Standardisation of Buoy Arrangements in the Korean Navigational Fairway

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Biography

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Abstract

When installing buoys in a navigational fairway, it is necessary to consider the scientific aspects based on shape and human factors for mariners' visual perception.

In this paper, trials aimed at these aspects were carried out and an improvement for the arrangement of buoys in the navigational fairway of South Korea was proposed.

Firstly, to determine the optimum standard arrangements for buoys, various methods for confirming the visible range of perception were made utilising sea trials, simulations and questionnaire methods, etc.

Secondly, after classifying the navigational fairways as inland and open sea-way, a standard arrangement for fairway buoys, in straight and curved routes, was proposed. For a straight route, the arrangement proposed was that two Aids to Navigation (AtoNs) in pairs could be seen at both sides of the route. For this arrangement, in open sea, a distance of 1 nautical mile (1.85 km) separated the buoy pairs. This was reduced to 0.54 nm (1km) in harbours. In a single staggered buoy arrangement and a single centre buoy arrangement, the distances between buoys were also proposed. The ideal distance between pairs of buoys can vary dependent upon environmental and sea-state conditions.

This investigation was aimed at ensuring arrangements of buoys in the navigational sea ways give a reliable, efficient and cost effective Buoyage Service.

Keywords: *Buoy Arrangement, Visible Range, Perception, Sea Trial, Simulation, Fairway, Background Factor*

1. Introduction

A marine Aid to Navigation (AtoN) is a device or system external to vessels that is designed and operated to enhance the safe and efficient navigation of marine vessels and/or vessel traffic. Buoys are defined as minor floating aids. Whilst it is normal that buoys are lit, there are instances where no light is installed. These types of aids to navigation are specifically covered by the IALA Maritime Buoyage System and tend to have circular hull forms in range of 1 to 3 m diameter. Buoys may be fitted with sound signals. [1]

The buoy serves a similar purpose to a beacon or lighthouse; however, the buoy is normally associated with locations where: it would be impractical to establish a fixed aid due to water depth, seabed conditions or cost; the hazard shifts over time (e.g. sand banks, an unstable wreck, etc.); the aid is at high risk of damage or loss from ice flows or ship impacts and as a consequence is treated as expendable; a temporary mark is required. [2]

Traffic environmental changes at sea have enhanced the importance of maritime safety facilities. From this viewpoint, buoyage systems at sea have become increasingly important in heavy traffic areas.

When installing buoys in a navigational fairway, it is necessary to consider scientific aspects based on the shape of the buoy and of the perception of the mariner.

In this research, various trials aimed at these aspects were carried out and an improvement for the arrangement of buoys in the navigational fairway of South Korea was proposed.

2. Confirmation of the Visible Range for Buoy Perception

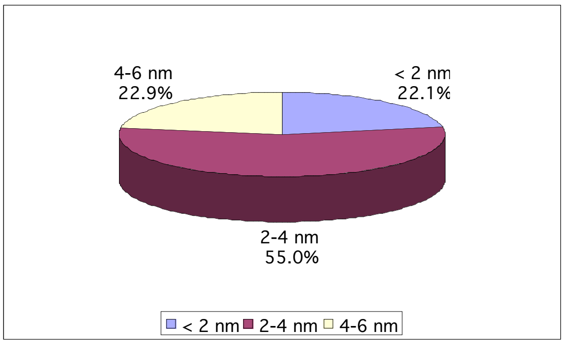
2.1 Analysis of User Questionnaires

In order to verify the visual range and arrangement of a lighted buoy from navigational officers' view, a questionnaire investigation was carried out on the in/out channel of the South Korean opened trade ports. At each port, 30～150 questionnaires were distributed to mariners. The number of questionnaires distributed depended upon the size of the port. Over a period of two months (Sept. – Nov. 2007), 131 completed questionnaires were used for analysis. [3]

