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Development of performance measures based on visibility for effective placement of aids to navigation

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ABSTRACT: *In order to develop the challenging process of placing Aids to Navigation (AtoN), we propose performance measures which quantifies the effect of such placement. The best placement of AtoNs is that from which the navigator can best recognize the information provided by an AtoN. The visibility of AtoNs depends mostly on light sources, the weather condition and the position of the navigator. Visual recognition is enabled by achieving adequate contrast between the AtoN light source and background light. Therefore, the performance measures can be formulated through the amount of differences between these two lights. For simplification, this approach is based on the values of the human factor suggested by International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA). Performance measures for AtoN placement can be evaluated through AtoN Simulator, which has been being developed by KIOST/KRISO in Korea and has been launched by Korea National Research Program. Simulations for evaluation are carried out at waterway in Busan port in Korea.*

KEY WORDS: Aids to navigation; Placement; Visibility; Performance measures; AtoN simulator.

INTRODUCTION

Aids to Navigation (AtoN) is an additive devices for navigation that inform navigators using human vision and can guide navigators to safe watercourse. The problem with placement of AtoN is to determine where to position AtoN after a waterway has been selected under the criteria set by a previous investigation for a safe voyage. Regulation and expert experience are only guidelines for placing AtoN. This paper describes an initial effort to investigate the effect of placement of AtoN. The greatest requirement for AtoN for navigators is visibility because AtoNs are additive devices through human vision. In this paper, we concentrate on visual AtoNs which make up the majority of AtoNs in use.

Visibility of AtoN depends on the light source, the weather condition, and the position of navigator on the sea. The visible range that the navigator can detect and identify AtoN within is increased according to the luminous intensity of the light source. The weather condition with clear air allows the visible range to be enlarged compared to the weather condition with fog. According to the position of navigator including the eye level, AtoN may be interfered with the background light or the other AtoNs beside the eye level affects the geographical range due to the curvature of the Earth.

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The light emitted from an AtoN is attenuated by dispersion and absorption during passage through air and the particulates within it. Thus these air conditions, and the distance, between AtoNs and the navigator set the actual level of attenuation. For estimation of visibility, the light arriving at the navigator is quantified as the luminous incidence or illuminance, and is termed the 'acquired illuminance' when perceived by the unaided eye.

Visual recognition is enabled by achieving adequate contrast between the target light and the background light (ITU-R, 2007; Waldman and Wootton, 1992). Therefore the differences in illuminance between the two lights allow the target light to be identified. Based on this fact, if the threshold of illuminance is determined so as to include the effect of the background light, it can be used as a criterion to be compared with the acquired illuminance. The threshold of illuminance can be defined by the minimum illuminance required for recognition, and is termed the 'required illuminance'. Consequently, the AtoN may be visually recognized by the navigator if the acquired illuminance is greater than the required illuminance.

The placement effect of AtoNs can be quantified by a performance measures for visibility, which has to contain the visibility for all AtoNs according to their placement. The amount of visibility can be described by an excess of acquired illuminance over required illuminance. Therefore the performance measures for visibility can be comprised of the total amount of illuminance differences for all AtoNs to be considered.

For the evaluation of the performance index for visibility, the simulation calculating the performance measures is carried out with the AtoN placement by AtoN Simulator (Kim et al., 2013), which has been developed by KIOST/KRISO in Korea and has launched by Korea National Research Program. For reasonable simulations, AtoNs are selected from the pre-installed AtoNs at Busan port in South Korea. The proposed method is evaluated by investing the results from simulation with example placement.

This paper is an expanded version of the previous studies (Fang, et al., 2013; 2014).

PREDICTION OF REQUIRED ILLUMINANCE

International Association of marine aids to navigation and Lighthouse Authorities (IALA) recommends the required illuminance which is needed to identify AtoN (IALA Recommendation, 2008). It does not mean the quantities for navigator to be able to figure out the existence of the AtoN, but the quantities for one to able to figure out the instruction of AtoN. Visibility of AtoN assumes that if the illuminance acquired on the eyes of the navigator is bigger than the required illuminance, the navigator can identify what the AtoN informs one of.

The required illuminance for visibility is given by 2×10^{-7} lux for night and given by 1×10^{-3} lux for day. One for night is based on the assumption of no background light. One for day is based on the assumption of meteorological conditions with bright cloud.

The required illuminance for night needs to be compensated by containing the effect of the background light since the visual recognition is carried out by getting the light contrast between the interested light source and the background light. The required illuminance has to be determined according to the status of the background light. The state of the background light is mainly changed with the existence of the background light, the distributed area, and the intensity of the light source.

