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The Proper Capacity of Anchorage in Ulsan Port with Reference to the Anchorage Operating Rate

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울산항 정박지 가동률 분석을 통한 적정 정박지 규모 제안에 관한 연구

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Abstract : *This study suggests methods to evaluate the availability of anchorage in Ulsan port and determine the proper capacity of future anchorage in accordance with port development. Accordingly, the concept of an Anchorage Operating Rate (AOR) is introduced to evaluate the capacity of anchorage that was available in Ulsan port in 2014. Calculations revealed that the operating rate of all anchorages in Ulsan port did not exceed 100 %. However, in 2020 it is estimated that the AOR at E1 anchorage will be the highest with a rate of 168.3 %, followed by E3 with 131.1 %, E2 with 118.5 % and M with 108.7%. These findings indicate a shortage of anchorage by 2020. In order to decrease the AOR to a level that will not exceed 100 %, in accordance with port development in Ulsan, areas to accommodate an additional 11 ships at E1 anchorage, 1 ship at E2 anchorage, 2 ships at E3 anchorage and 1 ship at M anchorage will be necessary.*

Key Words : *Ulsan Port, Capacity of Anchorage, Port Development, Evaluation of Availability, Anchorage Operating Rate (AOR)*

요 약 : 본 연구는 울산항의 정박지 규모의 적정성을 평가하기 위한 방법을 제시하고, 이를 통해 현재 뿐만 아니라 항만개발에 따른 미래의 정박지 규모의 적정성을 분석하는데 그 목적이 있다. 이를 위해 울산항의 정박지 적정성 평가를 위한 정박지 가동률 개념을 제시하였다. 그리고 이 가동률 개념을 울산항의 2014년 정박지에 적용하여 가동률을 계산한 결과 모든 정박지에서 가동률이 100 %를 넘지 않는 것으로 도출되어, 추가 정박지 지정이 필요하지 않은 것으로 분석되었다. 또한 울산항의 2020년 가동률을 추정한 결과 E1정박지가 168.3 %로 가장 높았으며, E3정박지가 131.1 %, E2정박지가 118.5 %, 그리고 M정박지가 108.7 %인 것으로 계산되어, 2020년에는 정박지가 부족할 것으로 판단된다. 따라서 울산항의 항만개발에 따른 정박지 가동률을 100 % 수준으로 낮추기 위해서는 E1정박지는 11척, E2정박지는 1척, E3정박지는 2척, M정박지는 1척이 추가적으로 정박할 수 있는 수역이 필요할 것으로 분석되었다.

핵심용어 : 울산항, 정박지 규모, 항만개발, 적정성 평가, 정박지 가동율(*AOR*)

1. Introduction

According to the statistics, Korea heavily relied on international trade about 98.6 % in 2014 (Statistics Korea, 2016) and it is important for the development of its economy to transport import or export cargoes efficiently through ports and establish relevant infrastructures. For the efficient port operation, it is essential to secure proper capacity of port facilities as well as anchorages for safe operation of ports. Although the size of economy is expanding, the development of port facilities has not been followed properly, and there seems to be a less interest in anchorages that are used as waiting place for entering/departing ships as well as have a close relation to the safety of ports.

Ulsan port, the biggest hub port that handles liquid cargoes, is recently planning the continuous expansion of port facilities and

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the relevant infrastructures in order to grow as a vital crude oil cargo port in Asia through the Far East oil hub business (Lee, 2014). However, as the optimum capacity of anchorages are not secured for the increasing number of entering/departing ships, it may increase the possibility of dangers in relation to the safety of ships anchoring and passing.

There are some studies on the capacity of anchorage so far, for instance, Deville (2011) suggested anchorage utilization by using simulation method according to the anchorage shape, Kim (2010) suggested standards for securing anchorage by comparing the degree of congestion and efficiency of anchorages, and Lee and Lee (2014) suggested Pyeongtaek port's according to the increase of harbour volume. However, there is no study on the suggestion of necessary capacity of anchorage according to the expansion of port in order to take a preliminary action on the demand of anchorage in the future.

