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Development of a Collision Risk Assessment System for Optimum Safe Route

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최적안전항로를 위한 충돌위험도 평가시스템의 개발

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Abstract : *In coastal waters where the traffic volume of the ship is high, there is a high possibility of a collision accident because complicated encounter situations frequently occurs between ships. To reduce the collision accidents at sea, a quantitative collision risk assessment is required in addition to the navigator's compliance with COLREG. In this study, a new collision risk assessment system was developed to evaluate the collision risk on ship’s planned sailing routes. The appropriate collision risk assessment method was proposed on the basis of reviewing existing collision risk assessment models. The system was developed using MATLAB and it consists of three parts: Map, Bumper and Assessment. The developed system was applied to the test sea area with simple computational conditions for testing and to actual sea areas with real computational conditions for validation. The results show the length of own ship, ship’s sailing time and sailing routes affect collision risks. The developed system is expected to be helpful for navigators to choose the optimum safe route before sailing.*

Key Words : *Encountering situations, Collision risk, Sailing route, Collision risk assessment, Bumper, Domain, Optimum safe route*

요 약 : 선박의 통행량이 많은 연안해역은 선박들 사이에 복잡한 조우상황이 자주 발생하기 때문에 충돌사고의 가능성이 높다. 따라서 해상에서 충돌사고를 줄이기 위해서는 항해사의 국제충돌예방규칙(COLREG) 준수에 더하여 정량적인 충돌위험평가가 요구된다. 본 연구에서는 선박의 계획항로에 대한 충돌위험을 평가하기 위한 새로운 충돌위험도 평가시스템이 개발되었다. 먼저 기존의 충돌위험 평가모델들을 검토함으로써 적절한 충돌위험 평가방법이 제시되었다. 시스템은 MATLAB을 사용하여 개발되었으며 해도, 범퍼 및 평가의 세 부분으로 구성된다. 개발된 시스템은 시험을 위해 간단한 계산조건으로 시험해역에 적용되었으며, 그리고 검증을 위해 실제 계산조건으로 실제해역에 적용되었다. 그 결과 충돌위험은 자선의 길이, 항해시간 및 항로 등에 의해 영향을 받는 것으로 나타났다. 개발된 시스템은 항해사가 출항전 최적안전항로를 선택하는데 도움을 줄 수 있을 것으로 기대된다.

핵심용어 : 조우상황, 충돌위험, 항로, 충돌위험평가, 범퍼, 점용영역, 최적안전항로

1. Introduction

In coastal waters where the traffic volume of the ship is high, there is a high possibility of a collision accident because a complicated encounter situation frequently occurs between ships. The number of Korean merchant ships was increased by 531 (49.0 %) from 1,083 in 2008 to 1,614 in 2017 (e-Nation Index, 2018), while the number of world merchant ships was increased by 7,630 (17.1 %) from 44,553 in 2008 to 52,183 in 2017 (Statista, 2017). In addition, the number of ship’s collision in Korea was increased from 74 in 2013 to 100 in 2017, and among these, the ratio of collision in Korean territorial waters is 81 % in 2013 and 91 % in 2017 (KMST, 2017).

This tendency of collision accidents is not limited to only Korea. According to the European maritime accident statistics, the ratio of collision for the entire marine accidents is 16 % during

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2011 to 2016, which is higher than other accident types, and the ratio of marine accidents on coastal waters is also very high amounting around 67 % (EMSA, 2017).

In order to effectively reduce the ship accidents in coastal and offshore waters, e-navigation projects are being carried out globally. In case of Korea, the Korean e-navigation project has been launched since 2016 with a plan to establish the system by 2020. The e-navigation system includes various services for the safety of ship, but the most important one is the optimum safe route service, which requires an evaluation of the collision risk for planned sailing route.

Thus, the purpose of this study is to develop a system which can be used to assess the collision risk of planned route quantitatively. The developed system can help navigators to select an appropriate route as a decision supporter.

There are several attempts to assess the risk of ship's collision. Fujii and Tanaka (1971) firstly proposed the concept of "Ship Domain (or Bumper)", certain area around a ship where the ship is regarded possessing a collision risk when another ship enters. The ship domain was also used in Traffic Congestion Model (Fujii et al., 1981) for evaluating the traffic congestion of waterway, and later, the size and shape of ship domain was modified to evaluate the risk of collision between ships in specific area (Zhao et al., 1993; Efficient Sea, 2012; Lee, 2017).