While the required illuminance is given by 2×10^{-7} *lux* for no background light, the required illuminances are recommended by 2×10^{-6} *lux* for minor background light and by 2×10^{-5} *lux* for substantial background light, respectively (IALA Recommendation, 2008). Let E_t denote the required illumination in lux and p_{rb} denote the ratio of the background light. p_{rb} is defined to employ the effect of the background light and is in the range from 0 to 1. It is defined that no background light corresponds to $p_{rb}=0$; minor and substantial background lights correspond to $p_{rb}=0.5$ and $p_{rb}=1.0$, respectively. Based on the relationship which Fig. 1 shows and using a linear interpolation method, the logarithm of the required illuminance is formulated by employing the ratio of background light as follows

$$\log\left(E_t\right)=\log\left(2\times10^{-7}\right)+\left[\log\left(2\times10^{-5}\right)-\log\left(2\times10^{-7}\right)\right]p_{rb} \tag{1}$$

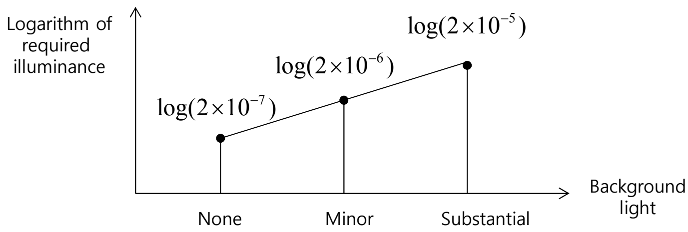

Fig. 1 Relationship between the required illuminance and the background light.

Then rearranging (1) for getting the required illuminance gives

$$E_t = 2 \times 10^{(2p_{rb}-7)} \tag{2}$$

Since the status of background light can be quantitated as the ratio of background light, the problem to be solved is to construct the modeling of the ratio of background. Considering the investigation throughout the navigation on waterway, AtoN may be interfered with the overlap with the background light as well as its existence. Namely, as the navigator on ship moves along with the waterway, the visibility is changed with a grade of overlap with the background light. The background light has no effect on the visibility in case of no overlap though the intensity of the background light is enormously high if it does not cause a glare effect. Therefore the ratio of background light can be modeled by the multiplication of the ratio of the overlap p_{rbo} and the ratio of luminance of background light p_{rbl} .

$$p_{rb} = p_{rbo} p_{rbl} \tag{3}$$

The ratio of luminance of background light represents the strength of light source in the ratio for the possible maximum value. It is supposed that this ratio can be realized by investigating the possible background lights over the harbor area.

AtoN can be hidden by the background light such as the lighting from port or building at harbor area, the other AtoNs or the ships. Fig. 2 shows the possible situation of the overlap for AtoNs. From Fig. 2, AtoN 1 observed by the navigator of ship may be interfered by AtoN 3 and AtoN 2 can be interfered by background light from port.

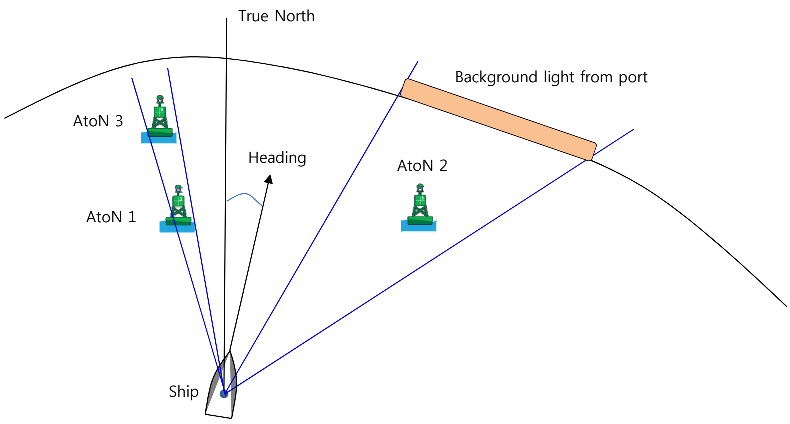

Fig. 2 Interference of background light for AtoN to navigator.

The interference of background light by the overlap is determined by the relative position of AtoN to Navigator and the height of the navigator. In addition, the ratio of the overlap can be defined by the areal overlap between the AtoN to be observed and the background light. As shown in Fig. 3, if S_i denotes the area of i -th AtoN light and S_b denotes the area of the background light from the other AtoN or light source, the area of intersection S_{cs} between two light sources can be derived through the geometric relationship. As the ratio of overlap is employed to represent the interference of the AtoN, it can be defined by the ratio of the area of intersection to the area of the AtoN

$$p_{rbo}^{i} = \frac{S_{cs}}{S_i} \tag{4}$$

where p_{rbo}^{i} denotes the ratio of overlap for i -th AtoN. The superscript will be used in later of this paper and be omitted for simplification.

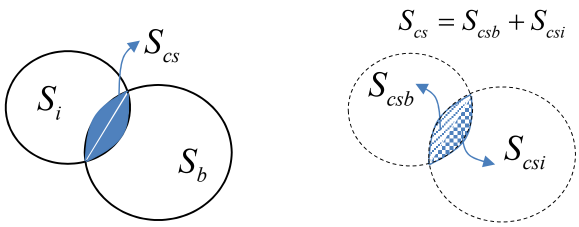

Fig. 3 Area of intersection in case of interference of background light.

