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ANALYSIS OF MINIMUM SPEED CONTROL EFFECT USING QUEUE MODEL FOCUSING ON BUSAN PORT

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Key words: queue, speed regulation, minimum speed, simulation, VTS(Vessel Traffic Service).

ABSTRACT

VTS aims to increase the efficiency of maritime traffic in two ways. The first is a decrease in marine accidents, and the second is an increase in the utilization rate of infrastructure such as waterways and port facilities. This means that, if safety is guaranteed, efficiency must also be considered in the VTS. The purpose of this study is to quantitatively analyze the effects of speed regulation under safe conditions for an efficient use of waterways. A model was developed using a queue approach, and the effect of the waiting time according to the minimum speed proposal was analyzed through a simulation. The simulation results showed a maximum reduction in congestion of 6.1% occurred when setting the minimum speed to 6 knots. The capacity of the routes was also analyzed, and the results indicate that 2.5 ships can have sufficient time to pass through the waterway at a safe distance.

I. INTRODUCTION

The VTS manual is intended to be a general source of reference on VTS policies to meet the needs of the profession and those responsible for managing its activities(IALA, 2016). According to the VTS manual, VTS increases the efficiency of marine traffic in two ways. The first is the reduction of marine accidents, and the second is the increase in infrastructure utilization, such as waterways and port facilities(IALA, 2016). In other words, both safety-side efforts for preventing marine accidents and measures for the efficient use of port facilities should be carried out. Taking a look at the efficient use of port facilities, proper control of the VTS can reduce the unnecessary waiting of ships on the waterway, and the reduction of an unnecessary waiting time could lead to economic benefits for shipping companies and port terminals.

In addition, towing vessels often navigate at low speeds. If such vessels are along an access port route, they will be banned from overtaking the route, forcing the subsequent ships to slow down, thereby reducing the efficiency throughout the waterway. In addition, the risk of waterways will be higher if unexpected circumstances force low-speed ships to be overtaken. As a result, the Yeosu Regional Office of Ocean and Fisheries has designated a minimum speed of 6 knots (kt) on the waterway. There are reports that slowing down to less than 6 kt along a route may cause congestion on the Busan North Port Waterway (Yeosu Regional office of Ocean and Fisheries, 2008; Ministry of Maritime Affairs and Fisheries, 2006). In the case of a tow-vessel sailing at a low speed within a VTS area, it is often directed to separate itself from the waterway and go under sail. However, there are no efficiency standards based on the minimum speed, and measures are taken according to the specific situation. Therefore, this study aims to quantitatively analyze the effects of minimum speed regulations for the efficient operation of waterways under situations in which safety in the VTS area is guaranteed. For this purpose, the queueing model is applied to a marine traffic survey conducted for 7 days along the Busan North Port access channel. Based on the simulation results, we would also like to analyze the effects of the minimum speed regulation using the congestion, service time, and average number of waiting vessels.

II. LITERATURE REVIEW

A speed limit is a means of forcing a vehicle to produce a speed within a certain range according to the rules of the road, railway, or other route of transportation(Kim, 2014). In addition, speed limits are mandatory because they determine the maximum and minimum speeds that a vehicle can drive on a road for traffic communication and safety. Hwang(2005) proposed that drivers driving on the road should choose the speed of the vehicle by taking into account various factors such as

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the geometric conditions of the road, the traffic conditions, the vehicle performance, the speed limit and level of control, and the value of the traffic. KoRoad(1998) stated that, in the relationship between the speed chosen by the driver and the speed limit, most drivers drive at a speed acceptable to the driver under certain conditions, and that there is little effect on the speed limit if the actual situation and the speed limit differ. In addition, unrealistic speed limits are not observed, and accidents are more likely to occur. Lee(2007) stated that a reliable speed limit for road traffic is defined as a safe speed that allows drivers, such as commuters, to drive safely to the maximum extent under a good traffic environment and road conditions.