This study proposed a model which can calculate the Anchorage Operating Rate (Hereinafter referred to as "AOR") and proposed an interactive formula by carrying out a regression analysis on the interrelation among the number of ships using anchorage, the length of ship, and the dwell time at anchorage and harbour volume. With this formula, this study analyzed the AOR at anchorages in Ulsan port at its present (2014) and the future (2020), and ultimately proposed the necessary capacity of anchorage in the upcoming future.

2. Establishment of Model for Evaluating AOR

In order to identify the extent of anchorages being used and analyze whether the anchorages are sufficient or not, the AOR model was suggested by considering the volume of ships using anchorage, the dwell time at anchorage and other various conditions. The concept of AOR and estimating methods will be discussed below.

2.1 Volume of ships using anchorage (ship/day), AV_R

The volume of ships using anchorage (Hereinafter referred to as "AV_R") can be defined as the average number of ships using anchorage per day among ships that used such anchorages for 1 year, without considering peak factors and types of ships. The formula is as follows (Formula 1).

$$AV_R = \frac{1}{T}\sum_{i=1}^{365} S_i \quad \cdots\cdots\cdots\cdots \text{ Formula (1)}$$

Where, S_i : The number of ships using anchorage per i day

T : The number of days using anchorage per year except for unavailable days of anchorage due to natural disaster

2.2 Volume of anchorage capacity (ship/day), AV_C

If there are many long-term waiting ships at anchorage, the volume of anchorage capacity would be decreased compared to many short-term waiting ships. Consequently, the volume of anchorage capacity (Hereinafter referred to as "AV_C") can be defined as the volume of ships using anchorage per day when the dwell time at anchorage is considered on the basis of the number of ships that can anchor at once and the formula is as follows (Formula 2).

$$AV_C = \frac{U \times 24}{\frac{1}{n}\sum_{i=1}^{n}(D_i)} \quad \cdots\cdots\cdots\cdots \text{ Formula (2)}$$

Where, D_i : Dwell time of ships using anchorage

U : The number of ships that can anchor at once

2.3 Anchorage operating rate (%), AOR

The AOR can be defined as the proportion of the average number of AV_R to the AV_C, and the formula is as follows (Formula 3). If AOR is 100 %, it means that the anchorage has reached the theoretical maximum number of ships that the anchorage can accommodate. If this figure is less than 100%, it means that the anchorage can accommodate more ships that wish to use the anchorage.

$$AOR = \frac{AV_R}{AV_C} \times 100\ (\%) \quad \cdots\cdots\cdots \text{ Formula (3)}$$

if, AOR = 100 % ; Maximum AOR

AOR < 100 % ; Sufficient anchorage

AOR > 100 % ; Insufficient anchorage (Additional anchorage required)

3. Survey of the Current Status of Anchorages in Ulsan Port

3.1 Arrangement and capacity of anchorages in Ulsan port

The anchorages in Ulsan port are consisted of E, W, M, T anchorages and they are designed to accommodate different size of ships according to natural environmental factors such as depth, wave. However, for the purpose of this paper, W and T anchorages are excluded for this research because W anchorage is rarely used and T anchorage is used only by ships calling at Mipo port. The capacity and area of E and M anchorages in Ulsan port are shown as below (Table 1).

Table 1. Capacity and area of anchorages in Ulsan port

Item / Anchorage	Anchorage	Capacity	Area
E anchorage	E1	10,000 GT	9.34 km^2
	E2	30,000 GT	10.21 km^2
	E3	150,000 GT	11.76 km^2
M anchorage	M1～7	2,000 GT	1.74 km^2

The M anchorage in Ulsan port is a group anchorage, located on the right side of No. 1 Fairway, and on the left side of the Hyundai Heavy Industry. The M anchorage can be used by ships below 2,000 GT and ships obtaining special permit from the Ulsan Regional Office of Oceans and Fisheries. E1～E3 anchorages are the main anchorages in Ulsan port, adjacent to the right side of No. 1 Fairway, it is easy for ships calling at Ulsan port to proceed to the fairway after using the anchorages. It was found that the E1 anchorage can be used by ships below 10,000 G/T, E2 anchorage by ships below 30,000 G/T, E3 anchorage by ships below 150,000 G/T.

