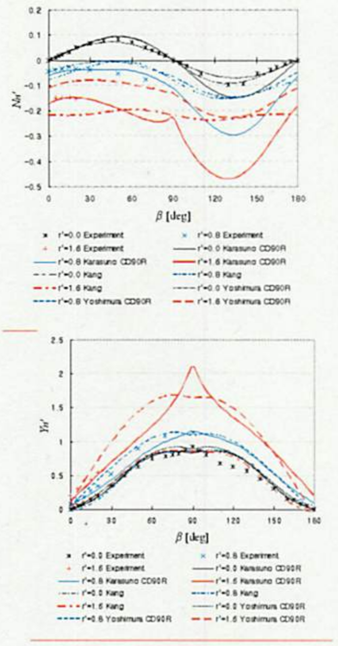


Fig. 12 Ship Manoeuvring Hydodynamic Forces and Moment with Wide Range of Drift Anglue (0 -> +/-180°) and Yaw Range [13].

7. AUTOMATIC BERTHING USING ARTIFICIAL NEURAL NETWORK (VERSION 2013) [17]

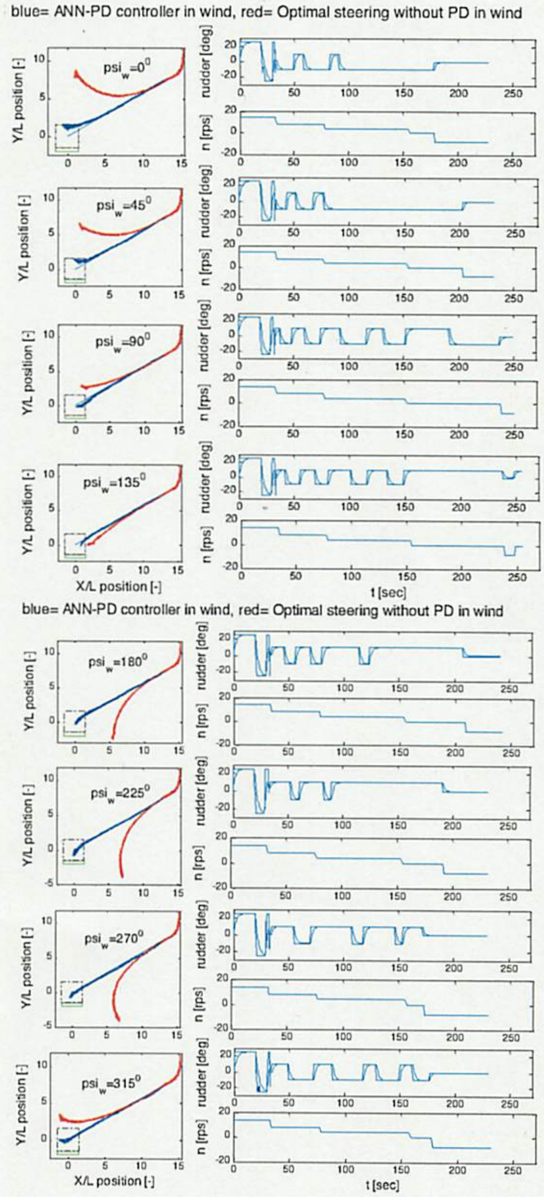


Fig. 13 Simulation Results of Automatic Berthing Using Artificial Neural Network Combined with Nonlinear Programing to Create Consistent Teaching Data Set (Version 2013) with Various Wind Conditions [17]

8. CONCLUSION

Some recent works done after the last workshop in Shanghai is introduced. Ship manoeuvrability and controllability is quite important in various situations.

Development of CFD will give very important insight for various situations, but still many experimental works should be done to understand the phenomena.

Mathematical model for low speed manoeuvring is still minor subject in ship manoeuvrability, but many things are not yet revealed.

AIS is the very useful tool for various problems and there are many challenging topics related.

