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A Study on the Visualization of HNS Hazard Levels to Prevent Accidents at Sea in Real-Time

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Abstract : *In order to develop an HNS safety management system to assess and visualize hazard levels via an automated method, we have conceptualized and configured a sample system. It is designed to quantify the risk of a vessel carrying HNS with a matrix method along navigational route and indicate hazards distribution with a contour map. The basic system which provides a visualized degree of hazards in real time has been introduced for the safe navigation of HNS ships. This is useful not only for decision making and circumstantial judgment but may also be utilized for HNS safety management with a risk base. Moreover, this system could be extended to address the navigational safety of marine traffic as well as of autonomous vessels in the near future if the sensors used are connected with IoT technology.*

Key Words : *HNS, HNS safety management system, Hazard level, Contour map, Visualization, Maritime accident, Risk*

1. Introduction

Domestic and international HNS (Hazardous and Noxious Substance) cargo quantities transported into Korean waters are increasing. HNS is defined as "any substance other than oil which, if introduced into the marine environment, is likely to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea." according to the Protocol on Preparedness, Response and Cooperation to Pollution Incidents by Hazardous and Noxious Substances, 2000 (IMO, 2000). Recently, about 251 million tons HNS cargo have been shipped, comprising approximately 19 % of total maritime transportation. Over the past ten years, an increase of around 66 % has taken place, which is more than two and a half times that seen in other countries. Additionally, almost four times as much oil as before is being transported (Lee et al., 2012; Cho et al., 2013; Kim et al., 2015; MPSS, 2016a). For this reason, the risk of HNS marine accidents has also continuously increased. Nonetheless, since preparedness, management, and response procedures for oil spills have mainly been targeted so far, it is fundamentally necessary to establish appropriate response measures for potential HNS maritime accidents as well.

There is also some recent history of HNS spills in Korean waters, with the chemical tanker Maritime Maisie's collision, fire and acrylonitrile spill nearby Taejongdae, Busan in 2013. Another such incident occurred when the container ship Maersk Cunene spilled hydrofluoric acid while entering Busan Port in 2014. Likewise, the chemical tanker Hanyang Ace had an explosion and spilled mixed acid in Ulsan Port in 2015, while the chemical tanker Sun Wing spilled mixed acid as a fire broke out, sinking the vessel (MPSS, 2016a).

Despite the frequent occurrence and severe consequences of HNS accidents, previously-developed risk evaluation methodologies and risk maps are limited in several ways. The statistics for harbor shipments of HNS cargo and past spill accidents from 2001 to 2011 were reviewed and plotted on a map during one study (Lee et al., 2012). Another used ETA (Event Tree Analysis) and a risk matrix based on past accidents from 2002 to 2011 (Cho et al., 2013). Furthermore, an HNS risk database was utilized to construct a risk-based HNS prioritization system (Kim et al., 2015). In addition, standardized HNS codes were proposed, and HATS (HNS Accident Tracking System) was designed and implemented applying data from 1994 to 2016 (Jang et al., 2017). Because all of these studies were based on statistics accumulated from the history of accidents, they are not reliable enough to use as a basis for evaluating the current situation. They represent only fixed risk mapping without the ability to change as the situation differs. In

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order words, a means of evaluating the current situation utilizing real-time data is essential, and such input should be quantified and visualized.

Therefore, the main purpose of this study is to identify assess and visualize hazards causing HNS accidents within Korean waters in real-time as the first step in developing real-time risk management in the future. A contour map that functions as a real-time HNS hazard chart would also be a significant component of an HNS safety system in order to avoid and reduce hazards to prevent maritime accidents. Such a tool would enable ships, companies, authorities and other actors to be better prepared to respond to hazards. As a result, AHDS and EHC have been suggested to contribute to developing real-time hazard evaluation methodology. Necessary hazard factors have been sorted out, a sample system and hazard chart have been configured, and these components have been visualized in this study.

2. HNS Safety Management System Configuration

2.1 The general concept of risk, risk charts, hazards and hazard charts

Normally, when discussing risk, degree of risk is defined based on frequency and severity of consequences (IMO, 2002). Then, risk can be considered in terms of two concepts: static and dynamic risk. Static risk is statistically induced from past HNS accidents that have occurred around Korean waters. On the other hand, dynamic risk must be identified by evaluating currently existing risk with reference to real-time changing data.