3.2 Survey of the current status of anchorage in Ulsan port

The number of anchoring ships in Ulsan port, average dwell time, average length of ships and the number of incoming ships between the year of 2005 and 2014 were explored through the Ulsan Regional Office of Oceans and Fisheries (2014), and the harbour volume in Ulsan port was also studied during the same period through the statistical data of the UPA (2015). The findings are as follows (Table 2).

Table 2. The current status of anchorage in Ulsan port

Item / Year	Harbour volume	Anchoring ships	Dwell time	Length of ships	Incoming ships
2005	162,414	13,165	17.1	120.2	25,710
2006	165,717	14,666	16.6	121.6	25,992
2007	168,652	15,446	18.6	123.0	27,904
2008	170,314	14,886	21.0	123.3	27,462
2009	169,382	13,299	20.0	123.1	25,607
2010	171,664	13,933	21.2	123.3	25,543
2011	193,869	14,226	26.4	126.3	25,828
2012	196,872	13,364	25.1	129.2	25,183
2013	191,030	13,510	23.5	128.6	25,200
2014	191,717	13,778	23.8	126.8	25,717

The table shows that the harbour volume in Ulsan port has generally increased for 10 years, and so does the average length of ships using anchorages in Ulsan port. However, the number of ships using anchorages was analyzed to have fluctuated during the period.

3.3 Depth and seabed of anchorages in Ulsan port

The depth and seabed of anchorages in Ulsan port were analyzed through the ECDIS data, and the findings are as follows (Table 3).

The seabeds of anchorages in Ulsan port are all ‘Mud’. The depth at E3 anchorage is the deepest with 60 m, and depth at M anchorage is the shallowest with 12 m.

Table 3. Seabed condition, depth of anchorages Ulsan port

Item / Anchorages	Seabed condition	Average depth
E1	Mud	40m
E2	Mud	50m
E3	Mud	60m
M	Mud	12m

4. Analysis of AOR at Anchorages in Ulsan Port in 2014

4.1 Analysis of the number of ships that can anchor at once

In order to calculate the number of ships that can anchor at once, first, it is necessary to examine the average length of ships using anchorages. Furthermore, after checking the turing radius

required for anchoring according to the formula for calculating the turning radius of anchorage specified in the MOF (2014), the number of ships that can anchor at once in Ulsan port can be identified by drawing the turing radius at E and M anchorages in Ulsan port. Accordingly, the number of ships that can anchor at once was analyzed by drawing through Autocad program after examining the average length of anchoring ships per anchorage in Ulsan port, and checking the turning radius according to the Korea Harbour and Fishery Port Design Standards.

1) Analysis of the Korea Harbour and Fishery Port Design Standards

The principle of anchorage designation is that the scale of anchorage is generally decided through the formula for calculating the turing radius of anchorage specified in the MOF (2014) and, among those anchorage designation methods, geographical and marine traffic conditions are comprehensively taken into account in order to designate the optimum anchorage.

The design standards for anchorage require that the radius of anchorage is calculated according to seabed condition and wind scale on the basis of length over all (LOA) of ships and depth (D) of anchorage. Accordingly, the turing radius of anchorage was analyzed on the basis of single anchor, which is generally used in practice when anchoring. The formula is as follows (Table 4).

Table 4. Korea standard for anchorage scale of single anchor

Anchoring method	Seabed condition	Radius (m)
Single anchor	Good	L (Length) + 6D (Depth)
	Bad	L + 6D + 30 m

2) Analysis of turing radius of anchorages in Ulsan port

Having analyzed average length of ships using anchorages in Ulsan port, depth and seabed of anchorages, the turing radius was calculated by applying the Korea Harbour and Fishery Port Design Standards. The findings are shown as below (Table 5).

Table 5. Turning radius of anchorages in Ulsan port

Item / Anchorage	Length of ship	Depth	Seabed condition	Turning radius
E1	104.1 m	40 m	Mud	344.1 m
E2	152.9 m	50 m	Mud	452.9 m
E3	213.0 m	60 m	Mud	573.0 m
M	66.5 m	12 m	Mud	138.5 m

3) Analysis of the number of ships that can anchor at once in Ulsan port

With the data from Table 5, which is about the turning radius of anchorages, the number of ships that can anchor at once in Ulsan port was drawn through Autocad and ECDIS program. The figure is as follows (Fig. 1).