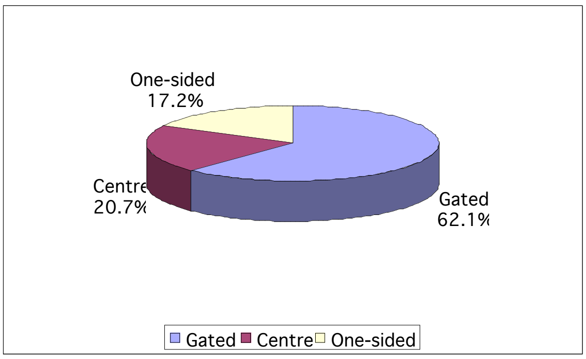
With either corrected or uncorrected vision, 55.0% of those mariners surveyed could perceive a distance of 2～4 nm during daytime and in bright weather conditions. <Figure 1>

The preferred layout for buoyage in the fairway, for 62.1% of those mariners surveyed, was a gated arrangement. <Figure 2>

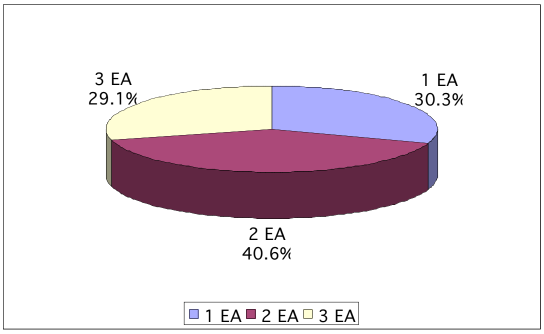
The preferred interval between buoys was on average 1.09 nm. Moreover, the preferred number of buoys which could be perceived without aided vision, further into the sequence, was two. This was the preference of 40.6% of those mariners questioned. <Figure 3>



<Figure 1> Visual Perceptive Range



<Figure 2> Preferred Arrangements of Buoys



<Figure 3> Preferred Numbers of Buoys

2.2 Sea Trials for Visual Perception of Buoy

(1) Background Factor

It is very difficult to determine the visible perception range of floating aids at sea as there are many factors to take into account in the visible perception range.

A new concept of “Background Factor” was developed from the ratio of the standard visible range and the actual visible range. The standard visible range is equal to the theoretic visible range in standard sea conditions. The Background Factor is equal to 1, when the following conditions apply:

- fine weather conditions are prevalent
- the height of the observer’s eyes equals 15m
- the background for observations is sea
- red floating aids are used
- brightness contrast between the background (sea) and buoy (red): 0.81
- visibility factor: 0.74
- dynamic eye sight: 0.95.

The Background Factor is a function of visibility, dynamic eye sight, brightness contrast and the height of the observer’s eye.

The visible perception range of the floating aid, utilising the Background Factor, can be defined by equation (1).

$$l_{d,B} = E_D \times V \times C \times B \times \sqrt{\frac{A}{\tan^2\theta} - h^2} \quad (1)$$

Where,

$l_{d,B}$: Visible Perception Range (on sea surface)

E_D : Dynamic Eye Sight

V: Factor of Visibility

C: Brightness Contrast

B: Background Factor

A: Cross sectional Area of Floating Aid

θ : Angle of Elevation (Sea surface to observer’s eye)

h: Height of observer’s eye

(2) Sea Trials for Visual Perception of Buoy

In order to determine the background factor of the fairway, where a buoy is deployed, sea trials for visual perception of the buoy were carried out in the fairways of the Ports of Busan and Ulsan.

Busan Metropolitan City, also known as Pusan, is the largest port city in the Republic of Korea. It has a population of about 3.65 million. Busan is also South Korea's second largest metropolis, after Seoul.

Ulsan is a metropolitan city in the south-east of South Korea, being located 70km north of Busan. The city forms the heart of the country's industrial area called the Ulsan Industrial District.

<Table 1> and <Table 2> show the results of the sea trials for Visual Perception of Buoy in the fairways for the two major ports.

The visible perception range of the Red LL-26(M) buoy (diameter 2.6 m) is the same as the theoretical value (Background Factor is nearly 1) in the fairway of Ulsan port, when the height of eye is 15m. When the observer’s eye is at 3m, the Background Factor reduced to 0.5885. It is thought that the background changing from sea to land with reducing eye height caused this reduction of the Background Factor.