In order to obtain the geometric properties for the area of intersection, the side view can be illustrated as Fig. 4. In Fig. 4, h_o, h_i, and h_b denote the height of eye of navigator, the height of the i -th AtoN, and the height of the background light, respectively. R_i and R_b denote the distance from navigator to the i -th AtoN and the one from navigator to the background light, respectively. Δh_i and Δh_b denote the length of AtoN in vertical direction and the one of background light, respectively. Then, projecting the background light on the vertical plane including the AtoN gives Fig. 5.

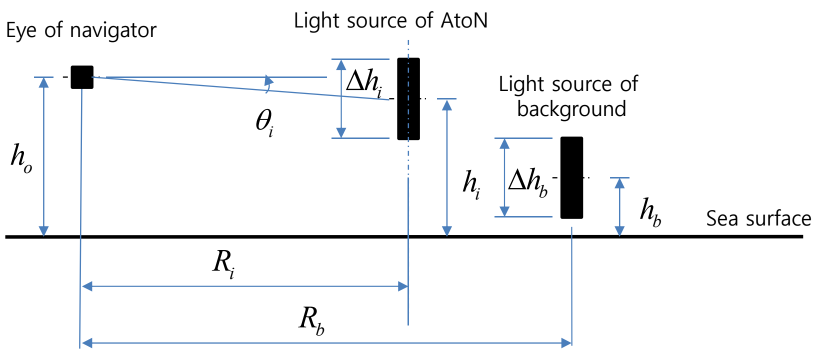

Fig. 4 Placement of navigator, AtoN, and background light in lateral view.

Fig. 5 shows the AtoN overlapped by the background light. The left and upper circle presents the AtoN, and the right and lower circle presents the background light which is projected on the plane of AtoN. The plane of AtoN means the vertical plane to the straight line connecting the navigator with AtoN and the plane to include AtoN. Then the properties in Fig. 5 can be obtained by using geometric relationships.

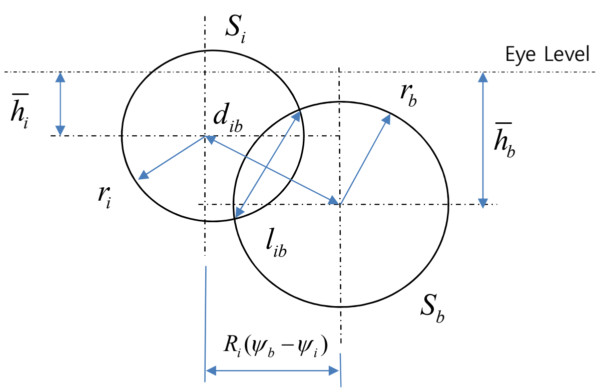

Fig. 5 Geometrical relation of AtoN overlap.

$$\bar{h}_i = R_i\theta_i = R_i \tan^{-1}\left(\frac{h_i - h_o}{R_i}\right) \tag{5}$$

$$\bar{h}_b = R_i\theta_b = R_i \tan^{-1}\left(\frac{h_b - h_o}{R_b}\right) \tag{6}$$

$$r_i = \frac{1}{2}R_i\Theta_i = \frac{1}{2}R_i\frac{\Delta h_i}{R_i} = \frac{1}{2}\Delta h_i \tag{7}$$

$$r_b = \frac{1}{2}R_i\Theta_b = R_i\frac{\Delta h_b}{2R_b}. \tag{8}$$

where θ denotes the elevation angle for the center of the light source. Θ denotes the subtended angle for Δh to the navigator.

The angle ψ_i is the heading angle of the vector from the navigator to AtoN and ψ_b is the heading angle of the vector from the navigator to the background light. If the latitudes and the longitudes of the navigator, AtoN, and the background light are known in advance, ψ_i and ψ_b can be calculated by using geometry of Earth (Stidwill and Fletcher, 2010). Let φ and λ be the latitude and the longitude, then the variations of the position between the navigator and AtoN for the i -th AtoN can be approximated in local tangent plane by

$$\Delta r_{N,i} = R_M(\varphi_i - \varphi_o) \tag{9}$$

$$\Delta r_{E,i} = R_N \cos\varphi(\lambda_i - \lambda_o) \tag{10}$$

where R_M and R_N denote the Earth's meridian radius of curvature and the Earth's prime vertical radius of curvature and are given by

$$R_M = \frac{a(1-e^2)}{(1-e^2\sin^2\varphi)^{3/2}} \tag{11}$$

$$R_N = \frac{a}{(1-e^2\sin^2\varphi)^{1/2}} \tag{12}$$

where a and e denote the semi-major axis of Earth's ellipsoid and the Earth's eccentricity. Then ψ_i can be calculated by

$$\psi_i = \begin{cases} \tan^{-1}\left(\dfrac{\Delta r_N}{\Delta r_E}\right), & for\ \ \Delta r_N > 0 \\ \dfrac{\pi}{2}\text{sign}(\Delta r_E) - \tan^{-1}\left(\dfrac{\Delta r_N}{\Delta r_E}\right), & for\ \ \Delta r_N < 0 \end{cases} \tag{13}$$

In order to detect the overlap, it is needed to obtain the distance between the origins of two circles. Using the heading angle of (13) and Fig. 5, the distance d_{ib} can be obtained by

$$d_{ib} = \sqrt{(\bar{h}_b - \bar{h}_i)^2 + R_i^2(\psi_b - \psi_i)^2} \tag{14}$$

The obtained d_{ib} allows us to detect the overlap occurrence. In order words, if d_{ib} is smaller than the sum of r_i and r_b, then it can be decided that the overlap occurs.

