

# Applications of Ship Domain Theory to Identify Risky Sector in VTS Area

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**Abstract** : This paper describes the application method of bumper area defined in the ship domain theory and it is to identify risky sectors in VTS(Vessel Traffic Services) area. The final goal of this work is to develop early warning system providing the location information with high traffic risks in Mokpo VTS area and to prevent the human errors of VTS Officer(VTSO). The current goal of this paper is to find evaluation and detection method of risky sectors. The ratio between overlapped bumper area of each vessels and the summing area of a designated sector, Ratio to Evaluate Risk(RER)  $\gamma$  is used as one of evaluation and detection parameter. The usability of overlapped bumper area is testified through three kinds of scenarios for various traffic situations. The marine traffic data used in the experiments is collected by AIS(Automatic Identification System) receiver and then compiled in the SQL(Structured Query Language) Server. Through the analysis of passing vessel's tracks within the boundary of Mokpo VTS area, the total of 11 sectors are identified as evaluation unit sector. As experiment results from risk evaluation for the 11 sectors, it is clearly known that the proposed method with RER  $\gamma$  can provide the location information of high risky sectors which are need to keep traffic tracks of vessel movements and to maintain traffic monitoring by VTSO.

**Key Words** : Ratio to Evaluate Risk(RER), Bumper area, Risky sector, Marine safety, Vessel traffic services, VTS Officer(VTSO), Human error

## 1. Introduction

The main task of Vessel Traffic Services(VTS) is to keep traffic tracks of vessel movements and to maintain traffic monitoring with Radar, Radio telephony and Automatic Identification System(AIS)(Wikipedia, 2014). The establishment of VTS is based on the International Convention for the Safety Of Life At Sea(SOLAS) Chapter V regulation 12(SOLAS, 2002) and Guideline for Vessel Traffic Services in Resolution A.857(20)(IMO, 1997). The guideline for VTS requires qualified VTS Officer (VTSO) to keep suitable monitoring the marine traffic situation and to provide recommendations to participating vessels.

The geographical boundary for VTS monitoring is called as VTS area including main passage routes and traffic entrance branches. Also, the specific separation boundary in VTS area is called risky sector which is to give concentration monitoring and to identify any risky situations by VTSO. If VTS area have many sectors then VTSO may makes some mistakes such as missing target tracking, failure to monitor the traffic situations and looking elsewhere, etc.

The final goal of this study is to develop early warning

system which is to give the location information of risky sectors in VTS area and for VTSO to recognize the risk in advance. The current goal of this paper, which is to fulfill the last target, is to find an identification method of risky sectors in VTS area using the bumper areas of vessels according to Ship Domain(SD) theory(Fujii and Tanaka, 1971; Kunz, 1998). The key contents of SD theory are to give enough safety boundary of a vessel. To define a risk evaluation method, the concepts for overlapped bumper area between vessels are introduced in this work, and the ratio between overlapped bumper area and the summing area of a passage route is used as one of risk evaluation parameter. The usability of the concept for overlapped bumper area is testified through simulation tests having three different traffic scenarios. As results from the experiments with AIS data in the Mokpo VTS area, it is clearly known that the proposed risk evaluation techniques can be use for the identification method of risky sectors in VTS area.

## 2. Application of Ship Domain Theory

### 2.1 Application Concepts of Ship Bumper Areas

The master and/or Officer Of Watch(OOW) of a vessel try to keep a certain safety zone from vicinity vessels, harmful objects and shallow water, etc. The safety area, so called bumper area,

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varies with navigational environment and weather conditions. This behavior of master and/or OOW can be defined as Ship Domain(SD) theory which is to give large enough bumper area of a ship(Frandsen et al., 1991). The bumper size is estimated area from the analysis results of traffic data obtained through Radar observations and it is proposed by Fujii et al.(1984). For passage routes with sufficient width, the average size of bumper area is defined as 8.0 L in the direction of progress and 3.2 L in the side direction, where L is the length of the vessel. In harbor, meanwhile, the average size of bumper area is defined as 6.0 L in the direction of progress and 1.6 L in the side direction(Kunz, 1998; AASHTO, 1991). This study used the average size of 6.0 L and 1.6 L to calculate the bumper area of a vessel passing the passage way of Mokpo harbor.