A risk chart has been suggested as a layer for ECDIS (Electronic Chart Display and Information System) displaying static or dynamic risks related to HNS accidents. The static method for describing risk has become common because it concentrates on and analyzes only previous data, assessing and displaying risk. Accordingly, static risk charts made from static risk analyses are limited to being only fixed maps. Static risk charts have a critical weakness for evaluating current situations, and so the concept of a dynamic risk chart was derived. Although beneficial for managing real-time risk, dynamic charts take significant effort and time to develop. For this reason, we have devised a real-time hazard evaluation method and corresponding contour map for ECDIS as the foundation for an HNS safety management system.

In general, a hazard refers to a potential threat to human life, health, property or the environment. In this study, an HNS hazard has been defined as having the potential to cause HNS accidents under an associated scenario. Among diverse kinds of HNS accidents, the scope of this study encompasses only HNS spills resulting from collisions, groundings, or other contacts in order to assess the most prominent hazards affecting the safety of navigation in Korean waters.

2.2 Configuration of AHDS (Automated HNS Hazard Display System)

In order to evaluate and visualize hazards at sea in real time, AHDS (Automated HNS Hazard Display System) represents an important part of an HNS safety management system. As shown in Fig. 1, AHDS is an integrated system connecting other devices and sensors via mapping software in compliance with international standards and regulations to apply real-time input data, and ultimately making it possible to identify and evaluate HNS hazards. AHDS helps manage and monitor both hazards and risks to offer the best basis for decision making in a corresponding situation.

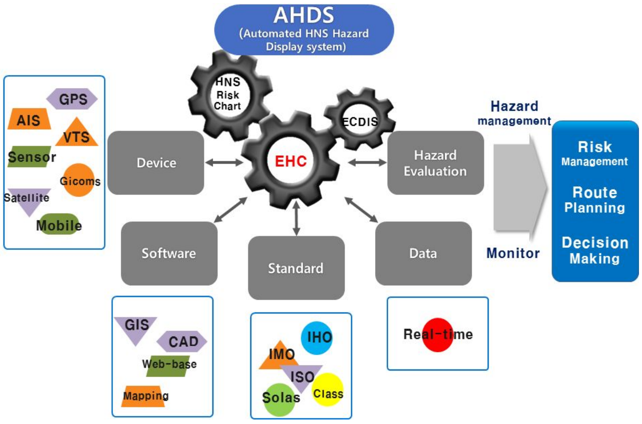


Fig. 1. Configuration of AHDS.

2.3 Configuration of EHC (Electronic Hazard Chart)

While AHDS is an integrated system for hardware and software, EHC(Electronic Hazard Chart) is a layer that can be added to the ENC of an ECDIS. It is a visualized contour map which plays a key role in AHDS and an HNS safety management system. EHC has been suggested in accordance with the vector method, so as not to be interrupted by the scale of the chart, and a GIS(Geographic Information System) format that contains both geospatial and attribute data for related HNS hazards.

Furthermore, depending on the purpose and situation, the aforementioned static risk charts can be used together with real-time hazard charts, making it possible to assess hazards and risks from diverse standpoints.

3. Real-Time Hazard Evaluation Methodology

3.1 Real-time HNS hazard evaluation methodology

According to the definition of HNS hazards in this study, we have established the following evaluation.

$$H_h = \frac{\sum_{i=1}^{n} k_i \times h_i}{P(x,y)} = \sum_{i=1}^{n} k_i \times h_i / \pi \bullet mile^2 \qquad (1)$$

where:

H_h = HNS maritime accident hazard index,

k_i = Total weight coefficient of each hazard factor index,

h_i = Index of each hazard factor, and

$P(x,y)$ = A designated unit circular area where hazards are evaluated

In other words, each HNS hazard is expressed as an index of the total sum of existing hazard factors multiplied by the coefficients of each hazard index within a unit circular area as in Eq. (1). In the equation, k_i stands for the coefficient of weight of each hazard factor, reflecting its intensity. One remarkable point is that $P(x,y)$ is a circular area, i.e., the square of the relevant miles times pi, where hazards are being assessed, differing from the grid-shaped areas used in most studies.

3.2 Determination of HNS hazard factors

In order to decide which hazard factors affecting HNS accidents, i.e., HNS spills resulting from collisions, groundings, and other contacts, should be selected for assessment, several previous papers (IMO, 2002; IALA, 2009; Kim and Lee, 2012; Lee and Kim, 2013) were reviewed, and hazards were addressed as a composition of factors as in Table 1.