From the viewpoint of road traffic engineering, the proper speed limit refers to the maximum speed allowed by the driver while minimizing the speed at which the majority (usually 85%) of drivers pass through free traffic conditions or the risk of an accident. In other words, reasonable speed limits can be defined as the optimum speed considering both the efficiency and safety of the operations. The Korean Act on the Arrival, Departure, etc. of Ships), Article 17 (Restrictions on Speed, etc.) stipulates that the maximum speed of a ship can be designated for the water zone of a port, which is thought to interfere with the safe operation of other ships when sailing at high speeds. While road traffic uses both the highest and lowest speeds, it uses only the highest speed at sea, and there is no limit to the minimum speed. However, it is also recommended to sail more than 6 kt to prevent congestion on the waterways (Yeosu Regional office of Ocean and Fisheries, 2008). In addition, the minimum speed is limited in areas where strong currents affect the steering performance.

In the case of Japan's Kanmon Strait, the Maritime Human Resource Institute(2012) stipulates that a sea speed of at least 4 kt (SOG) is to be sailed in the event of an adverse tide. Park(2009) analyzed the effects of minimum speed regulation using the ES model. Their study suggested that the effect of regulating the speed was high in five rates of passage per hour with minimum speed regulations of 5 and 7 kt, and that the minimum speed regulation effect would occur when the passage scale was set to at least 10 ships (for less than a 500 m wide) at a speed of at least 7 kt. Nieh et al. (2019) analyzed the current situation through a statistical method using the AIS data of vessels entering the KELLUNG Port.

Studies on speed limits have mostly focused on limiting the maximum speed for safety. There have also been limitations on the minimum speed, although such limitations have been studied in terms of ship passage safety. In this study, the effect of the minimum speed is analyzed in terms of efficiency in a situation in which safety is guaranteed

III. SIMULATION DESIGN

1. Waterway congestion model using queueing

A. Queueing

Queuing refers to the formation of customers waiting in line as a part of the customer's satisfaction of the services given by the provider of a service facility. Therefore, to understand the situation of the queue, it is necessary to observe two basic behaviors: customer arrival and service provisioning. Consequently, the focus of attention is the result of the interaction between these two acts, resulting in the number of customers in the queue system and the length of time spent in the queue system. Thus, from the customer's perspective, interest in the number of new customers participating will increase, and from the service-providing perspective, the number of customers leaving the service will be a problem. Queuing theory is a mathematical representation of several phenomena in which the distribution of these arrival and service rates are interpreted against the statistical probability model. The following symbols are used to describe the characteristic elements of a queue (Lee, 2006):

$$(x/y/z):(u/v/w)$$

where x : Arrival distribution
y : service time(or departure) distribution
z : number of parallel servers ($z = 1,2,..., \infty$)
u : service discipline
v : maximum number allowed in system ($v = 1, 2,..., \infty$)
w : size of calling source ($w = 1, 2,..., \infty$)

Mark the arrival distribution and service time as M for a Poisson distribution; D, for a certain time interval; Ek, for an Erlang distribution of order-k; K, for a Chi-square distribution; and HE, for a transcendental index distribution. In addition, if a particular distribution form is not visible, the arrival rate is expressed as GI and the service rate is expressed as G.

Queuing has been studied extensively in port areas where there waiting is, common because it can be used to quantitatively calculate the proper service size(Jagerman, D. and Altiok, T., 2003; Pasquale L and Rina M., 2019; Edmond & Maggs, 1978). Jang(1991) presented the waiting time per vessel as an indicator of the port's service and stated that the waiting estimation formula can be used when the arrival time and service time distributions indicate an Erlang distribution. Baek(1998) applied the queuing theory to analyze the arrival form and dock service time of ships and to establish the relationship between the average ship occupancy rate and the expected waiting time of ships. Lee et al. (2015) calculated the waiting rate and ship occupancy rate of the port as a way to develop the service indicators. As calculated, the waiting rate of Pohang Port was deemed to be high owing to the influence of general cargo ships and bulk carriers, whereas the occupancy rate of the berth was found to be high at Pohang New Port. Lee and Park(2018) used terminal operating data to derive the difference between the queuing rate of the theoretical queue and the actual queuing rate, and found that the theoretical calculation and the reality were largely different. Hess et al. (2007) proved that the operation of the bulk cargo handling terminal follows a queuing model. The proposed model was applied to the actual bulk terminal and was found to be helpful

