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A Study on the Improvement of Myeongnyang Waterways' Traffic Separation Scheme

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명량수도의 통항분리방식 개선에 관한 연구

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Abstract : *The fairway within the area of Yul-do and Songdo located near the Myeongnyang-sudo approaches south of Mokpo harbor is well guided by traffic separation scheme and other navigational aids. However, that part of the waterways where Yul-do is located sits at the cross-roads of marine traffic and is subjected to some potential risks in the voyage navigation: the effect of climatic phenomenon, the disregard of most ships in using the western sector of the fairway creating a congestion in the eastern sector, and lastly, the disadvantageous effect of the location and height of Yul-do island that hinders good lookout. This study investigates the environmental conditions that prevailed in the area in the span of 5-year period and the marine traffic situation taken from the data within the 72-hour period. The navigational hazards and marine casualties are also be presented. The results are analyzed and are made the basis of a proposal for an improved separation of traffic. Thereafter, an evaluation is carried out by using the components of marine traffic flow simulation and ES modeling index. It is evaluated through simulation by the use of full-mission ship handling simulator.*

Key Words : *Traffic separation scheme, Marine traffic, Navigational hazards, Marine traffic flow simulation, Environmental stress index model, Full-mission ship handling simulation*

요 약 : 명량수도 인근에 위치한 율도와 송도 해역의 항로는 통항분리대와 항로표지에 의해 잘 정비되어 있다. 그러나 율도 해역은 해상교통이 교차하고 있을 뿐만 아니라 항해에 잠재적 위험성이 있다. 안개 등의 기상 현상, 서측 통항대를 이용해야 하는 선박의 대부분이 동쪽 통항대를 이용하여 혼잡을 야기하기 하고 있으며, 율도의 위치와 높이로 인해 시야를 가리고 있기 때문이다. 이 논문은 통항분리대를 개선하여 수역에서의 항행을 효과적으로 가이드 하고자 한다. 이 연구에서는 지난 5년간의 환경 여건과 72시간 동안의 해상교통조사를 실시하고, 항해 위험과 해양사고를 도출하며, 그 결과를 분석하여 통항분리대 개선을 위한 기초 자료로 사용한다. 통항분리대 개선안에 대해 ES 모델 지표를 사용한 해상교통류시뮬레이션과 전기능 선박조종시뮬레이션을 이용하여 평가한다.

핵심용어 : 통항분리방식, 해상교통, 항행위험, 해상교통류시뮬레이션, 환경스트레스모델, 전기능선박조종시뮬레이션

1. Introduction

The waterways leading to Mokpo area experience an increase in maritime traffic movements(Kristiansen, 2005). Different types, classes and sizes of sea crafts use these waters for different and various reasons. Mokpo harbor likewise experiences adverse weather conditions that affect navigation.

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Because of its topography, the volume of maritime traffic, the effects of the natural phenomenon and the existing structures for the safe navigation of the tributaries leading to Mokpo area, the incidence of risk to navigation is now more than likely.

The subject of this study is the navigable channel in the area surrounding the Myeongnyang-Sudo. It is well guided by traffic schemes and navigational aids. The western fairway of Yul-do is designated for north-bound deep-draught vessels (DW) offering a good depth of water. The eastern and western sectors of the fairway are both designated as "two-way" channels. This area is also a cross-road of traffic by sea crafts from Hok Su-do to the tributaries of Jin-do; vessels going in and coming out of Myeongnyang-Sudo passage; North-bound traffic from Jeongdeung-Hae passage and from South-bound ships from Sia-Hae passage all converge in this area.

This study proposes an effective use of the traffic lanes in the existing TSS in the area surrounding the Myeongnyang - Sudo by analyzing the environmental and traffic situations including the climatic conditions. It identifies the navigational hazards and reviews the marine casualties that occurred in the area. It also illustrates the density of marine traffic in a given period by the ship's tonnage and types. Thereafter, the proposal was tested and evaluated quantitatively by using the marine traffic flow modeling and environmental stress value model, and further simulated using the Full Mission Ship-Handling simulator.

The major concerns that this study proposes to give solution to, were:

1) The restricted visibility due to fog and rain that descends to the area at certain times of the year.