It was analyzed that at M anchorage in Ulsan port, 20 ships can anchor at once and at E1 anchorage 18 ships, at E2 anchorage 11 ships, E3 anchorage 7 ships can anchor at once.

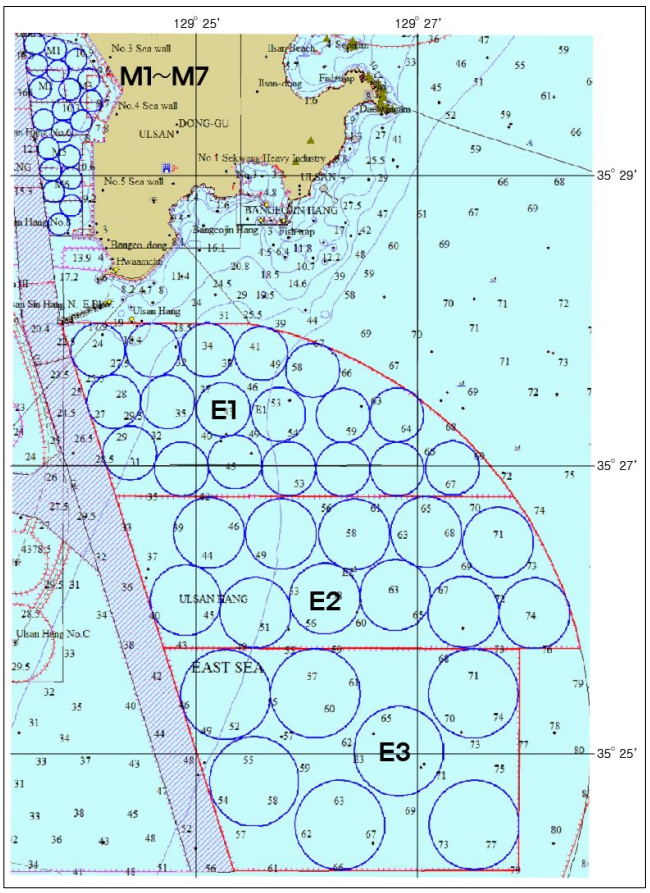

Fig. 1. The number of ships that can anchor at once in 2014.

4.2 Analysis of AOR at anchorages in Ulsan port in 2014

1) Analysis of volume of ships using anchorage and volume of anchorage capacity

In order to analyze AOR at anchorages in Ulsan port in 2014, the volume of ships using anchorage and volume of anchorage capacity were analyzed, and the findings are as follows (Table 6).

As it was found that the anchorages in Ulsan port have not been used for 3 days due to the influence of heavy weather and typhoon, the AV_R per day was analyzed by dividing the number of ships using anchorage for 1 year by 362 days.

For the AV_C, AV_C of M anchorage, which has the shortest dwell time, is the largest with 29.4 ship/day, followed by E1, E2 and E3 anchorages. Thus, it was analyzed that the volume of anchorage capacity is related to the anchorage dwell time.

Table 6. Status of ships using Ulsan port's anchorages in 2014

Item / Anchorage	Volume of ships	Average dwell time	Anchoring ship at once	AV_R	AV_C
E1	5,129	25.6	18	14.2	16.9
E2	2,054	28.9	11	5.7	9.1
E3	1,409	38.3	7	3.9	4.4
M	5,186	16.3	20	14.3	29.4

2) Analysis of AOR

The AORs were analyzed on the basis of the analysis of volume of ships using anchorage and volume of anchorage capacity, and the findings are as follows (Fig. 2).

Accordingly, among anchorages in Ulsan port in 2014, E3 anchorage is the highest with 88.6 %, followed by E1 anchorage with 84.0 %, E2 anchorage with 62.6 %, M anchorage with 48.6 %. Analysis shows that AORs at E3 and E1 anchorages in Ulsan port are over 80 %, which is a bit high, but below 100 %. Thus, it is considered that the current anchorages in Ulsan port have maintained the proper capacity of anchorages.