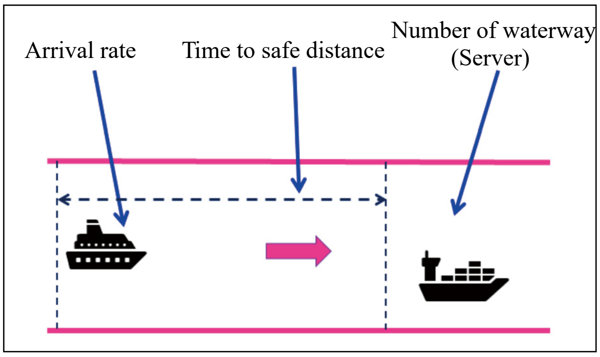

Fig. 1 Concept of queue in waterway

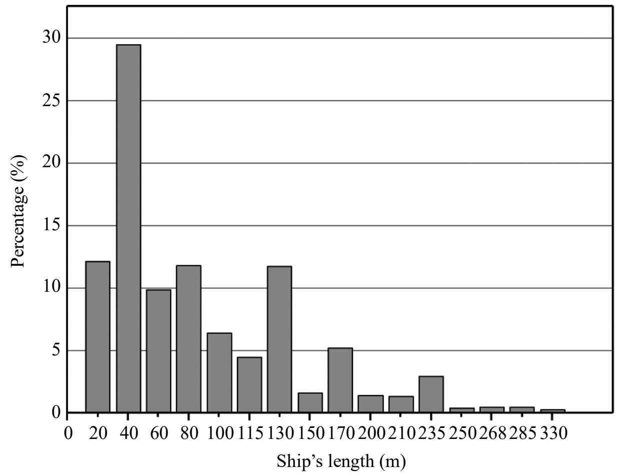

Fig. 2. Ship length distribution

in making decisions regarding greater efficiency. Based on queuing theory and a simulation, Park et al. (1991) analyzed the incoming and outgoing systems of the BCTOC in 1989 for container ships and systematized the actual container terminal cargo handling system into a queue model, comparing it with the simulation results for analyzing the operation status of the terminal. Koo(1997) calculated the congestion of the waterway using the queuing theory. Robert(1997) used a queue to quantitatively analyze communications in the New York Harbor VTS area. The arrival rate of a message was presented by the entry port of the ship, the location of the reporting point, the number of ships encountered in the VTS area, and the communication time within the VTS area, and proved that the communication within the VTS area follows a queue based on communication data from the San Francisco port. Ulusçu, Ö.S., Altıok, T(2009) consider a single-server queue subject to multiple type of operation-independent interruptions motivated by operations and vessel queuing at Strait of Istanbul.

B. Application

The queuing model applied to the route can be seen as the M/G/1 model. The arrival distribution is exponential, the service time has a general distribution, and one server is used. Because the service time does not follow an exponential distribution in the M/G/1 queue model, the remaining service hours of the customer receiving the service depend on the amount of service that the customer has already received (passing service time), which means that the customer is affected by both the past and the future. When applied to a waterway, the amount of time that a leading ship spends along the route is affected by the time when it enters and its progress through the route. When a model of a queue is applied to a waterway, the mean number of the waiting ship can be expressed in the following manner

$$L_q = \frac{\rho^2 + \lambda^2\sigma^2}{2(1-\rho)}$$

where, L_q: Mean number of the waiting ship
ρ : Utilization rate of waterway
λ : Ship arrival rate
σ : Standard deviation of service time

And the service time can be expressed in the following manner with the safety distance of the ship entering the waterway and the speed of the preceding ship.

$$s = \frac{SD}{v_a}$$

where, s : Service time for ships entering the waterway (s)
SD : Safe distance (m)
v_a: Preceding ship speed (m/s)

Figure 1 shows the concept of applying a queue in a waterway.