Inoue et al. (1997) developed Environmental Stress (ES) model to quantify the subjective burdens felt by navigators according to the distance from shore and ships. Later, Park et al. (2013) developed the Potential Assessment of Risk in Korea (PARK) Model which is upgraded version of ES model for Korean navigation conditions.

In Europe, the International Association of Lighthouse Authorities (IALA) Waterway Risk Assessment Program (IWRAP) was developed to compute the collision probability based on traffic volume and channel information (Friss-Hansen, 2008). Jeong et al. (2012) confirmed the usefulness of IWRAP model by applying it to the entrance waterway to Mokpo Port and comparing the results of Vessel Traffic Service (VTS) officer's viewpoint. Thanh et al. (2015) also applied IWRAP model to Malacca Strait and evaluated the collision risks in channels by applying new probabilistic distribution instead of existing normal distribution used for traffic volume assessment.

2. Existing collision risk assessment models

This chapter introduces existing collision risk assessment models and compares their features.

2.1 ES model

The ES model was developed by Inoue (1997). The Subjective Judgment (SJ) felt by navigator from topographic and traffic environments during ship operation is quantified and expressed it as ES of Land (ES_L) and ES of Ship (ES_S).

The ES_S is computed using Equation (1). Based on own ship's heading, the model searches the angles of 0～90° port and starboard side. And the time remaining to a land is calculated with own ship speed, and the time remaining to a ship is calculated with the speed between own ship and another. Here, the less the time remaining, the greater the burden which is the SJ felt by navigator (Gong, 2003).

$$SJ_L,\ SJ_S = \alpha \times TTC + \beta = \alpha \times (R/V) + \beta$$
$$ES_A = \sum_i^n \max((SJ_L)_i, (SJ_S)_i) \quad (i = -90 \sim +90) \qquad (1)$$

SJ_L, SJ_S : SJ of Land and Ship

α : Factor for own ship length in topographic environment

β : Factor for average length between two ship in traffic environment

TTC : Time remaining to detected obstacle (s)

R : Distance between own ship and obstacle (m)

V : Relative speed between own ship and obstacle (m/s)

Later, Inoue (2000) computed the ESs for typical encounter types as the ratio of head-on case. Here, the encounter situations are divided into 45° intervals based on heading of own ship, and the ES_S of each encounter type is calculated under certain conditions. Table 1 shows the ESs for each encounter type computed by ES model.

Table 1. The ES_S for typical encounter types

Encounter Type	ES_S
Head on	1.0
Crossing 45°	1.14
Crossing 90°	1.71
Crossing 135°	3.01
Overtaking	0.72
Overtaken	2.46

2.2 IWRAP model

The IWRAP model is recommended by IALA to use in waterway traffic assessments and it calculates the annual collision and stranding probability. As shown in Equation (2), annual collision probability is expressed as the product of the number of annual collision candidates (N_C) and causal probability (P_C) (Friss-Hansen, 2008).

$$P = N_C \times P_C \tag{2}$$

The number of annual collision candidates is calculated with topographic information including the width and depth of waterway, annual vessel traffic volume, and traffic information including the relative speed of vessels. The causation probability means the probability of inability to avoid accidents (Friss-Hansen, 2008). Table 2 shows standard values in IWRAP. IWRAP provides the causation probabilities of various researchers including Fujii and Mizuki (1998) and appropriate values can be selected according to sea area (Friss-Hansen, 2008).

Table 2. Causation probability of IWRAP

Researchers and locations	Encounter type	P_C ($\times 10^{-4}$)
Fujii and Mizuki (Japanese straits)	Head-on	0.49
	Crossing	1.23
	Overtaking	1.10
IWRAP	Head-on	0.5
	Crossing	1.3
	Overtaking	1.1

2.3 Traffic Congestion model

The traffic congestion model is an advanced model where the concept of bumper (Fujii and Tanaka, 1971) is applied to compute the traffic capacity of Japanese waters (Fujii and Tanaka, 1971). Using this model, traffic congestion of a channel per unit of area-time can be obtained, and Equation (3) shows the ratio of maximum traffic capacity to actual traffic volume (Kim et al., 2017).

$$S = \frac{Q_T}{Q_p} \times 100 \tag{3}$$

Q_T : Actual traffic volume

Q_P : Maximum traffic capacity

The traffic congestion model predicts the bottlenecks in channels and the risk of collision between ships. However, since the risk of collision cannot be obtained without considering the encounter relationship between vessels, the model cannot evaluate the collision risk quantitatively.