Figure 1 represents conceptual bumper areas and its application method to calculate the overlap areas having two kinds of bumper shapes(Larsen, 1993). The elliptical shape, as shown in Fig. 1(a), is depicted to the original SD theory and the square shape, as shown in Fig. 1(b), is modified type to calculate overlapped bumper area between vessels in this work. Although the elliptical shape gives more realistic form of a ship area, it is more difficult to calculate overlapped bumper area than the square shape.

Noting that the overlapped bumper area can be thought as one of evaluation parameter to evaluate any risk levels at given navigational situations. It is because of that as larger the overlapped bumper area as higher risks than small area. Also, the summing area of passage route must keep into consideration to define the risk concepts of overlapped bumper area. This reason is that the significant weight of overlapped bumper area varies with the summing area of passage route.

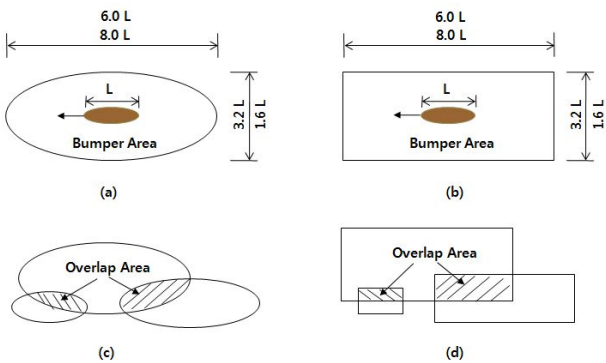


Fig. 1. Conceptual bumper area and its application method to calculate the overlap areas. (a) elliptical bumper area, (b) square bumper area, (c) and (d) picturized overlap area of (a) and (b), respectively.

## 2.2 Detection Theory of Risky Sectors in VTS Area

The ratio between the overlapped bumper area of vessels and the summing area of passageway route is used as one of evaluation parameter to detect risky sectors in a VTS area. Ratio to Evaluate Risk(RER)  $\gamma$  can be calculated as follows.

$$\gamma_i^t = \frac{\sum_{j=1}^{J-1} \sum_{m=j+1}^J (V_{i,j}^t \cap V_{i,m}^t)}{S_i} \quad (1)$$

where:

The term  $V_{i,j}^t \cap V_{i,m}^t$  means overlapped bumper area between each passing vessels  $j$  in a evaluation sector  $i$  at time  $t$ .

$j$  ( $j = 1, 2, 3, \dots, J$ ) is the number of passing vessels with maximum value  $J$ .

$i$  ( $i = 1, 2, 3, \dots, I$ ) is the number of evaluation sectors with maximum value  $I$ .

$V_{i,j}^t$  is pivot vessel's bumper area to compare other vessels which is denoted as  $V_{i,m}^t$  with index  $m$  ( $m = j+1, j+2, j+3, \dots, J$ ).

$S_i$  is the summing area of each evaluation sector  $i$ .

The bumper area of a vessel denoting as  $V_{i,j}^t$  and  $V_{i,m}^t$  in Eq.(1) can be expressed as follows.

$$V_{i,j}^t = (6.0 L_{i,j}^t) \times (1.6 L_{i,j}^t) \quad (2)$$

where:

$L_{i,j}^t$  is the length of a passing vessel  $j$  in a evaluation sector  $i$  at time  $t$ . The both number of 6.0 and 1.6 means the weighting values to give the average size of bumper area defined in SD theory(Kunz, 1998).

The geographical shapes of evaluation sector have various polygons such as rectangular, regular polygon, irregular polygon, etc. The summing area of each evaluation sectors with various shape of polygons can be calculate as follows(WikiHow, 2014).

$$S_i = \left[ (x_{i,N} \times y_{i,1}) + \sum_{k=1}^{N-1} (x_{i,k} \times y_{i,k+1}) - (x_{i,1} \times y_{i,N}) - \sum_{k=1}^{N-1} (x_{i,k+1} \times y_{i,k}) \right] \quad (3)$$

where:

$N$  is the number of sides of polygon in sector  $i$ .

