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Collision Risk Assessment by using Hierarchical Clustering Method and Real-time Data

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계층 클러스터링과 실시간 데이터를 이용한 충돌위험평가

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Abstract : *The identification of regional collision risks in water areas is significant for the safety of navigation. This paper introduces a new method of collision risk assessment that incorporates a clustering method based on the distance factor - hierarchical clustering - and uses real-time data in case of several surrounding vessels, group methodology and preliminary assessment to classify vessels and evaluate the basis of collision risk evaluation (called HCAAP processing). The vessels are clustered using the hierarchical program to obtain clusters of encounter vessels and are combined with the preliminary assessment to filter relatively safe vessels. Subsequently, the distance at the closest point of approach (DCPA) and time to the closest point of approach (TCPA) between encounter vessels within each cluster are calculated to obtain the relation and comparison with the collision risk index (CRI). The mathematical relationship of CRI for each cluster of encounter vessels with DCPA and TCPA is constructed using a negative exponential function. Operators can easily evaluate the safety of all vessels navigating in the defined area using the calculated CRI. Therefore, this framework can improve the safety and security of vessel traffic transportation and reduce the loss of life and property. To illustrate the effectiveness of the framework proposed, an experimental case study was conducted within the coastal waters of Mokpo, Korea. The results demonstrated that the framework was effective and efficient in detecting and ranking collision risk indexes between encounter vessels within each cluster, which allowed an automatic risk prioritization of encounter vessels for further investigation by operators.*

Key Words : *Maritime transportation, AIS data, Ship collision, Risk assessment, Hierarchical algorithm*

요 약 : 수역 내 충돌 위험 식별은 항해의 안전을 위해 중요하다. 본 연구에서는 거리 요인을 기반으로 한 군집화 방법인 계층 클러스터링을 포함하는 새로운 충돌 위험 평가 방법을 도입했으며, 주변의 선박이 많은 경우 실시간 데이터, 그룹 방법론 및 예비 평가를 사용하여 선박을 분류하고 충돌위험평가를 기반으로 평가하였다(HCAAP 처리라 부른다). 조우하는 선박들의 군집은 계층 프로그램에 의해 모아지고, 예비 평가와 결합되어 상대적으로 안전한 선박을 걸러내었다. 그런 다음, 각 군집 내에서 조우하는 선박 사이의 최근접점(DCPA) 및 최근접점까지의 도착시간(TCPA)까지의 시간을 계산하여 충돌위험지수(CRI)와의 관계를 비교하였다. 조우하는 선박들간의 군집에서 CRI와 DCPA 및 TCPA 수학적 관계는 음의 지수 함수로 구성되었다. 이러한 CRI로부터 운영자는 명시된 해역에서 항해하는 모든 선박의 안전성을 보다 쉽게 평가할 수 있으며, 프레임워크는 해상운송의 안전과 보안을 개선하고 인명 및 재산 손실을 줄일 수 있다. 본 연구에서 제안된 프레임워크의 효과를 설명하기 위해 국내의 목포 연안 해역에서 실험 사례 연구를 수행하였다. 그 결과, 본 연구의 프레임워크가 각 군집 내에서 조우 선박 간의 충돌 위험 지수를 탐지하고 순위를 매기는 데 효과적이고 효율적이라는 것을 보여 주었으며, 추가연구를 위한 자동 위험 우선순위를 지정할 수 있게 해주었다.

핵심용어 : 해상운송, 선박자동식별장치, 선박충돌, 위험평가, 계층 알고리즘

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1. Introduction

Maritime transportation is one of the most important industries in the world, contributing up to 90% of the world trade volume, each ship is a great asset and an essential link in the operation of global maritime transportation. Therefore, ensuring safety throughout the routes of the ship is always on top priority and developed by scientists every day. In which, ship collision is a major type of accident at sea that usually results in significant financial loss, fatalities, and environmental pollution. Thus, assessing of the risk of ship collision is considered the main factor to ensure safe navigation and relevant collision risk mitigations have been the main research focuses in decades.

Multi-vessel collision risk assessment for maritime traffic surveillance is a key technique to ensure maritime traffic and transportation safety and security. Typically, surveillance operators have to search and predict emerging conflict situations from many sailing vessels within a large sea area. Early detection of such risk situations provides critical time to take appropriate action, possibly before a disaster occurs. This paper proposes a real-time multi-vessel collision assessment framework by using Automatic Identification System (AIS) data to detect and rank potential vessel collision risk index by combining a distance clustering process named hierarchical cluster analysis (HCA) for detecting clusters of encounter vessels.