2) Ships traversing through the area, either on a northerly or southerly passage, do not use the western part of the traffic separation scheme and navigate through the eastern sector instead. The western lane is also designed for deep-draught vessels and both lanes are "two-way" route system.

3) Another serious concern is the obstruction of the height of Yul-do that causes a blind sector and hinders good lookout for vessels coming from the south.

Of these questions can be asked: What complications may occur if all the hazards mentioned descend to a ship at the same time? What can be done to minimize the risks and avoid any accident? What are the best measures to control and mitigate this risk and make full use of the traffic separation scheme in the area?

This paper emphasizes these effects to the safety of navigation in the subject area and shall be one of the major concerns and the object of this study.

2. Analysis of Environmental and Traffic Conditions

2.1 Analysis of Environmental Conditions

The recorded average air temperature in the area in a 5-year period is 13.8 °C. It is warmer than the average air temperature of 12.4 °C that is prevalent in the whole Korean peninsula(Gwangju Regional Meteorological Administration, 2003-2009).

The rainfall concentration around Mokpo area is greater in the summer season. The average amount of rainfall for the year is 1,304.76 mm. It is less than the southern coast of the peninsula which averages 1,400 ~ 1,800 mm.

The average annual wind velocity for the year is 3.67 m/s. It is stronger in the winter season compared to the other seasons for the year(4.4 ~ 4.7 m/s)(Korea Hydrographic and Oceanographic Administration, 2009). Maximum wind speed is less than 10 m/s in summer season and mostly southerly direction. In winter season, the maximum wind speed is around 10 ~ 15 m/s and is mostly toward North or Northwest direction.

The area surrounding Mokpo and its approaches are known to experience poor visibility at certain period. The annual average fog days for the year are 23.4 days. Mokpo area has fewer fog days than the West coast average(at Incheon, 47.8 and at Kunsan, 44.6). It also shows that it has more fog days than East coast average(Kangnung 10.2, Busan 19.4).

The numerous islands within the Mokpo sea area affect the behavior of tidal current. The ebb tide is stronger than flood tide. The direction of flood tide is Northerly from Jeongdeunghae and Myeongnyang-sudo to Myendo-sudo, Mokpo-gu and Aphaedo sea areas with an average of 4.0 knots while it is mostly SSW'ly to SW - W'ly around Sihahae during the ebb tide with 5.1 knots average strength.

The nav-aids installed in the subject area are the Gu-do Lighthouse N 34 34.1, E 126 11.9(F l4s, 29 m, 8 M) and the existing channel east and west of Yul-do island is marked by lighted buoys numbered from No. 9 to No. 18 with characteristics of Fl(2)6s "G" for port hand and "R" for the stbd hand following the System B regime.

2.2 Analysis of Navigational Hazard Elements

There are shallow patches with 15.3 m and 15.9 m depths in the navigational fairway between Gu-do and Song-do (Table 1).

2.3 Analysis of Marine Casualties

There were a total of three cases of collision and one case of grounding accidents that occurred in last five years (2002 ~ 2006). Only collision and grounding accidents(Traffic accident) were presented in this report because the improvement of the fairway passage was the primary aim of this study(Fig. 1).

Table 1. List of navigational hazards

Ave depth	N Bound	23.0~31.0 m
	S Bound	23.0~31.0 m
	DW	23.0~41.0 m
Reef	None	
Low depth	N Bound	Patches of 15.3 & 15.9m bet Gudo and Songdo
	S Bound	None
	DW	None
Nav aids	Nos. 9-18 Iso danger buoys Gudo Is. has a light(Fl4s29m8M)	

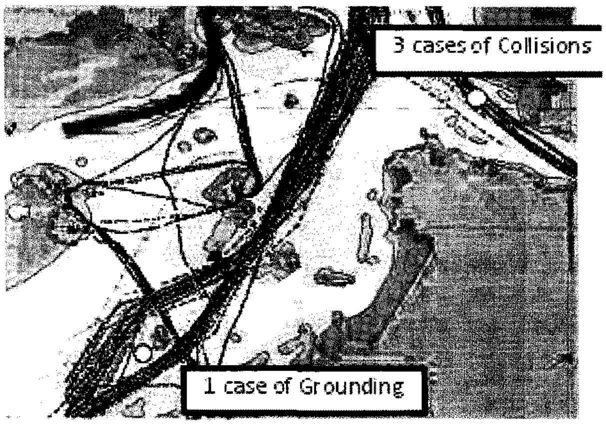


Fig. 1. Location of sea casualties.