From Figs. 3 and 5, the partial area of intersection, S_{csi}, can be represented as Fig. 6. The shaded area denotes S_{csi} and can be obtained by subtracting the non-shaded area of the triangle from the area of arc.

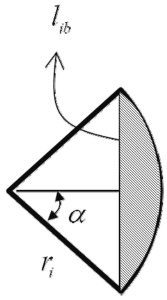

Fig. 6 Representation of area of intersection.

Therefore the area of the intersection is obtained by

$$S_{csi} = r_i^2 \sin^{-1}\left(\frac{l_{ib}}{2r_i}\right) - \frac{1}{2} l_{ib} r_i \cos\left[\sin^{-1}\left(\frac{l_{ib}}{2r_i}\right)\right] \tag{15}$$

where l_{ib} is obtained using Heron's formula.

$$l_{ib} = \frac{4}{d_{ib}}\left[\frac{d_{ib}+r_i+r_b}{2}\left(\frac{d_{ib}+r_i+r_b}{2} - d_{ib}\right)\left(\frac{d_{ib}+r_i+r_b}{2} - r_i\right)\left(\frac{d_{ib}+r_i+r_b}{2} - r_b\right)\right]^{1/2} \tag{16}$$

Consequently, the total area of intersection can be calculated using (14).

$$\begin{aligned} S_{cs} &= S_{csi} + S_{csb} \\ &= r_i^2 \sin^{-1}\left(\frac{l_{ib}}{2r_i}\right) - \frac{1}{2} l_{ib} r_i \cos\left[\sin^{-1}\left(\frac{l_{ib}}{2r_i}\right)\right] \\ &\quad + r_b^2 \sin^{-1}\left(\frac{l_{ib}}{2r_b}\right) - \frac{1}{2} l_{ib} r_b \cos\left[\sin^{-1}\left(\frac{l_{ib}}{2r_b}\right)\right] \end{aligned} \tag{17}$$

Since S_i is easily obtained, the ratio of overlap of (4) can be determined.

ACQUIRED ILLUMINANCE

IALA recommends the formulae of the illuminance acquired at eye of navigator, which is based on the physical laws called Allard's laws (Dickson and Hales, 1963; IALA Recommendation, 2008). The acquired illuminance by IALA is dependent on the luminous intensity of the light source, the relative distance, and the atmospheric transmissivity. The acquired illuminance from IALA Recommendations is given by

$$E_r = \frac{I}{3.43\times 10^6}\frac{T^R}{R^2} \tag{18}$$

where I is the luminous intensity of the light source of the AtoN in candela. R is the distance between the navigator and the AtoN in nautical mile. T denotes the atmospheric transmissivity.

Atmospheric transmissivity is the ratio of the luminous flux transmitted by the atmosphere over a unit distance to the luminous flux which would be transmitted along the same path in a vacuum (Waldman and Wootton, 1992). The meteorological visibility is an alternative way to describe the extinction by the atmosphere of the object. It is the greatest distance at which a black object of suitable dimensions can be seen and recognized the horizon sky. By definition the relationship between the transmissivity and the meteorological visibility is given by

$$V = \frac{\ln 0.05}{\ln T} \tag{19}$$

Once the meteorological visibility is determined, then the transmissivity can be determined by using (19). International Telecommunication Union (ITU), which is United Nations (UN) agency for information and communication technologies, recommends the international visibility code of Table 1 (ITU Recommendation, 2007). Table 1 shows the transmissivity corresponding to the meteorological visibility.

Table 1 International visibility codes for weather conditions.

Weather condition	Meteorological visibility [M]	Transmissivity
Dense fog	0.03	4.29E-44
Moderate fog	0.16	7.39E-9
Light fog	0.35	1.92E-4
Very light fog	0.54 ~ 1.03	3.90E-3 ~ 5.46E-2
Light mist	1.08 ~ 2.16	6.24E-2 ~ 0.2498
Very light mist	2.16 ~ 5.4	0.2498 ~ 0.5742
Clear air	5.4 ~ 10.8	0.5742 ~ 0.7578
Very clear air	10.8 ~ 27.0	0.7578 ~ 0.8950

The ability for visual recognition can be affected by the Field of View (FOV) of human eye. Fig. 7 shows the normal field of view of a pair of human eye (Parker and West, 1973).