$\{x, y\}$  is vertices position of the polygon.

$\{x_{i,1}, y_{i,1}\}$  and  $\{x_{i,N}, y_{i,N}\}$  are starting point and end point of polygon in the evaluation sector  $i$ , respectively.

### 2.3 Testifying Overlapped Bumper Area Applications

To testify the usability of overlapped bumper area application, three kinds of scenarios having different ship dimensions and passage characteristics are created as shown in Table 1.

The three figures from Fig. 2 to Fig. 4 shows the simulation results with the scene of vessel movement in the designed passage route and calculation results of overlapped bumper area between vessels using Eq.(2) and Eq.(3). Fig. 2 represents simulation results for the scenario 1 as in Table 1 and it is to mimic overtaking situation between 'Ship A' and 'Ship B' with different start/end position of time, different vessel speeds and same courses. The overlapping position is start around 2,300 m and finish around 8,000 m. Fig. 3 depicts simulation results for the scenario 2 as in Table 1 and it is to reproduce head-on situation between 'Ship A' and 'Ship B' with different start/end position of time, different vessel speeds and opposite courses each other. The overlapping position is start from around 800 m and finish around 2,600 m.

Fig. 4 shows simulation results for the scenario 3 as in Table 1 and it is to reproduce complex situation between 'Ship A', 'Ship B' and 'Ship C' with different start/end position of time, different vessel speeds and different courses each other.

As results from the three simulation, it is seen that the amount of overlapped bumper area are varies along with the x-axis(length of passage route) depending on the length of vessel, vessel's speed and course and the position of designated ship at given time. These results gives a fact that the Eq.(2) and Eq.(3) are reasonably suit to obtain RER  $\gamma$  in Eq.(1).

Table 1. Simulation scenarios to testify the usability of overlapped bumper area applications.

Scenario Number	1	2	3
Situation	Overtaking	Head-on	Complex
Passage routes	Width: 900 m Length: 10 km	Width: 300 m Length: 3 km	Width: 900 m Length: 10 km
Ship A	Length: 369 m Breath: 51 m Course: 090° Speed: 30 kts	Length: 369 m Breath: 51 m Course: 090° Speed: 30 kts	Length: 369 m Breath: 51 m Course: 090° Speed: 30 kts
Ship B	Length: 112 m Breath: 18 m Course: 090° Speed: 10 kts	Length: 112 m Breath: 18 m Course: 180° Speed: 10 kts	Length: 112 m Breath: 18 m Course: 045° Speed: 10 kts
Ship C	none	none	Length: 112 m Breath: 18 m Course: 225° Speed: 20 kts

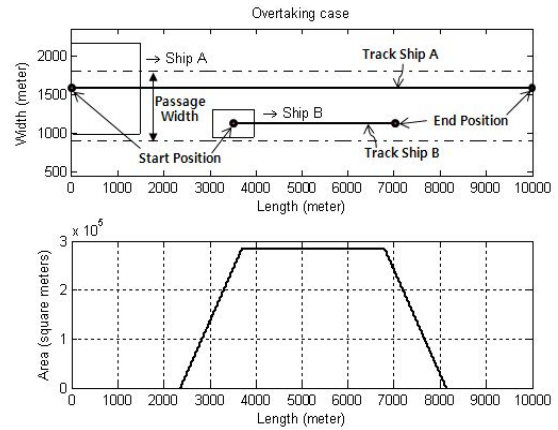


Fig. 2. Simulation results of scenario number 1 for overtaking situation. The scene of simulation(box above), the calculation result of overlapped bumper area(box below).

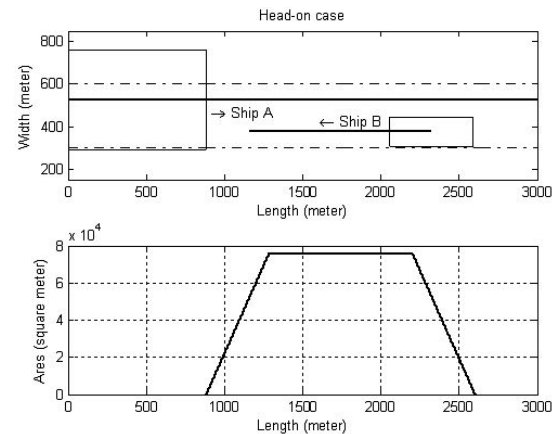


Fig. 3. Simulation results of scenario number 2 for head-on situation. The scene of simulation(box above), the calculation result of overlapped bumper area(box below).