2.4 PAWSA model

United States Ports and Waterways Safety Assessment (PAWSA) model was developed by United States Coast Guard (USCG) during establishing new VTS system. The model assesses the risk of local port and waterway through the brainstorming of experts in the area.

For qualitative brainstorming quantitatively, the weights to the experts are given for the evaluation elements. The evaluation elements consist of six main risk factors including marine traffic conditions and waterway conditions and four sub-factors under main risk elements, viz. 24 risk factors. The professional weights of expertise are categorized into the top, middle and low classes based on their background and experience. For each factor, the risk value is the product of the risk score and the expertise weight given by each expert (USCG, 2010).

Although PAWSA model considers different traffic characteristics of the area, each risk can be assigned differently according to the individual viewpoints. Thus, it can not be considered as a quantitative collision risk assessment model.

2.5 Comparison of each model

So far, four typical collision risk assessment models were reviewed. Those models has different characteristics in their purpose, quantitative and qualitative assessment, and the consideration for encounter situation.

First of all, the assessment area is varied upon four models. Because SJ in ES model is computed for 0~360° bearing, it can be computed everywhere and applicable for wide sea area. Conversely, collision probability in IWRAP model is computed for every leg (the line between two waypoints) and traffic volume in Traffic Congestion model is computed for square area, those are suitable for restricted waterways. On the other hand, assessment unit in PAWSA model could be variable by the target area.

Secondly, four models have difference in quantitative and qualitative assessment. ES, IWRAP and Traffic Congestion models evaluate the collision risk quantitatively. The SJ in ES model and the causation probability in IWRAP model can be considered as the value of collision risk. Although the traffic volume in Traffic

Congestion model is qualitative it could not be considered as collision risk because that is not the figure reflecting encounter situation. PAWSA model is a qualitative model using discussion.

Lastly, ES and IWRAP models provide the risk value for each encounter type. ES and IWRAP model also have complementary relationship. Therefore, Kim et al. (2011b) applied two models to Ulsan Port waterway. Conversely, Traffic Congestion model does not reflect encounter situation and PAWSA model assigns different risk values according to viewpoints of experts. Table 3 shows the result of comparison for four models.

Table 3. Comparison of models

	ES	IWRAP	Traffic Congestion	PAWSA
Purpose area	Sea area	Restricted Waterway	Restricted Waterway	Port and waterway
Indicator	Subjective burden	Causation Probability	Traffic volume	24 risk factors
Unit of assesment	Bearing	Leg	Area	-
Quan./Qual.	Quantitative	Quantitative	Quantitative	Qualitative
Encounter situation	Reflected	Reflected	Not Reflected	-

3. Development of collision risk assessment system

3.1 Basic theories for assessment system

In this section, basic theories concerned to collision risk assessment system are introduced.

3.1.1 Ship domain model

The concept of ship domain is the area surrounding own ship with certain dimension. If other ship enters this domain, it is considered that own ship has a collision risk. The concept of ship domain was firstly proposed by Fujii et al. (1971) and then Goodwin (1975) and Coldwell (1983) confirmed the existence of the ship domain and presented their own domain models. Later, Fujii and Mizuki (1998) proposed the revised ship domain model of which the domain size is changed by ship's speed. The ship domain model is very important and useful concept in marine traffic engineering and it has been used widely in traffic simulation models, for encounter criteria, traffic lane design criteria, VTS planning, risk assessment, collision avoidance, and for other applications (Zhao et al., 1993).

In this study, the ship domain model of Fujii and Mizuki (1998) is adopted to assess the collision risk of own ship against other ship, because its size is changed by ship's speed and the shape is symmetrical right and left which can be easily applied to the assessment system. The size of this model is determined by two kinds of ship's speed, such as 'navigation speed' and 'maneuvering speed'. Here, the navigation speed is used in open waters while the maneuvering speed is used in restricted waters such as waterway. For navigation speed, the domain size is 8.0L in the course direction and 3.2L in the lateral direction and, for maneuvering speed, 6.0L in the course direction and 1.6L in the lateral direction as shown in Fig. 1. where L is ship's length (m).

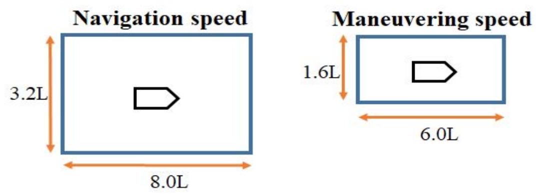

Fig. 1. Ship domain of Fujii and Mizuki (1998).