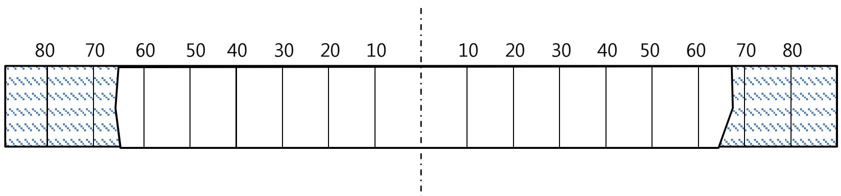

Fig. 7 Normal field of view of human eye.

The central white portion represents the region seen by both eyes. The shaded portions, right and left, represent the regions seen by the right and left eyes, respectively. The number over the box denotes the angel of view in degree. It is known that the binocular vision by white portion gives the binocular summation in which the ability for the perception of faints objects is enhanced (Stidwill and Fletcher, 2010). It can be considered that the ability of perception would abruptly be decreased as the angle of view goes beyond the white regions. In order to include the effect of FOV, the ratio of the binocular vision is employed using exponential function including the ratio of the angle of view to the gaze direction.

$$p_e = \exp\left[-b^{2/n}\left(\frac{\phi}{\pi/2}\right)^{2n}\right] \tag{20}$$

The ratio of the binocular is set to be one within the binocular vision, to rapidly be decreased between about 50 *deg* and about 80 *deg* in right and left eyes, and to be zero at 90 *deg* of both sides. In order to satisfy the above conditions, the parameters of (20) can appropriately be selected through some trial such as Fig. 8. Fig. 8 shows the ratios of the binocular vision with $b = 1.7$ and $n = 4, 5, 6, 7$.

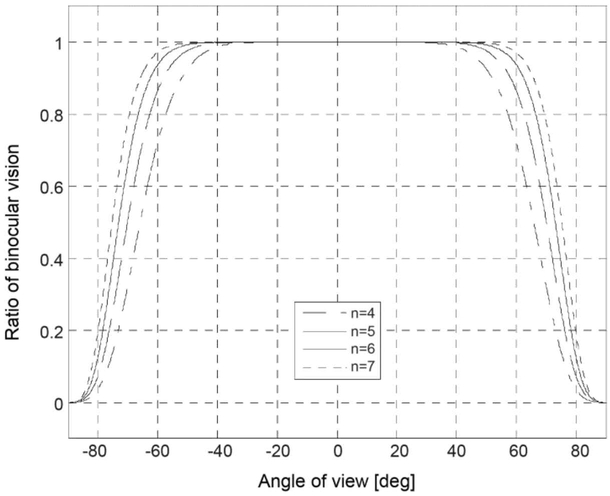

Fig. 8 Ratio of binocular vision for angle of view.

The acquired illumination of (18) can be compensated by including the effect of FOV. While the binocular vision with both eyes has no effect on the perception of the objects, the monocular vision makes the perception to be decreased. Therefore it can be considered that the ratio of binocular vision is the factor of the attenuation ratio for the acquired illumination. Consequently the equation of the acquired illumination can be proposed as

$$E_r = \frac{I}{3.43 \times 10^6} \frac{T^R}{R^2} p_e \tag{21}$$

PERFORMANCE MEASURES OF VISIBILITY

The performance measures for visibility is introduced in order to quantify how well the navigator recognizes the instruction of AtoN light. For simplification, the approach for quantitative model is carried out in two parts, which one is to model the required illumination for thresholds of detection and another is to model the acquired illumination arrived on eyes of the navigator. If the acquired illumination obtained through calculation is larger than the required illumination, the recognition for AtoN is then to be achieved. In addition, the surplus of the acquired illumination to the required illumination indicates the amount of the visual recognition.

Through the comparison between the acquired illumination and the required illumination, the decision of the recognition can be made for each AtoN in the waterway to be considered. Secondly, the amount of recognition can be calculated for each AtoN to be detected. Using the unit step function $H(\bullet)$, the number of the recognition is formulated by

$$N_D = \sum_{i=1}^{N} H\left[E_t(i) - E_r(i)\right] \tag{22}$$

where N denotes the total number of AtoN to be considered. Total amount of recognition is then given by

$$E_{TAR} = \sum_{i=1}^{N} \left[E_t(i) - E_r(i) \right] H \left[E_t(i) - E_r(i) \right] \tag{23}$$

Both the number and total amount of the recognition could be the fundamental performance measures for how well the navigator recognizes the instruction of AtoN light. As additive measures, average amount of recognition for each AtoN is derived from (22) and (23) as

$$E_{AAR} = \frac{E_{TA}}{N_D} \tag{24}$$

Eqs. (22), (23), and (24) represent values obtained at a specific position of the navigator. The amount of recognition should be investigated through the waterway which a ship is considered to pass along because the relative position between the navigator and AtoN is changed along with ship's position. The above three values can be obtained throughout the waterway if the waterway is predefined before evaluating AtoN placement. The amount of recognition considering all waterway can be suggested by (25) and (26). Cumulating the amount of recognition throughout waterway can give

$$CE_{TAR} = \sum_{j=1}^{m} E_{TAR}^{j} \tag{25}$$

$$CE_{AAR} = \sum_{j=1}^{m} E_{AAR}^{j} \tag{26}$$

where E_X^j denotes E_X obtained at the j–th position of navigator where the predefined waterway is divided into $m-1$ number of small waterways. It is assumed that the ship starts at the first position.