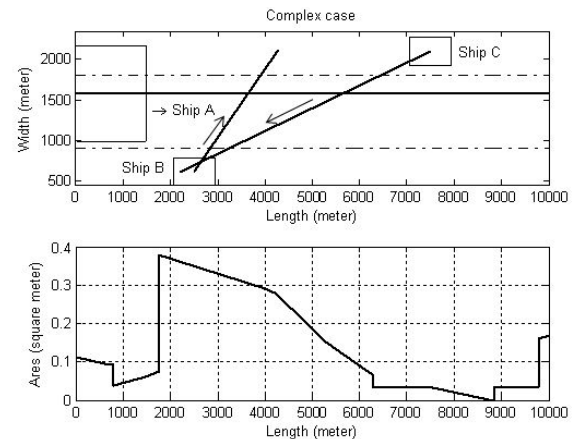


Fig. 4. Simulation results of scenario number 3 for complex situation. The scene of simulation(box above), the calculation result of overlapped bumper area(box below).

### 3. Experiments with AIS Data and Discussions

#### 3.1 Experiment Procedures

Fig. 5 represents experiment procedure to detect risky sectors in VTS area. The procedure consists of three parts; Data acquisition in Part A, Evaluation sector allocation in Part B and Sector evaluation in Part C.

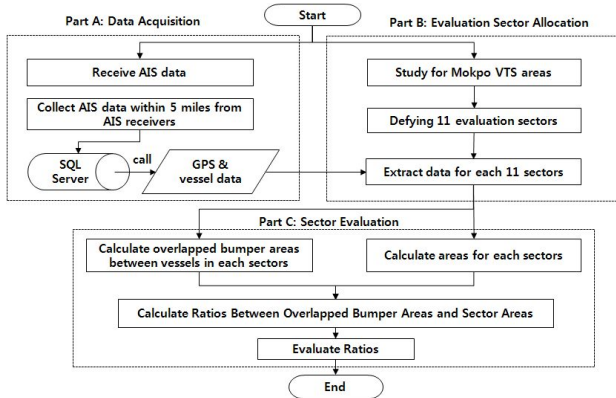


Fig. 5. Experiment procedure to evaluate risky sectors in VTS area with RER  $\gamma$  in Eq.(1).

#### 3.2 Studying Area and AIS Data Acquisitions

Fig. 6 shows Mokpo VTS area (Port of Mokpo, 2013) and studying area to detect risky areas in this work. The geographical feature of this area includes complex traffic routes, thus the studying area needs to keep traffic tracks of vessel movements and to maintain traffic monitoring. The vessel tracks within the studying area during four days from February 27 to March 2, 2014 are depicted in Fig. 7 with designated 11 sectors from A to K. The position of outer boundary of 11 sectors are referenced in Mokpo VTS(2014) and the separation lines of 11 sectors are decided from the analysis of vessel tracks with traffic course, sector size, traffic volume, geographical features, etc. The traffic data used in this experiment are collected and compiled during 80 Hours(Hrs) from February 27 to March 2, 2014, using AIS receivers and SQL (Structured Query Language) Server as shown in Fig. 8.

Before start the experiment work, the area sizes of 11 sectors are calculated using sector vertices position recorded in Mokpo chart No. 301(KHOA, 2011). The calculation results are as followings; Sector A: 1,095,569 m<sup>2</sup>, Sector B: 498,429 m<sup>2</sup>, Sector C: 464,435 m<sup>2</sup>, Sector D: 1,044,441 m<sup>2</sup>, Sector E: 738,470 m<sup>2</sup>, Sector F: 1,526,175 m<sup>2</sup>, Sector G: 1,075,006 m<sup>2</sup>, Sector H: 332,983 m<sup>2</sup>, Sector I: 495,983 m<sup>2</sup>, Sector J: 903,904 m<sup>2</sup>, Sector K: 462,366 m<sup>2</sup>.