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REFERENCS

[1] K. Hasegawa: Some Recent Researches on Next Generation Marine Traffic Models and Its Applications, Proc. of International Workshop on Next Generation Marine Traffic Model, Shanghai, Sep., 2012.

[2] K. Hasegawa, J. Fukuto, T. Takimoto and M. Yamazaki: Safety Assessment of Marine Traffic by Intelligent Marine Traffic Simulation (in Japanese), J. JIN, 125, pp. 33-41, Sep., 2011.

[3] J. Fukuto, K. Hasegawa and F. Sakai: Introduction of an Automatic Collision Avoidance Function to a Ship Handling Simulator (in Japanese), J. JIN, 125, pp.63-71, Sep., 2011.

[4] K. Hasegawa, K. Matsubara and F. Sakai: Intelligent Ship Handling Simulator and its Availability for Ship Casualties Analysis (in Japanese), Proc. JASNAOE, Nov., 2011.

[5] J. Fukuto, K. Hasegawa, R. Miyake and M. Yamazaki: Ship handling simulator for assessing on-board advanced navigation support systems and services --- Introduction of intelligent ship handling simulator ---, Proc. MARSIM 2012, Singapore, Apr., 2012.

[6] K. Hasegawa, J. Fukuto, R. Miyake and M. Yamazaki: An Intelligent Ship Handling Simulator with Automatic Collision Avoidance Function of Target Ships, Proc. 17th International Navigation Simulator Lecturers Conference (INSLC), Rostock, Germany, Sep., 2012.

[7] Marine Traffic Simulation System: Invention Registration No. C-201200006, Osaka University, March 1, 2013.

[8] Marine Traffic Simulation Program: Software Registration No. P-10215, National Maritime Research Institute, April 5, 2013.

[9] K. Hasegawa: First Experiment of Intelligent Ships, Press Release, Jan 25, 2001.

[10] K. Hasegawa: Demonstration at The 8th International Conference on ITST, pp.18-23, Phuket, Thailand, Oct., 2008.

[11] H. Imazu: Research on Collision Avoidance Manoeuvre (in Japanese). PhD Thesis, University of Tokyo, Japan, 1987.

[12] K. Hasegawa and M. Yamazaki: Qualitative and Quantitative Analysis of Congested Marine Traffic Environment – An Application Using Marine Traffic Simulation System, Proc. of 10th Jubilee International Conference TransNav 2013 on Marine Navigation and Safety of Sea Transportation, Gdynia, June, 2013.

[13] K.-G. Oh and K. Hasegawa: Ship Manoeuvring Hydrodynamic Forces and Moment in Low Speed, Proc. Of 5th Paames and AMEC 2012, Taipei, Sep., 2012.

[14] K.-G. Oh and K. Hasegawa: Low Speed Ship Manoeuvrability - Mathematical Model and Its Simulation, Proc. of 32th International Conference on Ocean, Offshore and Arctic Engineering, OMAE 2012, Nantes, France, June, 2013.

[15] K. Hasegawa, K.-G. Oh, Y. A. Ahmed and P. Rigo: Ship Manoeuvring Behaviour in Crossing Current, Proc. of International Conference on Ship Manoeurability in Shallow and Confined Water: Ship Behaviour in Locks, Paper No. SBL047-1-7, Ghent, Belgium, June, 2013.

[16] H. Makino, E. Kobayashi and K. Hasegawa: Analysis of Ship Evacuation in Tohoku Tsunami Using AIS Data (in Japanese), Proc. of Japan Society of Naval Architects and Ocean Engineers (JASNAOE) Spring Meeting, Hiroshima, May, 2013.

[17] Y. A. Ahmed and K. Hasegawa: Automatic Ship Berthing using Artificial Neural Network Trained by Consistent Teaching Data using Non-Linear Programming Method, Artificial Intelligence, IFAC, to be published in 2013 or 2014.