Eqs. (25) and (26) represent the cumulated values and continuously increase as the number of the divided waterway or the length of the waterway increases. In order to represent the amount of recognition for each small waterway, the mean value of (25) and (26) for each small waterway is given by

$$MCE_{TAR} = \frac{1}{m} CE_{TAR} = \frac{1}{m} \sum_{j=1}^{m} E_{TAR}^{j} \tag{27}$$

$$MCE_{AAR} = \frac{1}{m} CE_{AAR} = \frac{1}{m} \sum_{j=1}^{m} E_{AAR}^{j} \tag{28}$$

SIMULATION RESULTS FOR EVALUATION OF PERFORMANCE MEASURES

In order to evaluate the performance measures, the simulation calculating the performance measures is carried out through the AtoN placement. It can be considered that the most important factors in evaluating the performance index are properties of AtoNs such as the position and the luminous intensity. Therefore simulations should be carried out based on the AtoN database with high reliability. Korea Research Institute of Ship and Ocean Engineering (KRISO) has been developing AtoN Simulator which the national research program of Korea Ministry of Oceans and Fisheries has launched. AtoN Simulator of KRISO employed the AtoN database supplied from Korean authorities concerned with Korean AtoN management, Korea Association of Aids to Navigation (KAAN). Since KAAN has the purpose of efficiently managing facilities related to aids to navigation, it can be considered that the database provided from KAAN is most reliable.

For reasonable simulations, AtoNs are selected from the pre-installed AtoNs at Busan port in South Korea. Since it has been installed for a long time and has guided many navigators, the placement can be considered to have been well adjusted. For simplification, the background effect disturbed by facilities of harbor area is ignored.

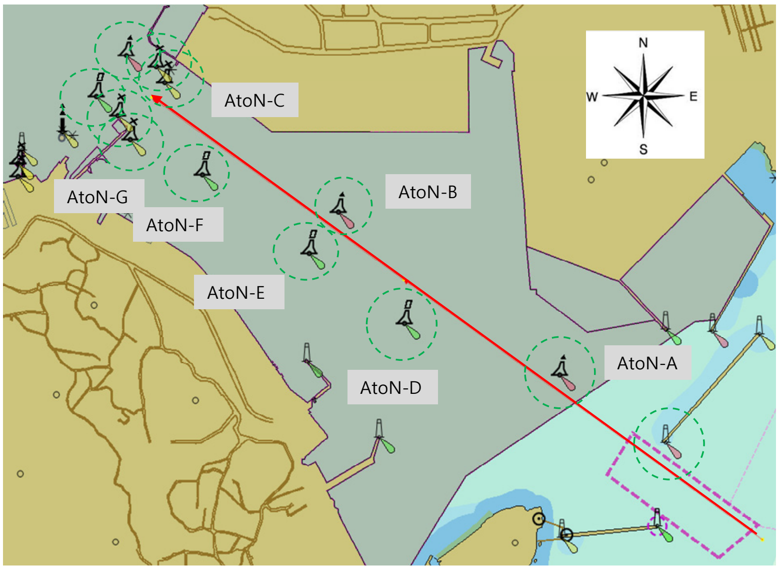

Fig. 9 Selected AtoN placement at Busan port.

Fig. 9 shows the example of AtoN placement selected from Busan port. AtoNs to be investigated for visibility appear to be circled by dotted line and 12 numbers. The path of the virtual cruise is built along with the known waterway and is shown as the arrow line of the carter-corner whose heading angle is -55.29° in Fig. 9. The virtual cruise starts in the bottom right-hand corner where is at latitude of 35.0785285° (north) and longitude of 129.11338° (east) and ends at latitude of 35.105793° (north) and longitude of 129.065496° (east). For calculating the amount of recognition, the specified waterway is divided into the small waterway which has the length of 10 meter and whose number is about 550.

Beside AtoNs' position, the nominal range and the height of light for AtoNs are also obtained from AtoN database. Table 2 shows some of properties for AtoN-A ~ AtoN-G. The luminous intensity can be obtained from the nominal range because the nominal range is the distance for navigator to be able to recognize AtoN in case of the transmissivity 0.7411 and the required illuminance 2×10^{-7} *lux*. Note that, from Table 1, the transmissivity 0.7411 is corresponding to the weather condition of the clear air. The height of navigator's eye is spontaneously determined according to ship database if the ship is selected for the virtual cruise. In simulations, the height of eye is set to be 20 meter. The weather condition is set to be the clear air with the transmissivity 0.7411.

Table 2 Properties of main AtoNs to be tested.

