Estimation of Marine Traffic Volume Considering Ship Speed

Yu-Min Kwon[*†]

* Graduate School, Mokpo National Maritime University, Mokpo 58628, Korea

선박의 속력을 고려한 해상교통량 평가에 관한 연구

권유민[*†]

* 목포해양대학교 대학원

Abstract : This study proposes marine traffic volume estimation method considering ship speed, a factor excluded from the existing method. Ten days of GICOMS marine traffic data from Pyeongtaek and Dangjin ports was applied to this study. As a result, converted traffic volume with the proposed estimation method showed an increase of 4.41 (± 0.99) times or decrease of 0.59 (± 0.04) at most, compared with the existing estimation method. Average marine traffic congestion for each time applying the proposed estimation method showed an increase of 1.43 (± 0.10) compared with the existing estimation method. The maximum marine traffic congestion for each time was 1.62 (± 0.34) times higher compared with the existing estimation method. Marine traffic peak time, defined as the highest point of marine traffic congestion, was evaluated to be different from that of the existing method because of distribution of vessel speed. In conclusion, considering ship speed is necessary when estimating marine traffic volume to produce a practical estimate of marine traffic capacity.

Key Words : Marine traffic volume estimation method, Marine traffic capacity, Converted traffic volume, Marine traffic congestion, Marine traffic peak time

요 약 : 본 연구에서는 선박의 속력을 고려한 해상교통량 평가 방법을 제안하였으며, 이를 선박의 속력을 고려하지 않은 기존의 방법과 비교하였다. 평가를 위하여 평택·당진항 10일간의 GICOMS 자료를 본 연구에 적용하였다. 그 결과 제안된 방법으로 평가된 환산교통량은 기존의 평가 방법에 비해 4.41(±0.99)배 증가하거나, 0.59(±0.04)배 감소하는 것으로 나타났다. 제안된 평가 방법을 적용한 각 시간대별 평균 해상교통혼잡도는 기존의 평가 방법 결과에 비해 1.43(±0.10)배 높게 나타났으며, 각 시간대별 최대 해상교통혼잡도는 1.62(±0.34)배 높게 나타났다. 해상교통혼잡도 최대 평가 결과인 피크타임 해상교통혼잡도는 선박의 속력 분포로 인하여 기존의 평가 방법과 다르게 평가됨을 확인하였다. 결과적으로 선박의 속력은 실용교통용량 평가 시 중요 값으로 적용되기 때문에 해상교통량을 평가할 때 선박의 속력을 고려하여야 할 것으로 사료된다.

핵심용어 : 해상교통량 평가방법, 해상교통용량, 환산교통량, 해상교통혼잡도, 피크타임 해상교통혼잡도

1. Introduction

The marine traffic congestion is a measure of the ratio of the actual marine traffic volume to the marine traffic capacity of the evaluated fairway and is a measure of the ability of the route to handle the marine traffic volume. Evaluate the converted marine traffic volume based on current or future numbers and sizes of ships of the fairway by comparing with practical traffic volume. When the marine traffic congestion level approaches 100%, the marine traffic volume reaches to the traffic capacity of the fairway.

Regarding the traffic congestion, the Marine Traffic Safety Audit was introduced in Korea and implemented as an amendment to the Maritime Traffic Safety Act in 2009 and is included as a safety assessment item.

As a prior study on marine traffic congestion and traffic capacity, Koo (1997) used the queuing theory for the entry of a single fairway to the congestion of the fairway, and the traffic simulation for the fairway which cannot be queued theory. Seong (2014) set various traffic situation in the narrow channel and harbor area, proposed the fairway design method considering the traffic volume and compared it with the current fairway design method. Um et al. (2012) presented the criteria for maritime traffic

† ymk@mmu.ac.kr, 061-240-7816

congestion assessment and analysis of maritime traffic congestion, which were conducted through Marine Traffic Safety Audit.

