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A Study on Basic VTS Guideline based on Ship's Operator's Consciousness

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ABSTRACT: VTS controls vessels using VHF for 24 hours a day. Therefore, from the analysis of VHF communication, we can understand the current status of marine traffic and VTS's control pattern in VTS area. This study objective is to propose a basic VTS guideline with ship's CPA/TCPA, collision risk, control frequency, and minimum safety distance using analysis of VHF communication. We analyzed a 7 day VHF communication and AIS data from Busan VTS area, thereafter calculated risk of collision using Park model which is based on ship operator's consciousness and plotted minimum safety distance and vessel's high-risk control frequency using Poisson distribution.

1 INTRODUCTION

Korea's VTS (Vessel Traffic Service) is currently installed in 15 ports and 3 coastal areas, in order to maintain marine traffic safety using radar, VHF, AIS, etc., and to protect the marine environment. VTS monitors identified vessels in the VTS area and provide the necessary information. As a result of these efforts, marine casualties were reduced by 39.3 %, from 126.6 cases to 76.8 cases after the establishment of the VTS (Kim, 2015a). However, there are still marine casualties in the VTS area and there is no quantitative VTS officer's control guideline, so that the service user, the ship operator, may receive different services according to the VTSO even under the same circumstances.

In the VTS area, general reporting such as arrival, departures, and passage of vessels, as well as specific instructions on vessel traffic, are made by the VHF control channel. Therefore, it is possible to analyze communication pattern of VTSO and movement of a ship through communication analysis of VTS area.

We have obtained various information by analyzing the communication of the VTSO (Kim, 2015b) and proposed the control distance through the communication analysis (Park, 2015). However, there is no study on the probability of the dangerous control through the communication analysis or the minimum safety domain of the VTSO.

In this paper, we analyzed the communication in the VTS area and drew the probability of occurrence of the communication of the dangerous situation by the VTSO, and suggested the guideline of the quantitative control by drawing the minimum safety domain.

For this purpose, Busan Port, which has the largest number of vessel traffic in Korea, has been monitored for 7 days and the ship's AIS data were collected to confirm the risk level at the time of communication.

The monitoring frequency of the dangerous ship was confirmed to follow the Poisson distribution and the interval of the control was calculated using the exponential distribution. In addition, the minimum safety domain of the VTSO was drawn using the bearing and distance at the time of control of the dangerous ships.

2 VHF COMMUNICATION ANALYSIS IN BUSAN PORT VTS AREA

2.1 *Research methods and targets*

Inoue and Hara (1973) suggested that 6 to 7 days of marine traffic observation would be appropriate for representative population.

Based on this reason, we analyzed the communication of VTSO in the Busan Port area and identified the dangerous encounters of the vessels for 3 days (6th April, 2015 ~8th April, 2015), for four days (11th December 2015 ~ 14th December 2015), a total of 7 days (168 hours). We also collected the AIS information of the ship at the same time to calculate the maritime traffic risk.

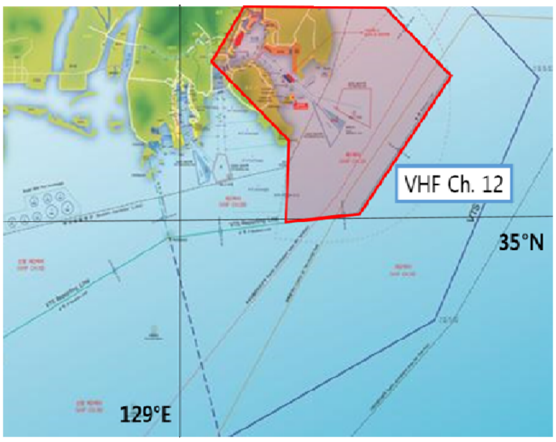

Figure 1. Busan port VTS area.

2.2 *Risk model based on Ship Operator Consciousness*

VTSO use CPA and TCPA in many cases, but this is the value indicated by the distance, speed, and heading factors between the vessels. However, it is common for the ship's operator to determine the risk between vessels by reflecting the factors such as the size of the vessel, the type of the vessel, and the surrounding sea room.