Among the hazards affecting HNS accidents, only external hazards were considered, excluding other internal hazard factors such as human error or machinery failure such that this study deals only with navigational safety as related to the area of concern.

First of all, HNS hazards have been qualitatively divided into four hazard sectors: environmental, traffic, meteorological, and technical hazards. Then, real-time hazards were evaluated with reference to this standard.

Table 1. Division of hazard sector and hazard factor

Division	Hazard Sector	Hazard Factor
Hazard	Environmental Hazard	Water depth
		Impediments
		Distance from shore
	Traffic Hazard	Commercial vessel traffic
		Small ship traffic
	Meteorological Hazard	Wind
		Visibility
		Current
	Technical Hazard	Position accuracy
		Charted data accuracy

Fig. 2 represents the conceptual structure used for HNS hazard evaluation in real time. Among the many existing factors related to HNS accidents, hazards in this study were narrowed down to ten to allow for quantitative evaluation with the use of a matrix. Each hazard factor was calculated by a numerical rating criteria, assigning individual weight and intensity coefficients.

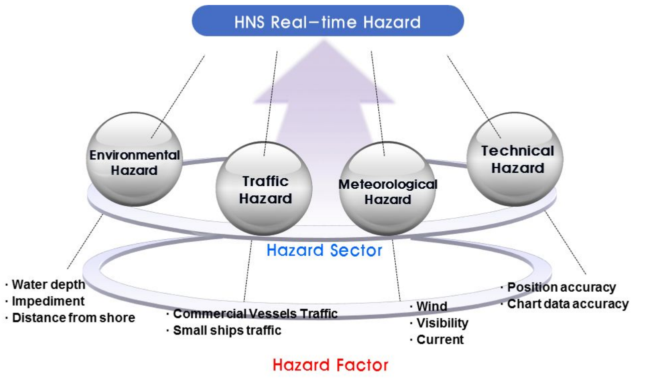


Fig. 2. Conceptual structure for HNS hazard evaluation in real time.

3.3 Hazard evaluation matrix

The matrix used to evaluate HNS hazards is introduced in Table 2. All of the factors from the four hazard sectors were quantified into five rating indexes based on statistical data from 785 maritime accidents including collisions, groundings, and other contacts in 2015 (MPSS, 2016b). Reliable external sources, ideas from brain-storming discussions and questionnaires answered by an expert group of ten people consisting of professors and senior ship officers were also taken into consideration. Only data from 2015 was analyzed in keeping with the ultimate goal of this study, to

Table 2. The matrix of hazard factors for hazard evaluation

Sector	Environmental Hazard			Traffic Hazard		Meteorological Hazard			Technical Hazard	
Rating	Water Depth	Number of Impediments	Distance From Shore	Number of Commercial Vessels	Number of Small Ships	Wind	Visibility	Current	GPS HDOP	ECDIS CATZOC
5	h/T ≦ 1	≧ 4	d/V≦1min	≧ 4	≧ 4	≧ 21㎧	< 200yard	c/V>0.4	> 9.0	D,U
4	h/T ≦1.2	≦ 3	d/V≦3min	≦ 3	≦ 3	< 21 ㎧	< 1000yard	c/V≦0.4	≦ 9.0	C
3	h/T ≦1.5	≦ 2	d/V≦6min	≦ 2	≦ 2	< 14 ㎧	< 1 mile	c/V≦0.3	≦ 6.0	B
2	h/T ≦3.0	≦ 1	d/V≦12min	≦ 1	≦ 1	< 8 ㎧	< 5.5 mile	c/V≦0.2	≦ 4.0	A2
1	h/T > 3.0	0	d/V>12min	0	0	< 3.3 ㎧	≧ 5.5 mile	c/V≦0.1	≦ 2.0	A1

where, h = minimum depth in the area, T = draft of the HNS vessel, d = distance from the nearest shore,
V = speed of the HNS vessel, and c = maximum speed of the current in the area.