Yoo et al. (2013) suggested that it is more appropriate to calculate the marine traffic congestion based on the actual survey than the Port Management Information System (Port-MIS) statistics. Kang et al. (2017) also suggested that seasonal differences should be considered during the evaluation because there is seasonal variation in marine traffic congestion. Moreover, Kim et al. (2017) proposed a method to evaluate marine traffic congestion by comparing the area occupied by a vessel with the area of its route. The method reduced the error occurrence compared to the method of analyzing the marine traffic volume per unit time. When the actual marine traffic volume per unit time is high under the condition that the practical traffic volume of the fairway is the same, the marine traffic congestion is evaluated to be high.

The marine traffic volume can exceed 100 % due to the influence of one or two large vessels because the converted traffic volume is high when large vessels or many vessels are navigating along the fairway. However, even if the converted traffic volume is high, there is no influence on the environment where the vessels are not in the actual evaluation fairway per unit hour because there is no vessel per unit time. Conversely, the marine traffic congestion is low due to the low converted traffic volume, but it is possible that the vessels exist in the evaluation fairway exceeding the unit time and affect the vessels that pass through the next time zone. This may be related to the speed of the vessel navigating along the fairway.

In case of road traffic capacity, the service level is used as a qualitative concept explaining the service status, and the service level greatly influences the speed of the vehicle. Considering the characteristics of a vessel, it cannot be judged that the speed is similar to the effect on the safety of the vehicle. However, the vessel is also affected by the speed due to the amount of traffic on the fairway or the vessel navigating forward. For vessels of the same size, vessels with slower speeds will stay on the fairway for a longer time than those with faster speeds. Comparing two vessels in unit hour will result in wider sea area for slower vessels. However, the existing marine traffic assessment method considers only the size of each vessel and evaluates the converted marine traffic volume without considering the speed of each vessel.

While previous studies have been done on the congestion change with regard to the application of speed, the study applied the speed of vessels collectively to all ships. Moreover, the application of vessel speed follows the existing marine traffic congestion assessment method applied only to the basic traffic capacity.

This study proposes a method to apply the speed of each vessel in converting the maritime traffic volume of the vessel per unit hour and to verify the validity of each vessels' speed application by comparing with the existing method.

2. Marine traffic congestion assessment models with parameters

The evaluation of the marine traffic congestion is carried out according to the safety audit items for each project according to the safety audit in Annex 2 of Article 11 of the Guideline for the Implementation of the Marine Traffic Safety Audit by Article 15 of the Maritime Safety Act. The evaluation can be applied to the bumper model and the queuing model, but in this study, the evaluation according to the bumper model is examined.

2.1 Assessment models
2.1.1 Bumper model

The bumper model is a model in which a ship's domain is applied, and the ship's domain is an area where a ship operator tries to keep a certain distance. In the case of a ship which is stationary, it may be defined as an area to prevent entry of the area and as an avoidance area in the case of a ship under sailing. The marine traffic congestion using the bumper model is evaluated by comparing the practical traffic volume with the current actual marine traffic volume or the future marine traffic volume as shown in the following Equation (1).

$$T_C = \frac{Q_T}{Q_P} \times 100\,(\%) \tag{1}$$

where, T_C : Traffic Congestion
$\quad Q_T$: Traffic Volume
$\quad Q_P$: Practical Traffic Volume

2.1.2 Traffic volume

The traffic volume of the fairway can be divided into basic traffic capacity and practical traffic capacity. Based on the study(Fujii et al., 1966) that the basic traffic capacity is the maximum allowable traffic volume of the fairway and that the speed of the ship and the value of the dynamic motion of other

ships can be expressed as a linear function of the length of the ship is calculated as shown in the following Equation (2).

$$Q = \frac{W \times V}{L \times S} \tag{2}$$

where, Q : Basic Traffic Capacity(vessel/hour)

W : Fairway Width(km)

V : Vessel Speed(km/hour)

L : The Major Axis of Ship's Domain(km)

S : The Minor Axis of Ship's Domain(km)