Therefore, this study intends to use the Potential Assessment of Risk (PARK) model, which is implemented for the risk of the ship operator who navigates the actual coastal waters of Korea. PARK model is based on the ship type, tonnage, ship length, ship width, angle and direction of approaching the ship, the relative speed of ships and the distance between ships (Park et al., 2015).

The risk of the PARK model ranges from 1 to 7, with 0 to 3 being safe. 3 to 5 are classified as safe and not dangerous, and 5 or more are classified as dangerous. In this paper, we analyzed the control communication with a risk value of 5.0 or more, which is considered to be a dangerous situation.

2.3 *Identification of risk situation based on communication analysis of Busan Port VTS*

The communication in Busan Port VTS area was classified as VTS to ship, ship to VTS and ship to ship calls. The amount of communication was analyzed as shown in Table 1 for 7 days.

Table 1. Number of communication via VHF Ch.12 in 7days

Day	Ship to VTS	VTS to ship	Ship to ship	Total
1st day	739	143	93	882
2nd day	702	132	102	834
3rd day	787	149	118	936
4th day	553	99	62	652
5th day	641	172	88	813
6th day	847	135	130	983
7th day	853	167	98	1,020
Total	5,122	998	691	6,811

A total of 6,811 communications were conducted on the VTS VHF channel 12 of Busan Port for a period of 7 days. The average number of communication per hour was 40.54 at every 1.5 minutes. To identify the case where the VTSO instruct the vessels directly, among the contents of the VHF channel No.12 of the Busan Port VTS, the analysis was divided into 7 items: control, radio check, intention, information, vessel check, channel change and others. To identify the case where the VTSO monitors the ship to ship communication, the analysis was divided into 4 items: intention, channel change, chat, and others.

Table 2. Number of VTS communication items in 7days

Time	Control	Radio Check	Intention	Info.	Vessel Check	Channel Change	etc.	Total
0000-0200	18	0	1	9	6	2	2	38
0200-0400	12	0	3	6	4	1	0	26
0400-0600	16	0	2	9	8	0	4	39
0600-0800	86	0	7	19	9	1	12	134
0800-1000	44	1	6	30	10	1	8	100
1000-1200	43	3	2	24	11	2	5	90
1200-1400	47	0	5	24	14	3	5	98
1400-1600	48	0	4	19	15	0	8	94
1600-1800	68	0	5	25	15	2	11	126
1800-2000	81	0	7	12	14	2	12	128
2000-2200	30	0	6	8	6	0	10	60
2200-2400	35	0	1	15	12	0	2	65
Total	528	4	49	200	124	14	79	998

2.3.1 *VTS to ship communication analysis*

Table 2 shows the contents of the VTS calling the ship for 7 days and the number of communication by the time of day.

As for the amount of communication per hour, it was found that the daytime zone (06: 00-18: 00) was 642 and the night time zone (18: 00- next day 06:00) was 356.The number of communication in the daytime zone was 1.8 times that of night time zone. Table 3 shows the comparison of traffic volume and communication volume by time. It is observed that VTS had many calls to the ship at daytime because of high vessel traffic.

Table 3. Comparison of traffic volume and communication by timeline

Day time		Night time	
Traffic volume (ships)	Communication (case)	Traffic volume (ships)	Communication (case)
2,230	642	819	356

In order to analyze the VTS to ship communication, we extracted 145 cases of direct control in two or more of the 528 communications that the VTS called the vessel for 7 days.

However, this paper exclude cases where there is no AIS information, and that there is no interconnection between the ship, berthing and un-berthing ships

In order to check the risk of VTSO control of vessels, the location of the vessels with 145 communications plotting is as illustrated in Figure 2.