C. Scenario

The changes in waiting time and congestion were analyzed when the minimum speed was regulated from zero to 6 kt to analyze the impact. In the absence of a speed regulation, three speed scenarios were applied, i.e., 2, 4, and 6 kt. If the generated speed is less than the suggested regulatory speed, the minimum speed is set, and each scenario is simulated 1,000 times (1000h).

2. Element

The target area for the designed simulations was selected as the VTS area for Busan North Port. To check the traffic conditions in the target area, traffic surveys were conducted for a total of 7 days from February 26 (Tuesday) to March 4, 2019 (Monday) (Inoue & Hara, 1973).

A. Ship length

The average length of the ships entering Busan North Port was 64 m. The standard vessel length used by the current maritime traffic safety audit was slightly shorter than 70 m (Um, 2012). This shows that ships using Busan North Port are smaller than average. Figure 2 shows a graph of the distribution of the length of ships entering the port using the approach route to the north of Busan.

As shown in the graph, the length of the vessel does not

Table 1 Vessel representative length ratio

Standard length(m)	20	40	60	80	100	115	130	150
Ratio(%)	12.15	29.48	9.86	11.82	6.40	4.45	11.71	1.61
Standard length(m)	170	200	210	235	250	268	285	330
Ratio(%)	5.20	1.40	1.32	2.92	0.44	0.47	0.48	0.29

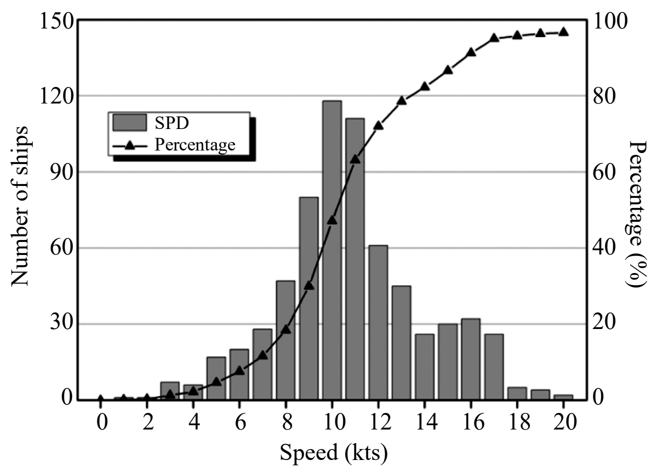

Fig. 3. Ship speed distribution

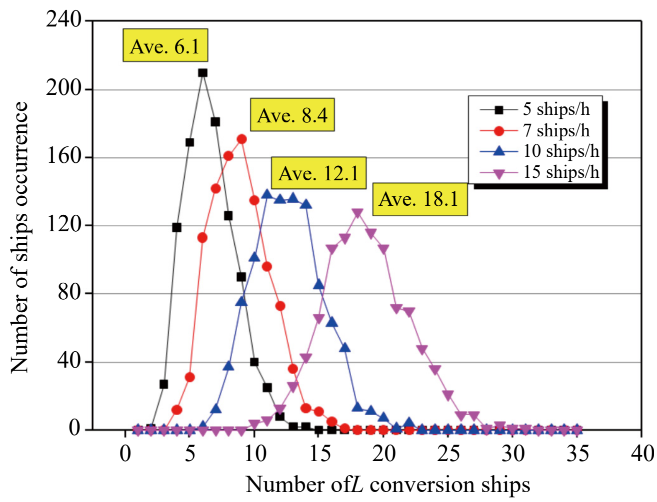

Fig. 4. L conversion ship distribution (simulation)

follow a constant distribution, and it was determined that ships with a length of 70 m or less account for 69.5% of the total number. Table 1 shows the ratio based on the representative length. As a result of the maritime traffic survey, the size of the vessel did not follow a constant distribution, and thus the simulation was designed according to the ratio of the size of the vessel obtained during the survey period.