Table 3. Weight and intensity coefficient of hazard sectors and factors for hazard evaluation

Sector Weight	Environmental Hazard			Traffic Hazard		Meteorological Hazard			Technical Hazard	
	2.6			2.5		1.7			1.05	
Factor Weight	Water Depth	Number of Impediments	Distance from Shore	Commercial Vessel Traffic	Small Ship Traffic	Wind	Visibility	Current	GPS HDOP	ECDIS CATZOC
	1.44	0.96	0.60	1.40	0.60	1.05	1.20	0.75	1.20	0.80
Rating	Intensity									
5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.0
4	0.75	0.72	0.80	0.90	0.65	0.70	0.9	0.80	0.70	0.73
3	0.50	0.40	0.60	0.70	0.40	0.40	0.8	0.50	0.35	0.51
2	0.25	0.30	0.40	0.30	0.15	0.20	0.5	0.25	0.20	0.22
1	0.10	0.05	0.20	0.10	0.03	0.02	0.2	0.10	0.10	0.16

assess real-time hazards, which implies focusing on only a short period of time and visualizing relevant data, which makes it fundamentally necessary to use recently accumulated information.

First of all, environmental hazards are related to the external waterway conditions. This includes water depth, impediments, and distance from the nearest shore. Water depth was assessed in accordance with a depth to draft ratio (PIANC, 2014; Pritam and Premchand, 2015). When the h/T value is less than 1, depth is equal to or less than draft, and an HNS vessel would be grounded. For impediments, rating was based on the number of wrecks, rocks, obstructions, and other unintended obstacles in the area. Additionally, distance from shore was determined based on how far a given area was from the nearest shoreline in comparison with the distance and speed of an HNS ship in real time.

Secondly, traffic hazards are related to the volume of traffic in the area, including both large commercial vessels and small ships such as fishing boats. These were quantified following the same criteria as for impediments.

Third, meteorological hazards refer to hazardous sea and weather conditions that can trigger accidents. A scale for wind was derived from a combination of the Beaufort scale and the wind wave advisory of the Korea Meteorological Administration (KMA, 2017). Visibility range was determined on the basis of American Practical Navigator criteria (NIMA, 2002). Current was assessed in relative relation to the speed of a ship as a cause of set and drift.

Lastly, technical hazards are defined as elements weakening the accuracy of navigational equipments for position fixing. Position accuracy was evaluated by HDOP (Horizontal Dilution of Precision) in the area at the time. HDOP values are correlated with GPS (Global Positioning System) measurement precision, one of the most commonly used solutions for ship positioning. The rating refers to practical standards in the United States (USCG, 2016). Chart data accuracy was judged based on CATZOC (Category Zones of Confidence) in the area. CATZOC is a composite data quality indicator for ENCs (UKHO, 2016). However, as electronic chart data has limitations for describing the real world accurately, despite the efforts of hydrographic offices around the world, hazards affecting accidents may remain.

3.4 Determination of weight and intensity coefficients

After all hazard factors for hazard evaluation were determined, weight coefficients for each sector and factor were required in order to calculate real-time hazard indexes. In this study, coefficients were derived as shown in Table 3 based on both statistical data from 785 accidents in 2015 (MPSS, 2016b) and the brain-storming results of an expert group on how to quantify hazards in the same way as quantified hazard factors.

Table 4. Hazard ratios related to causes of accidents as per statistical data from 2015

Hazard	Environmental Hazards	Traffic Hazards	Meteorological Hazards	Technical Hazards
Ratio	33.12%	31.97%	21.53%	13.38%
Accident case	260	251	169	105

To begin with, sector weight coefficients prioritized according to the four hazard sectors were designated by ratio of occurrence based on the statistics. Among the 785 accidents in 2015, the main accident-causing hazard factor of each case was determined with resulting ratios indicating that 33.12% were environmental hazards, 31.97% were traffic hazards, 21.53% were meteorological hazards, and 13.38% were technical hazards, as in Table 4. Then, these ratio values were multiplied by 7.85 in order to center the maximum value of the hazard index at one hundred.

Among the hazard factors belonging to each sector, factor weight coefficients were determined to compare relative importance via the input of experts through discussions and questionnaires. The ratio of each factor was multiplied by two or three depending on the number of factors belonging to the sector in order to center the maximum value for hazards at one hundred as well, as above. Finally, intensity coefficients for the impact of hazards were separately assigned to each index. The range of these intensity coefficients extended from 0 to 1 in accordance with influential strength, and these values also followed contributions from experts in the same way.

Therefore, the k_i value of Eq. (1) can be expressed as follows.

$$k_i = w_s(w_f \times I) \tag{2}$$

where:

k_i = Total weight coefficient of each hazard factor index,

w_s = Sector weight coefficient of the corresponding sector,

w_f = Factor weight coefficient of the corresponding factor, and

I = Intensity coefficient of the corresponding index.