Name	Latitude [*deg*]	Longitude [*deg*]	Nominal range [*M*]
AtoN-A	35.088611	129.097161	7
AtoN-B	35.098583	129.079858	7
AtoN-C	35.106611	129.066527	6
AtoN-D	35.091833	129.085333	7
AtoN-E	35.096083	129.077497	7
AtoN-F	35.100972	129.0691	7
AtoN-G	35.103167	129.063833	6

The performance measures calculated from AtoN placement of Fig. 9 are shown in Fig. 10. Two graphs of the upper side represent the values of (25) and (26) respectively. Ones of the lower side represent values of (27) and (28) respectively. The horizontal axis denotes the position number of a navigator, whose multiplication with the length of small waterway of 10 meter corresponds to the position onto the virtual path apart from the starting position. As the navigator passes through any AtoN, the breakpoint appears on the curve due to the effect of binocular vision. The graph of MCE_{TAR} and MCE_{AAR} clearly shows the breakpoints.

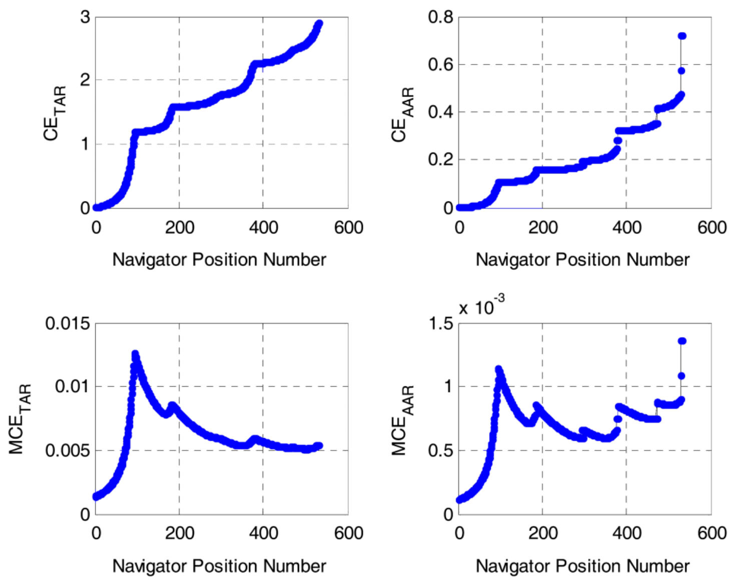

Fig. 10 Performance measures of AtoN placement.

If there are candidates of AtoN placements which are considered in order to decide the best placement in the sense of the visibility, comparing the graphs for all of performance measures of candidates allows us to figure out the best placement. However if there are only small differences or the inconsistency on the breakpoints between candidates, it may not be clear to decide the best placement. Therefore, if we elect the representative point which stands for the curves throughout the position number of the navigator, it could be better to compare the candidates.

CE_{TAR} and CE_{AAR} denote the cumulated amount of recognition for all AtoN to be interested. The values at the last position number therefore can stand for the amount of recognition throughout the virtual path. Since MCE_{TAR} and MCE_{AAR} denote the means of the amount of recognition, total for all of position number can stand for those. Let the maximum values of CE_{TAR} and CE_{AAR} be $MAXCE_{TAR}$ and $MAXCE_{AAR}$ and totals of MCE_{TAR} and MCE_{AAR} be $TOTMCE_{TAR}$ and $TOTMCE_{AAR}$.

For investigation for performance measures, consider candidates of AtoN placement. In order to clearly represent the effect of replacement for AtoN placement, we assume that only one AtoN can be moved. There are three cases that AtoN-D in Fig. 9 moves to three ways. AtoN-D is at latitude of 35.091833° and longitude of 129.085333°. The placement including AtoN-D at such position can be considered to be Candidate 1. Positions of AtoN-D in Candidates 2, Candidate 3, and Candidates 4 are given in Table 3.

Table 3 Position of AtoN-D in candidate placement.

Candidate	Position of AtoN-D	
	Latitude	Longitude
1	35.091833	129.085333
2	35.093373	129.082629
3	35.090294	129.088038
4	35.089610	129.083460

All of Candidates are on about 300 meter apart from the original position and do not cross the virtual path. AtoN-D in Candidate 2 is moved parallel to the direction of the virtual cruise's path. AtoN-D in Candidate 3 is moved opposite to the direction of the virtual cruise's path. AtoN-D in Candidate 4 is moved to the normal direction of the virtual path. Performance measures for all of Candidates can be calculated and are given by Table 4.

Table 4 Performance measures for candidate placements of AtoN-D.

Candidate	$MAXCE_{TAR}$	$TOTMCE_{TAR}$	$MAXCE_{AAR}$	$TOTMCE_{AAR}$
1	2.890865	3.264034	0.722716	0.361856
2	<u>2.891331</u>	3.247240	<u>0.722833</u>	0.358285
3	2.890468	<u>3.282783</u>	0.722617	<u>0.365785</u>
4	2.795547	3.200130	0.698887	0.353569

From Table 4, Candidate 2 has the maximum values (underlined values) in the $MAXCE_{TAR}$ and $MAXCE_{AAR}$. Candidate 3 has the maximum values in the $TOTMCE_{TAR}$ and $TOTMCE_{AAR}$. Candidate 4 has the lowest values for all of performance measures. While Candidate 4 has the lowest performance measure because AtoN-D goes away from the virtual path, Candidate 2 and 3 do not show the meaningful differences compared to Candidate 1 because AtoN-D is parallel to the virtual path.