3.1.2 Collision risk index

Many researchers presented the collision risk index (CRI) such as Fujii and Mizuki (1998), Inoue (2000), Kim et al. (2011a), and Kim and Lim (2016), etc. As stated earlier, Inoue (2000) computed the ES_S values for typical encounter types as the ratio of head-on case.

In this study, the ES_S values are adopted as CRI for the collision risk assessment system, because it considers all encounter situations including overtaken and the ES model is well-known and being used widely for collision risk assessment.

As shown in Table 1, the ES_S values are given for encounter types such as head-on, crossing 45°, crossing 90°, crossing 135°, overtaking and overtaken. For the angle of which the CRI value is not given such as the angle between 0° and 45°, the CRI value is computed by interpolation algorithm. The Fig. 2 shows the computed CRI values according to crossing angles.

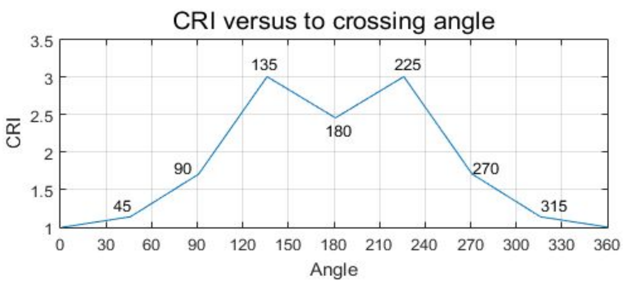

Fig. 2. CRI values versus to crossing angle.

If the speed of own ship is faster than the speed of other ship and own ship is approaching to other ship with the angle between 112.5° and 247.5° based on other ship, it is considered as overtaking and the CRI value is set to 0.72. Here, the angle between 112.5° and 247.5° reflects 'Rule 13, Overtaking' in COLREG.

3.2 Configuration of assessment system

A collision risk assessment system was developed with MATLAB and it consists of three parts such as Map, Bumper and Assessment part. Map part displays the area map using m-map Package (UBC, 2018). The Fig. 3 shows the flow chart in each part of collision risk assessment system.

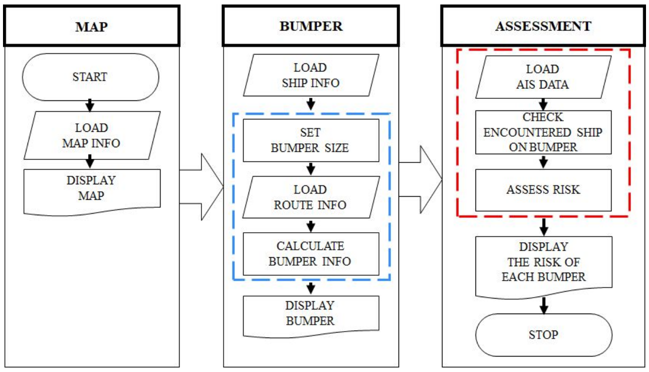

Fig. 3. Flowchart of collision risk assessment system.

Bumper part computes bumpers (or ship domains) with ship and route information and displays the computed bumpers on the route. Bumpers are numbered in ascending order from departure position (Bumper number) and the number of bumpers deployed on the route is varied upon ship's length. For example, the number of bumpers of length 50m is doubled compared to that of length 100m. Assessment part identifies encounter situation on the planned route based on Automatic Identification System (AIS) data and computes the sum of CRI values (Collision risk) in each bumper, and finally displays the results with colors from light blue to magenta after converting the values into the percentile. Here, the maximum value among the collision risks in bumpers is assigned as 100 of percentile.

4. Test and validation of collision risk assessment system

To examine the effectiveness of collision risk assessment system, test and validation were performed respectively. Firstly, the test of the system was done in test sea area with relatively simple computing conditions to check whether the model is running properly or not. Secondly, the validation of the model was done in actual sea area with complex computing conditions to confirm the applicability of the system. Table 4 shows the summary of computing conditions for both test and validation.

Table 4. Conditions for test and validation

Purpose	Test	Validation
Area	Ulsan approach	Busan to Yeosu
Route	Optional route	Actual route
Sailing time	Not considered	Considered
AIS data	1 day	10 days

4.1 Test of collision risk assessment system

The test sea area of the system is Ulsan Port approaching area. This area has a high risk of collision because the encounter types of arriving and departing vessels are very complicated (MOF, 2015). The Fig 4 shows the results of system run for test sea area.