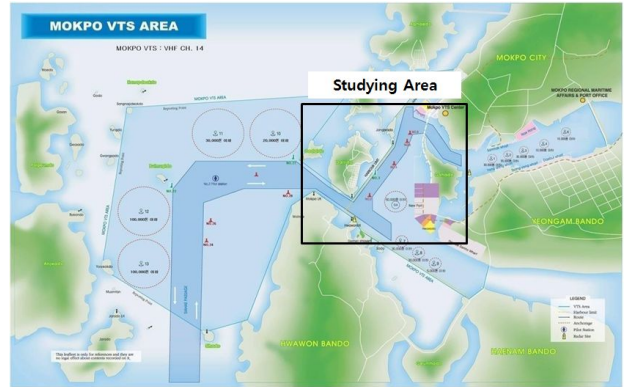


Fig. 6. Map of Mokpo VTS area (Port of Mokpo, 2013) and studying area.

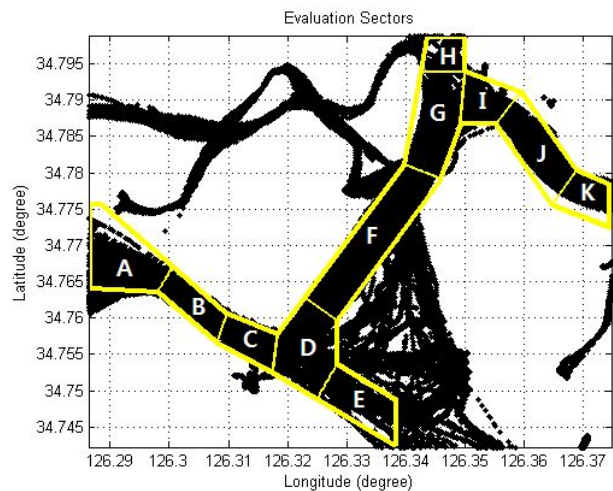


Fig. 7. Plotting vessel tracks on studying area with AIS data, and the allocation results of 11 sectors.



Fig. 8. AIS receivers to collect traffic data within Mokpo VTS area (left) and SQL Server to compile the data (right).

### 3.3 Experiment Results and Discussions

Fig. 9 represents overall risk evaluation results for 11 sectors from sector A to sector K. Ratio to Evaluate Risks(RERs)  $\gamma$  in Eq.(1) for all of sectors are picturized using various colors and line types. The x-axis shows consecutive time(hours) from 0 hours to 80 hours for four days, and y-axis denotes RER  $\gamma$ . If RER is 1.0 then it means that the overlapped bumper area and summing area of individual sector is same size. So, we can thought that the position of time with the RER of 1.0 is a reference values to decide whether the risky sector or not. In this study, we call it the name of "Warning Criteria". If RER is over 1.0 then VTSO have to give their concentration of monitoring and tracking vessel movement for the corresponding sectors.

In Fig. 9, the positions of time with high risk traffic situation are appeared in Sector J, G and B at around 10 Hrs, Sector J at around 33 Hrs, Sector F and B at around 40 Hrs. To provide more ease of understanding and to explain specific calculation results for each corresponding sectors, the three kinds of factors such as RER, the number of ship and the overlapped bumper area are represented in the figures from Fig. 10 to Fig. 20.

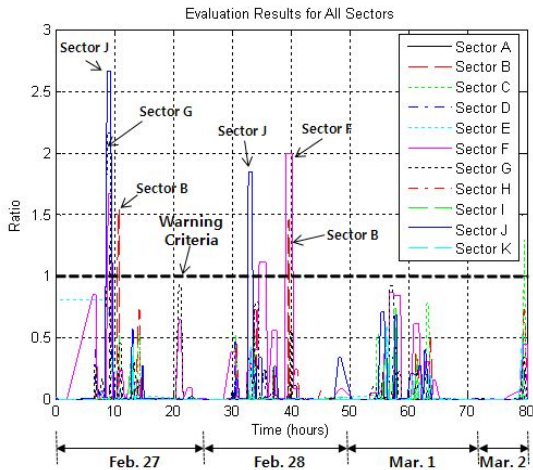


Fig. 9. Overall risk evaluation results for 11 sectors from sector A to sector K in studying area.