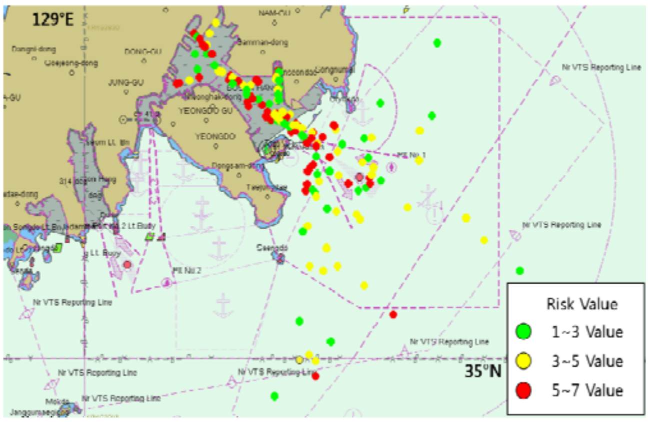

Figure 2. VTS advice starting point by Risk value.

In this case, the safe situation (1 ~ 3) is green, the safe but not dangerous situation (3 ~ 5) is yellow, and the dangerous situation (5 ~ 7) is red.

When the VTSO instruct the vessel directly, there were 48 cases (33.1%) of the 145 cases with a risk of 5.0 or more, and most of them were in the port.

2.3.2 *Vessel communication on VTS channel analysis*

Table 4 shows the contents of the vessel's communication on VTS channel for 7 days and the number of communication by the time of day.

Table 4. Number of vessel communication via VHF channel

Time	Intention	Channel Change	Chat	etc.	Total
0000-0200	8	0	1	0	9
0200-0400	36	2	3	0	41
0400-0600	30	2	2	0	34
0600-0800	71	4	12	4	91
0800-1000	68	3	9	0	80
1000-1200	60	4	4	0	68
1200-1400	57	3	8	0	68
1400-1600	57	3	10	2	72
1600-1800	70	6	5	1	82
1800-2000	46	8	3	0	57
2000-2200	38	3	3	1	45
2200-2400	39	3	2	0	44
Total	580	41	62	8	691

The contents of communication between vessels on the VTS channel of the Busan port can be viewed as part of the observation confirmation, which is the first stage of the VTS's control procedure (MOF, 2014)because the VTSO can also listen to the contents. In the case of intention confirmation communication regarding the traffic, VTSO can monitor the situation without intervening when it is judged that the traffic situation at that time is appropriate. Therefore we assumed this procedure as an indirect control.

Among the 580 communications between vessels, 145 cases which were between two or more vessels were extracted, except when there was no AIS information. The ship's locations and risk value were plotted as shown in Figure 3.

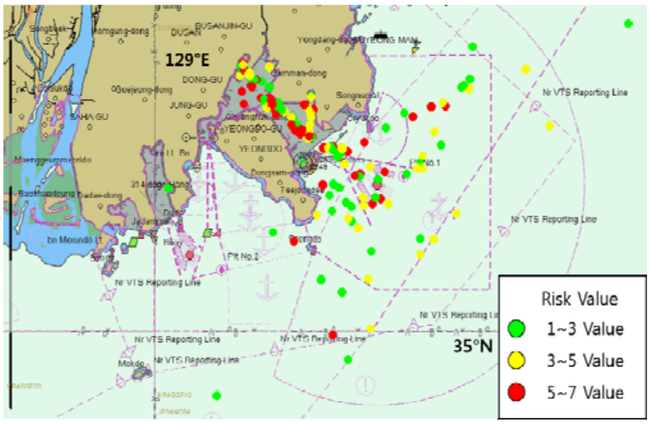

Figure 3. Passing vessels communication starting point by risk value

In this case, the safe situation (1 ~ 3) is green, the safe but not dangerous situation (3 ~ 5) is yellow, and the dangerous situation (5 ~ 7) is red.

There were 44 cases (30.3%) of the 145 cases with a risk of 5.0 or more, and it was confirmed that vessels communicate over the entire VTS area rather than the direct control from VTS.

3 ANALYSIS AND PREDICTION OF RISK TRAFFIC INTERVAL USING POISSON DISTRIBUTION

3.1 *A method of risk interval*

Poisson distribution is the distribution of random variables that are less likely to occur in a particular event among many events. It is also a discrete probability distribution that represents how many events occur within a unit of time. Thus, the Poisson distribution is used to determine the number of occurrences of events occurring in a given time and space (Park et al., 2013).