B. Approach speed

For the simulation design, we analyzed the speed of ships entering the approaching route to the Busan North Port, excluding the speed of the passenger ship. Figure 3 shows the percentage of the speed distribution and speed of the ships entering this route. From the perspective of road traffic engineering, the proper speed limit is determined to be the speed at which the majority of people pass by when the driving speed is examined under free traffic conditions, and the speed that maximizes the driver's consent while minimizing the risk of accidents is usually 85% of the examined speed.

The average speed of ships entering Busan North Port was 10.4 kt, followed by a normal distribution of 3.1 kt for the standard deviation. According to the attached Table 4 of the "Rules on Navigation of Busan Port," the maximum speed of the entrance of the breakwater at Busan North Port was designated as 8 kt, whereas the speed by the earth is judged to be higher owing to the algae at the entrance of the breakwater. The 85% speed was analyzed to be approximately 14 kt. Accordingly, the purpose of the simulation configuration is to generate the speed of the vessel according to the normal distribution for an average of 10.4 kt and a standard deviation of 3.1 kt.

C. Marine traffic

Korea's major ports have a distribution of 5–20 ships per hour, with 5, 7, 10, and 15 ships (Park et al., 2008; Park, 2009). At this time, the number of ships was standardized through an L conversion because the VTS officer's feelings varied depending on the size of the ship. In other words, the ship was created by considering its size ship. Figure 4 shows a graph of the vessel scale generated by the conversion of L.

When converted into an L shape, an average of 6.2 ships were produced for 5 ships, an average of 8.4 ships were produced for 7 ships, an average of 12.1 ships were produced for 10 ships, and an average of 18.2 ships produced. A larger number of ships converted into an L than the designated number means that there are more ships larger than the standard ship of 70 m, and from the VTS officer's point of view, more burdened ships entered the port. The average length of the ship was 64 m during the data collection period, which was smaller than the length of the standard ship, although the ratio of ships over 80 m was higher than that of the standard ship, and thus it was determined that the L conversion scale is large..

Figure 5 shows a graph of the distribution of time taken until the next vessel arrives.

It took an average of 14.05 min for one vessel to enter the route after entering the approach route to the Busan North Port. A chi-square test was then used to verify that the index distribution was followed, and at a 95% significance level with a p-value of 0.12, the distribution of time taken until the next

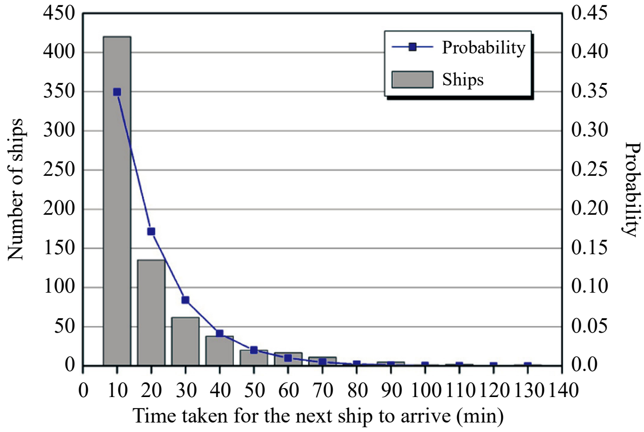

Fig. 5. Arrival distribution of next ships

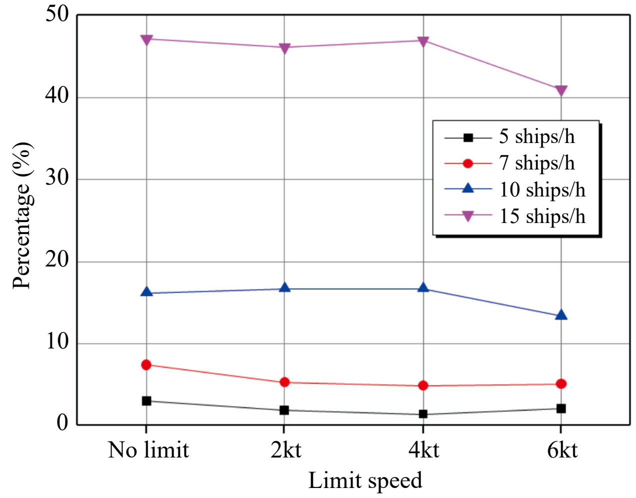

Fig. 6. Congestion ratio by limit speed

vessel arrived was verified to follow the exponential distribution. Therefore, for the simulation configuration, the number of times a ship enters the waterway has a Poisson distribution.