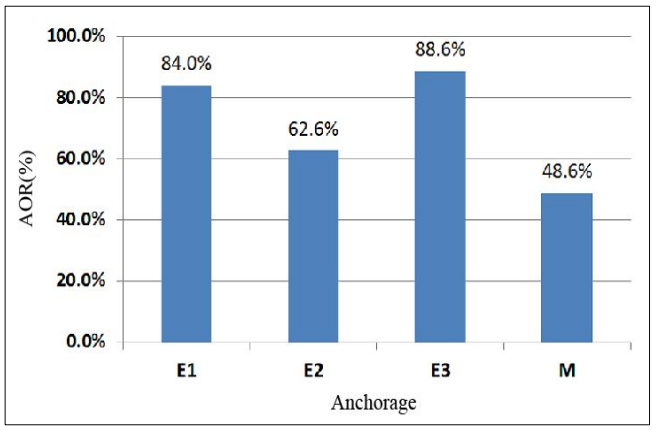

Fig. 2. AOR at Ulsan anchorages in 2014.

5. Prediction of Future AOR in Ulsan Port

5.1 The method for predicting AOR in Ulsan port

In order to predict future AOR in Ulsan port, the estimation shall be required with regard to the number of ships using anchorage, the size of ships using anchorage (length of ship) and the dwell time at anchorage at the time of analysis. For the estimation of those factors, the interrelation among harbour volume, ships using anchorage and incoming ship, which are generally used as the index of port development plan, can be examined. This study carried out a regression analysis of interrelation among the number of ships using anchorages in Ulsan port, average length of ship, average dwell time, harbour volume and the number of incoming ships between the year of 2005 and 2014, and consequently suggested an approximate formula.

The regression analysis (Fig. 3~5) were carried out in order to estimate the number of ships using anchorage, the average length of ships using anchorage and the average dwell time at anchorage and the formulas are as follows (Formula 4~6).

$$Y_A = 0.70X_H - 4072.75 \quad \cdots\cdots \text{Formula (4)}$$

$$Y_L = 0.0002X_V + 86.23 \quad \cdots\cdots \text{Formula (5)}$$

$$Y_D = 0.0002X_V - 20.25 \quad \cdots\cdots \text{Formula (6)}$$

Where, Y_A : Ship using anchorage (ship)
X_H : Ship incoming harbour (ship)
Y_L : Ship's length (m)
X_V : Harbour volume (kton)
Y_D : Dwell time (h)

The statistical analysis using SPSS program was carried out in order to test for significance of formulas induced via regression analysis and the findings are as follows (Table 7).

With the result of suitability analysis of the regression model, it was found out that the explanatory power of all formulas are over 80 % and the Durbin-watson test was within the range of 1 ~3, approving the independence of residual. With the result of significance test of dispersion model, it was found out that the significance probabilities against "F" are below 0.05, satisfying the suitability of regression model. Furthermore, the test for significance of regression coefficients was conducted and the levels of significance (p) are below 0.05, being statistically significant at the level of 5 %.

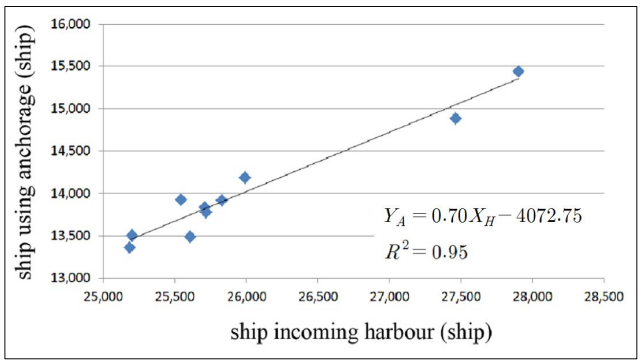

Fig. 3. Regression analysis of ships using anchorage.

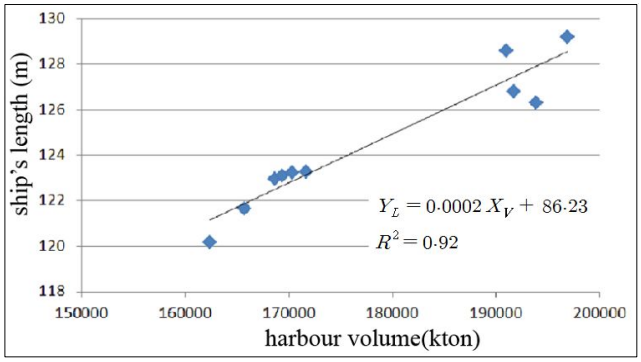

Fig. 4. Regression analysis of ship's length.