In this study, we used the Poisson distribution to predict the probability of controlling the dangerous situation in the VTS area per unit time. The Poisson distribution can be expressed as Equation (1).

$$f(x) = \frac{\lambda^x e^{-\lambda}}{x!} \quad (1)$$

where,

x: Number of contacts with a risk of 5.0 or more per unit time

λ: The expected value of controlling the risk above 5.0 for a unit of time within the VTS area

3.2 *Analysis and prediction of risk interval in the VTS area*

Based on the 7 days communication in the Busan port area, we analyzed how much control was conducted per unit time for the dangerous traffic vessels, directly or indirectly, by the VTSO.

3.2.1 *Case 1 (Direct control)*

Figure 4 is a graph of the frequency of control by VTSO for dangerous vessels (risk above 5.0) and the probability of occurrence by Eq. (1) at intervals of 2 hours within the Busan port VTS area.

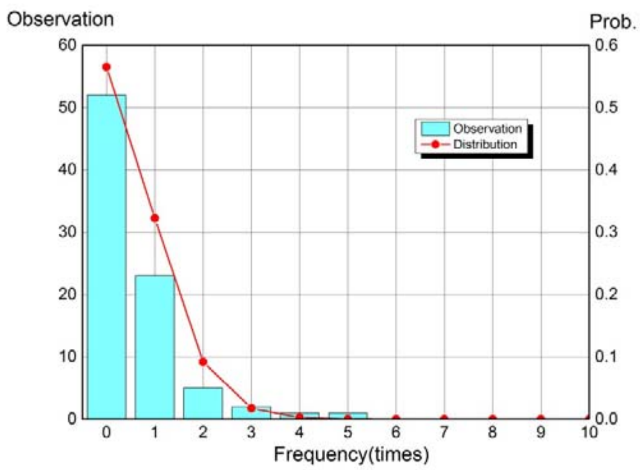

Figure 4. Observation No. and probability of control for dangerous ships in VTS area.

Using the data in Figure 4, verification of whether this distribution follows the Poisson distribution was carried out using chi - squared for 84 samples (168 hours / 2 hours)

If the frequency is less than 5(using chi-square), it affects the value of expected frequency (Tabata, 1994). Therefore, the size of the sample should be increased, or two or more categories should be reduced or integrated into one.

In this paper, the frequency of observations of 2 to 5 categories is integrated into 9.

Table 5 shows the chi-square test results. P value was 0.21. The null hypothesis that there is no difference between the observation frequency and the expected frequency can not be rejected at the 5% significance level, and this distribution follows the Poisson probability.

Table 5. Chi-square test for validation of the Poisson distribution on VTS control (N=84)

Frequency (times)	Expectation	Observation	Degree of freedom	$\chi^2(p)$
0	47.43 (51.58)	52		
1	27.10 (25.16)	23		
2	7.74 (6.14)	5(9)	1	1.52*
3	1.47 (0)	2(0)		(0.21)
4	0.21 (0)	1(0)		
5	0.02 (0)	1(0)		

*p>.05

Since the frequency of controlling the ships with a risk of 5.0 or more per 2 hours has proved to follow the Poisson distribution, it can be said that an average of 0.57 times per unit time controls the ships with a risk of 5.0 or more. The waiting time to control the next ship with a risk of 5.0 or more follows an exponential distribution with an expected value of 0.57 and can be expressed as Equation (2).

$$f(T) = 0.57e^{-0.57T} \left(T \geq 0\right) \quad (2)$$

where,

T= Waiting time to next dangerous communication (unit: 2hour)