[18] Z. I. Awal and K. Hasegawa: Bridge Resource Simulator – A New Tool for Ship Accident Analysis, J. of Japan Society of Naval Architects and Ocean Engineers, to be published in 2013 or 2014.

[19] Wikipedia Article: Costa Concordia disaster, http://upload.wikimedia.org/wikipedia/commons/2/23/Costa_Concordia_map_13-1-2012.svg.
[20] Di Lieto, Antonio: Costa Concordia Anatomy of an organisational accident, http://www.enavinternational.com/wosmedia/273/costaconcordiaanatomyofanorganisationalaccident.pdf.

The following author's papers are introduced in [1], but listed again for your future reference and all references are downloadable from his homepage at http://www.naoe.eng.osaka-u.ac.jp/~hase/.

[21] K. Hasegawa and A. Kouzuki: Automatic Collision avoidance System for Ships Using Fuzzy Control (in Japanese), J. The Kansai Society of Naval Architects of Japan (KSNAJ), 205, pp.1-10. June, 1987.
[22] K. Hasegawa: Automatic Collision Avoidance System for Ships Using fuzzy Control, Proc. Eighth Ship Control Systems Symposium (SCSS), 2, pp.34-58, The Hague, The Netherlands, Oct., 1987.
[23] K. Hasegawa: Fuzzy Modelling of the Behaviours and Decision-Making of Ship Navigators, Proc. 3rd International Fuzzy Systems Association (IFSA) Congress, pp.663-666, Seattle, Aug. 1989.
[24] K. Hasegawa, A. Kouzuki, T. Muramatsu, H. Komine and Y. Watabe: Ship Auto-navigation Fuzzy Expert System (SAFES) (in Japanese), J. Society of Naval Architects of Japan (SNAJ) 166, pp.445-452, Dec. 1989.
[25] K. Hasegawa: Automatic Navigator-Included Simulation for Narrow and Congested Waterways, Proc. Ninth SCSS, 2, pp.110-134, Bethesda, Md., U.S.A., Sep., 1990.
[26] K. Hasegawa: An Intelligent Marine Traffic Evaluation System for Harbour and Waterway Designs, Proc. 4th International Symposium on Marine Engineering Kobe '90 (ISME KOBE '90), pp.(G-1-)7-14, Kobe, Oct., 1990.
[27] K. Hasegawa and Y. Fujita: An Extension of Ship Auto-navigation Fuzzy Expert System for Safety Assessment of Narrow Waterway Navigation (in Japanese), J. KSNAJ, 220, pp.129-133, Sep., 1993.
[28] K. Hasegawa: Knowledge-based Automatic Navigation System for Harbour Manoeuvring, Proc. Tenth SCSS, pp.2:67-90, Ottawa, Oct., 1993.
[29] K. Hasegawa, T. Takimoto and I. Hayakawa: Reconfiguration of Ship Auto-navigation Fuzzy Expert System (SAFES) (in Japanese), Proc. Spring Meeting of KSNAJ, pp.191-196, May, 1997.
[30] K. Hasegawa, Y. Shigemori and Y. Ichiyama: Feasibility Study on Intelligent Marine Traffic System, Proc. 5th IFAC Conference on Manoeuvring and Control of Marine Craft (MCMC) 2000, pp.327-332, Aalborg, Denmark, Aug., 2000.
[31] K. Hasegawa, S. Kiritani and K. Tachikawa: Evaluation of alternative sea lane plans using congested sea area traffic simulator (in Japanese), Proc. Spring Meeting of KSNAJ, pp.71-74, May, 2001.
[32] K. Hasegawa, G. Tashiro, S. Kiritani and K. Tachikawa: Intelligent Marine Traffic Simulator for Congested Waterways, Proc. 7th IEEE International Conference on Methods and Models in Automation and Robotics, Miedzyzdroje, Poland, Aug., 2001.
[33] K. Hasegawa and K. Tachikawa: Marine Traffic Simulator and Marine ITS (in Japanese), Proc. of the 2001 Symposium of Kansai Branch, pp184-189, The Society of Instrument and Control Engineers (SICE), Osaka, Japan, Oct., 2001.
[34] K. Hasegawa: Some Recent Developments of Next Generation's Marine Traffic Systems, Proc. IFAC Conference on Control Applications in Marine Systems, (CAMS) 2004, pp.13-18, Jul., 2004.
[35] K. Hasegawa, K. Hata, M. Shioji, K. Niwa, S. Mori and H. Fukuda: Maritime Traffic Simulation in Congested Waterways and Its Applications, Proc. The 4th Conference for New Ship and Marine Technology (New-STech) 2004, pp.195-199, Shanghai, China, Oct., 2004.
[36] K. Hasegawa, K. Niwa, S. Mori, H. Fukuda, M. Shioji and K. Hata: Simulation-based Master Plan Design and Its Safety Assessment for Congested Waterways Management, Proc. International Maritime Conference on Design for Safety, pp.265-270, Sakai, Japan, Oct., 2004.
[37] K. Hata, K. Hasegawa, K. Niwa and H. Fukuda: AIS Simulator and ITS Applications, Proc. 48th International Symposium ELMAR-2006, pp.223-226, Zadar, Croatia, Jun., 2006.
[38] K. Hata, J. Fukuto, K. Hasegawa and K. Niwa: Evaluation of AIS Communication Using AIS Simulator -Influence of Installation Condition for Class B AIS- (in Japanese), J. Japan Institute of Navigation (JIN), 117, pp27-33, Sep., 2007.
[39] K. Hata, K. Hasegawa and K. Niwa: AIS simulator (in Japanese), J. Japan Society of Naval Architects and Ocean Engineers (JASNAOE), 6, pp.91-98, Dec., 2007.
[40] S. Watanabe, K. Hasegawa and P. Rigo: Inland Waterway Traffic Simulator, Proc. 7th International Conference on Computer and IT Applications in the Maritime Industries, (COMPIT)'08, pp.578-588, Liege, Belgium, Apr., 2008.
[41] K. Hasegawa, K. Hata, K. Niwa, and J. Fukuto: Transmission Evaluation of Ship-borne Automatic Identification System (AIS) in Congested Waterways, Proc. The 8th International Conference on ITST, pp.18-23, Phuket, Thailand, Oct., 2008.
[42] K. Hasegawa: Advanced Marine Traffic Au

