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A Study on Estimate Model for Peak Time Congestion

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Abstract : *This study applied regression analysis to evaluate the impact of hourly average congestion calculated by bumper model in the congested area of each passage of each port on the peak time congestion, to suggest the model formula that can predict the peak time congestion. This study conducted regression analysis of hourly average congestion and peak time congestion based on the AIS survey study of 20 ports in Korea. As a result of analysis, it was found that the hourly average congestion has a significant impact on the peak time congestion and the prediction model formula was derived. This formula(*C_p = 4.457C_a + 29.202*) can be used to calculate the peak time congestion based on the predicted hourly average congestion.*

Key Words : *Marine traffic congestion, Hourly average congestion, Peak time congestion, Bumper model, AIS survey, Regression analysis*

1. Introduction

It is essential accurate prediction of marine traffic congestion the width of passage for port engineering. Time series analysis models should be used to predict future traffic for the evaluation of marine traffic congestion according to the marine traffic safety assessment scheme.

In previous studies on the evaluation of marine traffic congestion, Koo(1997a) applied the bumper model to the Gadeoksudo passage for the development of Busan New Port and Koo(1997b) applied the theory of queuing to Ulsan New Port to predict the marine traffic congestion. According to the study of Yeo et al.(1998), the marine traffic congestion of Busan Port was evaluated by numerically modeling the situation of passage and applying it to the simulation language, Awe-Sim (Average Waiting Simulation). The types of marine traffic congestion evaluation methods are classified into the bumper model, the theory of queuing, and the simulation method.

Many preceding studies have evaluated the marine traffic congestion using the bumper model for the occupancy of vessels and the standard vessels. Considering the studies on the occupancy, Japanese Vessel Technology Center surveyed the marine traffic in the late 1960s to derive the occupancy of small · medium · large vessels(Fujii et al., 1966a; Fujii et al., 1966b). A study was conducted to calculate the occupancy using radar survey at the port of Shanghai in China(Jeong et al., 2006) and another study was conducted to calculate the clearance distance for safety awareness by surveying the vessel operators(Park et al., 2010). The studies on the standard vessels include the study on the length of standard vessels of each port(Um et al., 2012) and the study that suggested the standard vessels by analyzing the base point where the accumulated frequency took 50 % of more based on the number of calling vessels per tonnage(Lee and Ahn, 2013). Considering the findings these preceding studies, it was found that the selection of occupancy and standard vessels has a significant influence on the marine traffic congestion value.

The previous marine traffic congestion can predict the traffic and the quantity of goods transported according to port development to calculate the hourly average congestion, but it has limitations in predicting the peak time congestion. It applied the hourly average value instead of the peak time congestion to predict the marine traffic congestion to distort the marine traffic characteristics. The previous prediction of hourly average congestion applied regression analysis, such as logarithmic function·exponential function models, to the past traffic data of the Port Management Information System (Port-MIS) for the prediction(Kim et al., 2006; SK Gas, 2011).

This study applied regression analysis to evaluate the impact of hourly average congestion calculated by bumper model in the congested area on the peak time congestion, to suggest the model formula that can predict the peak time congestion.

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2. Discussion of Marine Traffic Congestion Theory and Selecting the Parameters

2.1. Marine Traffic Congestion Formula

The marine traffic congestion using the bumper model is found by comparing the practical traffic volume that can be accommodated by the passage and the actual marine traffic volume. In other words, the number of vessels entering or departing the port in the present or the future is surveyed to estimate the traffic volume(Q_T) and compared with the practical traffic volume that can be accommodated by the passage(Q_P) to assess the traffic congestion(T_C). Traffic congestion is acquired by dividing the traffic volume based on traffic survey by practical traffic volume and converting the quotient into percentage as shown in the following formula(1):

$$T_c = \frac{Traffic\ Volume\ (Q_T)}{Practical\ Traffic\ Volume\ (Q_P)} \times 100(\%) \quad (1)$$