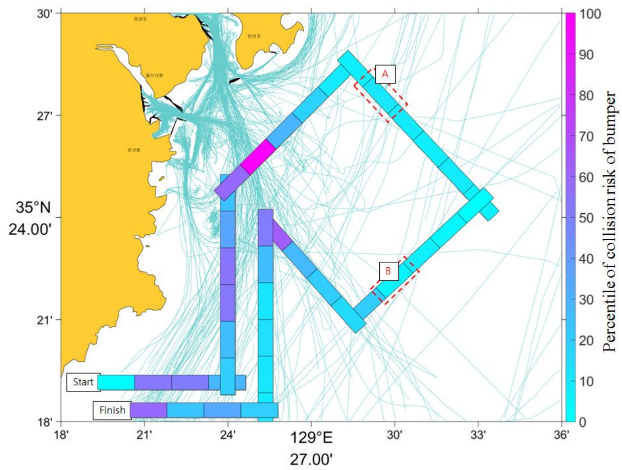

Fig. 4. The results of system run for test sea area.

For test of the system, an artificial 8-azimuth test route was used. The AIS data for 1 day of 21st May, 2015 were used for system run and the sailing time was not considered for computation. From the results of computation as shown in Table 5 and 6, it was confirmed that the encounter angle of ships were well identified and the collision risk in each bumper was correctly computed. Here, Bumper A and B are arbitrarily selected to check the CRI calculation results, which is to confirm the CRI calculation results for all the crossing situations as possible.

Table 5. Collision risk computation for bumper A

Bumper A							
MMSI	UTC	t-spd	o-spd	t-cog	o-cog	c-angle	CRI
353116000	02:23:02	11.6	16.5	016.9	136.9	060.03	1.33
440084000	12:22:44	6.7	16.5	192.8	136.9	235.93	0.72
440100670	19:05:33	6.8	16.5	196.1	136.9	239.23	0.72
440106310	13:16:23	11.8	16.5	067.2	136.9	110.33	2.30
440121010	11:51:58	11.0	16.5	016.2	136.9	059.33	1.32
440140050	19:28:50	3.9	16.5	119.6	136.9	162.73	0.72
Sum							7.11

Table 6. Collision risk computation for bumper B

Bumper B							
MMSI	UTC	t-spd	o-spd	t-cog	o-cog	c-angle	CRI
273442740	12:15:56	11.9	16.5	046.0	227.0	359.00	1.10
304019000	21:09:55	15.0	16.5	033.5	227.0	346.50	1.11
352879000	03:19:52	15.7	16.5	127.0	227.0	080.00	1.58
354374000	20:11:43	8.6	16.5	209.6	227.0	162.60	0.72
440109610	01:59:48	10.1	16.5	211.0	227.0	164.00	0.72
440113900	08:50:37	9.4	16.5	044.1	227.0	357.10	1.10
Sum							6.33

Table 5 and 6 show the results of collision risk computation for bumper A and B. Here, 't-', o-, and 'c-' mean 'target ship', 'own ship' and 'crossing', respectively.

4.2 Validation of collision risk assessment system

There are not many vessel transits in bumper A, but some crossing vessels exist. The sum of CRI was calculated as 7.108 for bumper A and 6.339 for bumper B.

For this study the actual sea area for validation of the system was the area from Busan to Yeosu along the southern coast of Korea. This area has much traffic due to major trading ports and fishing ports and linked to Pacific Sea and South China Sea (MOF, 2010). For validation of the model, the actual sailing conditions were applied. For example, actual sailing route, sailing time, and AIS data for 10 days were used to compute the collision risk on the planned route. Kang et al. (2017) found that Korean marine traffic has seasonal characteristics and Korean Maritime Traffic Safety Diagnosis Scheme and Inoue and Hara (1973) require more than 7 days traffic data for marine traffic investigation. Therefore, we used 10 days AIS data for the period of 15 to 24 April 2017, standing for spring.

To consider the sailing time, the time when own ship arrives at each bumper (bumper time) is calculated and AIS data of ships which are passing through the bumper for 30 minutes before and after bumper time are extracted. Then, collision risk of the bumper is computed. The Fig. 5 shows the results of system run for actual sea area. In the figure, the collision risk increases from light blue to magenta.