[43] tomation and Management System for Congested Waterways and Coastal Areas, Proc. the International Conference In Ocean Engineering (ICOE) 2009, Feb., 2009.
[44] F. Sakai, K. Hasegawa, K. Niwa and K. Hata: Marine Traffic Simulation of the Straits of Malacca and Singapore, (in Japanese), J. JIN,122, pp.91-96, Mar., 2010.
[45] K. Hasegawa and E. Fu: Marine Traffic Simulator and its Application of Safety Assessment in Huangpu River of Shanghai, The 15th Academic Exchange Seminar between Shanghai Jiao Tong University and Osaka University, Oct. 2010.
[46] K. Hasegawa, J. Fukuto, M. Yamazaki and M. Shigematsu: Feasibility Study On Utilizing AIS For Future Marine Traffic Managing System (in Japanese), Proc. JASNAOE, May, 2012.
[47] T. Takimoto, K. Hasegawa J. Fukuto, R. Miyake and M. Yamazaki: Marine Traffic Simulation Based on AIS Data (in Japanese), Proc. JASNAOE, May, 2012.
[48] T. Nakano and K. Hasegawa: . Proc. Manoeuvring and Control of Marine Crafts (MCMC) 2012, Arenzano, Italy, Sep., 2012.
[49] T. Nakano, K. Hasegawa, K. Niwa and K. Hata: Effect of Collision Avoidance Algorithm in Marine Traffic Simulation, Proc. Autumn Meeting, JIN, Nov., 2010.