2.2. Practical Traffic Volume

Practical traffic volume is determined by the weather condition, level of service based on the traffic system, and the capacity to accommodate actual vessels based on the basic traffic volume. In other words, practical traffic volume is the actually allowable limit of traffic volume and about 25 % of basic traffic volume(Fujii, 1981). According to Koo and Yeo(2001), the yearly accommodation performance of Uriga Waterway in Japan was 19.26-19.52 % of basic traffic volume. This is lower than 25 %, which is the theoretical conversion rate of practical traffic volume, but 20 % of basic traffic volume was applied to practical traffic volume as it is thought to indicate the possible limit of safe traffic based on a reliable Vessel Traffic Service(VTS). This study applied 25 % for the practical traffic volume as further studies are required to identify the practical traffic volume that meets the circumstances in Korea.

2.3. Standard Vessel

As the ports have vessels in various sizes, it is necessary to calculate how many vessels can pass per hour based on the standard vessel in order to assess marine traffic congestion. The average length of vessels is continuously increasing as the size of vessels is increasing. Practical traffic volume and actual traffic volume can change according to the size of standard vessel, but it has minimal impact on the congestion value(Um et al., 2012). This study applied to the length of standard vessel 70m, which is the length of 1,000 to 1,500 ton vessels close to the average vessels operated in Korea.

3. Results of Survey Study

3.1. Methodology

1) Target Ports and Time of Survey

In this study, survey is carried out 20 major trading ports. It takes more than a year of continued observation for the accurate analysis of traffic. There is a finding that more than 7 days of survey is valid to have representation(Inoue and Hara, 1973). This study used using the data collected from AIS for 10 days from January 1, 2012 to January 10.

2) Methodology

The gateline was set at the passages where the sailing tracks of vessels merge or separate for each port as shown in Fig. 2 to survey the number of vessels and their speed. The hourly average congestion and the peak time congestion at each gateline were calculated to derive the model formula for predicting the peak time congestion through regression analysis. The procedure of study is as shown in Fig. 1.

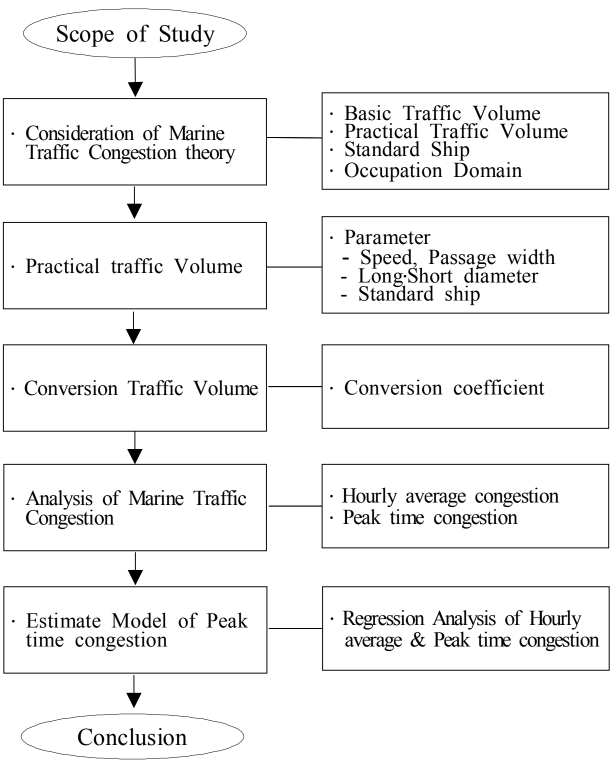
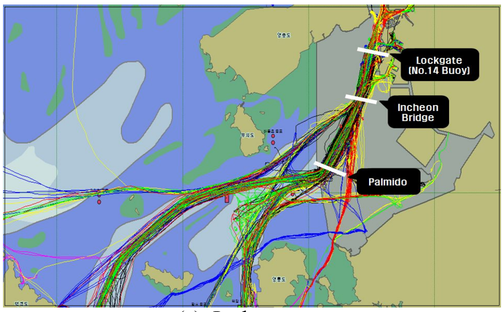
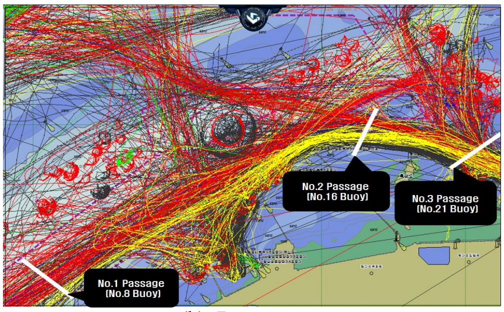