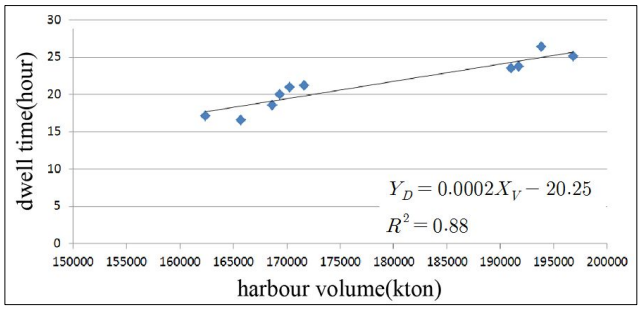

Fig. 5. Regression analysis of dwell time.

Table 7. Descriptive statistics of regression analysis

Regression	Data set	Ship using anchorage		Ship's length		Dwell time	
Model summery	R^2	0.95		0.92		0.88	
	Durbin-watson	2.17		2.00		1.04	
Analysis of variance	F	151.22		88.02		58.35	
	Significance level	0.00		0.00		0.00	
Coefficients	Coefficients	-4,072.75	0.70	86.23	0.0002	-20.25	0.0002
	p	0.03	0.00	0.00	0.00	0.01	0.00

5.2 Analysis of parameters per anchorage in Ulsan port in 2020

The future harbour volume in Ulsan port specified in the (MOF, 2011) will be 252,611 kton/year, and the Ulsan Port Authority anticipates that the number of incoming ships in 2020, when the construction of New Port and Oil hub Port is completed, will be 29,828 ships. With this data, the number of ships using anchorage, average length of ship and average dwell time at anchorage in 2020 is predicted as follows (Table 8).

Table 8. The prediction of parameters per anchorage in 2020

Parameters	Regression analysis	Predictions			
		E1	E2	E3	M
The number of ships using anchorage (ship)	16,789	6,330	2,316	1,360	6,783
Average length of ships using anchorage (m)	136.8	112.3	165.0	229.8	71.7
Average dwell time at anchorage (hour)	36.6	39.4	44.4	58.9	25.1

The total number of ships using anchorages, average length of ships using anchorage and average dwell time at anchorage in 2020 were estimated on the basis of the approximate formula provided in paragraph 5.1. The total number of ships using anchorages was divided according to the ratio of incoming ships per anchorage, and the average length of ships and average dwell time were also estimated in proportion to data of each anchorage.

5.3 Prediction of AOR in Ulsan Port in 2020

1) Analysis of the number of ships that can anchor at once

On the basis of Table 9, led by parameter analysis per anchorage in Ulsan port in 2020, the number of ships that can anchor at once in Ulsan port was drawn through Autocad and ECDIS program. The findings are as follows (Fig. 6).

Table 9. Turning radius of ships using anchorage

Parameter / Anchorage	Length of ships	Depth	Seabed condition	Turning radius
E1	112.3	40 m	Mud	352 m
E2	165.0	50 m	Mud	465 m
E3	229.8	60 m	Mud	590 m
M	71.7	12 m	Mud	144 m