<Table 1> Results of Sea Trials (Port of Ulsan)

Port of Ulsan	LL-26(M)-Red	Theoretic visual range	Reflected upon Height of Eye	Reflected upon Visibility (×0.74)	Reflected upon Brightness Contrast (×0.81)	Reflected upon Dynamic Sight (×0.95)	Measured (m)	Background Factor
	H 15m	3867.46	3867.43	2861.90	2318.14	2202.23	2222	1.0090
	H 3m	3867.46	3867.46	2861.92	2318.16	2202.25	1296	0.5885
						Average	1,759	

<Table 2> Results of Sea Trials (Port of Busan)

	h 4m	Theoretic visual range	Reflected upon Height of Eye	Reflected upon Visibility (×0.74)	Reflected upon Brightness Contrast	Reflected upon Dynamic Sight (×0.95)	Measured (m)	Background Factor
Port of Busan	LL-26(M)-Red	3867.46	3867.46	2861.92	(×0.81) 2318.14	2202.23	1766.67	0.8022
	LL-26(M)-Green	3867.46	3867.46	2861.92	(×0.65) 1860.25	1767.24	1933.33	1.0940
						Average	1,850	

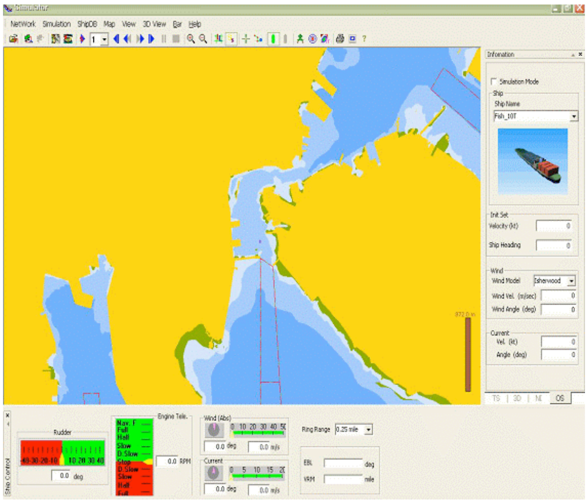
In the fairway at the Port of Busan, the background factor of Red LL-26(M) buoy is 0.8022, when the height of eye is 4m. In the case of the Green LL-26(M) buoy, the factor increased to 1.0940. This is due to the background colour of the Port. Further work will be required to clarify the correlations between the factor and background of the port.

2.3 Simulations for Visual Perception of Buoy

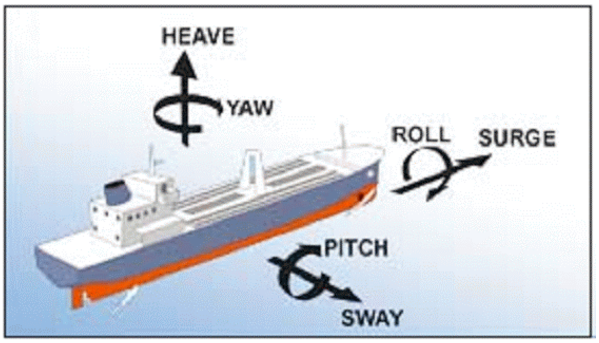
A ship handling simulator was used to verify the visual perception of the buoy using a model ship and port based on the actual factors. The equipment comprised the following:

- Conning Console: control console, manoeuvring console, external forces console
- Mathematical Model: shallow water effect, bank effect, variable current, mutual interference of ships, anchor force, tug effect, etc.
- Printer
- Electronic Navigation Chart (ENC) converter

<Figure 4> shows the Ship Handling Simulator Display layout and <Figure 5> shows the coordination system of the simulator.
The simulation experiments for visual perception of the buoy were carried out with five groups of observers who were classified by their sea experience. The first group consisted of sea professional and was further sub-divided into 3 groups. These groups were: chief officer and master; second and third mate; and trainee. The second group consisted of a further 2 classifications. Participants in these groups had very little or no sea experience. The experiments for each observer were undertaken 5 times and the mean value of each observer's results was taken.