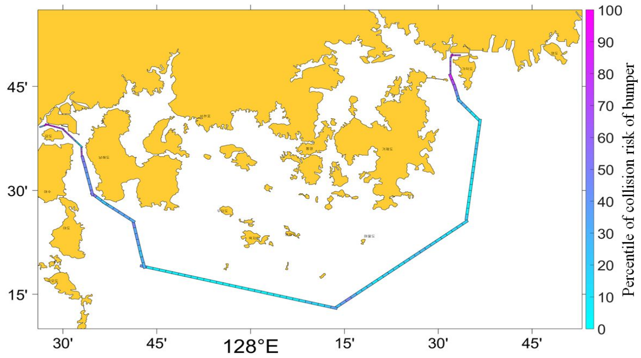

Fig. 5. The results of system run for actual sea area.

4.2.1 The collision risks according to ship's length

To check the difference in collision risk according to ship's length, the collision risks were computed by varying the length of own ship to 50, 100 and 200m, respectively. The Fig. 6 shows the results of computed collision risk for various ship's length.

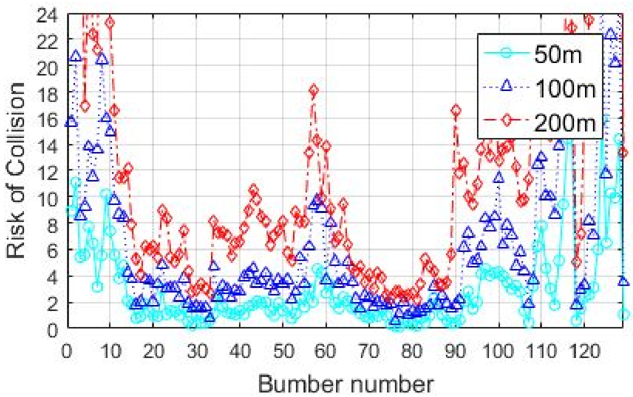

Fig. 6. Collision risks according to ship's length.

The bumper number on X-axis are assigned in ascending order from departure to arrival position. The number of bumpers is varied upon ship's length on a route. To compare the computed results for different ship's length, the computed results of length 50m and 100m are processed with the method of systematic sampling to meet the number of bumpers of length 200m. So the bumper number of departure and arrival position is 0 and 129, respectively.

From the figure, it can be observed that the larger the ship the higher the collision risk and particularly ship of length 200m has great risk. Thus, the length of own ship could be an important factor to be considered when the route planning is made.

4.2.2 The collision risks according to ship's sailing time

To check the difference in collision risk according to ship's sailing time, the collision risks were computed by varying the departure time of ship to 12:00, 15:00, 18:00, and 21:00 UTC, respectively. The Fig. 7 shows the results of computed collision risk for various departure times.

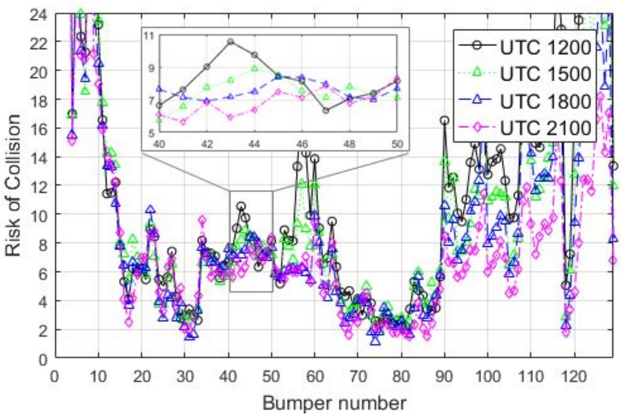

Fig. 7. Collision risks according to ship's sailing time.

In the figure, it is shown that the collision risk varies depending on departure time and particularly the collision risk is large at departure time of 12:00 and 15:00 UTC. For reference, the time of 12:00 UTC represents for night. Thus, ship departure time could be another important factor to be considered before sailing is made.

4.2.3 The collision risks according to routes

To check the difference of collision risk according to sailing routes, collision risks for actual and recommended route were computed. Here, the actual route is one used by a large container ship on the spot. The recommended route is one modified manually from actual route after considering the traffic flow, water depth and distance from shore. The model ship has length 250m and draft 11.6m. First of all, recommended route is chosen avoiding main traffic flow where own ship encounter other vessels frequently. And water depth only over 12.76m and minimum 0.5miles off from shore were adopted for safe navigation. Fig. 8 shows actual and recommended route on map and Fig. 9 shows the result of collision risk assessment of both route.