In the previous research, Rong Zhen has introduced a method that used a spatial clustering process named DBSCAN (Zhen et al., 2017) using the clustering algorithm proposed by Martin Ester at al. (1996) is quite complex to enforcement. For practical considerations, there are three major disadvantages DBSCAN method has to face: Firstly, the time complexity is mostly governed by the number of *regionQuery* invocations, DBSCAN visits each point of the database possibly multiple times lead to prolongation of execution time. Moreover, the position of objects changes continuously in the survey area over time. Secondly, if the data and scale are not well understood and have a clear basis, choosing a meaningful distance threshold ε can be difficult. And DBSCAN is not taking advantage of the available distance data between objects in the survey area, especially identifying the cluster of two vessels close to each other.

On the other hand, using real data from AIS means reducing wasting time when evaluating because of continuity. Therefore, to solve the above problems, in this paper, the author used the HCA solution to cluster vessels with highly simple, faster and take advantage of distance data in comparison with DBSCAN. This paper is organized into five sections as below.

2. Case study

2.1 Risk assessment

Normally, a risk assessment is the combined effort of identifying and analyzing potential (future) events that may negatively impact individuals, assets, and/or the environment (i.e. risk analysis); and making judgments "on the tolerability of the risk based on a risk analysis" while considering influencing factors (i.e. risk evaluation).

To assess the safety level quantitatively and take actions to reduce the possibility of collision in monitored waters, a variety of researchers have published work that assesses risk in various ways. Bearing in mind the type of methods and their objectives, the studies published can be categorized approximately into three broad groups (Li et al., 2012; Zhang et al., 2016):

1. Risk modeling and risk analysis based on the probability of accidents and their consequences.
2. Statistical analysis of maritime accidents.
3. Analysis of non-accident information to obtain safety levels in maritime traffic.

In the study of risk modeling and risk analysis, the maritime risk can be measured by a variety of methods, such as the product of probabilities and consequences, three or more levels of state indicators and fuzzy, probit regression model, dynamic ship domain and collision judgment model (Kim. and Kim, 2018), quantitative (Koo, 2018; Jeon and Jung, 2018). The research on maritime accidents analysis is a crucial aspect of assessing and improving safety at sea. There are several research works focusing on maritime accident analysis with the results of the theoretical models were compared with actual accident statistics. To assess marine risks from accident data, large amounts of maritime traffic accident data accumulated across many years and contexts should be gathered and analyzed. However, data that contains maritime accidents are rare; therefore, the non-accident data is frequently utilized by researchers to obtain safety levels in the traffic. In the analysis of encounter and near miss situation between vessels, certain maritime traffic risk indexes that correlate the position, speed, and course of the vessels would always be defined and modeled. Then, the risk index can be applied to assess the risk values in the maritime surveyed sea area.

2.2 The AIS data and its application

The AIS system was introduced in the International Convention for the Safety of Life at Sea (SOLAS) amendment, which stated that all vessels over 300 Gross Tonnages (GT) engaged in international voyages, all cargo vessels over 500 GT and all passenger vessels are required to be equipped with AIS from 31 December 2004. Through the installation of AIS receivers in the base station and satellite, substantial AIS information is stored and accumulated by the maritime traffic authority and research group. The AIS transmits ship-related data that can be divided into three groups: dynamic data, static data and voyage-related data (Aarsæther and Moan, 2009).

Vessel Traffic Service (VTS) is vital for ensuring safe and smooth maritime traffic in designated areas. With the rapid development of technologies and the extensive implementation of AIS, a lot of data are available to support the decision-making processes in VTS. Besides the original purpose of identification and collision avoidance between ships at sea, the AIS data serve as an important input and source for maritime traffic risk assessment, and indeed, as an input for research in this area.

The DCPA and TCPA values was used to calculates and ranking the dynamic collision risk and developed by the basic risk, relative multipliers of TCPA and DCPA which are calculated from the AIS data by considering the distance between two ships, the relative speed of the ships, and the difference between the headings of the ships.