Practical traffic capacity is $20 \sim 25\%$ of the basic traffic capacity (Gong and Kim, 2005), Taking into consideration the marine conditions of service, freedom of ship navigation and traffic system. In this study, 25% of the basic traffic capacity was applied. When the practical traffic volume is 25%, the concept of practical traffic volume is shown in Fig. 1.
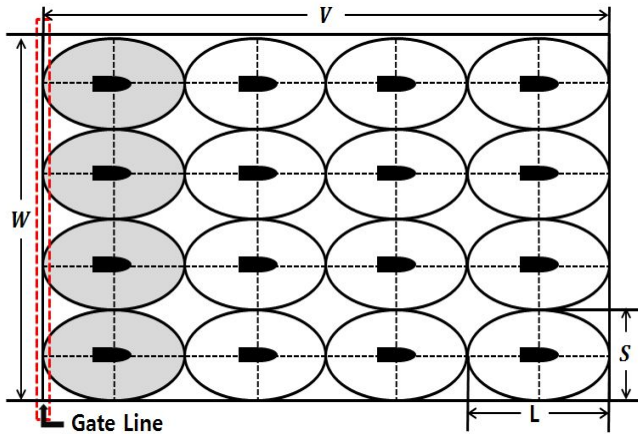

Fig. 1. Concept of Practical Traffic Volume.

2.1.3 Converted traffic volume

The area of the sea surface needed for the vessel is usually proportional to L^2, so the marine traffic volume is calculated using this. L^2 is the square of the L conversion factor indicating the ratio to the standard vessel. The L^2 converted traffic volume is evaluated differently depending on how the length of the standard vessel and the interval of the L conversion factor are set and differs depending on the agency for marine traffic safety Audit.

In this study, the standard vessel length and the interval of the L conversion factor of Mokpo Maritime University, which is an agency for marine traffic safety audit, are applied.

2.2 Parameter configuration

Practical traffic capacity and marine traffic volume for marine traffic congestion assessment differ depending on the setting of the standard vessel, the ship's domain and how the speed of the vessel is applied. This difference affects the marine traffic congestion results. In the study by Park and Jeong (2014), the sensitivity of each element was analyzed, and it was analyzed that the influence of $34\% \sim 43\%$ was the greatest when the major axis of ship's domain was changed to 1L.

2.2.1 Description of the standard vessel

Based on Port-MIS data, Lee and Ahn (2013) proposed a standard vessel length based on 60,000 ship particulars, and it was necessary to apply the standard vessel length considering the characteristics of the trade ports. However, since the traffic capacity applied to the marine traffic congestion assessment is calculated as a ratio to the standard vessel length, the congestion value does not change as the standard vessel increases (Um et al., 2012). In the study of Kim et al. (2017), the agency for marine traffic safety audits have different lengths of standard vessels for assessment of marine traffic capacity, 70 m or 82 m. In this study, a ship with a gross tonnage of 1,000 tons and a length of 70 m was defined as a standard vessel.

2.2.2 Ship domain

The research on the ship's domain has been carried out for a period of nearly half a century. Most studies on ship's domain use statistical methods that analyze actual vessel data or quantitative analysis methods based on the experience of operators. Wang et al. (2009) analyzed existing studies on the ship's domain and compared various shapes such as circles, ellipses, and polygons.

In Korea, there is a study (Park and Jeong, 2014) that compares and analyzes the ship's domain based on the traffic data for the time of the return of the vessel after the typhoons of Jinhae Bay and other studies analyzed based on actual traffic and Park et al. (2010), which quantifies the appropriate separation distance considering the safety consciousness of the vessel operator according to the situation. The ship's domain can be defined as the area around the ship that is necessary to ensure the safety of navigation.

In this study, the major axis of ship's domain was 6 L, and the minor axis was 1.6 L based on the elliptical Fujii model (Fujii and Tanaka, 1971) used in the marine traffic safety audit.

2.2.3 Ship speed

The ship's speed applied instantaneous speed when transit through the gate line. For the evaluation of the basic traffic capacity, the average speed of all vessels was applied, and the individual speeds of each vessel were applied in the evaluation of the converted traffic volume.

