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MARITIME TRAFFIC CHARACTERISTICS IN WATERWAY WITH TIME VARIANT CPA

ABSTRACT

This paper aims at evaluating the collision risk between the encountering vessels under time-variant CPA situations and then assessing the maritime traffic characteristics. Radar and AIS data are collected from Mokpo VTS in Korea. All crossing vessels that are navigating within CPA 1 miles of Mokpo-Gu waterway are analyzed. The maritime traffic characteristics is analyzed by surveying the distribution of CPA as a function of TCPA. To make it clear, the traffic operating rate in the Mokpo waterway is also computed. The averages of CPA and TCPA were observed until the encountered vessels pass safety each other after they come in a certain ship domain. As a consequence, the distribution of CPA as a function of TCPA gives a useful information to evaluate the maritime traffic safety.

Keywords:

maritime traffic management, operation rate, risk assessment, collision, CPA, TCPA.

INTRODUCTION

The risk assessment at sea is one of important issues for maritime traffic management. Many researchers have evaluated the collision risk between vessels on the basis of the CPA (closest point of approach) and TCPA (Time to CPA). The risk assessment based on the CPA and TCPA quantifies the risk by considering the time margin to the target ship in a spacial domain [3, 5]. Szlapczynski derived a unified methodology of collision risk from ship domain concept [4]. In fact, the assessment of the collision risk based on CPA and TCPA has focused on the collision avoidance of an individual ship under the encountered situations. On the other hand, from the viewpoint of maritime traffic, the IALA risk management tool, IWRAP (IALA

Waterway Risk Assessment Programme), evaluates quantitatively both collision and grounding risk in waterways [1, 2]. The IWRAP calculates the causation factor by Bayesian Belief Network and then the risk of collision and grounding, considering both human factors and external navigational environments on the basis of geometric collision model. However, it is difficult to calculate the causation factor exactly without the quantitative evaluation of human error and external environments.

According to the maritime accident statistics in Korea, it is reported that 63% of the total accidents occurs within 5 minutes after a mariner firstly recognizes a target vessel. 70% of all collision accidents occurs within 1 minute after an initial evasive action between the encountered vessels in coastal areas. 70% of all collision accidents occurs within 5 miles after a mariner firstly recognizes a target ship. Taking into the accidents statistics account, it follows that the variation of CPA and TCPA should be reflected as an important factor to evaluate the collision risk.

This paper aims at assessing the maritime traffic safety by analyzing the CPA distribution as a function of TCPA. Radar and AIS data are collected from Mokpo VTS in Korea. All crossing vessels that are navigating within CPA 1 miles of Mokpo-Gu waterway are analyzed. The maritime traffic characteristics is presented by surveying the traffic operating rate in the Mokpo waterway. As a result, this paper gives some comments regarding the collision risk in terms of CPA/TCPA variation, distribution. The operating rate of a waterway is evaluated to find the relationship with respect to CPA/TCPA variations. The result gives a useful seeds for the maritime traffic risk assessment in waterways.

COLLISION RISK MODELS

Navigators assess the collision risk between ships on the basis of the changed data of the bearing, range, and the aspect angle of the relative motion line of the target ship. Naturally, the action for collision avoidance should be taken before the target ship moves inside the risky domain from the own ship. Traditionally, the CPA and TCPA has been used to evaluate whether the own ship is in the risky domain or not. In fact, the CPA exist at any point on the circle with the radius equivalent to the closest distance between the two ships. Several collision risk models based on CPA and TCPA have been proposed. Even though a circular-shaped ship domain using the CPA is

popular, a safe ship domain varies with ship maneuvering characteristics and navigation situations. Many researchers have studied a ship domain, e.g, Fujii model, Goodwin model, and Coldwell [3] etc. However, it is very difficult to determine the risky ship domain which is defined as the surrounding effective waters that the navigator of a ship wants to keep clear of other ships or objects. On the other hand, the risk model considering maritime traffic flow in waterway dates back to the approach defined by Fujii et al., and by MacDuff. Recently, the IWRAP (IALA Waterway Risk Assessment Program) has been developed by the Technical University of Denmark and introduced by IALA [1]. The IWRAP evaluates the probability of collision and grounding in a given waterway. The collision or grounding frequency, λ is given as Eq. (1)

$$\lambda = P_C \cdot N_G, \quad (1)$$

where:

P_C — a causation factor;

N_G — the geometric number of collision or grounding candidates.