Among the figures from Fig. 10 to Fig. 20, the six sectors as shown in Fig. 11 to sector B, Fig. 12 to sector C, Fig. 13 to sector D, Fig. 15 to sector F, Fig. 16 to sector G and Fig. 19 to sector J are shows high risk position of time with the RER of over 1.0.

In case of Fig. 11 to sector B, the two position of time, denoting as B-1 and B-3, indicates RER of over 1.0 and it is corresponding to the number of vessel as shown in the top right side box. Meanwhile, the position of time B-2 indicates RER of

0.75 in spite of most large number of vessel as 6 ships. It is because of that the equation of RER in Eq.(1) is only depending on the overlapped bumper area between vessels. So it is known that the RER can be use as one of evaluation parameter to detect risky sector with the position of time. Fig. 19 to sector J shows the highest RER of 2.8 among the 11 sectors. This sector is located in the entrance of port of Mokpo with busy traffics all the day.

The common features of passage routes in the designated sectors with high RER of over 1.0 are narrow width and keeping parallel traffics between inbound and outbound vessels. Meanwhile, the sector D in Fig. 13 shows relatively low RER of 1.3 in spite of very complex traffic route. It is because of that the passing vessels in sector D give large room for bumper area to avoid collision each others, and this fact comes from the analysis of vessel tracks as shown in Fig. 7.

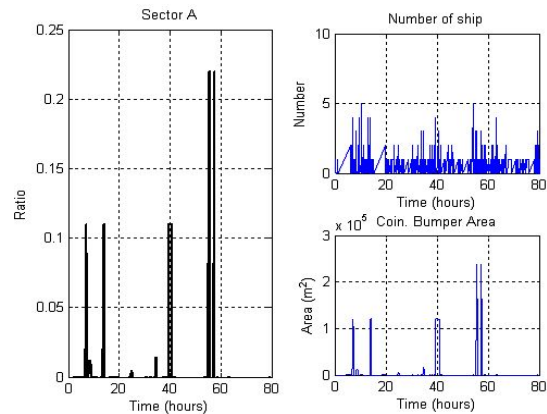


Fig. 10. Risk evaluation results for sector A. Calculation results for RER  $\gamma$  in Eq.(1)(box left), number of ship in sector A(box right top), calculation results for overlapped bumper area of each ships(box right below).

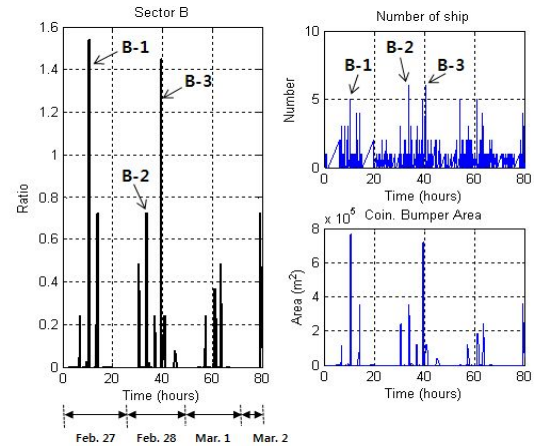


Fig. 11. Risk evaluation results for sector B. The meaning of this figure is same as in Fig. 10.

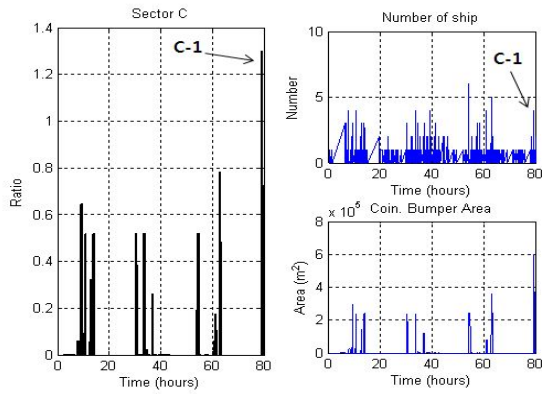


Fig. 12. Risk evaluation results for sector C. The meaning of this figure is same as in Fig. 10.