3. Marine traffic volume estimation method

Marine traffic volume refers to the number of vessels navigating along the fairway per unit time. The purpose of analyzing the marine traffic volume is to reflect the efficient operation of the fairway and the design of the fairway for the safe passage of the vessel.

3.1 Existing estimation method

In this study, the calculation method of L^2 conversion factor of Mokpo Maritime University, which is an agency for marine traffic safety audit, was applied.

Table 1 shows the standard length and the L^2 conversion factor according to the gross tonnage group after selecting a standard vessel with a gross tonnage of 1,000 tons and a length of 70 m.

Table 1. Vessel's length by tonnage group and L^2 conversion factor

Tonnage group	L.B.P. (m)	Length (m)	L Conversion factor	L^2 Conversion factor
~100	7~16	20	0.29	0.08
100~500	26~50	40	0.57	0.32
500~3K	50~90	70	1.0	1.0
3K~5K	90~110	100	1.43	2.04
5K~7K	110~120	115	1.64	2.69
7K~10K	120~140	130	1.86	3.46
10K~20K	140~180	150	2.14	4.58
20K~50K	180~220	200	2.86	8.18
50K~100K	220~300	280	4.0	16.0
100K~	300~	330	4.7	22.2

The existing calculation method is calculated as the total sum of the L^2 conversion factor of each vessel as shown in the following Equation (3).

$$Q_T = \sum_{i=1}^{n} C_i \tag{3}$$

where, Q_T : Traffic Volume

C_i : Conversion Factor of i^{TH} Vessel

3.2 Proposed estimation method

Currently, the estimation of the converted marine traffic volume is based on only the size of the vessel. The average speed is applied to the vessel's speed when evaluating the basic traffic capacity, but the converted traffic volume is evaluated without considering the ship speed of each vessel. The marine traffic congestion is to assess the traffic capacity of the vessel per unit hour, depending on the speed of the vessel, the time occupied by the vessel on the fairway is different. The different occupancy time means that the sea area occupied by the vessels is different. Consequently, vessels with slow speed occupy wider sea area on the fairway per unit than those with faster speeds, which affects marine traffic volume at that time.

That is Fig. 2, if the vessel's speed is high, there is no vessel on the fairway as it has already passed the fairway, and if the vessel's speed is low, the vessel will pass through the fairway for more than one hour.
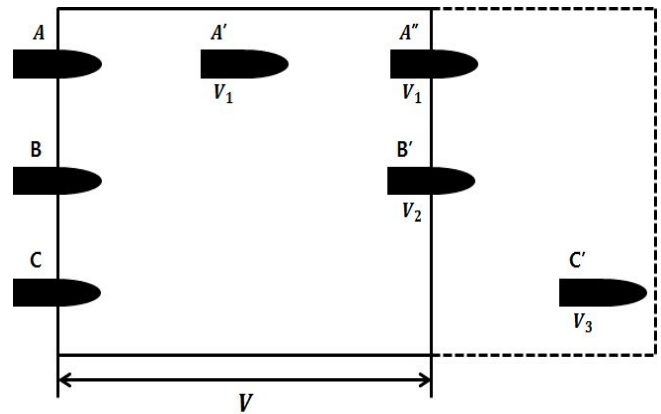

Fig. 2. Vessel's position according to speed per hour.

Therefore, this study proposes an evaluation formula to calculate the converted traffic volume that considers the effect of each vessel's speed on the marine traffic volume per hour. The following formula (4) estimates L^2 converted traffic volume considering the ship's speed.