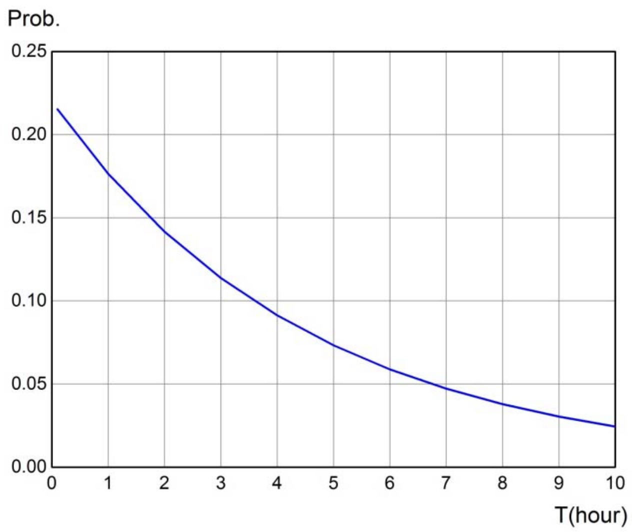

Figure 5. Probability of control for next dangerous ships in VTS area

Figure 5 is a graph showing the exponential distribution of the waiting time until a vessel with a risk of 5.0 or more is controlled within the control area of the Busan Port. The x-axis represents the waiting time until the ship is in danger of 5.0 or higher and the y-axis represents the probability. For example, it can be seen that the probability of controlling a risk of 5.0 or higher again after 2 hours is 32.2%.

Since the expected value of control risk over 5.0 for 2 hours in the VTS area is 0.57 (times per unit time), the average of the control time interval probability variable is 1.75 unit time (2 hours) and controls the vessel in dangerous condition once every 3.50 hours. The exponential distribution is a probability distribution with the elapsed time between events as a random variable. If an event occurs according to the Poisson distribution probability, the time elapsed during the occurrence of this event follows the exponential distribution. In this study, it is verified that the frequency of communication with vessels with a risk of 5.0 or more per unit hour depends on the probability of Poisson distribution. This means that the time interval between the execution of the dangerous situation and control of the next dangerous situation follows the exponential distribution. This exponential distribution is used to predict control interval of vessels in dangerous situation

3.2.2 *Case 2 (Indirect control)*

Figure 6 is a graph of the frequency of communication of dangerous vessels (risk above 5.0) and the probability of occurrence by Eq. (1) at intervals of 2 hours within the VTS area of Busan Port.

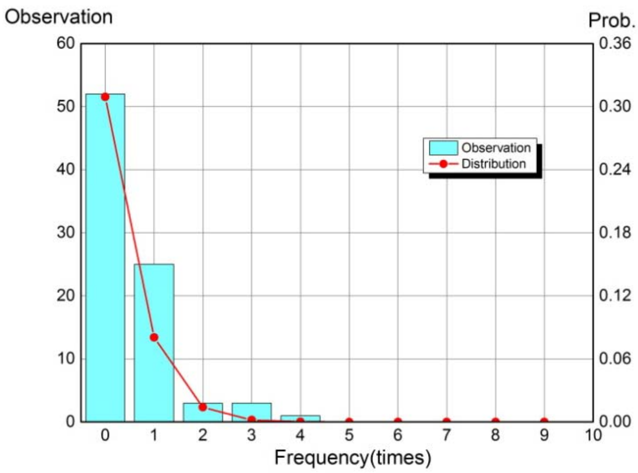

Figure 6. Observation No. and the probability of communication of ships in a dangerous situation.

Using the figure 6 data, the verification of whether this distribution follows the Poisson distribution was carried out by using chi - squared for 84 samples (168 hours / 2 hours)

Table 6 shows the chi-square test results. P value was 0.56. The null hypothesis that there is no difference between the observation frequency and the expected frequency can't be rejected at the 5% significance level, and this distribution follows the Poisson probability.

Table 6. Chi-square test for validation of the Poisson distribution on VTS monitoring (N=84)

Frequency (times)	Expectation	Observation	Degree of freedom	$\chi^2(p)$
0	61.90 (52.80)	52		
1	29.76 (24.51)	25		
2	3.57 (5.69)	3(7)	1	0.32*
3	3.57 (0)	3(0)		(0.56)
4	1.19 (0)	1(0)		

*p>.05

Figure 7 is a graph showing the exponential distribution of the waiting time until the ship to ship communication occurs again at a risk of 5.0 or more.

For example, it can be seen that the probability of ship to ship communication on the risk of 5.0 or higher occurring again after 2hours is 31.0%.