D. Ship's domain

The service time can be obtained from the route using the safety distance of the ship and the speed of the preceding ship. The safe distance here is the minimum safe distance between ships, and in this study, we intend to use the ship domain.

The ship domain refers to a certain area around the main line in which the navigator who controls the ship does not allow other ships or obstacles to enter, and judges that it is safe when the ship does not enter. Potential ship-to-ship encounters are determined through the ship domain, and the ship domain is heavily affected by marine traffic conditions (waterside environment, traffic density, and VTS management level) and environmental conditions (wind and visibility), particularly in restricted waters(PIANC, 2014). Fujii(1971) proposed a ship domain as a result of observing Japanese waters during the late 1960s.

Coldwell proposed a domain based on encounters and overtaking conditions in restricted waterways and shifted the center of the ship to port in a head-on situation, reflecting the impact of COLREGs(Coldwell, 1983). Goodwin investigated ship traffic in the North Sea and suggested a sector-type domain as a result of radar simulator crash experiments(Goodwin, 1975). A domain is divided into three sectors around the vessel, 0.85 miles in a zone of 0° to 112.5°, 0.45 miles in a zone of 112.5° to 247.5°, and 0.7 miles in a zone of 247.5° to 360°, with starboard larger than port and the stern being the smallest in the form of a fan shape in application of the COLREG

Goodwin's proposed D for domain is unsuitable for running computer simulations in a discontinuous form, and thus Davis proposed the concept of Arena, which is used to combine the distances of these sectors together to move the ship's center position and determine the time for the navigator to take collision avoidance actions (Davis et al., 1980, 1982). Arena determines the navigator's behavior according to whether the vessel intrudes into the domain as it enters the area larger than the ship domain. If the other vessel in Arena is on an intruding course and speed into the domain, the navigator will take an alternate course. Jeong et al. (2006) investigated the navigation of other ships sailing under radar around the training ship when entering Shanghai, China, and analyzed the trajectory and use area of the vessel. The ship domain was derived with a long diameter of 5.9 L and a short diameter of 2.2 L.

Park et al. (2010) suggested the minimum clearance of the ship navigation based on the ship operator's safety awareness as 7.5 L in long diameter and 5.2 L in short diameter. Kim(2013) conducted a survey of the minimum safe distance. Park et al. (2014) derived a ship domain with a long diameter of 3.2 L and a short diameter of 2 L using transportation data on the timing of the return after the typhoon at Jinhae Port, which is estimated to have the largest amount of ship traffic. Lee(2017) conducted a survey of 70 VTS officers to derive the minimum safety distance for Korean officers, and Domain averaged 11.3 L in long diameter and 8.7 L in short diameter.

In this study, for an efficient operation at minimum speed in situations in which safety is secured, a long diameter of 11.3 L, derived from the survey of VTS officers, is intended to be used as the safe distance.

IV. RESULT & DISCUSSION

1. 100% or higher congestion rate

Figure 6 shows the percentage of congestion at above 100%. More than a 100% congestion rate means that the time interval between ships entering the route and the time when the ship enters the route and travels a safe distance is the same. Therefore, a congestion level of over 100% can be attributed to the next vessel entering the route before securing a safe distance. In the case of traffic levels of five ships per hour without minimum speed limits, 3 h from among 1,000 h considered had more than 100% of the traffic. By contrast, for a rate of 15 ships per hour, 47.1% of the simulation time made up more