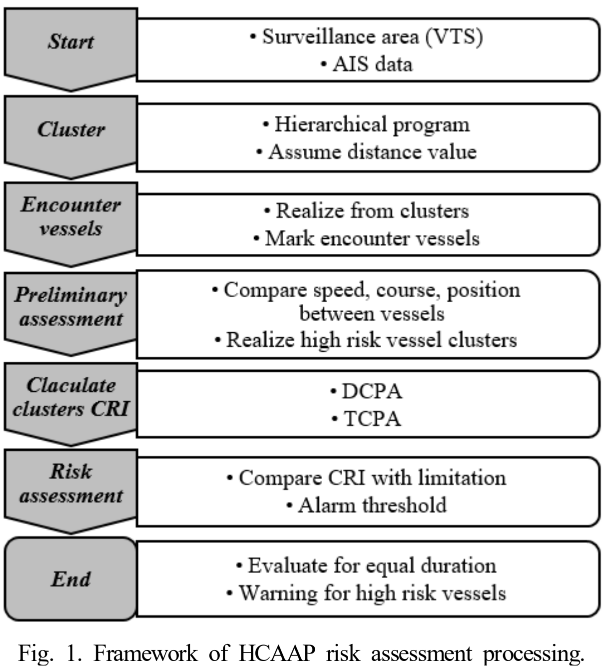


Fig. 1. Framework of HCAAP risk assessment processing.

2.3 Collision risk index

For the purpose of maritime traffic surveillance in real time, the authors adopt the collision risk index from the research of ship collision avoidance presented in Chen et al. (2015) and situations of near miss between vessels were assessed and investigated in Zhang et al. (2015). The CRI is defined in the notation of the International Regulations for Preventing Collisions at Sea (COLREGS), evaluates the probability and severity of a vessel colliding with other vessels around it. This is an important criterion to rank the risk from other ships, giving the ship officers the time and extent to take evasive actions. Moreover, the CRI index is usually quantified for automated ship collision avoidance, and it has three significant characteristics: ambiguity, uncertainty, and instantaneity. The CRI is impacted by the DCPA, TCPA, distance from the threatening vessel (D), relative bearing (B) and the ratio of speed (K). Based on the factors above, the CRI can be calculated using the combination of DCPA and TCPA. However, the logic for the modeling of CRI is based on the application of automated vessel collision avoidance; the CRI is calculated from the perspective of the own ship to the ships surrounded. The obtained CRI is the basis for the own ship to assess the risk and take intelligent evasive actions of anti-collision.

When assessing the collision risk values in the whole monitored sea area, maritime traffic surveillance systems should determine the CRI between all the vessels that sail within the spatial sea area; however, such a process can be very computationally expensive. On the other hand, real-time data collect from VTS stations always ready, fully and particularly. Moreover, such risk values should be presented to the operators of the surveillance systems in an understandable and comprehensible manner. This is the challenge to presenting an efficient and computationally inexpensive method for assessing collision risk within large surveillance.

3. Theoretical framework

3.1 Framework

To assess and detect vessels at risk of collision from a huge number of sailing vessels within a large sea area, the authors designed an analytical framework illustrated that processes AIS data collected from the maritime surveyed area in real-time (support from VTS stations). Firstly, a hierarchical diagram to extract vessels positioned close to each other and marked, then combine with the preliminary assessment to filter out safe vessels these did not closely located vessels around them. Next step, the DCPA and TCPA are calculated for the couples of closely positioned vessels in encounter clusters. Finally, the collision risk index is estimated in real-time following the proposed function that is described in Figure 1.

3.2 Hierarchical method

When multiple ships operate within the scope of a VTS surveillance system, need an essential solution for operator assistance to propose the list and ranking collision risk of the ships that can be easily monitored, alerted and have solutions to help those ships navigate safer as reduce CRI index also.

A collision occurs when vessels reach standard conditions such as speed, time, and especially distance close enough to happen. To detect the vessel encounter situation from large number of vessels sailing within large sea area automatically, the author used the hierarchical method.

Hierarchical clustering also called hierarchical cluster analysis or HCA is a method of cluster analysis that seeks to build a hierarchy of clusters. Strategies for hierarchical clustering generally fall into two types:

Agglomerative: This is a "bottom-up" approach: each observation starts in its own cluster, and pairs of clusters are merged as one moves up the hierarchy.