<Figure 4> Ship Handling Simulator Display



<Figure 5> Coordination System

The results between the experienced and inexperienced groups show a considerable difference. This is caused by their advanced perception and estimation of the buoy position.
<Table 3> and <Table 4> show the results of these experiments. Experimental conditions were as follows:

○ Experimental condition

- The visual monitor (resolution 1024*768) with 3 Channels
- Observing point: 1.2m from the monitor
- Model ship
  . LOA: 122m
  . Width: 19m
  . Depth: 15m
  . DWT: 7,000tons

○ Results of Experiment

- Groups with sea experience

<Table 3> Results of Visual perception (experienced)

	Green(m)	Red(m)
Group 1	1,225	1,881
Group 2	1,336	2,085
Group 3	1,683	2,650
Mean	1,424	2,206
	1,815	

- Groups with little/no sea experience

<Table 4> Results of Visual perception (non-experienced)

	Green(m)	Red(m)
Group 1	683	922
Group 2	1,076	1,430
Mean	880	1,176
	1,028	

The mean perception range for observers' with sea experience is 1,815m (0.98 n.m.). The visual perception range for simulation is similar to that for the sea trials. Further clarification work is required to determine the correlation between the actual perception range and simulated perception range.

2.4 Visible Range for Buoy Perception

The user questionnaire was further utilised to develop an optimum perception range from the viewpoint of the ship's officer. Consequently, the optimum perception range for buoyage was found to be 2,020.86 m. This was found by using equation (2).

$$L_{op} = \frac{\sum_{1}^{131} L_i}{131} = 2020.86 \qquad (2)$$

Where:
L_{op} is the optimum perception range, and
L_i; is the perception range of individual

If the background of the Port and the sea are discounted, the actual visible range will be the same as the theoretical visible range when the Background Factor is 1 (the standard condition). From equation (2), a Background Factor of 0.9818 can be derived. Hence, the optimum perception range can be shown as equation (3).

$$L_{op} = 0.918 \times l_{d,B} \qquad (3)$$

Where,
$l_{d,b}$ is the theoretical perception range (in standard condition)

This equation includes changes to the visible range which are caused by the individual difference of the viewing officer's perception. This is the perception range at which most officers can recognise a buoy on the sea.

3. Standardisation of Buoy Arrangements

3.1 General Proposals

It is proposed that buoyage arrangements in the South Korean Fairway, which reflect the results of the user questionnaire, sea trials, simulations and references, are as follows; [4][5]

- The gated arrangement of paired buoys should be utilised. Alternatively, when the width of fairway is excessively narrow, one-sided or a staggered arrangement of buoys can be used.
- Buoys should be consecutively arranged in order that two or more sets of buoys can be perceived forward of the current ship's position.
- Buoys should be arranged in order to make an equidistant and symmetrical characteristic.
- Where it is important to mark dangers or a change of course, a lighted beacon can be used in addition to the buoy system.
- In the fairway, buoys should be numbered sequentially. (Numbering, Flash rhythm at course change and flashing after the position change)

3.2 Standardisation of Buoy Arrangements

1) Gated Buoy Arrangement

In a gated buoy arrangement in the open sea, 1 nm (1.85 km) should be applied, as the interval between buoys. This can be reduced to 0.54 nm (1km) in harbours. This value can be changed from 0.5 to 2 times of the distances, subject to environmental sea-state conditions. <Figure 6>