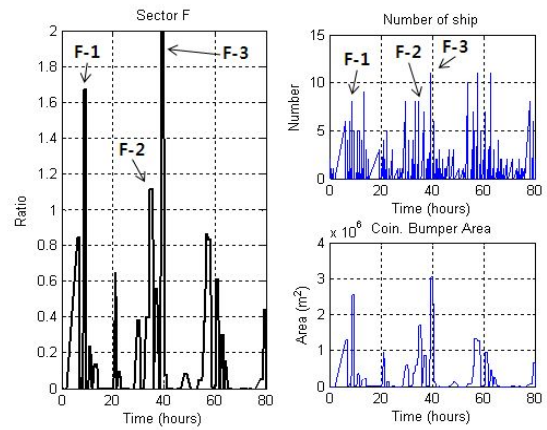


Fig. 15. Risk evaluation results for sector F. The meaning of this figure is same as in Fig. 10.

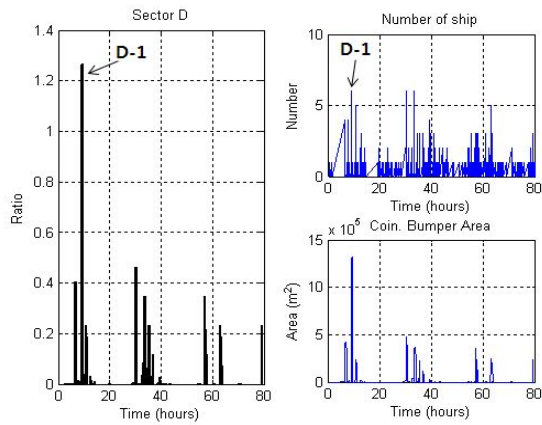


Fig. 13. Risk evaluation results for sector D. The meaning of this figure is same as in Fig. 10.

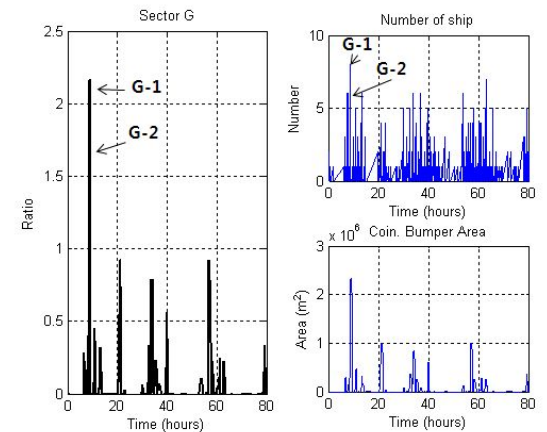


Fig. 16. Risk evaluation results for sector G. The meaning of this figure is same as in Fig. 10.

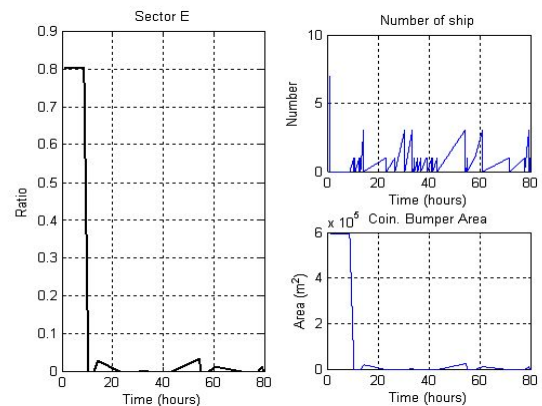


Fig. 14. Risk evaluation results for sector E. The meaning of this figure is same as in Fig. 10.

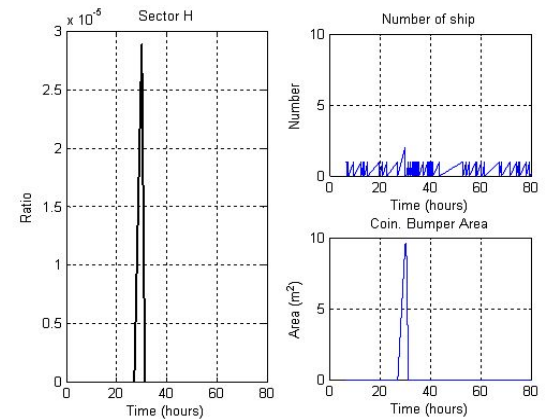


Fig. 17. Risk evaluation results for sector H. The meaning of this figure is same as in Fig. 10.