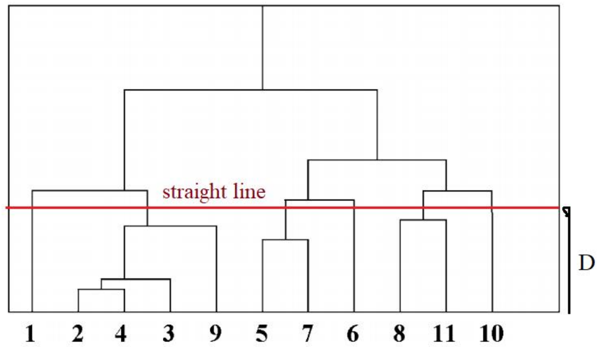
Divisive: This is a "top-down" approach: all observations start in one cluster, and splits are performed recursively as one moves down the hierarchy.

As the HCA program is illustrated in Fig. 2, the distance value (D) will decide where the cut-line is and the number of clusters we have, it is pretty clear that the HCA meets the requirement of detection of encounter vessels and filtration of safer vessels.

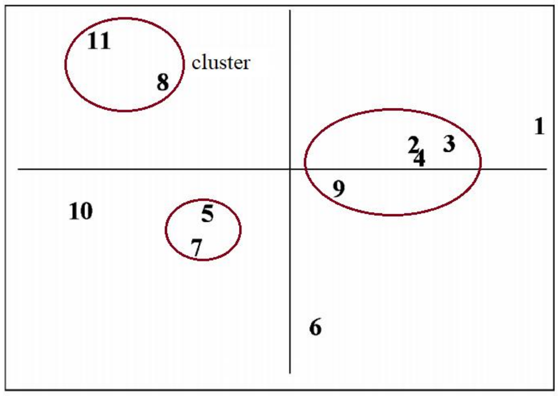
When applying HCA, the applicant's mission is to decide the value of distance D that shows the number of object clusters based on the safety of maneuvering in that situation. In the nautical, the distance between vessels is usually calculated from the AIS data using the Euclidean distance method or Mercator method. Because of the limitation of paper, we do not re-introduce those solutions here. After applying HCA, we can get the clusters of encounter vessels named C_1 to C_n (n is the total number of clusters obtained by HCA).

3.3 Preliminary assessment in clusters

Before assessing the collision risk in each cluster of vessels, the important and necessary is preliminary assessment the collision possibility in clusters by using individual vessel AIS records data combine with the assumptions and coefficients present by the



Making decision distance value (D) for clustering



Clusters after put D value in

Fig. 2. HCA theory.

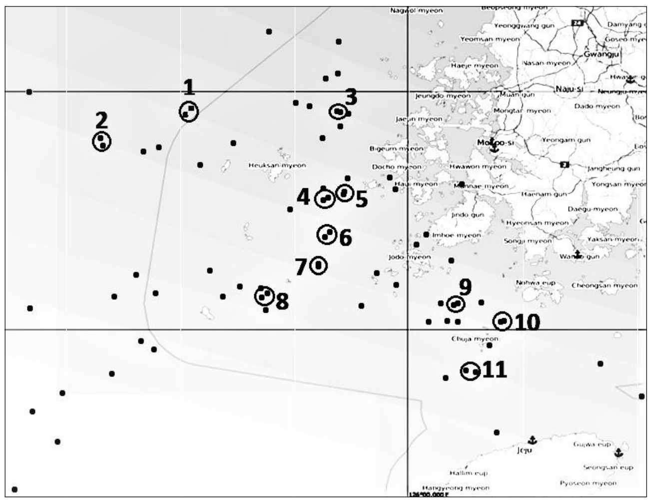


Fig. 3. Encounter vessels clusters at Mokpo port area.

applicant and formula below:

$$\overline{u_i} = \frac{\sqrt{(lat_{t2}-lat_{t1})^2+(long_{t2}-long_{t1})^2}}{t_2-t_1} \quad (1)$$

Where $\overline{u_i}$ is the average speed for vessel i, lat_{t1}, lat_{t2}, $long_{t1}$, $long_{t2}$ are the longitude and latitude coordinates of vessel i at time $t2$ and $t1$ before. $t2$ and $t1$ are the maximum and minimum time relates to collision risk and bases on the set of applicants.