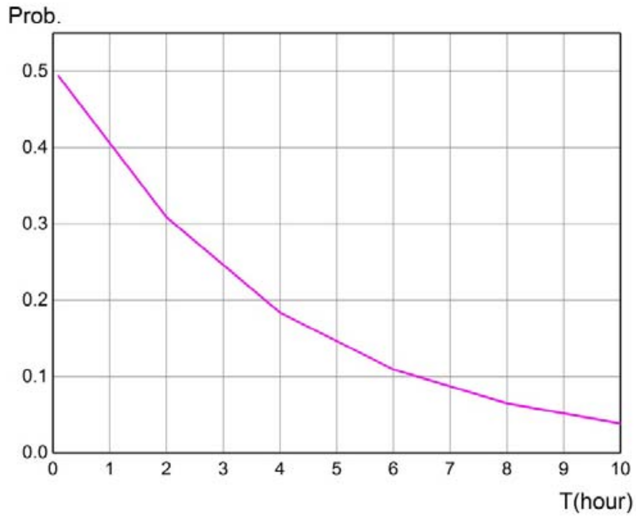

Figure 7. Probability of monitoring next dangerous ships

Since the expected value to communicate between vessels on risk over 5.0 for 2 hours in the VTS area is 0.52 (times per unit time), the average of the control time (indirect) interval probability variable is 1.92 unit time (2 hours), and VTSO indirectly controls the vessel in dangerous condition once every 3.84 hours.

4 MINIMUM CONTROL DOMAIN USING COMMUNICATION DISTANCE & BEARING

While monitoring VTS area, VTSO calls the vessel when they need to control the situation. Ship operator also calls other vessels when they need to check their intention. We assumed that VTSO and ship operator contact point on VHF channel is minimum control domain

4.1 *Ship's length and communication distance*

To draw minimum control domain in VTS area, we researched ship's length and communication distance.

Figure 8 is a graph showing the relationship between the length of ships and vessels under direct control or indirect control from VTSO. The average length of the ship under VTSO direct control was

82.9m and 68.1m for the ship under indirect control from VTSO. This means that VTSO controls large vessels on average because small vessels have relatively good maneuverability and there were many shifting vessels in VTS area.

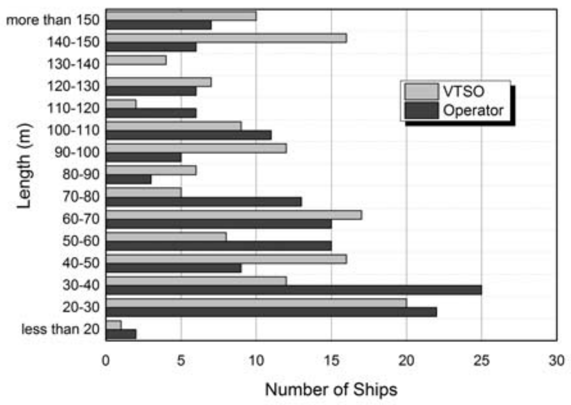

Figure 8. Communication vessel's length

Figure 9 is a graph showing the distance at which the VTSO started to control the ship directly and indirectly. The case of direct control was 2,617m (1.41NM), indirect control was 2,357.7m (1.27NM). The case of indirect control was shorter than direct control because there were some cases that individual vessels contacted other vessels again after VTSO's control to confirm each other's position.

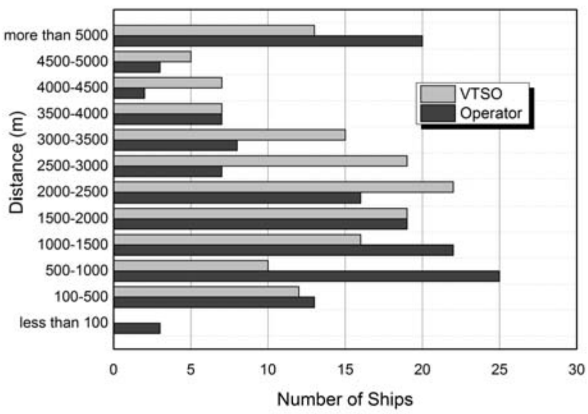

Figure 9. Communication distance (m)

4.2 *Minimum control domain*

4.2.1 *Method*

To draw VTSO's minimum control domain, we put the object vessel to zero point and used relative bearing and distance as demonstrated in Figure 10.