$$Q_T = \sum_{i=1}^{n} (\frac{V}{V_i} \times C_i) \qquad (4)$$

where, V : Average Speed of Vessel

V_i : Speed of i$^{\text{TH}}$ Vessel

4. Estimation of marine traffic volume and marine traffic congestion

4.1 Analysis of marine traffic volume

The marine traffic volume was analyzed in order to compare the converted traffic volume according to the speed of each vessel. The spatial range for the analysis was set as Pyeongtaek·Dangjin Port main fairway, which has a large volume of vessel traffic and no changes in the shape of the fairway. The temporal range is set from April 11th to 20th, 2013. To analyze the ten days General Information Center on Maritime Safety and Security (GICOMS) data, EyeMap-MTAS, the fairway evaluation management system, was used. As shown in Fig. 3, four gate lines were selected.
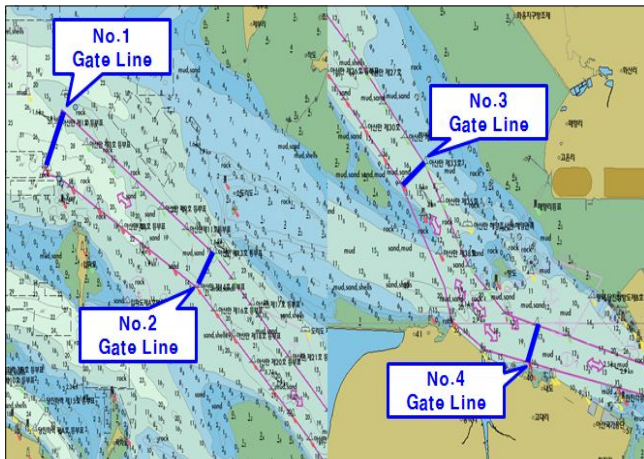

Fig. 3. Gate line selection (Chart source: EyeMap-MTAS).

Table 2 shows the number of vessels transit through each gate line by G/T group. The ratio of vessels less than 3,000 G/T whose L^2 conversion factor is 1 was analyzed as 52.2 % at No. 1 gate line, 46.8 % at No. 2 gate line, 48.7 % at No. 3 gate line and 64.5 % at No. 4 gate line.

Table 2. Number of transit vessels by G/T for gate line during 10 days (Unit: vessel)

Gate Line		1	2	3	4
	~100	170	99	89	155
	100~500	64	71	86	226
	500~3K	99	101	115	98
	3K~5K	94	94	93	72
G/T	5K~7K	21	21	21	19
	7K~10K	43	43	42	43
	10K~20K	31	33	33	27
	20K~50K	75	76	76	67
	50K~100K	34	34	34	30
	100K~	7	7	7	6
Total		638	579	596	743

Fig. 4 to Fig. 7 are graphs showing the speeds of the each vessel according to the G/T group and average speed of all vessels for gate line. In the speed distribution of each vessel by G/T group for No. 2, No. 3 and No. 4 Gate line, the distribution of vessels faster than the average speed was analyzed to be more in the group of vessels with a G/T greater than 7,000 tons. Based on this distribution, the ratio of vessels faster than the average speed in all G/T groups was 37.5 % at No. 1 gate line, 41.8 % at No. 2 gate line, 42.3 % at No. 3 gate line and 40.9 % at N0. 4 gate line.
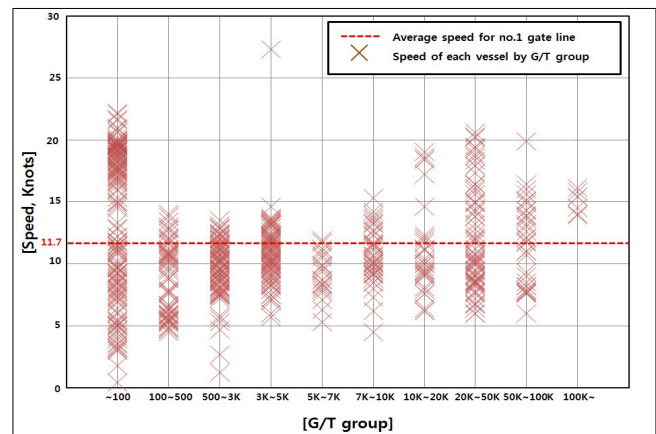