3.5 Level of HNS hazards

In order to describe real-time hazards at sea within the designated circular area, factors were not only quantified but also divided into a ten-tiered level system, which standardized the range of the hazard indexes as in Table 5.

Table 5. Standardized ranges for hazard indexes

Level	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
H_h	0~ 10	11~ 20	21~ 30	31~ 40	41~ 50	51~ 60	61~ 70	71~ 80	81~ 90	91~ 100

In order to create equivalent ranges for each level and make hazards easier to understand in the manner of a contour map, levels were defined according to a standardized range, comprised of H10(100-91), H9(90-81), H8(80-71), H7(70-61), H6(60-51), H5(50-41), H4(40-31), H3(30-21), H2(20-11), and H1(10-0).

4. Real-Time Hazard Visualization

4.1 Sample hazard distribution

In order to visualize real-time hazard charts (EHC), it was necessary to conduct a sample hazard distribution to verify the methodology. Therefore, a sample hazard distribution with several hazard factors as in Fig. 3 was established, analyzed and visualized in real time.

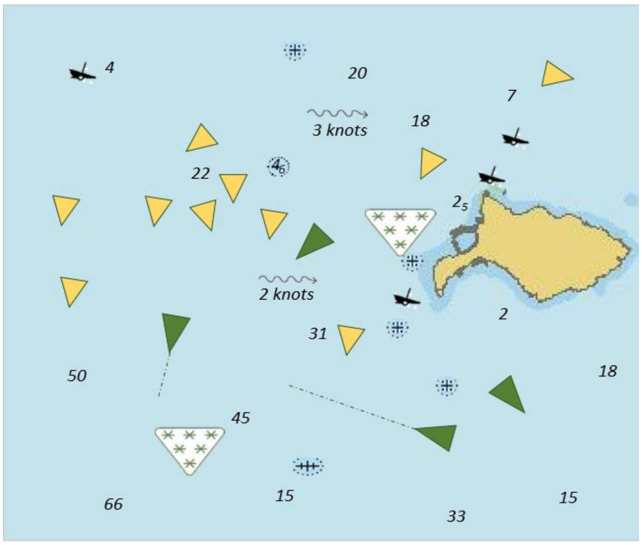


Fig. 3. Sample hazard distribution for real-time hazard assessment.

In Fig. 3, yellow ship symbols represent small ships and green ones represent large commercial vessels. Other than the hazard factors already marked on the map, wind, visibility and other missing data were randomly simulated in each area. For areas without specific hazard factor data, factors were given a rating of 1 when evaluated.

Afterwards, the charted course of an HNS ship with a speed of 10 knots and draft of 10m and circular areas with a radius of one mile were drawn as in Fig. 4. The area evaluated for hazards has a circular shape to make it possible to judge hazards in accordance with the course plotted given distance in relation to the ship's speed (the circumference of a circle is a collection of infinite points with the same distance from the center). Even if a circle was drawn with an one mile radius in the sample hazard distribution, it could be easily varied in proportion to the ship's speed and how much resolution is desired in the evaluation and visualization of hazards according to unit area.

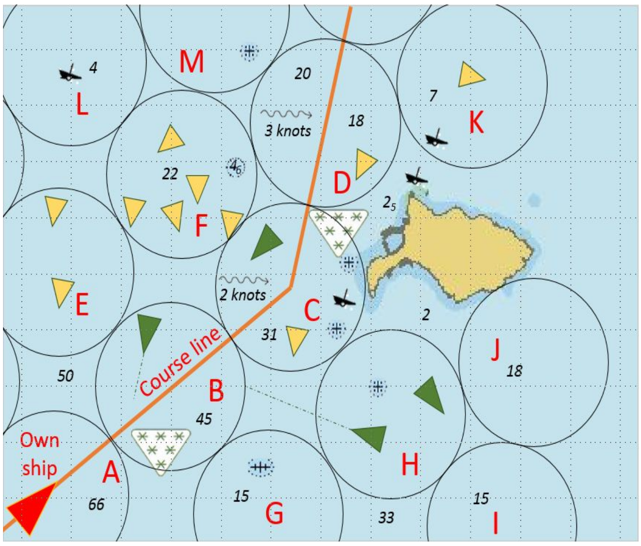


Fig. 4. Sample hazard distribution with ship's course line and circular areas to be evaluated.