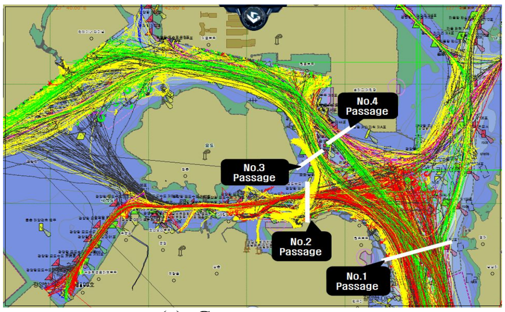
Fig. 1. Analysis procedure in this study.



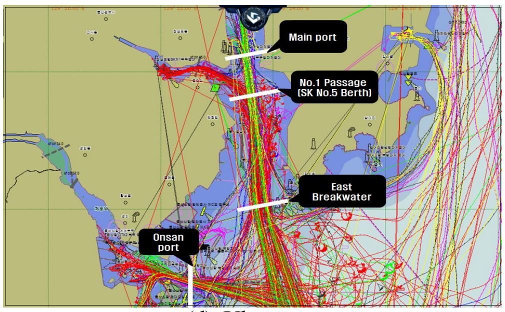
(a) Incheon port



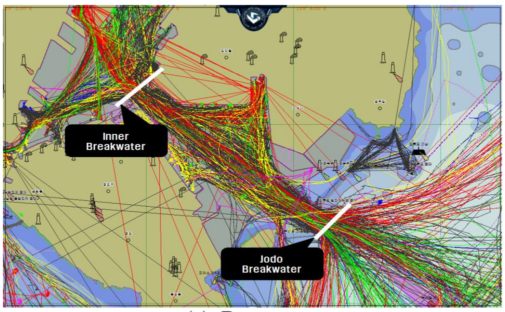
(b) Daesan port



(c) Gwangyang port



(d) Ulsan port



(e) Busan port

Fig. 2. Gateline in each port.

3.2. Analysis of Practical Traffic Volume

Practical traffic volume was calculated as in Table 1 using the average speed, width of passage, long diameter, and short diameter at each gateline.