Table 5 shows the performance measures obtained in case of AtoN-B in Fig. 9. AtoN-B in Candidate 5 and 6 is moved as same as AtoN-D in Candidate 2 and 3, respectively. However AtoN-B in Candidate 7 is moved to reverse direction of AtoN-D in Candidate 4. Candidate 7 has the lowest performance measures for all. Performance measures in Candidate 1, 5, and 6 have the slight differences.

Table 5 Performance measures for candidate placements of AtoN-B.

Candidate	$MAXCE_{TAR}$	$TOTMCE_{TAR}$	$MAXCE_{AAR}$	$TOTMCE_{AAR}$
1	<u>2.890865</u>	3.264034	<u>0.722716</u>	0.361856
5	2.890782	3.235858	0.722695	0.355517
6	2.889387	<u>3.293974</u>	0.722347	<u>0.367639</u>
7	2.632809	3.165681	0.658202	0.347204

From the results of Table 4 and Table 5, it can be seen that it is hard to properly choose the best placement. Therefore the performance measures needs to include an additional effect of AtoN placement. Korea regulations for Function and Standard of AtoN by Ministry of Ocean and Fisheries of Korea indicates that the distance between AtoNs should be consistent in the waterway. The dense AtoNs can specifically be allowed in part of waterway demanding the high attention such as curved waterway. Excepting the dense AtoNs in Fig. 9, AtoNs of AtoN-A ~ AtoN-G need to be placed with the consistent distance. For AtoNs onto the straight waterway, the Factor for the Consistent Distance (FCD) can be suggested as (30) using (9) and (10). This means the reciprocal to total of the disturbed distance from (29) of the mean distance.

$$D_{mean} = \frac{1}{m_H - 1} \sum_{j=1}^{m_H - 1} \sqrt{R_M^2 (\varphi_{j+1} - \varphi_j)^2 + R_N^2 \cos^2 \varphi_j (\lambda_{j+1} - \lambda_j)^2} \tag{29}$$

$$FCD = D_{mean} / \sum_{k=1}^{m_H} \left| D_{mean} - \sqrt{R_M^2 (\varphi_{k+1} - \varphi_k)^2 + R_N^2 \cos^2 \varphi_k (\lambda_{k+1} - \lambda_k)^2} \right| \tag{30}$$

where m_H denotes the number of AtoNs to be located at half plane divided by the virtual path. If the distance between neighbor AtoNs closes to the mean distance, the denominator of (30) will decrease and FCD will then be increased.

Table 6 FCD and combined performance measures in left-hand side.

Candidate	FCD	Combined Performance measures			
		$MAXCE_{TAR}$	$TOTMCE_{TAR}$	$MAXCE_{AAR}$	$TOTMCE_{AAR}$
1	1.8497	2.7867	3.1226	0.8354	0.5106
2	1.4140	2.7436	3.0639	0.7919	0.4639
3	1.3512	2.7365	3.0896	0.7855	0.4643

Table 7 FCD and combined performance measures in right-hand side.

Candidate	FCD	Combined Performance measures			
		$MAXCE_{TAR}$	$TOTMCE_{TAR}$	$MAXCE_{AAR}$	$TOTMCE_{AAR}$
1	4.3136	3.0331	3.3690	1.0818	0.7570
5	1.7287	2.7746	3.0851	0.8233	0.4928
6	8.7070	3.4711	3.8353	1.5208	1.2016

Table 6 shows the FCD and the performance measures combined with FCD obtained by calculating the factor for consistent distance in left-hand side including AtoN-D. The weighted average method is employed for combining FCD and the weighting factors are set to be 0.9 and 0.1 for the performance measures and FCD, respectively. Table 7 shows the combined performance measures obtained in right-hand side including AtoN-B. From Table 6 and 7, it can be seen that Candidate 1 is the best placement in left-hand side and that Candidate 6 is the best one in right-hand side. It means that, to get the best placement, AtoN-D should stay in position and AtoN-B should move opposite to direction of the virtual path. In spite of absence for any explicit methodology to determine the best AtoN placement, it can be considered that the best placement by the combined performance measures is reasonable because the combined performance measures includes effects of the visibility and the consistent distance for AtoN placement.

CONCLUSIONS

In this paper, an initial effort to investigate the effect of placement of AtoN is described. This effect can be quantified in the form of a performance measures, which includes measures of the visibility for all AtoNs. This measure is defined by comparing the required illuminance and the acquired illuminance based on IALA human factors.

The evaluation by simulation is carried out for AtoNs in Busan port by using AtoN Simulator which has been developed by KRISO in South Korea. Investing the simulation results, the performance measures is modified to include the factor of the consistent distance. It is shown that employing the modified performance measures can provide the reasonable method for achieving the best performance in spite of absence for any explicit methodology to determine the best AtoN placement.

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