For crossing situations, the geometric number of crossing collision candidates is calculated by Eq. (2)

$$N_G = \sum_{i,j} \frac{Q_i^{(1)} Q_j^{(2)}}{V_i^{(1)} V_j^{(2)}} D_{ij} V_{ij} \frac{1}{\sin \theta}, \quad (2)$$

$$\text{for } 10^\circ < |\theta| < 170^\circ$$

where:

V_{ij} — the relative speed between vessels;

D_{ij} — the apparent collision diameter;

$Q_i^{(1)}, Q_j^{(2)}$ — the number of passages per time unit for i^{th} ship on No. 1 fairway and j^{th} ship on No. 2 fairway, respectively;

θ — the crossing angle between vessels.

From Eq. (2) it is clear that $Q_i^{(1)}$ and $Q_j^{(2)}$ have explicitly much effects on the geometric number of crossing collisions candidates. Herein, it is meaningful to

investigate the effects of traffic capacity in terms of maritime traffic management and then to find out the CPA variation as a function of TCPA, and then the ships' spatial distribution in an interest of area, given the traffic capacity. The average of CPA/TCPA variations within a certain boundary needs to reflect in evaluating the collision risk in waterway.

CHANNEL OR NAVIGATIONAL THROUGHPUT CAPACITY

The traffic capacity of a fairway has been used to design the waterway at its early stage. Assuming that ships are passing the channel with the width W , the basic traffic capacity Q_b is defined as Eq. (2)

$$Q_b = \frac{1}{ab} WV, \quad (3)$$

where:

- a and b — a major axis of ship bumper area and a minor axis, respectively;
- V — an average speed of the vessels passing the fairway;
- Q_b — the theoretical number of vessels which can pass the fairway per hour.

In this equation ab is the ship bumper area where a vessel actually occupies in the waterway and includes a zone around the vessel in which other vessels' bumper areas should not overlap. Fujii observations give the following empirical rules.

For harbor speed,

a in ship course direction : $6.0L$

b in ship's side direction : $1.6L$

For Sea Speed,

a in ship course direction : $8.0L$

b in ship side direction : $3.2L$

where L — ship's length.

In real marine environments, a practical traffic capacity is reduced by effects due to weather and sea state, physical obstructions, vessel traffic management system, and ship movements on the fairway etc. In general, if VTS is not provided, the practical traffic capacity Q_p is assigned to 20 to 25% of the basic traffic capacity. Because of many kind of vessels with various sizes navigate on fairway, the practical traffic capacity is calculated with respect to a reference vessel of 1,000 G/T, approximately 70 m length. Let's consider a channel throughput capacity to provide an indication of the maximum volume of vessel traffic that can use a channel during a given period of time. Herein, the channel throughput capacity is defined as an operating rate of a fairway, T_C , as in Eq. (4)

$$T_C = \frac{Q_T}{Q_p} \times 100 [\%], \tag{4}$$

where:

Q_T — the L^2 traffic capacity normalized by the reference vessel.

The Operating rate of Mokpo Waterway in hour for one day is presented in Fig. 1.