Table 1. Practical traffic volume of each gateline

Gateline	Average Speed (kts)	Passage width (m)	Diameter (m)		Practical traffic volume (ship/hour)
			Long	Short	
Incheon Palmido	11.9	1,020	6L	1.6L	119.3
Incheon Bridge	12.0	625	6L	1.6L	73.8
Incheon Lockgate (No.14 Buoy)	8.3	480	6L	1.6L	39.5
Pyeongtaek Passage (No.16 Buoy)	12.4	740	6L	1.6L	90.4
Dangjin Passage (No.3 Buoy)	8.0	610	6L	1.6L	48.0
Daesan No.1 Passage (No.8 Buoy)	11.0	1,055	6L	1.6L	114.3
Daesan No.2 Passage (No.16 Buoy)	10.0	290	6L	1.6L	28.6
Daesan No.3 Passage (No.21 Buoy)	7.7	500	6L	1.6L	37.6
Janganseo	12.2	1,640	6L	1.6L	196.8
Taean	11.9	805	6L	1.6L	61.6
Boryeong Passage (No.2 Buoy)	7.0	525	6L	1.6L	55.5
Gunsan South Breakwater	10.2	925	6L	1.6L	93.0
Gunsan Passage (No.7 Buoy)	10.0	495	6L	1.6L	48.8
Mokpogu	12.7	450	6L	1.6L	56.5
Mokpo Bridge	10.5	400	6L	1.6L	41.3
Gwangyang No.1 Passage	10.3	760	6L	1.6L	77.0
Gwangyang No.2 Passage	10.2	435	6L	1.6L	43.7
Gwangyang No.3 Passage	9.2	380	6L	1.6L	34.4
Gwangyang No.4 Passage	9.3	400	6L	1.6L	36.4
Masan Passage (No.15 Buoy)	9.7	1,665	6L	1.6L	159.1
Machang Bridge	10.3	330	6L	1.6L	33.8
Jinhae Passage (No.2 Buoy)	8.3	940	6L	1.6L	77.1
Gohyun Passage (No.2 Buoy)	8.2	1,150	6L	1.6L	92.5
Tongyeong Passage (No.3 Buoy)	8.0	600	6L	1.6L	47.4
Busan Jodo Breakwater	12.2	340	6L	1.6L	41.1
Busan Inner Breakwater	10.7	345	6L	1.6L	36.4
Gamcheon Breakwater	9.0	255	6L	1.6L	22.6
Gadeoksudo (No.11 Buoy)	10.3	1,685	6L	1.6L	170.9
Busan New port (No.110 Buoy)	11.7	560	6L	1.6L	64.7
Ulsan East Breakwater	9.9	490	6L	1.6L	47.6
Ulsan No.1 Passage (SK No.5 Berth)	9.2	310	6L	1.6L	28.0
Ulsan Main port	8.2	300	6L	1.6L	24.4
Onsan port	9.0	380	6L	1.6L	34.0
Pohang South Breakwater	7.5	300	6L	1.6L	22.3
Donghae South Breakwater	7.2	210	6L	1.6L	14.8
Samcheok South Breakwater	5.7	150	6L	1.6L	8.4
Mukho South Breakwater	7.7	170	6L	1.6L	12.9
Okgye South Breakwater	5.9	150	6L	1.6L	8.7

3.3. Hourly Average Congestion

Fig. 3 shows the analysis of hourly average congestion index and peak time congestion index through survey study.

The port of the highest hourly average congestion was Busan Jodo Breakwater(37.6 %), followed by Ulsan no.1 passage(SK no. 5 Berth)(27.3 %), Ulsan Main Port(25.2 %), and Busan New Port (22.1 %). It was found that the hourly average congestion is high for Busan Port and Ulsan Port. The port of the lowest hourly average congestion was Jinhae passage(0.5 %) and Taean port(0.8 %). Busan Jodo Breakwater was the only gateline whose hourly average congestion exceeded 30 %, while five gatelines at Busan Port and Ulsan Port had 20-30 % hourly average congestion, 11 gatelines at Incheon port, Pyeongtaek port, Gwangyang port, Pohang port, and Donghae port had 10-20 %, and the remaining 21 gatelines had 10 % or less. The hourly average congestion showed that the traffic volume was relatively greater for the ports in Busan, Ulsan, Incheon, Pyeongtaek, Gwangyang, and Pohang.

3.4. Peak Time Congestion

The port of the highest peak time congestion was Ulsan Main Port(179.1 %), followed by Ulsan no.1 passage(SK no. 5 Berth) (166.7 %), Pohang South Breakwater(160.8 %), and Busan Jodo Breakwater(157.6 %). There were 11 gatelines whose peak time congestion was 100 % or higher(Gwangang no.1 passage, Gwangyang no.3 passage, Busan Jodo Breakwater, Busan Inner Breakwater, Busan New Port, Ulsan East Breakwater, Ulsan no.1 passage(SK no.5 berth), Ulsan Main Port, Onsan Port, Pohang Port, and Donghae Port). The ports of the lowest peak time congestion were Jinhae Passage(12.0 %) and Masan Passage(21.2 %).