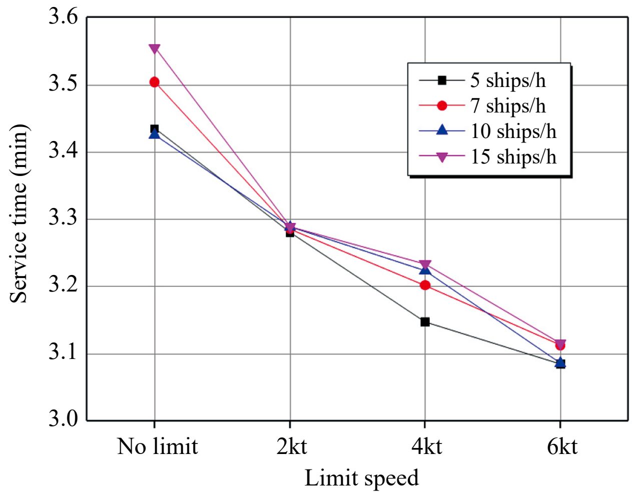

Fig. 7. Service time based on the limit speed

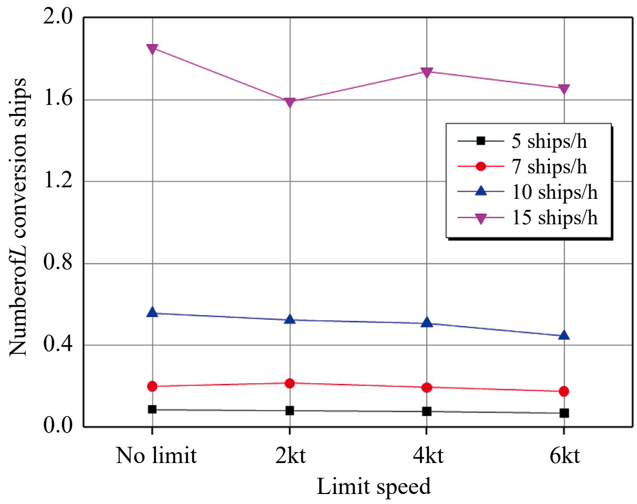

Fig. 9. Number of waiting ships based on speed limit

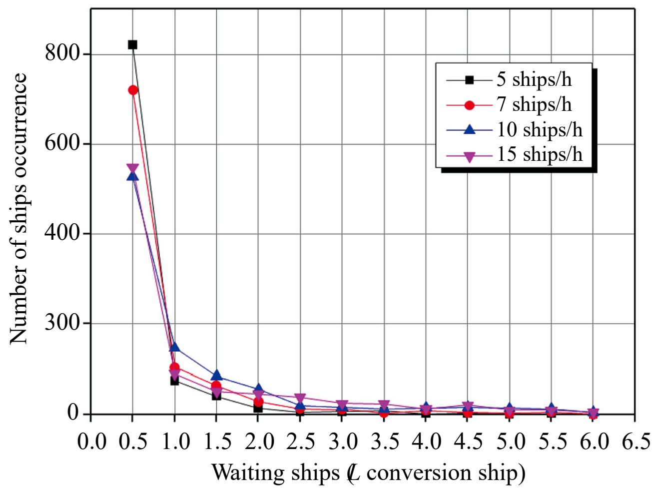

Fig. 8. Waiting ships distribution

than 100% of the congestion. When proposing a minimum speed of up to 6 kt, it was confirmed that the larger the regulation, the smaller the ratio. The 6 kt limit could be reduced by 0.9% for five ships per hour and 6.1% for 15 ships per hour. The higher the traffic, the greater the effect of the restriction. A change occurs between the case with no limit and the case with a 6 kt limit, whereas the change between 2 and 4 kt was insufficient. In other words, the 6 kt limit is effective, and 2 and 4 kt are not.

2. Service time

Figure 7 shows a graph of the average service time for each speed limit. The service time refers to the time it takes for a ship to enter a course and travel a safe distance, which is a factor that directly affects the speed of the ship. This is unrelated to the number of ships or service time in hours because the speed of the vessel is generated according to the distribution regardless of the number of ships. As the regulated speed increases, it can be seen that the service time decreases. Without regulations, the service hours were up to 3.55 min, and if the minimum speed was regulated to 6 kt, it could be reduced to 3.08 min.