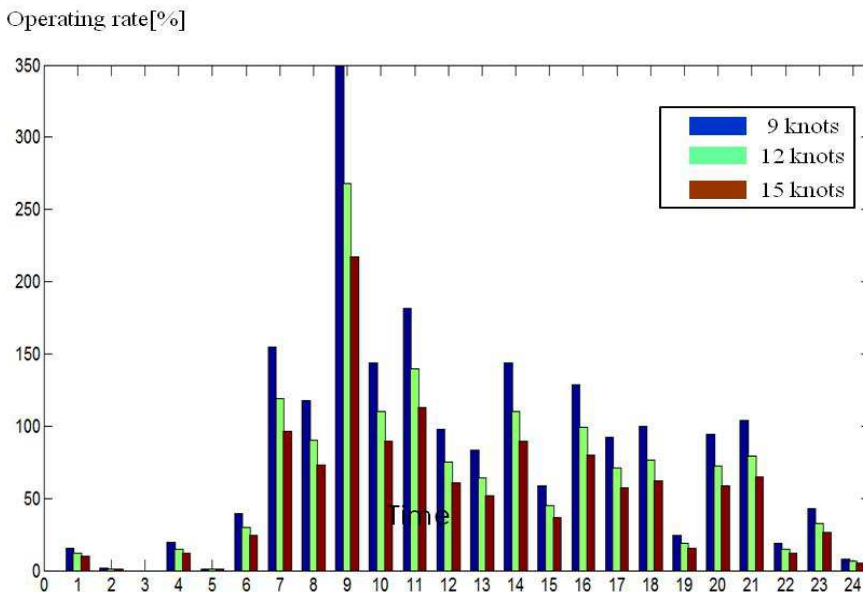


Fig. 1. The Operating Rate of Mokpo Waterway, Korea, for one day — 25 Aug. 2011 [own study]

**COMMENTS ON RISK MODEL BASED
ON TRAFFIC ENVIRONMENTS**

In coastal area, various kind of vessels generate crossing, head-on situations, and overtaking. Among them, some fishing vessels including small vessels may disturb the safe passage of vessels on the route. To investigate the maritime traffic characteristics, the average CPA/TCPA distribution in a certain area and the CPA/TCPA varying with time represent a useful information for risky ship domain and risk indicator. Herein, we introduce the CPA normalized by the major diameter in ship's course direction, $6L$ so as to compare CPA with the bumper area.

Fig. 2 shows the traffic pattern and the spatial distribution of ships passing waterway in Port Area of Mokpo, Korea. Fig. 3 represents the variations of CPA normalized by $6L$ and TCPA between Crossing Vessels with vessels in Table 1. For Case 1 and 3, the CPAs normalized by $6L$ keep less 0.5 until TCPA becomes zero, while the normalized CPAs for Case 3 and 4 rapidly reduce.

Figs. 4, 5 show the average CPA and TCPA observed from the ship position with CPA 1 mile and TCPA 3 minutes for one day.

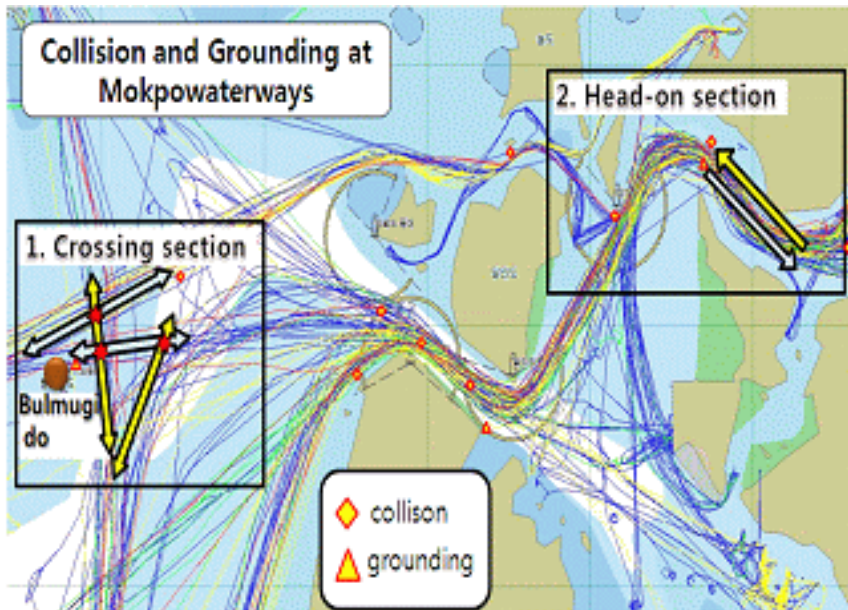


Fig. 2. Traffic Pattern of Mokpo Waterway [own study]