4. Peak Time Congestion Prediction Model by Regression Analysis

4.1. Regression Analysis Model

Regression analysis was performed on the influence of hourly average congestion on peak time congestion. As a result of regression analysis, it was found that hourly average congestion has a significant($p<.001$) influence on peak time congestion (Table 3) and peak time congestion increased with higher hourly average congestion(B=4.457) (Table 4). The explanatory power of hourly average congestion for peak time congestion was 81.1% (Table 2) and had a strong influence(β=.901).

The peak time congestion model formula derived by the regression analysis is as shown in Formula (2) (Fig. 4).

$$C_p = 4.457\,C_a + 29.202 \qquad (2)$$

* C_p : Peak time congestion, C_a : Hourly average congestion

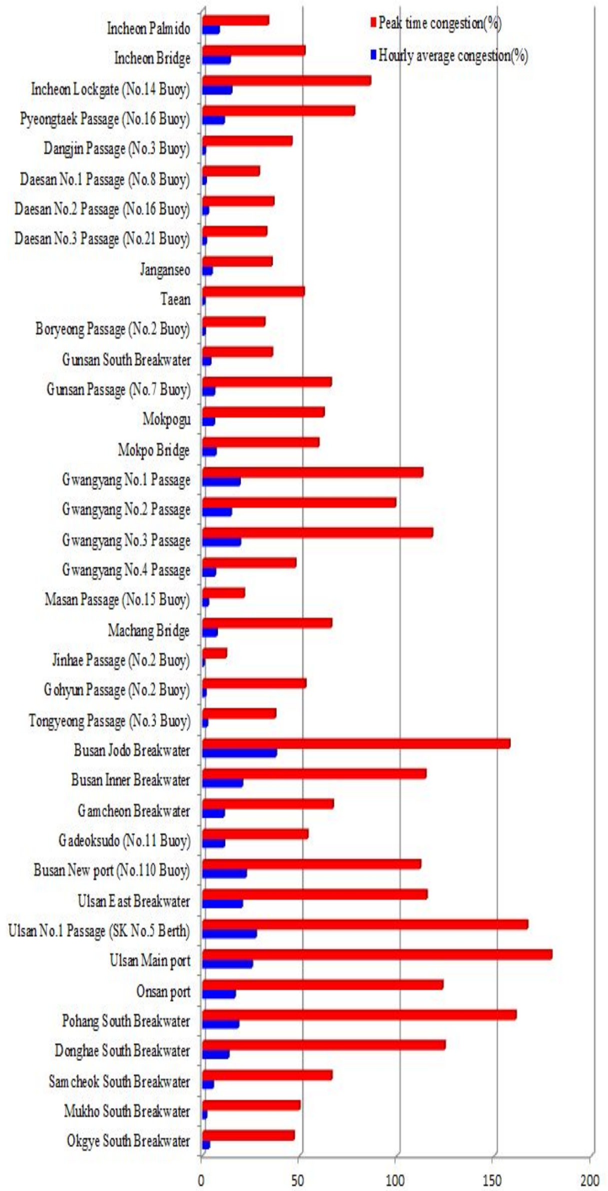


Fig. 3. Hourly average congestion and peak time congestion.