It would be pointed out that all the motionless vessels (vessels with speed lower than 0.1 knots) do not affect the collision risk in shipping routes. After obtaining the time mean speed for all the ships of clusters, clusters with motionless vessels would be easy to dismiss.

Secondly, assessment bases on the correlation courses and position between vessels in each cluster. For a cluster, the own vessel has a correlation position and course that never cross the other over time (courses are not crossing in forward by correlation position), which means this cluster is safe. In detail, we can easily compare correlation position between two vessels at current time and t time *before* by using relative Euclidean distance formula, ignore the curvature of the earth:

$$d_0 = \sqrt{(lat_{a0} - lat_{b0})^2 + (long_{a0} - long_{b0})^2} \tag{2}$$

$$d_0 = \sqrt{(lat_{at} - lat_{bt})^2 + (long_{at} - long_{bt})^2} \tag{3}$$

Where d_0, d_t is the relative distance between two vessels a and b at present and t time before, lat_{a0}, $long_{a0}$, lat_{at}, $long_{at}$ is latitude and longitude of vessel a at current time and t time sequent and similarly with $b0$, bt.

Then, if $d_0 \leq d_t$, that means possible collision risk, do the detailed assessment in the following steps.

3.4 Calculation of DCPA, TCPA and CRI in each cluster

For two vessel A, B in each cluster with the correlative position (lat_a, $long_a$), (lat_b, $long_b$). The distance between vessels can be obtained:

$$Distance = \triangle long / \sin(Bearing) \tag{4}$$

With the related values can be calculated below:

$$\triangle long = |long_a - long_b| \tag{5}$$

$$\triangle lat = |lat_a - lat_b| \tag{6}$$

$$MP = 7915.7045 \log\left[\tan\left(\frac{\pi}{4} + \frac{lat}{2}\right)\left(\frac{1 - \epsilon\sin(lat)}{1 + \epsilon\sin(lat)}\right)^{\epsilon/2}\right] \tag{7}$$

$$DMP = |MP_a - MP_b| \tag{8}$$

$$Bearing = \arctan(DMP / \triangle long) \tag{9}$$

The relative speed (S_r) and relative course (C_r) are calculated as shown below:

$$S_r = \sqrt{Sog_a^2 + Sog_b^2 + 2Sog_a Sog_b \cos(Cog_b - Cog_a)} \tag{10}$$

$$C_r = \begin{cases} Cog_a - \arccos\left(\dfrac{S_r^2 + Sog_a^2 - Sog_b^2}{2S_r Sog_a}\right) & Cog_a < Cog_b \\ Cog_a + \arccos\left(\dfrac{S_r^2 + Sog_a^2 - Sog_b^2}{2S_r Sog_a}\right) & Cog_a \geq Cog_b \end{cases} \tag{11}$$

Then, the DCPA and TCPA can be calculated following (Li and Pang, 2013):

$$DCPA = Dist^* \sin(C_r - Cog_a - Bearing - \pi) \tag{12}$$

$$TCPA = Dist^* \cos(C_r - Cog_a - Bearing - \pi) / S_r \tag{13}$$

Where *Dist* is the distance between the target vessel to own vessel, the *Bearing* is the bearing of the target vessel measured from own vessel. The unit of DCPA is nautical miles (NM), and the unit of TCPA is minutes (mins).

The value of CRI is from 0 to 1 in the traditional automated vessel collision avoidance system. The DCPA and TCPA are the most important factors in assessing the risk of collision between vessels in a practical scenario. CRI based on the DCPA and TCPA respectively by a negative exponential function following the recommendations presented in Mou et al. (2010). The mathematical expression of the relation ship between CRI and DCPA, TCPA is expressed below:

$$CRI_d = a_d \exp(b_d DCPA) \tag{14}$$

$$CRI_t = a_t \exp(b_t TCPA) \tag{15}$$

Where a and b are the adjusted coefficients that can be estimated according to the opinions of maritime experts and officers on watch in the vessel traffic system.

The combined *CRI* based on CRI_d and CRI_t is calculated following by:

$$CRI = \alpha CRI_d + \beta CRI_t \tag{16}$$

The parameters α and β are the weight of CRI_d and CRI_t, the sum of α and β is 1, and their value can be set according to the specific characteristics of the maritime traffic application.