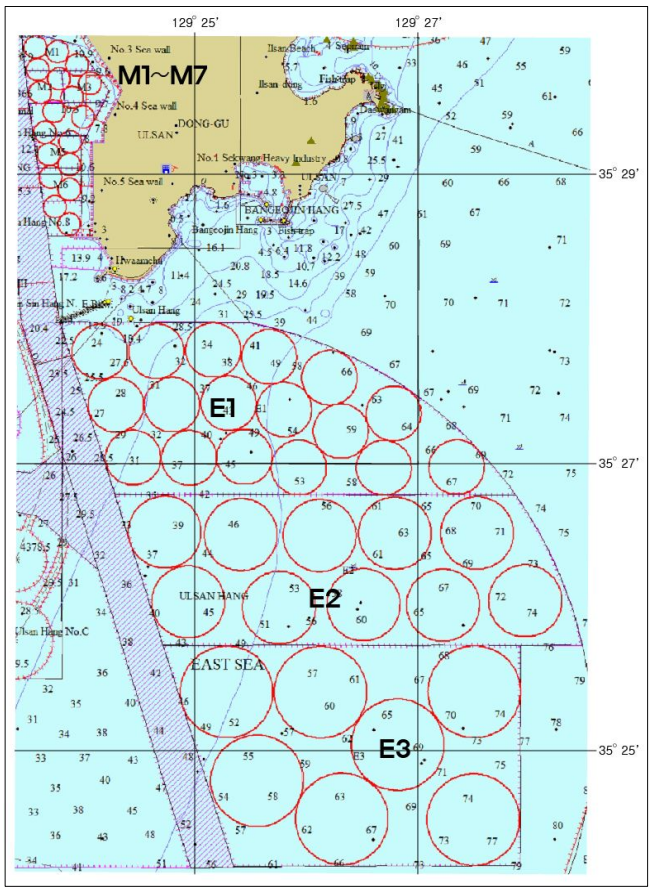

Fig. 6. The number of ships that can anchor at once in 2020.

It was analyzed that at M anchorage in Ulsan port, 18 ships can anchor at once and at E1 anchorage 17 ships, at E2 anchorage 10 ships, E3 anchorage 7 ships can anchor at once. Accordingly, it was found that the number of ships that can anchor at once at E1, E2, M anchorages in 2020 is 1 ship less than those in 2014.

The AOR can be defined as the proportion of the AV_R to the AV_C.

2) Volume of ships using anchorage and volume of anchorage capacity

In order to predict the AOR at anchorage in Ulsan port in 2020, the volume of ships using anchorage and volume of anchorage capacity were analyzed and the findings are as follows (Table 10). When calculating the AV_R, 362 days, which is the same as 2014, was used for the average days using anchorage for 1 year.

For the AV_C, AV_C of M anchorage, which has the shortest dwell time, is the largest with 17.2 ship/day, followed by E1 anchorage with 10.4 ship/day, E2 anchorage with 5.4 ship/day and E3 anchorage 2.9 ship/day.

Table 10. Status of ships using Ulsan port's anchorage in 2020

Item / Anchorage	Volume of ship	Average dwell time	Anchoring ship at once	AV_R	AV_C
E1	6,330	39.4	17	17.5	10.4
E2	2,316	44.4	10	6.4	5.4
E3	1,360	58.4	7	3.8	2.9
M	6,783	25.1	18	18.7	17.2

When calculating the AV_R, 362 days, which is the same as 2014, was used for the average days using anchorage for 1 year. For the AV_C, AV_C of M anchorage, which has the shortest dwell time, is the largest with 17.2 ship/day, followed by E1 anchorage with 10.4 ship/day, E2 anchorage with 5.4 ship/day and E3 anchorage with 2.9 ship/day.

3) Prediction of AOR

The AOR in 2020 was anticipated on the basis of the analysis of volume of ships using anchorage and volume of anchorage capacity, and the findings are as follows (Fig. 7).

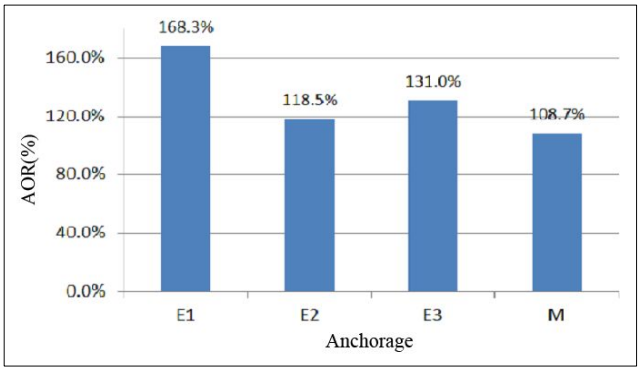

Fig. 7. AOR at Ulsan anchorages in 2020.

Accordingly, among anchorages in Ulsan port, it was analyzed that, in 2020, the AOR at E1 anchorage will be the highest with a rate of 168.3 %, followed by E3 anchorage with 131.0 %, E2 anchorage with 118.5 %, M anchorage with 108.7 %.