2.4 Survey of Marine Traffic Volume

In the present situation, mostly passenger ships and small crafts use the Myeongnyang Strait. Vessel movements from entering and departing ships are passing through the area around Yul-do.

Investigation of tracks in a 5-year period showed that large vessels of more than 10,000 tons that entered or departed Mokpo Port mostly did not use the route for deep draught vessel(DW) on the western sector of the fairway at Yul-do. These vessels commonly use the channel route on the eastern part between Yul-do and Song-do. Most of the ships that enter the port or leave Mokpo Harbor are observing the designated route at the east of Yul-do.

However, some ships of 1,000 ton to 10,000 ton donot observe regulatory route regardless of class and tonnage. The reasons given for their actions were that the channel between Jakdo and Yul-do(western track) is not wide enough for a two-way traffic at the second altering point in the vicinity of Jak-do. Likewise, vessels coming from the south, while using the western sector of the fairway on a northerly direction, experience a blind sector of traffic coming from the north on a southerly course. This is due to the height of Yul-do which obscures the direct line of sight which produces an extra burden on navigation because it increases the risk of collision and/or close-quarter situations for the vessels using the western sector of the fairway coming from the south.

Furthermore, the present "two-way" system of transit in the fairway for both the eastern and the western sectors of the traffic separation scheme around the Yul-do increase the risk of collision. As was previously stated, most ships used the eastern sector of the fairway, thereby creating a convergence of traffic at this area and further escalating the risk by the presence of crossing sea-crafts coming from different direction within the tributaries from both sides of the channel.

In a 72-hour investigation, ships use Myeongnyang Strait and adjacent area comprised a total of 66 ships where an average of 22 ships passed through the subject area in a day. 32 vessels were tracked on a northerly direction while 34 vessels on southerly courses. The 1,000-3,000 ton ships and the 3,000-5,000 tonnage ships showed the frequent passers of about 22 % followed not so distantly by the lower tonnages of 500-1,000 ships at about 17 %.

By ship types, general cargo and passenger ships both have about 45 % each and the tanker vessels were accounted at a farther distance for 9 %.

For the same period of observation, the survey also showed that the frequency of transit in the Myeongnyang strait and adjacent areas, irrespective of northerly nor southerly direction, were higher at 10 am, 11 am and 5 pm. The average passage was about 3 ships per hour. Level of marine traffic congestion in peak time is 0.2682 and the value of tolerance limit is within 1.0000.

The maximum tonnage of vessels entering Samhak, Daebul, and Mokpo new port is around 30,000 DWT. Vessels over 50,000 DWT were only maneuvering from Hyundae Samho Heavy Industry and Sabjin Industry for sea-trial cruises

3. Improvement in the Use of the Traffic Separation Scheme(TSS)

3.1 Main Factors for Improvement

The focus of TSS improvement is to separate the usage of north-bound lane at the eastern sector between the Yuldo and Songdo and a separate route shall be assigned for ships on southerly direction at the western sector of Yuldo. The western route shall, also, be designated for vessels constrained by their draft, regardless whether they are on northerly or southerly direction. This lane offers more depth than the eastern sector which has two patches of 15.3 and 15.9 meters at the middle of the track(Table 2).

Table 2. Consideration of fairway arrangement

Considerations	Propriety
Ship motion dynamics	OK
Land marking efficiency	OK
Feasibility of lineable sea route	OK
Semi-diameter of fairway curve 5 times bigger than ship's LOA. (If possible, 10 times bigger)	OK
5 times of lineable fairway versus ship's LOA if there has bridge or narrow fairway	OK

3.2 Width of Fairway

The study referred to the different existing fairway arrangements and thereby met their qualifications of propriety as shown in Table 3.

Existing data for the width of fairway standards for 30,000 DWT vessels are described in Table 3. The 800 meters suggested width of the proposed route in the fairway satisfies the standards.

3.3 Water Depth

Based on requirements of the PIANC rule, the water depth found in the proposed route has enough room of at least 120% versus draft of the sample vessel when it ran with high speed in the fairway where swell flows from the quarter part of the vessel. In the waiting area of the subject sea area, 115% of the draft of the vessel is required. Water depth criterion is summarized at Table 4.