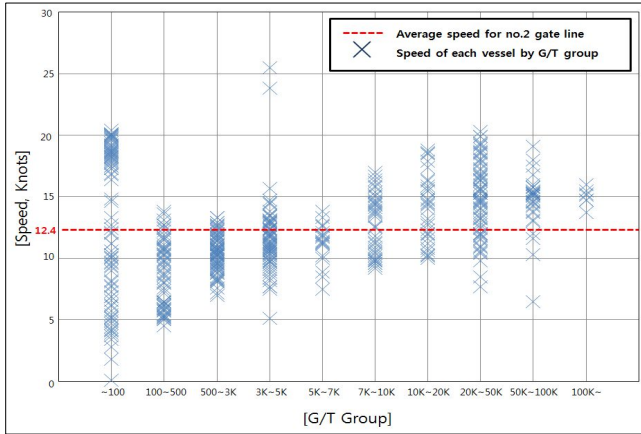Fig. 4. Speed of each vessel by G/T group for no.1 gate line.

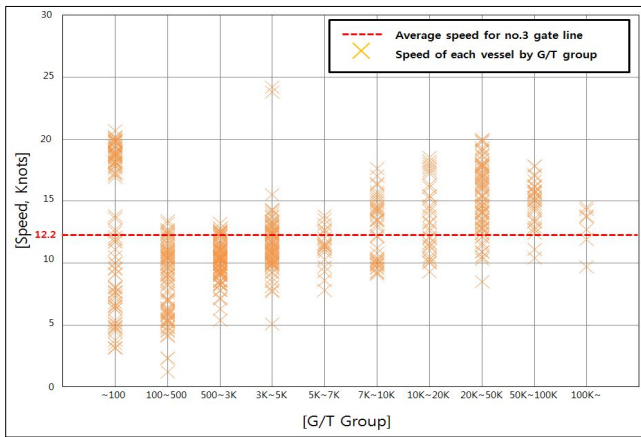Fig. 5. Speed of each vessel by G/T group for no.2 gate line.

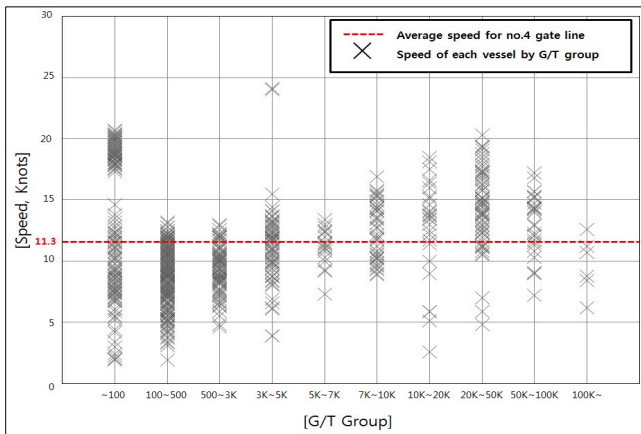Fig. 6. Speed of each vessel by G/T group for no.3 gate line.

Fig. 7. Speed of each vessel by G/T group for no.4 gate line.

4.2 Estimation of converted traffic volume

The converted traffic volume was estimated for 240 hours (10 days). Table 3 shows the total converted traffic volume calculated

using the existed method and the proposed method by applying the speed of ship mentioned in Chapter 3. The results of the existed method were obtained by summing up the L^2 conversion factors according to the size of each vessel. The proposed method calculates the speed ratio (V/V_i) of each vessel to the average speed applied in the basic traffic capacity with the L^2 conversion factors. The total converted traffic volume increased to 10.7 % in No. 1 gate line, but decreased by 1.8 ~ 7.0 % in No. 2, 3 and 4 gate line. This is because the distribution of vessels that are slower than the average speed at No. 1 gate line is distributed more than other gate line. Especially, the vessel speed of the large vessel group is distributed in the area slower than the average speed.

Table 3. Total converted traffic volume

Gate Line	1	2	3	4
Existing Method	1984.99	2000.89	2013.39	1814.41
Proposed Method	2196.90	1886.44	1873.42	1781.40

In order to compare the difference of each hour during 10 days, the L^2 converted traffic volume was calculated by the existed method and the proposed method. Table 4 shows the largest increase and decrease rate in the each gate line.