4.2 The result of HNS hazard evaluation

Via a sample hazard distribution, an evaluation of hazards was carried out within each area. Table 6 represents the results of the hazard evaluation, and each index value was converted into one of the levels defined before so as to enable visualization of the HNS hazard chart. The top three areas with high hazard indexes were C, L, and K of Fig. 4 due to existing impediments, low depths, traffics and other external conditions. It can be seen that the hazard levels and hazard indexes coincide with how many hazards exist in the relevant areas and how intense they are.

Table 6. The result of HNS hazard evaluation

Area	H_h	Level
A	8.4137	H1
B	6.0981	H1
C	42.6183	H5
D	13.0373	H2
E	10.1687	H2
F	18.7391	H2
G	10.8281	H2
H	17.7225	H2
I	9.9130	H1
J	16.1513	H2
K	29.4731	H3
L	32.0633	H4
M	9.7865	H1

4.3 Chart of visualized hazards

After real-time hazard evaluation was conducted within the designated areas, a contour map of hazard levels was derived from the indexes displayed. Areas with the same hazard level should be connected with a number of equal curves. These curves compose the EHC visualizing layer to be superimposed upon AHDS.

Fig. 5 represents the sample hazard evaluation in AHDS when planning a route to Busan Port, Korea. Several circular areas were displayed in accordance with the course. Then, data from other sources was input through the system.

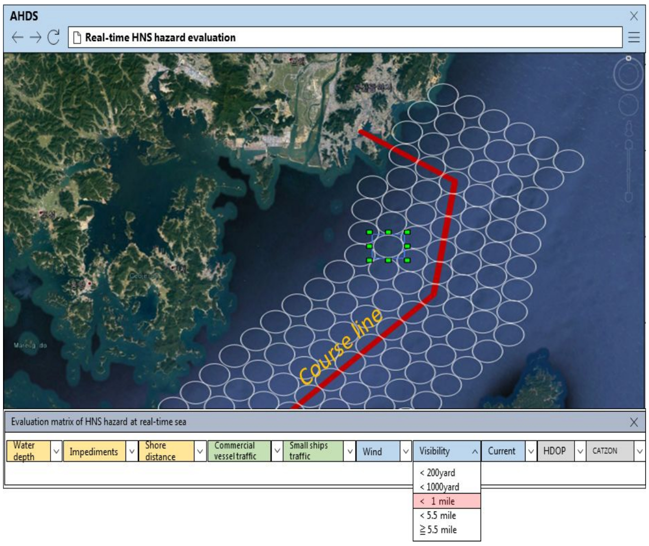
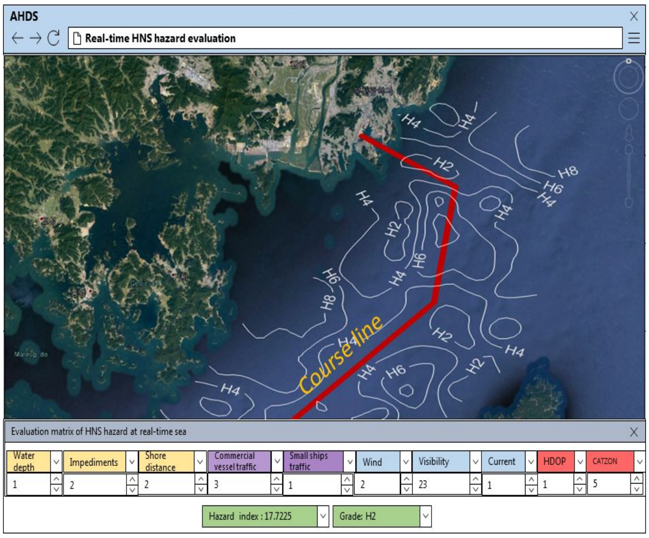


Fig. 5. The concept of the sample hazard evaluation in AHDS.

Upon gaining hazard indexes after evaluation, a sample hazard visualization chart, i.e., a contour map, was drawn as in Fig. 6.

When connecting areas with the same hazard level, the curves were designed to adopt a kriging interpolation. Additionally, the contours in Fig. 6 were based on the hazard levels as of interval two, but this option is flexible with regard to the users' decisions. These equal curves ultimately enable HNS ships to assess the real-time situation via input data as the curves change over time in response to data changes. Then, users can utilize this information for route planning and monitoring to provide optimum safety for HNS ships by avoiding hazards.