#### 4. Conclusions

The application method of bumper area denoting in the ship domain theory is explored to detect risky sectors in VTS area. In this paper we proposed Ratio to Evaluate Risk(RER)  $\gamma$  as one of evaluation parameter to detect risky sectors and to give warning criteria to VTSO for their concentration of monitoring work. The usability of overlapped bumper area is testified through three kinds of scenarios for various traffic situations. Through the analysis of vessel tracks within the boundary of Mokpo VTS area, total of 11 sectors are allocated as evaluation unit sector. As experiment results from risk evaluation for the 11 sectors, it is clearly known that the proposed application method can provide the location information of specific risky sectors in the position of VTS area needing concentration monitoring work by VTSO. With this application method, we are going to develop the early warning system for VTSO to recognize the risk in advance.

#### Acknowledgements

This Project was supported by Honam Sea Grant R&D Program fund of 2014.

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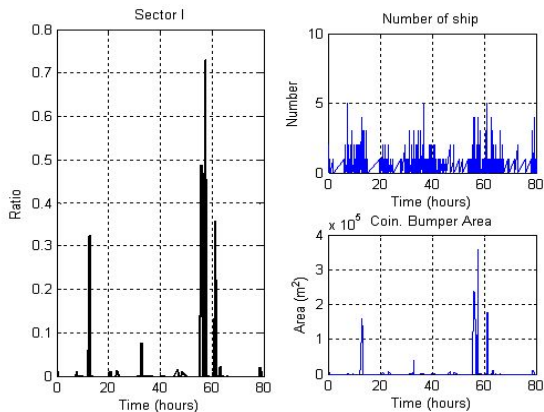


Fig. 18. Risk evaluation results for sector I. The meaning of this figure is same as in Fig. 10.

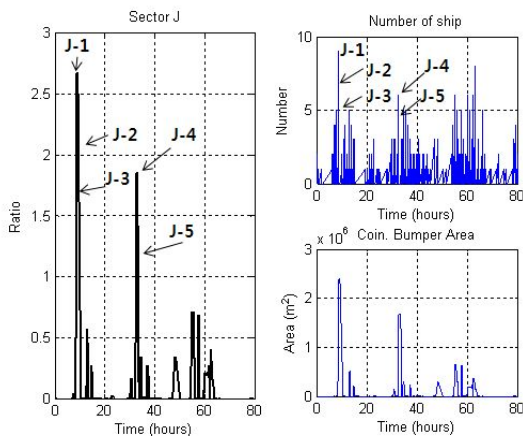


Fig. 19. Risk evaluation results for sector J. The meaning of this figure is same as in Fig. 10.

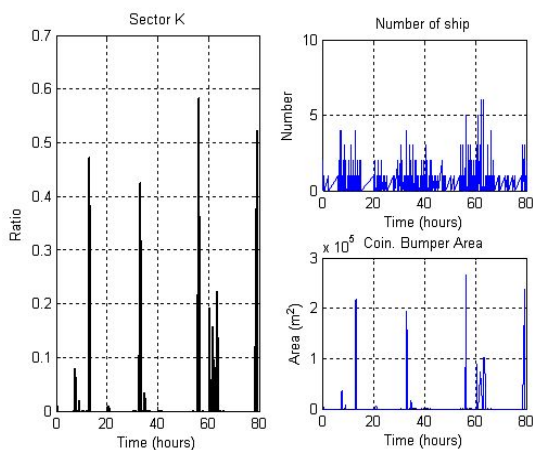


Fig. 20. Risk evaluation results for sector K. The meaning of this figure is same as in Fig. 10.

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Received : 2014. 04. 11.

Revised : 2014. 05. 29. (1st)

: 2014. 06. 10. (2nd)

Accepted : 2014. 06. 25.