On the 5th day from 04:00 to 05:00, the result of the existed method was 3.08, and the proposed method was calculated as 16.63. The proposed method was 5.40 times higher compared with the existed method at No. 1 gate line. On the 2nd day from 01:00 to 02:00, the result of existed method was 0.08, and the proposed method was calculated as 0.04. The proposed method was 0.55 times lower compared with the existed method at No. 4 gate line.

Table 4. Maximum and average rate for gate line by one hour

Gate Line	1	2	3	4
Max. Increasing rate	5.40	5.04	3.94	3.42
Max. Decreasing rate	0.58	0.62	0.60	0.55
Average rate	1.14	1.07	1.05	1.03

During the largest increase in time, 4 vessels of less than 3,000 tons were passed. Of these, the speeds of the 3 vessels were less than 5knots. This was analyzed as the reason for the increase in

the converted traffic volume when compared with the existed method. 1 vessel passed during the largest decrease. The transit speed of the vessel was 20.7 knots, and it was analyzed that the converted traffic volume decrease greatly.

4.3 Estimation of marine traffic congestion

In order to evaluate the marine traffic congestion for the gate line, practical traffic capacity was calculated as shown in Table 5. Average speed is applied as set in Chapter 2, and $6 L \times 1.6 L$ is applied to the ship's domain. Moreover, practical traffic capacity is applied at 25 % of the basic traffic capacity.

Table 5. Practical Traffic Volume

Gate Line	1	2	3	4
Fairway Width (km)	1.30	1.20	1.07	1.05
Average Speed (km/h)	21.67	22.94	22.59	20.93
Basic Traffic Capacity (vessel/hour)	598.83	585.84	513.95	467.13
Practical Traffic Volume (vessel/hour)	149.71	146.46	128.49	116.78

Table 6 shows the increase and decrease rate of average and maximum marine traffic congestion for each time period during 10 days. The average marine traffic congestion at 00:00 to 01:00 on the No. 1 gate line increased from 0.0124 to 0.0188 (1.52 times). At 23:00 to 24:00 on No. 4 gate line decreased from 0.0297 to 0.0240 (0.81 times). The maximum marine traffic congestion at 00:00 to 01:00 on the No. 1 gate line increased from 0.0546 to 0.1065 (1.95 times). At 23:00 to 24:00 decreased from 0.0552 to 0.0358 (0.65 times).

Table 6. Maximum and average rate for average traffic congestion by one hour

Gate Line		1	2	3	4
Max. Increasing rate	Average	1.52	1.21	1.25	1.33
	Maximum	1.95	1.46	1.28	1.74
Max. Decreasing rate	Average	0.91	0.81	0.83	0.81
	Maximum	0.65	0.78	0.76	0.74
Average rate	Average	1.15	0.97	0.95	0.98
	Maximum	1.21	0.98	0.92	1.01

Table 7 shows the peak times and results with the highest marine traffic congestion for 10 days. When evaluated by the proposed method, the most congested time was evaluated differently from the time of the existed method. And the peak time congestion results were also different. This is the consequence of the distribution of the vessel which is slower than the average speed, such as the difference of the converted traffic volume in Section 4.2.

Table 7. Peak time and marine traffic congestion results

Gate line		1	2	3	4
Existing method	Peak time	3rd day 15:00	3rd day 15:00	4th day 08:00	6th day 18:00
	Result	0.5014	0.4712	0.3563	0.4336
Proposed method	Peak time	4th day 07:00	4th day 16:00	3rd day 16:00	3rd day 14:00
	Result	0.6146	0.3350	0.3132	0.4246

5. Conclusion

The marine traffic congestion is used as a measure of the ability of the route to handle the marine traffic volume. However, existing marine traffic congestion estimation method is not efficiently reflecting actual marine traffic congestion since the speed of the vessel is applied when assessing the basic traffic capacity but not applied when assessing the converted traffic volume. Therefore, this study proposed an evaluation method to apply speed of each vessel when evaluating the converted traffic volume.

In order to compare the difference of each hour during 10 days, the L^2 converted traffic volume was calculated by the existed method and the proposed method. As a result, the converted traffic volume increased the largest at $3.42 \sim 5.40$ times or decreased the smallest at $0.55 \sim 0.62$ times for each gate line when each vessels speed was applied.