As a result of the estimation of the AOR in 2020 on the basis of the current status of anchorages and port operation data in Ulsan port between the year of 2005 and 2014, it was

analyzed that AOR at all anchorages will be over 100% in 2020 and it is considered that additional anchorages need to be secured.

The number of necessary anchored ships was examined in order to decrease the AOR to the level of 100 %, and the findings are as follows (Fig. 8). It is therefore analyzed that more areas which can accommodate additional 11 ships at E1 anchorage, 1 ship at E2 anchorage, 2 ships at E3 anchorage and 1 ship at M anchorage respectively would be necessary. As a whole, it is considered that the proper capacity of anchorages that can accommodate the total of 67 ships at the same time would be required.

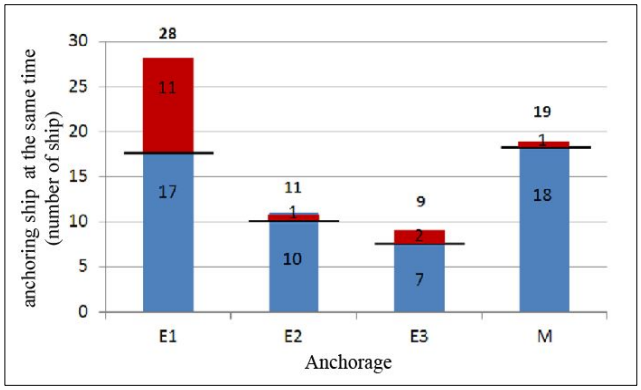

Fig. 8. Necessary anchoring ship at the same time.

6. Conclusion

This study proposed methods to evaluate the proper capacity of anchorage in Ulsan port by introducing the concept of AOR and suggested the formula by carrying out a regression analysis on the interrelation among the number of ships using anchorage, the length of ship, and the dwell time at anchorage and harbour volume. With this formula, this study anticipated the AOR at anchorages in Ulsan port in 2020 and proposed the necessary capacity of anchorage.

The results of this study are as follows.

First, the AOR was introduced by considering the number of ships using anchorage, the dwell time, the length of ship, and the standards for calculating the proper capacity of anchorage were proposed.

Second, having analyzed the AOR at anchorages in 2014, the AOR at E3 anchorage is the highest with 88.6 %, followed by E1, E2 and M anchorages. Analysis shows that AORs at E3, E1, E2 and M anchorages in Ulsan port are less than 100 %, thus, it is considered that the current anchorages in Ulsan port have maintained the proper capacity of anchorages.

Third, in order to anticipate the necessary capacity of future anchorages in Ulsan port, the interactive formula among the number of ships using anchorage, the dwell time, the length of ship and harbour volume was proposed on the basis of the current status of anchorages and port operation data in Ulsan port between the year of 2005 and 2014.

Fourth, as a result of the estimation of the AOR at anchorages in Ulsan port in 2020, it was analyzed that the AOR at E1 anchorage will be the highest with 168.3 %, followed by E3 anchorage with 131.0 %, E2 anchorage with 118.5 %, M anchorage with 108.7 %. Thus, it was analyzed that AOR at all anchorages will be over 100 % by 2020 and it is considered that additional anchorages need to be secured.

Last, the number of necessary anchoring ships was examined in order to decrease the AOR to the level of 100 %, and it is analyzed that more areas which can accommodate additional 11 ships at E1 anchorage, 1 ship at E2 anchorage, 2 ships at E3 anchorage and 1 ship at M anchorage respectively would be necessary.

With this concept of AOR, the AOR at anchorages in Ulsan port can be analyzed and the quantitative propose can be possible as to whether the anchorages are sufficient or not and the necessary capacity of anchorages. Thus, it would contribute to the systematic management of anchorages by port planner or operating authorities.

Future study is needed to study the techniques that can analyze the AOR considering the characteristics of the port, such as peak time, type of ship. Moreover, with this concept of AOR specified in this paper, the AOR at all anchorages in South Korea can be analyzed and it can ultimately contribute to the safety of ships within ports by applying the proper capacity of anchorage to the Korea Harbour and Fishery Port Design Standards.

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