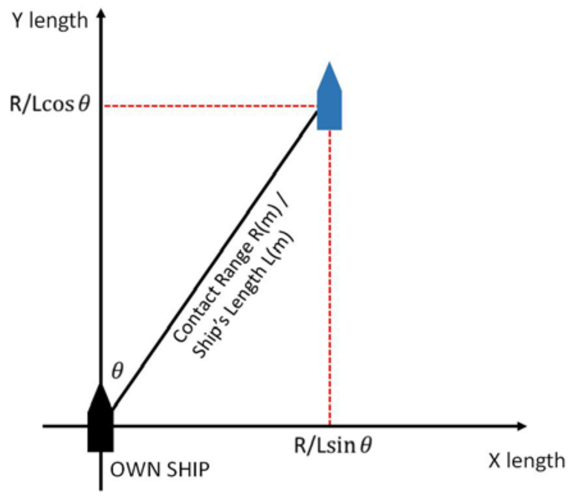

Figure 10. A method of plotting domain
where,
θ= Relative bearing (Rad)
R = Contact Range (m)
L = Ship's Length (m)

4.2.2 *Minimum domain*

Figure 11 is a graph showing VTSO's direct and indirect control starting plot. VTSO's direct control domain was 4L X 2L and indirect control domain was 2L X 2L. This means that VTSO controls the vessel in advance compared to ship operator. And also it can be seen that a lot of control communication is performed with respect to the ship ahead of the ship in astern.

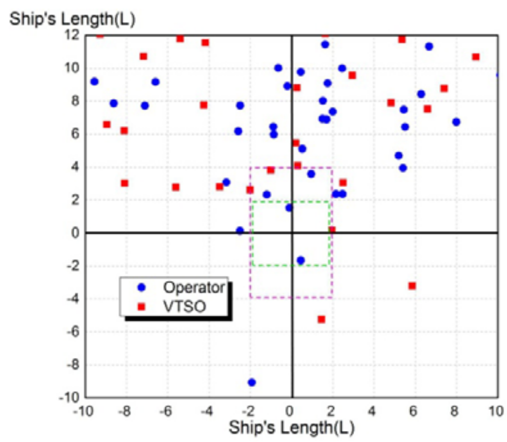

Figure 11. VTSO control domain

5 CONCLUSION

The communication carried out by the VTSO and the vessel operator for safety operation on the VHF within the VTS area reflects the perception, scope, and intention of the risk of the VTSO or the ship operator. Therefore, it can be used as a measure of the risk in VTS area. This study analyzed the VHF communication of Busan Port and confirmed that the probability of controlling the vessels with a risk of 5.0 or more by the PARK model per unit time in the VTS area follows the Poisson distribution. The time interval was predicted. Also, based on the distance from which the communication was started, the minimum control domain of the VTSO was derived. The results of this study are as follows.

1 A total of 6,811 communications over 7 days were found at Busan Port VTS VHF Channel 12, with 40.54 average communication per hour and 1.5 minutes per hour. Of these, the communication that the VTSO called the ship was analyzed that the day time had about 1.82 times the communication amount than the night time.
2 Within the VTS area, the probability that the VTSO will, directly and indirectly, control the vessel in a dangerous situation (risk above 5.0) for a unit of time is analyzed to follow the Poisson distribution.
3 Based on the verification of the Poisson distribution, the VTSO in the VTS area were observed to monitor dangerous vessels on an average of 3.50 hours and indirectly control the vessels under risk conditions every 3.84 hours.
4 It was analyzed that VTSO has 4L X 2L minimum control domain and ship's officer have 2L X 2L minimum domain.

In next step, the relationship between the probability of the Poisson distribution and the actual marine accident will be verified to form a model that can estimate the number of marine accidents. A study on VTSO's control guideline based on VHF communication analysis in the VTS area should be continued.

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