The above mathematical model is applied to every cluster of vessels, the CRI of each vessel threatened by the other vessels in the same cluster is obtained. Hence, the CRI matrix of each encounter vessel clustered can be ranked, the vessels with the high collision risk index in the clusters are filtered and highlighted to

Table 1. Assumptions and coefficients for CRI_d and CRI_t

DCPA(Nm)	CRI_d	a_d	b_d
1.5	0.01	1.374613	-3.282228
0.1	0.99		
TCPA(mins)	**CRI_t**	**a_t**	**b_t**
30	0.01	2.481774	-0.183805
5	0.99		

the operator on watch in the vessel traffic surveillance center. Thus, the operator can give instructions to these vessels and coordinate the risk situation between them, relieving intense risk situations between vessels within the large surveillance sea area.

4. Experimental results

In order to illustrate the effectiveness of the proposed framework, the author carried out an experiment in the port of Korea under the range of Mokpo's VTS (Fig. 3, 4).

4.1 Input parameters D for identifying encounter vessels

As mentioned in section 3.2, D is an important initial parameter input to HCA process, this parameter will decide the number of vessel clusters. This means these clusters have a high risk of collision, must be assessed and act proactively in the situation of collision. The D parameter is decided by operators based on the actual surveillance area, regular state, the maneuverability of the ships and changed many times for optimal reasons. In this study, the author defines the distance for the encounter vessel as 2.5 nm after some empirical specification of radius tests in which the ranges from 1 nm to 5 nm and the reason of necessary preparation

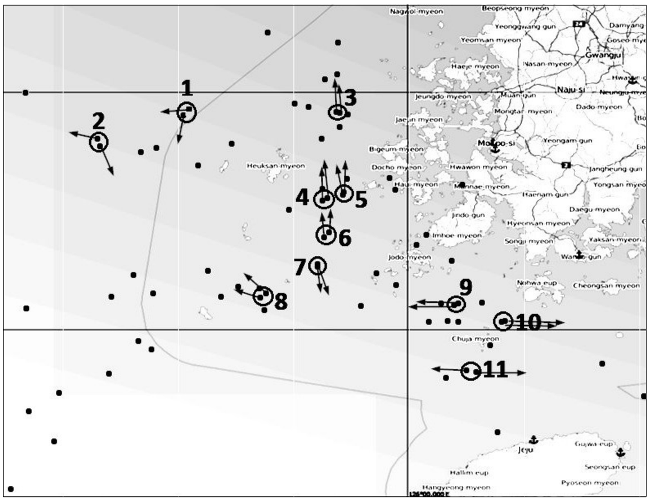


Fig. 4. Course of vessels in clusters.

Table 2. AIS real-time data and calculations of encounter clusters

No	Lat	Long	COG	SOG	Dist.	P.A	B	Cr	Sr
1	34.906	125.021	194	12.3	2.09	O	25	157	22.2
	34.936	125.038	262	14.5					
2	34.779	124.660	168	13.7	2.15	X	-	-	-
	34.811	124.646	285	11.4					
3	34.918	125.700	357	9.7	0.94	O	284	362	20.4
	34.921	125.685	347	10.8					
4	34.552	125.624	359	9.4	1.47	O	64	360	20.5
	34.561	125.646	357	11.1					
5	34.574	125.711	342	8.6	0.75	X	-	-	-
	34.586	125.716	0	12.3					
6	34.395	125.631	353	12.4	1.87	X	-	-	-
	34.418	125.652	0	7.1					
7	34.274	125.604	172	13.1	0.69	O	351	170	27.3
	34.285	125.602	175	14.2					
8	34.147	125.356	294	11.3	1.68	X	-	-	-
	34.164	125.378	301	15.9					
9	34.113	126.195	267	8.9	1.11	O	64	266	20.3
	34.120	126.212	268	11.4					
10	34.045	126.401	93	14	0.91	O	71	93	24.5
	34.049	126.415	93	10.5					
11	33.835	126.290	10.6	10.6	2.47	X	-	-	-
	33.841	126.249	10.6	10.6					