For arriving vessel, the existing eastern section of Yul-do fairway is used. The consideration is done by applying Draft + 0.15 D. The calculated available draft of the vessel is based on the least depth of 15.3 m found at the eastern sector of the fairway. For vessels constrained by draft, the western sector(deep-water) is the route recommended.

Table 3. Existing standards on fairway width

Organization proposer	VLCC (300 k DWT Class)		
	N Bound fairway (m)	S Bound fairway (m)(DW Route)	Propriety
Chosun general doctrine	265-293	265-293	OK
Amjeongcheong	288-345	288-345	OK
United Nations conference on trade and development	288	288	OK
The joint working group PIANC and IAPH, cooperation with IMPA and IALA	109-414	109-414	OK
Gregory P. Tsinker	207-345	207-345	OK
Fairway standards (Korea and Japan)	315	315	OK
Fairway standards (United States)	161-357	161-357	OK

Table 4. Water depth as to type of sea area

Sea area	Required water depth
Open sea	Draft+0.2 D
Waiting area	Draft+0.15 D
Fairway	Draft+0.15 D
Berthing and un-berthing	Draft+0.15 D

4. Evaluation by Marine Traffic Flow Simulation

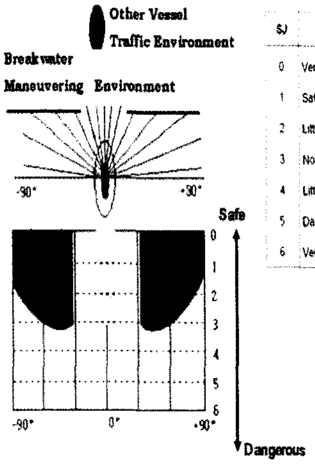
In this section, marine traffic flow simulation was performed for the proposed separate traffic lanes at Myoungyang-Sudo. The results of the simulation were evaluated by applying quantitative index(Environment Stress Model) for the representative marine traffic flow (Inoue and Park, 2002).

4.1 Evaluation Index Model

In order to maintain marine traffic safety, it is important to evaluate how much effect on the interaction and relationship among ship, operator, and environment has on each other. Herein, Environment Stress model, ES model(Fig. 2), is used to evaluate the interaction and relationship among these three factors and, thereafter, presents the result quantitatively.

Maneuvering Environment Stress(Load) can be defined as the stress or load on the ship operator brought upon him by the different maneuvering environment such as the maneuvering area and of the obstacles therein, while, Traffic Environment Stress(Load) is a stress or load by the traffic environment such as traffic volume and size. Therefore, the Environment Stress model(ES model) assesses and represents both Maneuvering Environment Stress(Load) and Traffic Environment Stress(Load) quantitatively.

The value of Maneuvering Environment Stress(Load) and Traffic Environment Stress(Load) can be mentioned as "Value of Land ES" and "Value of Ship ES" respectively. Finally, the combination of the values obtained in each equation is defined as "Value of Aggregation ES".



SJ	Mariner's Judgment	ES value	Stress Ranking	Acceptance Criteria
0	Very safe	0-500	Negligible	Acceptable
1	Safe	500	Marginal	
2	Little safe	750	Critical	Unacceptable
3	Normal	900	Catastrophic	
4	Little Dangerous	100		
5	Dangerous			
6	Very Dangerous			

$$ESL = \sum_{\psi}(w_{\psi}(R/V)_{land} \rightarrow S/L)$$

$$ESS = \sum_{\psi}(w_{\psi}(R/V)_{ship(i)} \rightarrow \max[S/S_i])$$

$$ESA = \sum_{\psi} \max(S/L, S/S)$$

Fig. 2. Marine traffic flow simulation model.

4.2 Result of Traffic Flow Simulation in the Proposed Separate Lane

Fig. 3 and Fig. 4 are the results of Value of Aggregation ES for the existing route and for the proposed route in the surrounding area of separate traffic lane in Myoungnang-Sudo.

In the existing route graph, Fig. 3, showed the result of the Value of Aggregation(ESA) was high due to the crossing situations between entering and departing vessels and because of the narrow parallel passing distance created by the two-way system in the existing route designation.