Table 2. Model Summary

R	R^2	$adj\ R^2$	Std. Error of the Estimate
.901	.811	.806	19.553

Table 3. ANOVA

	Sum of Squares	df	Mean Squares	F	p
Regression	59069.412	1	59069.412	154.498	.000
Residual	13763.986	36	382.330		
Total	72833.309	37			

Table 4. Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	p
	B	Std. Error	β		
Constant	29.202	4.842		6.0.31	.000
Hourly Average Congestion	4.457	.359	.901	12.430	.000

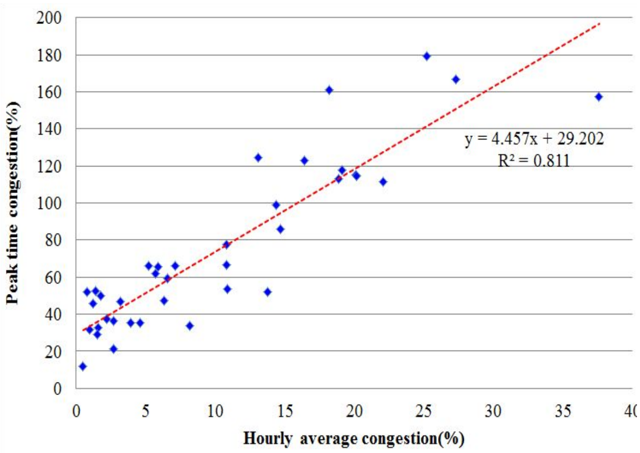


Fig. 4. Scatter plot and regression equation.

4.2. Evaluation of Residual

To review the normalcy of residual, the histogram of residual normal distribution in Fig. 5 was analyzed to conclude that the absolute value of standardized residual was 3 or smaller and there was no abnormal residual value. Also, most of the standardized residual values were in between -1 and 0, indicating that the median of residual is close to 0.

For more accurate evaluation of the hypothesis on the residual normal distribution, the distribution of expected cumulative probability and observed cumulative probability was drawn as in Fig. 6 to show that the two probability values were mostly close to a straight line. Therefore, the residual values of the regression analysis was mostly normal.

Next, the distribution of predicted value and residual was drawn as in Fig. 7 to analyze the standardized scatter of residual. The relationship between the two values should be irregular around '0' without a certain shape in order to satisfy the standardized scatter. As a result, the standardized residual was irregularly scattered around '0' as in Fig. 7 to satisfy the standardized scatter of residual.

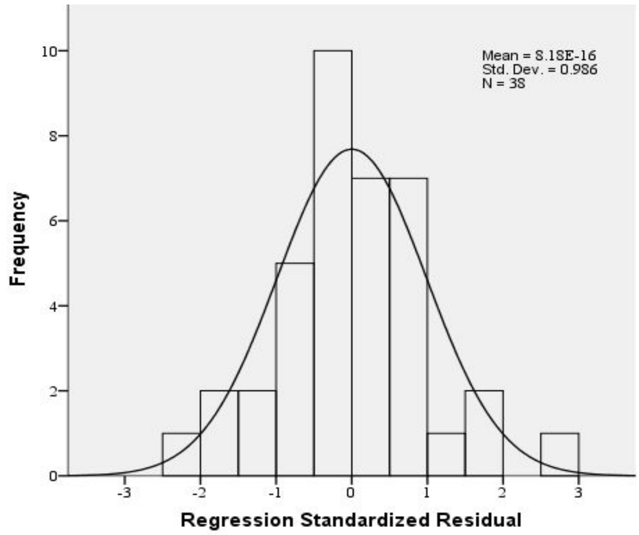


Fig. 5. Histogram of residual normal distribution.