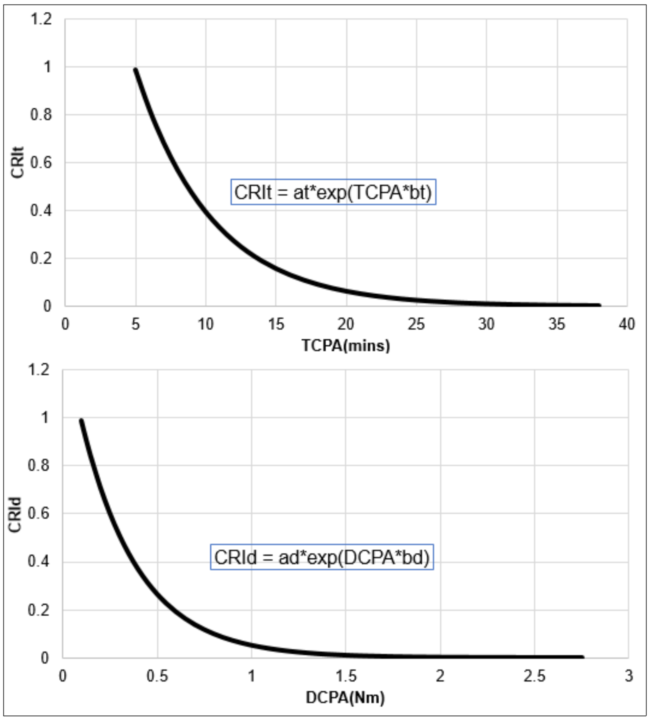


Fig. 5. Estimation of CRI_t and CRI_{-d}

for avoidance collision situations of vessels in survey area. There are 11 clusters of encounter vessels generated when D is specified as 2.5 nm as presented in Fig. 4. and Table 2. The existence of other vessels may influence the own vessel behavior or trajectory, so the encounter situation between vessels has been estimated considering this factor.

The CRI ranges from 0 to 1, the coefficient a and b in Eqs. (14) and (15) are used for quantifying the exponential relationship between CRI and DCPA, TCPA respectively. Based on the study of research works of R.Zhen et al. (2017) regarding automated vessel collision avoidance methods, the author assumed an exponential relationship between CRI and DCPA, TCPA respectively, and the correlated a and b are calculated from the assumptions shown in Table 1.

After calculating the coefficients for Eqs. (14) and (15), the relation can be plotted as shown below. As seen in Figs. 5 the CRI decreases non-linearly with increasing values of DCPA and TCPA, thus the mathematical estimation of CRId and CRIt fit our assumptions. In order to assess the CRI from the influence of spatial and temporal features of threatening vessels, the comprehensive CRI is computed by the sum of weighted CRId and CRIt. The spatial and temporal features have the same impact on the CRI. So α and β in Eq. (16) are 0.5. Finally, the combined CRI change with DCPA and TCPA is shown in Fig. 6.

4.2 Identification and assessment of clusters

1) Preliminary assessment

After receiving the real-time data and entering the parameter D = 2.5 nm into the HCA system, the results obtained at the time of study in Mokpo water surveillance area had 13 clusters of vessels close together with the indicators as Table 2 and Fig. 4. The preliminary assessment has shown that 5 clusters have the impossible to collision because of passed each other or course, velocities and distance responses the safety conditions through determination methods as mentioned in section 3.3.

2) Assessment of encounter vessels clusters

It is clear that, based on the standard of distance, the closer ships lead to a higher risk of collision. In addition, the higher correlation speed between two ships, the faster collision could happen. As data are shown in Table 2, after through the preliminary assessment, the closest distance between vessels in clusters is cluster no.7 with 0.69 nm, and the cluster with the highest correlation speed is also cluster no.7. Therefore, it can be

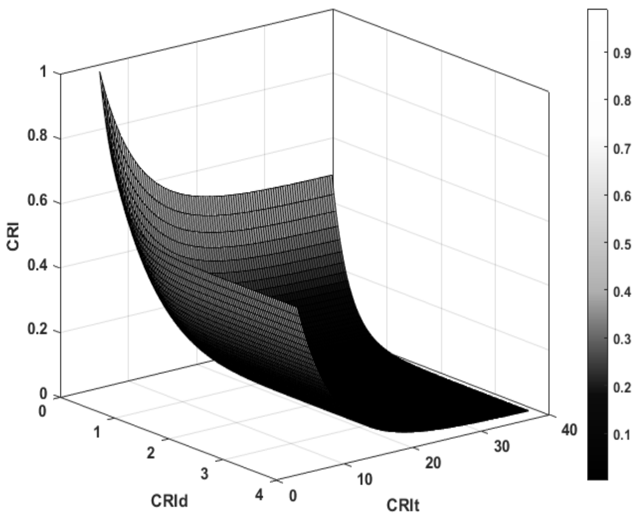


Fig. 6. CRI changes depend on DCPA and TCPA.

quickly concluded that cluster of vessels no.7 has highest risk of collision. To concrete the collision risk assessment of all clusters, the CRI quantification and ranking has required.