While in the proposed route arrangement(Fig 4) the Value of Aggregation(ESA) was found to be below the 750 ES value for Critical and Unacceptable level.

Therefore, the graph showed that it is clear of the dangerous levels and thus acceptable, supporting the proposal of a separated traffic lanes.

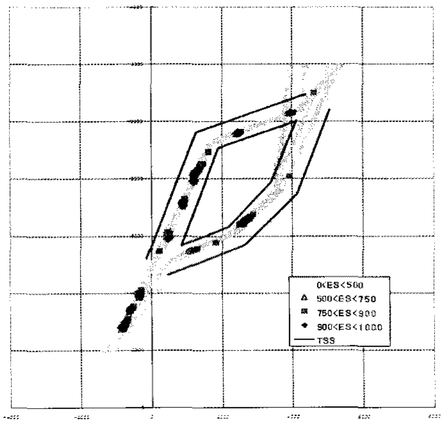


Fig. 3. Distribution for value of aggregation ES(Existing route).

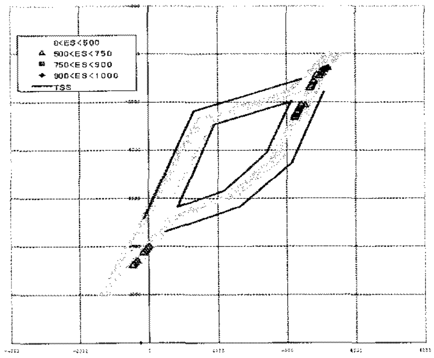


Fig. 4. Distribution for value of aggregation ES(Proposed route).

5. Evaluation by Full Mission Ship Handling Simulator

5.1 External condition in performing the simulation

External condition in this task included higher values for wind, tidal current and wave height. The values used are from National Oceanographic Research Institute showing environmental conditions described in Table 5.

This test proved the efficiency of steady course and course changeability including spiral test, zig-zag test, and turning test. The maneuvering test for speed changeability is performed by acceleration test, crash stop test, and coasting test.

In addition, International Maritime Organization(IMO) established a Maneuverability Standard in order to prevent casualties and oil pollution of the sea, which is shown in Table 6.

Table 5. Environmental condition for simulation

Items	North bound vessel	South bound vessel
Model Ship	30000 DWT vessel,	30000 DWT vessel,
Wind (Knots)	NW, 26 knots	NW, 26 knots
Current (Knots)	Max. Flood 010°, 4.0 knots Max. Ebb 230°, 5.1 knots	Max. flood 010°, 4.0 knots Max. ebb 230°, 5.1 knots
Wave(m)	1.5 m	1.5 m

Table 6. Ship's maneuverability standard(IMO)

Items	IMO standards
Condition	Deep water, Full load test speed, Calm environment
Turning ability	Ad < 4.5 L, DT < 5 L
Initial turning ability	$\delta = 10°$, $\omega = 10°$, Track reach < 2.5L
Yaw checking & course keeping ability	10° - 10° Zig-zag test $\omega_1 < 10°$ (L/U < 10) $\omega_1 < 5 + \frac{1}{2}(L/U)$ (10 < L/U < 30) $\omega_1 < 20°$ (L/U ≥ 30) 20° - 20° Zig-zag test $\omega_1 < 25°$
Stopping ability track	Reach <15 L

5.2 Evaluation of Traffic Safety on the Proposed Separate Traffic Lane

1) Analysis of the North-bound Passage Simulation.

a) Vessel's Tracks

In case of max flood and max ebb current, the passage for all vessels of 300,000 tons class was possible to keep the vessel in the middle of the traffic lane after changing the courses three times at the planned altering points(Fig. 5, Fig. 6)

As in the case of above, the vessels were likely to sway to within 15° toward port and starboard side during the turn. Nevertheless, keeping the courses was attained in appreciable time after each alteration movement.

b) The Level of Distance-Approach to Hazard

In the flood and ebb current, the experimental vessel was able to keep a safe distance from the shallow area in the south area of Jaeyuldo because the vessel passed in the middle of existing navigational traffic lane relatively without difficulty.

c) The Level of Control

In the maximum flood current, the usage index of the steering gear and absolute average value of the angle of the gear were relatively small as the value was 8.7, and the index was 4.9.