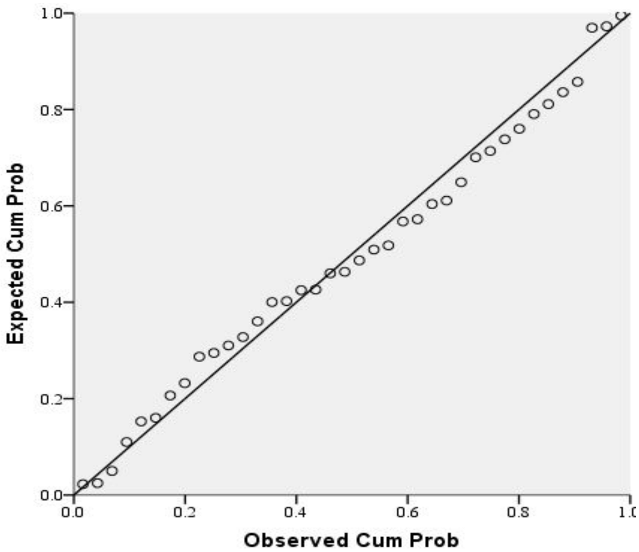


Fig. 6. Normal P-P plot of regression standardized residual.

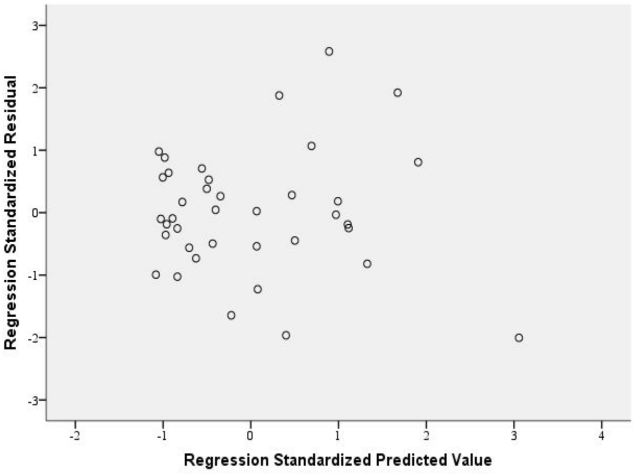


Fig. 7. Scatter plot of standardized predicted value and residual.

4.3. Evaluation of Model Formula

The previous peak time congestion was predicted based on the regression analysis of the number of entries to calculate the predicted hourly average congestion and assume that the ratio of entries would remain consistent for each hour.

Table 5 compares the peak time congestion of Ulsan Main Port in 2020 using the formula of preceding study(SK Gas, 2011) and the prediction model formula. The previous method predicted that peak time congestion would be 31.06% when the speed is 8 knots and the flow of traffic would remain smooth. Based on this prediction model formula (C_p=4.457C_a+29.202), however, the predicted peak time congestion would be 111.56% with a fast increase in traffic to cause traffic congestion at all times. This means the need to improving passage and require traffic management by VTS. The difference between the values from he previous method and from the prediction model formula is about 3.12-3.59 times according to the speed applied. The previous method calculates the peak time congestion too low and distorts the traffic characteristic of the current passage to conclude that it has smooth traffic when it is congested.

Table 5. Comparison of peak time congestion of future at Ulsan Main Port (in 2020)

Speed	Hourly average congestion	Peak time congestion		
		by existing method	by Estimate model	Ratio
4knot	36.94 %	62.09 %	193.84 %	3.12
6knot	24.64 %	41.41 %	139.02 %	3.35
8knot	18.48 %	31.06 %	111.56 %	3.59

5. Conclusion

The previous marine traffic congestion prediction method has used hourly average congestion, but it applied the mean value to distort the marine traffic characteristics. This study performed regression analysis of hourly average congestion and peak time congestion based on 10 days of AIS data of 20 ports. As a result, the following formula was derived:

$$C_p = 4.457C_a + 29.202$$

The previous marine traffic congestion method predicted the quantity of goods transported and the traffic volume following the port development to calculate the hourly average congestion, but it could not predict the peak time congestion. The prediction model can calculate the peak time congestion(C_p) based on the hourly average congestion(C_a).

This study would lay the foundation for the studies on marine traffic control through hourly separation of marine traffic, the scope of surveillance of VTS by sector/passage, and the arrangement of senior VTS operator for peak hours. It would also be useful for setting the width of passage for port development.

However, future study should apply the occupancy of vessels suitable for each port.

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