Evaluation matrix of HNS hazard at real-time sea

Water depth	Impediments	Shore distance	Commercial vessel traffic	Small ships traffic	Wind	Visibility	Current	HDOP	CATZON
1	2	2	3	1	2	23	1	1	5

Hazard index : 17.7225

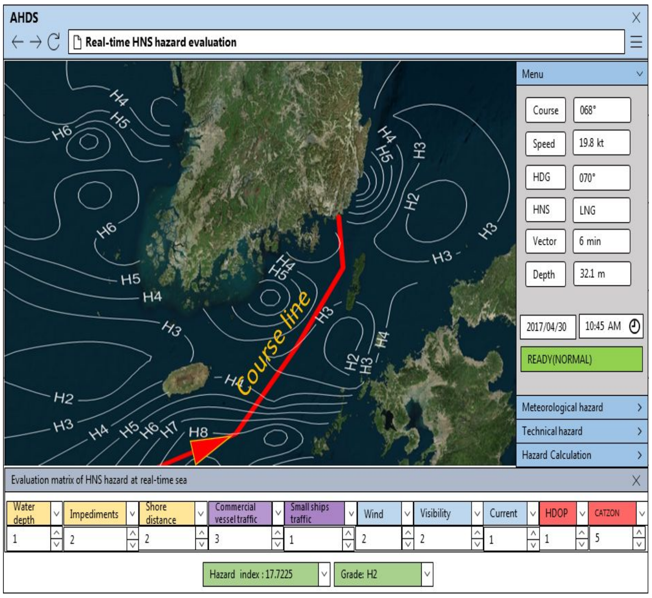
Grade: H2

Fig. 6. The sample chart of the hazard visualization.

4.4 Application and hazard management project

Fig. 7 represents the configuration of the sample system design in operation for Korean waters overall. AHDS is definitely expected to help with understanding current situations and allow for more efficient decisions following the evaluation of the hazards in real time for monitored areas.

Although this study mainly deals with HNS accidents resulting from collisions, groundings, and other contacts, this real-time hazard management system could be broadened to encompass other areas as well. In addition to HNS ships, other types of ships could also adopt real-time hazard evaluation and hazard charts to anticipate and better manage hazards. Once more data is available for the system via data science and the connection of necessary devices or sensors, ships could also become autonomous according to the assessment of hazards in real time as well as optimum ship routing and avoidance procedures. In the long run, AHDS and EHC will contribute to not only the prevention of HNS maritime accidents, but also the overall safety of marine traffic throughout the country.



Course: 068°

Speed: 19.8 kt

HDG: 070°

HNS: LNG

Vector: 6 min

Depth: 32.1 m

2017/04/30 10:45 AM

READY(NORMAL)

Evaluation matrix of HNS hazard at real-time sea

Water depth	Impediments	Shore distance	Commercial vessel traffic	Small ships traffic	Wind	Visibility	Current	HDOP	CATZON
1	2	2	3	1	2	2	1	1	5

Hazard index : 17.7225

Grade: H2

Fig. 7. The configuration of the sample system design.

5. Conclusion

As there are more than 6,000 kinds of HNS cargo shipped through Korean waters, with maritime transportation representing a higher portion of trade movement than before, the likelihood of HNS accidents has also increased. Therefore, it has become necessary to manage the hazards of HNS transportation in a systematic method. This study was carried out as a fundamental step in establishing such a method to manage safety, attaining the following results.

First, concepts for AHDS and EHC were suggested as a means of hazard management by automatically utilizing data from HNS hazards in real time instead of employing manual methods. Secondly, hazards were identified, quantified, and evaluated in order to create a visualization. Finally, using quantified hazard indexes and levels, a hazard contour map connecting areas of equal hazard level was drawn and displayed with the concept and configuration for a sample system in real time.

One aspects that could strengthen future research would be the adoption of more hazard factors to accumulate more data for further determination of the coefficients. Furthermore, it is necessary to consider using diverse methodologies for visualization such as various resolutions so that every case could be addressed without restriction. Then, how the real-time hazard data is input with equipment, as suggested in the system configuration, should be studied further to improve management of hazards and risks.

Nevertheless, the assessment of real-time hazards is advantageous and plays a significant role in helping improve understanding of the current situations to enable an optimum corresponding ship route that avoids existing hazards. Moreover, such a method could be extended to improve the fundamental safety of marine traffic overall as well as facilitate navigation for autonomous ships in the near future.

Acknowledgements

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