In the maximum ebb current, the usage index of the steering gear and absolute average value of the angle of the gear were likewise relatively small as the value showed 4.7, and the index was 2.4.

Therefore, the vessel's marginal level of control is 86.04 % in the maximum flood current and 93.25 % in the ebb current which means there is considerable room in case of emergency.

d) The Vessel Operator's Comment

In the proposed separated one-way lane and applying the maximum values of environment condition described in Table 5, the navigator experienced no difficulty in his maneuverability in both scenarios of maximum ebb and flood current. Furthermore, the width of the North-bound lane in the eastern sector of the fairway is around 800 meters.

2) Analysis of the South-bound Passage Simulation.

a) The Vessel's Tracks

In the maximum flood and maximum ebb current scenarios, the corresponding vessel was, also, able to navigate in the middle of the traffic lane after changing courses two times at the designated altering points(Fig. 7, Fig. 8).

Also, owing to the 010° (T) direction of the tidal current, the vessel swayed to starboard side of the lane due to the effects of maximum flood current. Nevertheless, after each alteration of course, the vessel has no difficulty to maneuver back to the middle of the channel.

b) The Level of Distance-Approach to Hazard.

In the flood and ebb currents, the sample vessel was able to maintain her position in the middle of the channel keeping a relatively safety distance from the patches of shallows(175 m and 185 m) abeam of Gosado until she cleared the test area in the vicinity of Jakdodo without much difficulty.

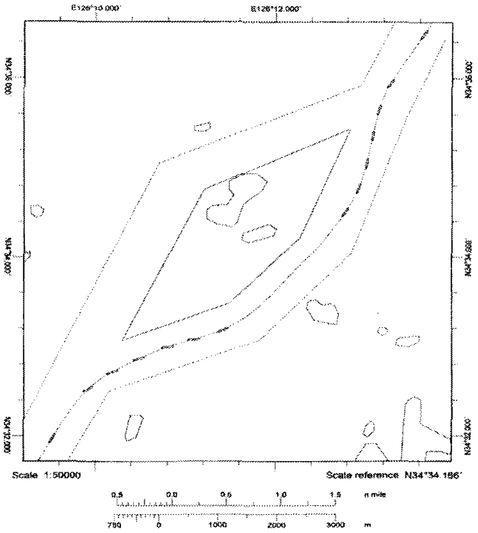


Fig. 5. Ship's track(North-bound).
[30 K DWT Cargo ship, Max. flood current]

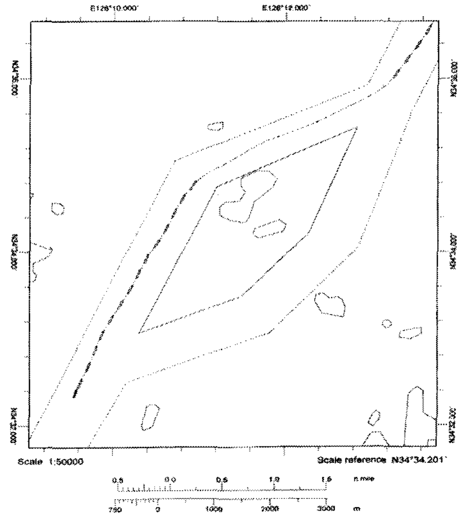


Fig. 7. Ship's track(south-bound).
[30 K DWT Cargo vessel, Max flood current]

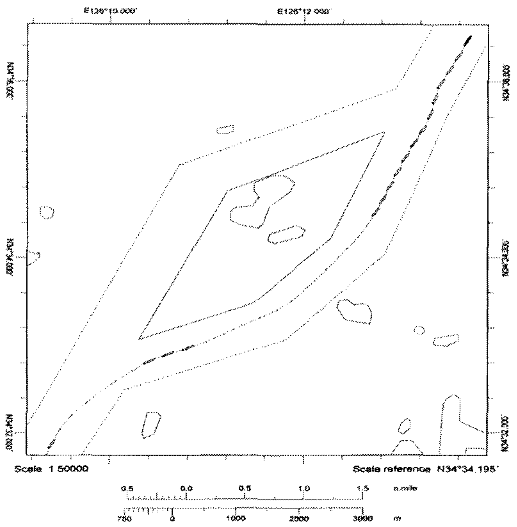


Fig. 6. Ship's track(North-bound).
[30 K DWT Cargo ship, Max ebb current]