4.3 Quantification and ranking of CRI

For each cluster of encounter vessels, we calculate CRI index following Eq. (16). The collision risk index can be identified through the CRI threshold set from the related research literature and maritime experts' opinions collected. In some automated collision avoidance research literature (Bi, 2000; Zhao et al., 2016, R.Zhen et al., 2017), 0.5 is the criteria for the vessel taking evasive anti-collision actions. Based on the existed references and suggestions from operators in the maritime traffic service center, the author set the threshold as 0.5. The high CRI pairs of vessels whose CRI are more than 0.5 would be identified and ranked, the direction of the blue arrow is the heading of each vessel, the situation between high CRI vessels could be identified through the direction of the vessel. The results can be seen in Table 3.

There are six couples of vessels identified with a red triangle in the eleven clusters, according to their high CRI threshold. Then, the encounter situation of each couple of vessels can be obtained based on the difference of COG value and definition of encounter situation in the COLREGS in Naeem et al. (2012). The specific information about CRI values, rankings and type of encounter situation are described in Table 3.

It is clear to recognize that the no. 7 vessels cluster has a high risk of collision, exceeds the safety threshold, requires immediate and appropriate emergency avoidance action to ensure the safety of

Table 3. CRI and Ranking encounter vessels clusters

Cluster No.	1	3	4	7	9	10
CRI	0.74	0.82	0.77	>1.0	0.8	0.83
Ranking	6	3	5	1	4	2

the ship. The remaining clusters also have a very high collision risk index, which should be carefully monitored and notified controllers to have ready for responding or actively maneuvers to avoid collision. The results described above illustrate the feasibility and effectiveness of our proposed framework of real-time multi-vessel collision risk assessment for maritime traffic surveillance. As the AIS data is updated in real-time, the clustering process and collision risk index calculation should be processed in real-time as well. This framework can be easily implemented in practical maritime traffic surveillance applications.

5. Discussion and conclusion

The above experiment has shown that the results of the study are consistent with the reality, convenient for officers and operators to predict in advance of vessel clusters in collision situations.

As mention in the introduction section, in comparison with the DBSCAN method R. Zhen et al. (2017), this method is simple and easier to implement because the data exploited and compared directly from the AIS, especially easy for operators when evaluate the appropriate parameter D. The selection of the input parameter D is very important for classifying the closest pair of vessels at high collision risk. Moreover, the flexible change of D parameter leads to optimally in assessing the risk of collisions of vessels close together. It also contributes significantly to reducing the cost of safety assessment. Obviously, the collision occurs or not, apart from the distance factor as the HCA method mentioned, it also depends on many factors such as vessels speed, currents, and traffic density in the survey water area, weather conditions,… but it can be said that this is the simple and most optimal method to quickly classify a cluster of ships with a high risk of collision. On the other hand, a flexible change of D parameter contributes to the elimination of additional external factors that affect the purpose of the study to assess the collision risk in practical maritime traffic surveillance applications.

An objective challenge is the selection of the DCPA and TCPA limits, requiring operators to have experience in handling because these factors are intimately tied to the maneuvering possibility of the ships within the scope of investigation area combined with consideration of the impact external conditions. If these indicators too high, it can cause the ship controllers to stress in unnecessary situations or it is difficult to cause a collision. On the contrary, these indicators are too low, making the ship controllers subjective in being ready for avoidance maneuvers, leading to unpredictable consequences.

In addition, the discontinuous AIS data affect to the results of this method, requiring continuous evaluation measures as soon as data is received from the AIS and repeated frequently to bring the optimal results. It is hard to apply in heavy traffic areas such as channels, creeks, and wharves. In the next studies, we will endeavor to overcome these limitations, incorporate external elements into the CRI assessment to provide more accurate assessment results.

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