The results of analysis of the average marine traffic congestion results by the time were analyzed to be the largest increase by $1.21 \sim 1.52$ times or the greatest decrease by $0.81 \sim 0.91$ times for each gate line. As a result of analyzing the maximum marine traffic congestion for each time, there was the largest increase by $1.28 \sim 1.95$ times or the greatest decrease by $0.65 \sim 0.78$ times for each gate line.

In this study, it was found that the ship's speed distribution is different according to the vessel G/T group, and it was found

through the proposed method that the distribution of speed has a significant effect on the marine traffic volume per unit time. Especially, peak time, which is the highest result of marine traffic congestion, was evaluated to be different from that of the existing method. The results were also different according to the distribution of the vessel which is slower than the average speed.

The marine traffic congestion is the value of the marine traffic capacity per unit hour of the fairway. The proposed method is effective to reflect the traffic characteristics as compared with the existed method since the proposed method can consider both the size and speed of the vessel. Further verification of the individual application of each ship's speed through analysis of various harbors and more data such as characteristics of the ship, factors affecting the speed of the ship will be performed in the next phase of the study.

References

[1] Fujii, Y., K. Watanabe, K. Tanaka, K. Yamada and H. Sawai(1966), Basic Traffic Capacity of a Fairway, The Journal of Navigation, Vol. 35, No. 36, pp. 7-14.

[2] Fujii, Y. and K. Tanaka(1971), Traffic Capacity, The Journal of Navigation, Vol. 24, pp.543-552.

[3] Gong, I. S. and Y. G. Kim(2005), A Review on the Concept of Operating Rate of Fairway and Its Application, Journal of Ship & Ocean Engineering, Vol, 40, pp. 173-178.

[4] 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, Journal of the Korean Society of Marine Environment & Safety, Vol. 23, No. 1, pp. 1-8.

[5] 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, Journal of the Korean Society of Marine Environment & Safety, Vol. 23, No. 2, pp. 153-160.

[6] Koo, J. Y.(1997), Evaluation of Traffic Congestion in Channels within Harbour Limit - On Channels in Ulsan New Port Development, Journal of Port and Harbor Research, Vol. 8, pp. 61-77.

[7] Lee, Y. S. and Y. J. Ahn(2013), A Study on the Standard Ship's Length of Domestic Trade Port, Journal of the Korean Society of Marine Environment & Safety, Vol. 19, No. 2, pp. 164-170.

[8] Park, Y. S., J. Y. Jeong and J. S. Kim(2010), A Study on the Minimum Safety Distance between Navigation Vessels based on Vessel Operator's Safety Consciousness, Journal of the Korean Society of Marine Environment & Safety, Vol. 16, No. 4, pp. 401-406.

[9] Park, Y. S. and J. Y. Jeong(2014), A Study on the Marine Traffic Congestion by Analysis of Ship's Domain, Journal of the Korean Society of Marine Environment & Safety, Vol. 20, No. 5, pp. 535-542.

[10] Seong, Y. C.(2014), Assessment on Navigational Stress and Fairway' Width according to Traffic Flow, Journal of Korean Navigation and Port Research, Vol. 38, No. 3, pp. 253-259.

[11] Um, H. C., W. J. Jang, K. M. Cho and I. S. Cho(2012), A Study on the Assessment of the Marine Traffic Congestion and the Improvement of a Technical Standards, Journal of the Korean Society of Marine Environment & Safety, Vol. 18, No. 5, pp. 416-422.

[12] Wang, N., X. Meng, Q. Xu and Z. Wang(2009), A Unified Analytical Framework for Ship Domains, The Journal of Navigation, Vol. 62, pp. 643-655.

[13] Yoo, S. R., C. Y. Jeong, C. S. Kim, S. H. Park and J. Y. Jeong(2013), A Study on Evaluation of Marine Traffic Congestion based on Survey Research in Major Port, Journal of the Korean Society of Marine Environment & Safety, Vol. 19, No. 5, pp. 483-490.