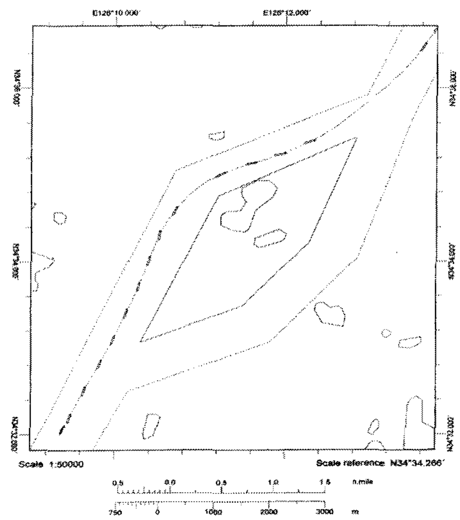


Fig. 8. Ship's track(south-bound).
[30 K DWT Cargo vessel, Max ebb current]

c) The Level of Control

In the maximum flood current, the usage index of the steering gear and absolute average value of the angle of the gear were relatively small as the value was 7.0, and the index was 2.7 respectively.

In the minimum ebb current, the usage index of the steering gear and absolute average value of the angle of the gear were relatively small as the value was 6.0, and the index was 4.8 respectively.

The vessel's marginal level of control is at 92.43 % in the maximum flood current, and 86.4 % in the ebb current respectively which means there is considerable room in case of emergency.

d) The Vessel Operator's Comment

Throughout the southerly transit in the designated fairway at the subject area, the vessel did not encounter any difficulty. Furthermore, vessel has enough sea room at starboard side of the route near Gosado after altering course to around 198^{O}(T) when she cleared Jokdo. In this scenario, the vessel can safely maneuver out of the lane in case a situation warrants it. It has also a relatively straightforward distance to navigate in the Jeongdeung-Hae fairway before approaching Jeodo island.

5.3 Evaluation of the North-bound and South-bound transits Simulations

The results of the simulations conducted for North-bound and South-bound passages, using all the modeling data discussed in this section, were collected and tabulated as illustrated in Table 7.

Considering all the parameters of the simulations, it showed that the safety level on all conditions was excellently met by the proposed route.

Table 7. Evaluation result of the simulation

Simulated vessel	Rudder angle	Ship's marginal rate of control	Track	Level of approach distance	Level of control	Operator's comment	Safety level
Arr 30 k DWT [Max. flood]	8.7	86.00	□	□	□	□	Exellent
Arr 30 k DWT [Max. ebb]	4.7	93.50	□	□	□	□	Exellent
Dep 30 k DWT [Max. flood]	7.0	92.43	□	□	□	□	Exellent
Dep 30 k DWT [Max. ebb]	6.0	86.40	□	□	□	□	Exellent

6. Conclusion and Recommendation

To maintain a safer navigation in the waterways leading to Mokpo harbor and adjacent areas, dynamic and sustainable endeavors are necessary to a long-term effect of ever-changing maritime regime in the area. Strategic planning is vital. With this aim, Mokpo will enhance navigational traffic safety and promote an efficient maritime commerce that is a life-blood of a sustainable economy.

In order to resolve the problems posed by this study, and after collecting and thoroughly evaluating all the data, comprehensive analyses were performed. It is then the aim of this study to recommend:

1) To make the existing "two-way" route of the traffic separation scheme on both navigable sides of Yul-do into special routes:

a) That the Eastern sector of the TSS shall be designated into a "Single Southerly Route" for departing vessels coming from the North and also for "Special Deep-draught Route" for vessels with limited under-keel clearance either on a southerly or northerly passages.

b) That the Western sector of the fairway shall be designated solely for "One-way, Northerly passage" for vessels entering the Mokpo harbor.

2) Better management of DW route by shore-based VTS. This can be done by issuing timely traffic information of vessels constrained by their drafts that will use the fairway.

These recommendations shall mitigate and reduce collision risks between vessels navigating in the sea area. This shall, likewise, minimize, if not outwardly remove, any confusion on the part of the navigator on which route his ship, regardless of size, type, limitations, etc, has to follow in the subject area and, similarly, assist the local traffic regulators to better monitor the shipping movements around the Myeongnyang waterways.

Acknowledgements

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