The reduction in service time means that a faster operation is possible by increasing the rotational speed of the route. Conversion to an hourly vessel scale allows 16.9 ships per hour to enter the waterway before regulation, and 19.4 ships per hour can then enter the waterway after regulation, and approximately 2.5 ships can enter the waterway while maintaining a safe distance.

3. Number of waiting ships to enter the waterway

Figure 8 shows the distribution of the number waiting ships on route. While most representative values of a distribution use average values, the median is more persuasive than the mean value when the model is skewed to one side(Cho, 2006). Thus, in this study, the effect of a speed regulation from the distribution of the vessels waiting in the waterway to the median value was analyzed.

Figure 9 shows a graph representing the representative L-conversion vessel scales of ships waiting to approach the regulation route. The occurrence of the standby ships means a situation in which the preceding ships cannot enter the port owing to a lack of safe distance. If a safe distance is not maintained, safety must be ensured by deceleration or alteration prior to entry, and if deceleration or alteration occurs in the approaching waters of the course, the nearby waters will become congested. There have been no occurrences of ships with a median value of one or more ships per hour or less. At least one waiting vessel occurred in traffic of more than 15 ships per hour, and when regulated at 6 kt, there was a reduction of approximately 0.2 ships. However, when it was regulated at 2 kt, the number of L conversion ships had the highest reduction effect. In other words, the number of L conversion ships waiting does not seem to have a significant impact on the speed regulation. In this study, the length of the ship in the simulation was the ratio of the traffic survey, and it is believed that for the ship's speed the length of the ship was not considered.

4. Discussion

In an actual situation, if the safe distance is not secured at the entrance of the route, the speed can be reduced to maintain the gap with the preceding vessel. Therefore, congestion cannot occur at 100% (the number of ships entering and the number of ships that can maintain a safe distance). However, the simulation did not consider the situation of reducing the speed of a ship in front of a course to check its effect on the speed limits. Therefore, there was a situation in which the congestion level was over 100%, which was confirmed as an effect of the speed regulation.

Meanwhile, the factors that make up the service time are the length of the ship entering the waterway, the speed of entry, and the safe distance of the VTS officer. In the case of the safe distance of the VTS officer, the distance was unified to the same safety distance in this experiment because the coefficient does not affect the ratio.

Because the length of the vessel reflects the characteristics of the target port and controls the speed of the vessel that has the same proportion and enters the port according to the particular scenario, the faster the speed limit is, and the service time is considered to be insufficient because the only variable is the speed.

V. CONCLUSIONS

To analyze the impact of speed regulation on ship congestion, this research was conducted through a simulation based on a study applied to Busan Port as a queuing model.

(1) The time interval of ships entering Busan port follows an exponential distribution with an average of 14 min, and the safe distance of ship movement when entering the port was applicable to the queue model M/G/1 following a general distribution. The queue model was able to analyze the congestion of routes and the average waiting vessel in the system.

(2) By organizing a simulation with a 0–6 kt speed regulation, it was found that the congestion level can be reduced by 6.1% for a rate of 15 ships per hour, and the higher the traffic, the greater the regulatory effect.

(3) The service time decreased as the speed regulation increased, regardless of the traffic volume. This means that the capacity of routes to enter and maintain a safe distance will increase. It was found that 2.5 ships can have sufficient time to pass safely.

(4) The results showed that 15 ships per hour were waiting with a median value of more than 1 ship. The 2 kt regulation showed a 4% reduction in the appearance rate of one or more ships. The median number of L conversion vessels waiting was not related to the degree of speed regulation.

Through this study, regulatory effects were quantitatively identified. The results of the study are believed to be useful as basic data for regulating the minimum speed to increase the efficiency when the safety of the VTS area routes is secured. Furthermore, it can be used as the basis for port access owing to the emergence of autonomous ships. However, the relationship between the number of L conversion vessels waiting and the speed limit must be determined. In addition, this study was applied to Busan Port and analyzed; however, to standardize it for use in other waterways, an additional analysis is needed according to the average speed of the ships approaching the waterway, and thus further research is required.

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