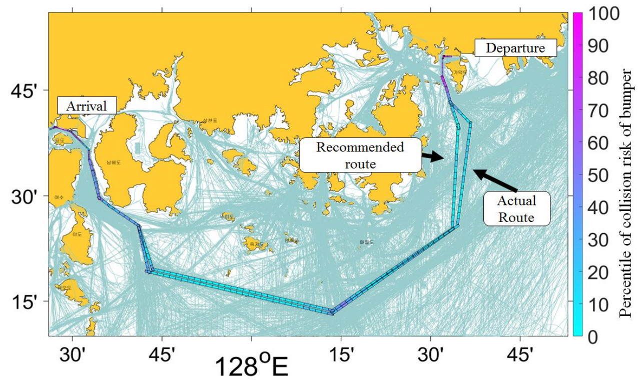

Fig. 8. Actual and recommended route

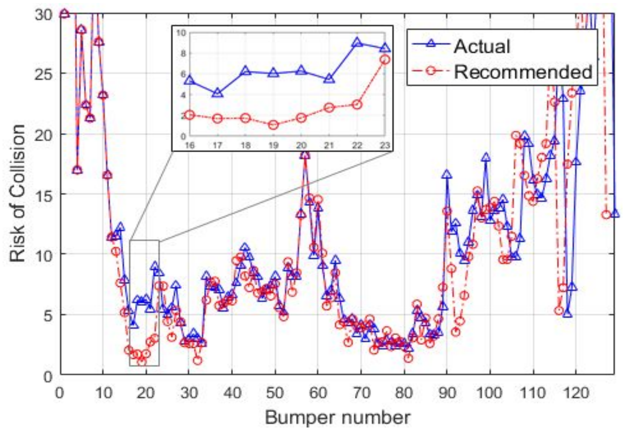

Fig. 9. Collision risks according to sailing routes.

In above figure, it is shown that the collision risks of recommended route are about 7.46% lower than those of actual route over entire section. But, in section of bumper No. from 16 to 23, the collision risks of recommended route are lower about 57.67% compared to those of actual route. This suggests that the collision risk assessment system can be used for selecting the optimum safe route if an automatic algorithm to produce the optimum safe route is added.

5. Conclusion

The increase in the number of ships and complex encountering situations between ships in coastal waters are estimated to contribute for increasing the collision accidents. To reduce the collision accidents at sea, the quantitative collision risk assessment is required in addition to navigator's compliance with COLREG. The existing collision risk assessment tools are suitable to evaluate the collision risks for specific area and waterway, but not suitable to evaluate the collision risks on planned sailing route. Therefore, in this study, a collision risk assessment system was developed consisting three parts such as map part to display the area map, bumper part to compute the bumper size from own ship and route information, and assessment part to compute and display the sum of CRI in each bumper from AIS data, respectively.

For the test of this system, it was applied to test sea area with simple computational conditions and confirmed that the system did run normally. Also, to check the validation of the system, it was applied to actual sea area with complex computational conditions, same to actual sailing conditions as possible, and confirmed that the system also work satisfactorily. Furthermore, to investigate the difference in collision risks according to the length of own ship, ship's sailing time and sailing routes, various experiments were performed, and got useful results.

The developed collision risk assessment system has only the functions of computing the collision risk on planned sailing route and of showing the results. But, if an automatic algorithm to produce the optimum safe route is developed in future study, the system can be used as like the navigation system in road traffic. The limitation of developed system is that it cannot take into account vessels which are not equipped with AIS (e.g. small vessels), because it runs based on AIS data.

Acknowledgements

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References

[1] Efficient Sea(2012), Analysis of the near-collisions using AIS data for the selected locations in the Baltic Sea, p. 4.

[2] EMSA(2017), European Maritime Safety Agency, Annual overview of marine casualties and incidents 2017, p. 20, p. 24.

[3] e-Nation Index(2018), Status of dominant fleet of major shipping countries (in Korean), http://www.index.go.kr/potal/main/EachDtlPageDetail.do?idx_cd=1262.

[4] Friss-Hansen, P.(2008), Basic Modelling Principles for Prediction of Collision and Grounding Frequencies, Technical University of Denmark.

[5] Fujii, Y. and K. Tanaka(1971), Traffic Capacity, Journal of Navigation, Vol. 24, No. 1, pp. 543-552.

[6] Fujii, Y., T. Makishima and K. Hara(1981), Marine Traffic Engineering (in Japanese), Kaibundo, p. 45, pp. 119-129.