2) Staggered Buoy Arrangement

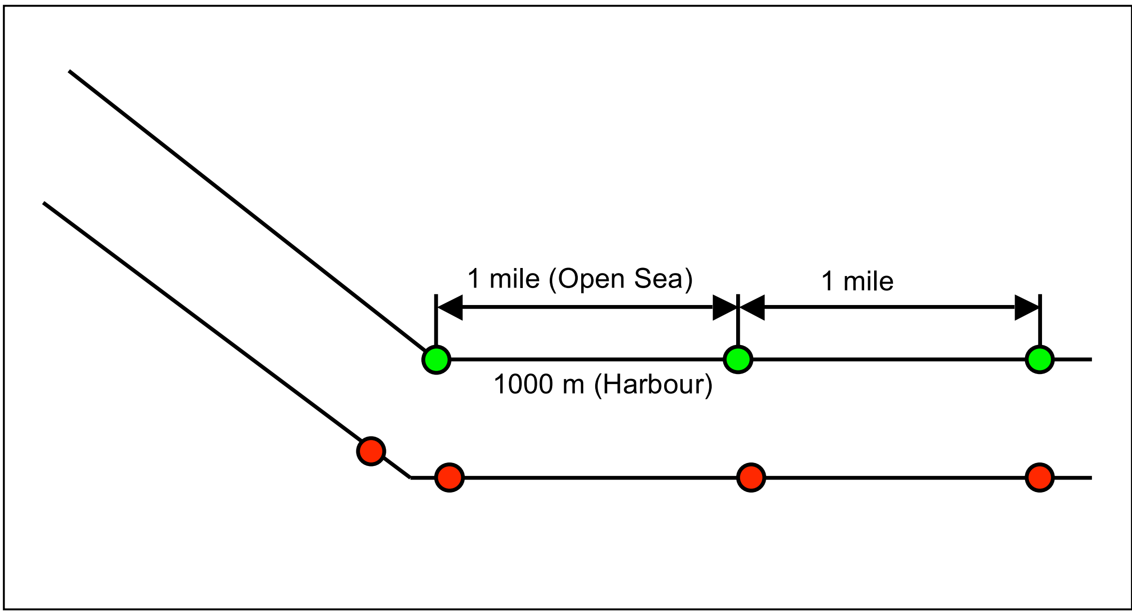
In a staggered buoy arrangement in the open sea, 0.8 nm (1.48 km) should be applied, as the interval between buoys. This can be reduced to 0.43 nm (800 m) in harbours. (At each end of the fairway, distances of of 1.6 nm and 0.86 nm respectively should be applied) These values can be changed from 0.5 to 2 times of the distances, subject to environmental and prevailing sea-state conditions. <Figure 7>

3) One Sided Buoy Arrangement

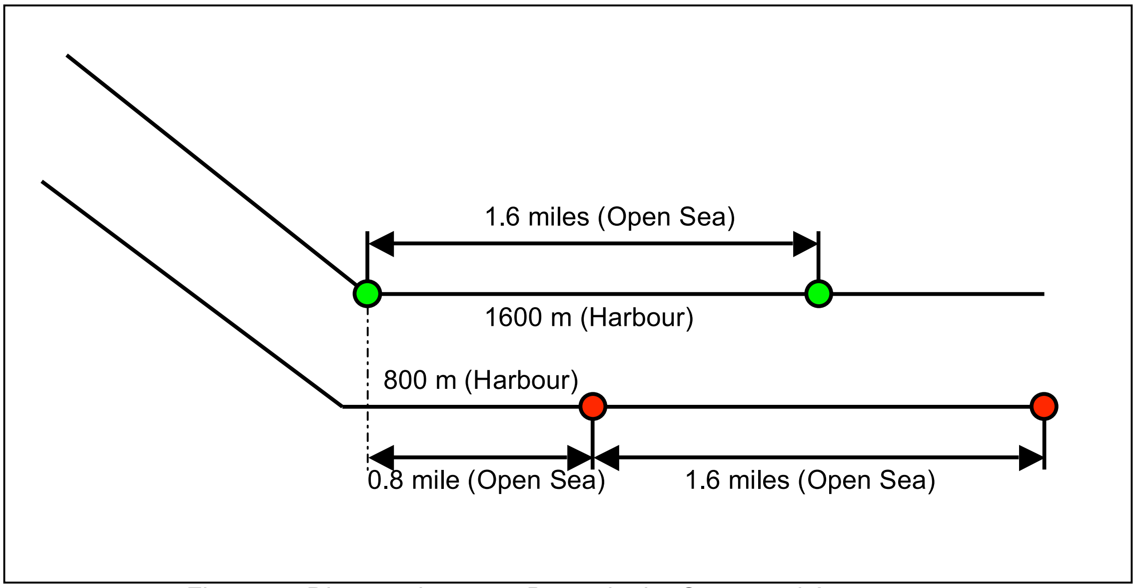
In one sided buoy arrangement in open sea, 0.5 nm (926 m) should be applied, as the interval between buoys. This can be reduced to 0.27 nm (500 m) in harbours. This value can be changed from 0.5 to 2 times the distances, subject to the sea-state conditions. <Figure 8>

4) Single Centre Buoy Arrangement

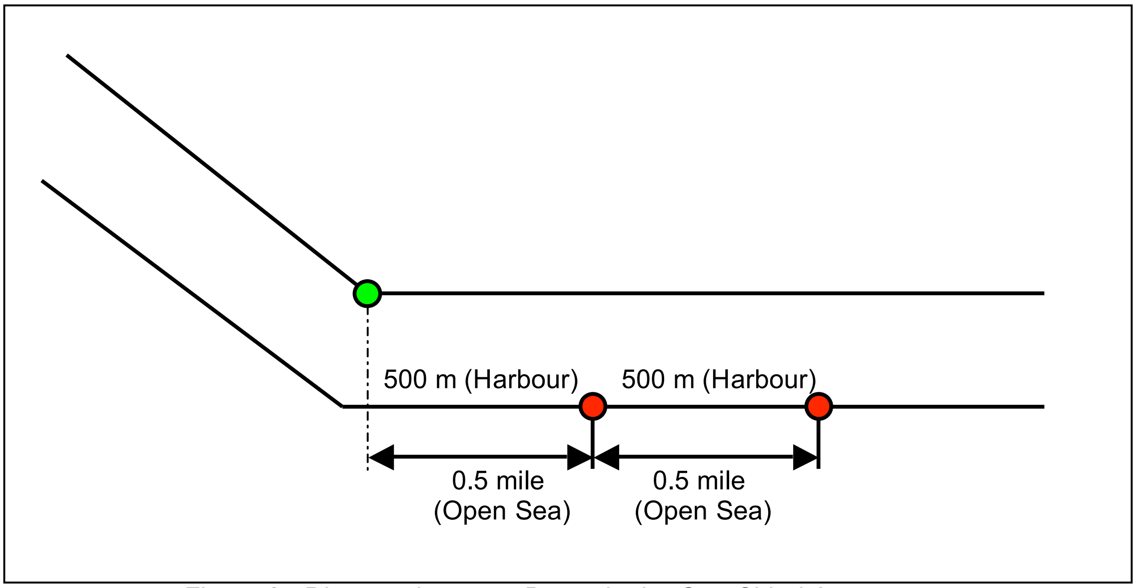
In a single centre buoy arrangement for buoys at sea, 1 nm (1.85 km) should be applied, as the interval between buoys. This can be reduced to 0.54 nm (1km) in harbours. This value can be changed from 0.5 to 2 times the distances, subject to the sea-state conditions.



<Figure 6 > Distance between Buoys in the Gated Arrangement



<Figure 7> Distance between Buoys in the Staggered Arrangement



<Figure 8> Distance between Buoys in the One Sided Arrangement

4. Conclusions

This research proposes a standardisation for buoy arrangements in South Korean fairways. The proposal was derived by investigation and analysis of user questionnaires, sea trials and simulations for visual perception of buoyage. When deploying buoys in a navigational fairway, it is necessary to consider scientific aspects based on shape and human perception for mariners.

The trials aimed at these aspects were carried out and an improvement for the arrangement of buoys in the South Korean navigational fairway was proposed.

Firstly, to determine the optimum standard arrangements for buoys, various attempts for confirming the visible range of perception were made using sea trials, simulations and questionnaire methods.

Secondly, after classifying the navigational fairways as inland and open sea-way, a standard arrangement of buoys in the fairways was proposed. In a straight route, the arrangement proposed was that two AtoNs could be seen at both sides of the route in a gated arrangement. For this arrangement in the open sea, 1 nm (1.85 km) should be applied, as the interval between buoys. This can be reduced to 0.54 nm (1km) in harbours. For a staggered buoy arrangement, the distances between buoys were also proposed as 0.8 nm for the open sea and 800 m in harbours.

In a one sided buoy arrangement, the distances between buoys were proposed as 0.5 nm in the open sea and 500m in harbours. In a single centre buoy arrangement, the distances proposed were the same as the gated arrangement. The ideal distance between pairs of buoy can vary dependent upon environmental and sea-state conditions.

This research provides a substantial understanding of perception, ensuring arrangements of buoys in the navigational sea ways provide a reliable, efficient and cost effective Buoyage Service.

Further investigation and experimentation regarding the Background Factor is strongly recommended to verify these results.

Acknowledgements

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