[7] Fujii, Y. and N. Mizuki(1998), Design of VTS systems for water with bridges, Proc. of the International Symposium on Advances in Ship Collision Analysis. Gluver & Olseneds, Copenhagen, Denmark, 10-13 May, 1998, pp. 177-190.

[8] Gong, I. Y.(2003), A Review on the Characteristics of Environmental Stress Model for Maritime Traffic Safety Assessment (in Korean), Journal of Korean Navigation and Port Research, Vol. 27, No. 5, pp. 479-486.

[9] Inoue, K. and K. Hara (1973), Detection Days and Level of Marine Traffic Volume, Japan Institute Navigation, Vol. 50, pp. 1-8.

[10] Inoue, K., M. Kubono, M. Miyasaka and D. Hara(1997), Modeling of Mariners' Perception of Safety when Being Faced with Imminent Danger (in Japanese), The Kansai Society of Naval Architects of Japan, Vol. 97, pp. 235-245.

[11] Inoue, K.(2000), Evaluation Method of Ship handling Difficulty for Navigation in Restricted and Congested Waterways, Journal of Navigation, Vol. 53, No. 1, pp. 167-180.

[12] Jeong, J. S., K. I. Kim and G. K. Park(2012), A Quantitative Collision Probability Analysis in Port Waterway (in Korean), Journal of Korean Institute of Intelligent Systems, Vol. 22, No. 3, pp. 373-378.

[13] Kang, W. S., T. H. Song, Y. D. Kim and Y. S. Park(2017), A Study on Seasonal Variation in Marine Traffic Congestion on Major Port and Coastal Routes (in Korean), Journal of the Korean Society of Marine Environment and Safety, Vol. 23, No. 1, pp. 1-8.

[14] Kim, J. S., Y. S. Park, T. Y. Heo, J. Y. Jeong and J. S. Park(2011a), "A Study on the Development of Basic Model for Marine Traffic Assessment Considering the Encounter Type between Ships" in Korean, Journal of the Korean Society of Marine Environment and Safety, Vol. 17, No. 3, pp. 227-233.

[15] Kim, S. T., H. K. Rhee and I. Y. Gong(2017), Improving Assessments of Maritime Traffic Congestion Based On Occupancy Area Density Analysis for Traffic Vessels (in Korean), Journal of the Korean Society of Marine

Environment and Safety, Vol. 23, No. 2, pp. 153-160.
[16] Kim, D. S. and J. B. Lim(2016), A Study on the Collision Risk Perception Index to OOW's According to Vessel Encountering Situations (in Korean), Journal of the Korean Society of Marine Environment and Safety, Vol. 22, No. 1, pp. 98-107.
[17] Kim, D. W., J. S. Park and Y. S. Park(2011b), Comparison Analysis between the IWRAP and the ES model in Ulsan Waterway, Journal of Korean Navigation and Port Research, Vol. 35, No. 4, pp. 281-287.
[18] KMST(2017), Korea Maritime Safety Tribunal, The White paper of Accident 2017 (in Korean).
[19] Lee, J. S.(2017), The Development of the Ship Collision Risk Model from the VTSO's Viewpoint (in Korean), Korea Maritime and Ocean University, Graduate school, PhD Dissertation.
[20] MOF(2010), Ministry of Oceans and Fisheries, Finding the risk factors of marine traffic in South Sea and preparing countermeasures (in Korean), p. 15.
[21] MOF(2015), Ministry of Oceans and Fisheries, Summary Report for Ulsan Port (in Korean), p. 8.
[22] Park, Y. S., J. S. Kim and V. Aydogdu(2013), A Study on the Development the Maritime Safety Assessment Model in Korean Waterway (in Korean), Korean Journal of Navigation & Port Research, Vol. 37, No. 6, pp. 567-574.
[23] Statista(2017), Number of ships in the world merchant fleet between January 1, 2008 and January 1, 2017, by type, https://www.statista.com/.
[24] Thanh, N. X., Y. S. Park, J. S. Park and T. G. Kim(2015), A Study on the Marine Traffic Assessment based on Traffic Distribution in the Strait of Malacca, Journal of the Korean Society of Marine Environment and Safety, Vol. 21, No. 1, pp. 25-33.
[25] UBC(2018), University of British Colombia, "m_map", https://www.eoas.ubc.ca/~rich/map.html.
[26] USCG(2010), United State Coast Guard, Introduction to PAWSA.
[27] Zhao, J., Z. Wu and F. Wang(1993), Comments on Ship Domains, Journal of Navigation, Vol. 46, pp. 422-436.

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