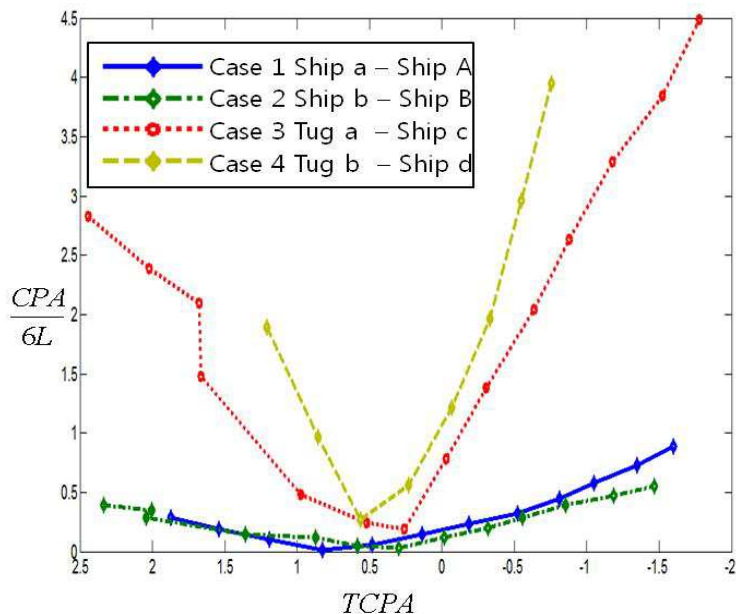


Fig. 3. Variations CPA normalized by 6L and TCPA between Crossing Vessels [own study]

Table 1. Types, size, speed of crossing vessels in Port of Mokpo Waterways at LT. 08:00–09:00, 25 Aug. 2011 [own study]

Ship Type	G/T	Length [m]	Breadth [m]	Ave. Speed [knots]
Cargo Ship A	50,869	235	37.4	14.6
Cargo Ship B	89,411	283	45.0	15.4
Cargo Ship a	500	40	15.0	10.6
Cargo Ship b	500	40	15.0	13.2
Cargo Ship c	300	40	12	14.5
Cargo Ship d	300	20	12	11.6
Tug a	200	20	10	6.5
Tug b	216	32	10	6.6

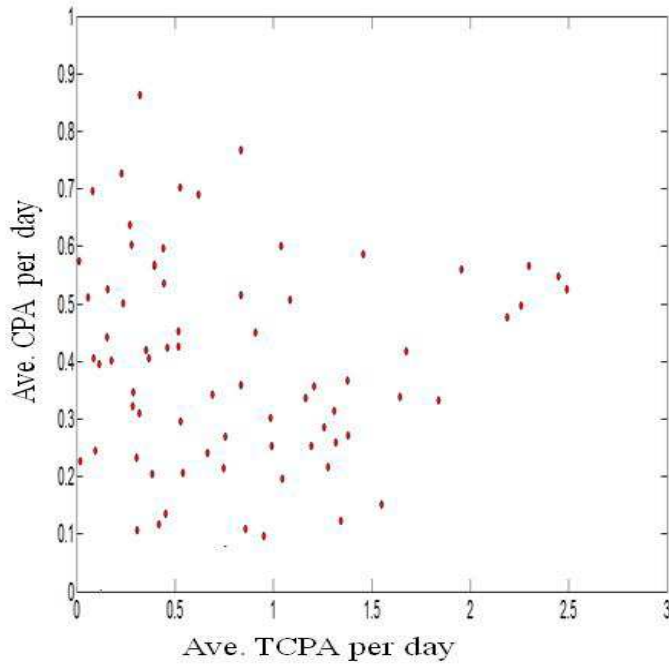


Fig. 4. Average CPA/TCPA distribution at 13 May 2011 in Mokpo Waterway – Operating Rate 25% [own study]

Fig. 4. is the case that the operating rate of the Mokpo Waterway is 25%, while Fig. 5 is the case of the operating rate 65%. The results of observation can be summarized as follows:

1. CPA/6L is one of important factor to assess the collision risk.
2. The range between the encountering vessels which is scaled by CPA/6L, may be used to assign the boundary of a safe ship domain.
3. If once the encountering vessels come within the designated ship domain boundary, the variation of CPA as a function of TCPA should be monitored.
4. The average CPA/TCPA distribution is a major factor to assess the risk of maritime traffic.
5. The traffic capacity of the water may have an effects on the CPA/TCPA distribution.

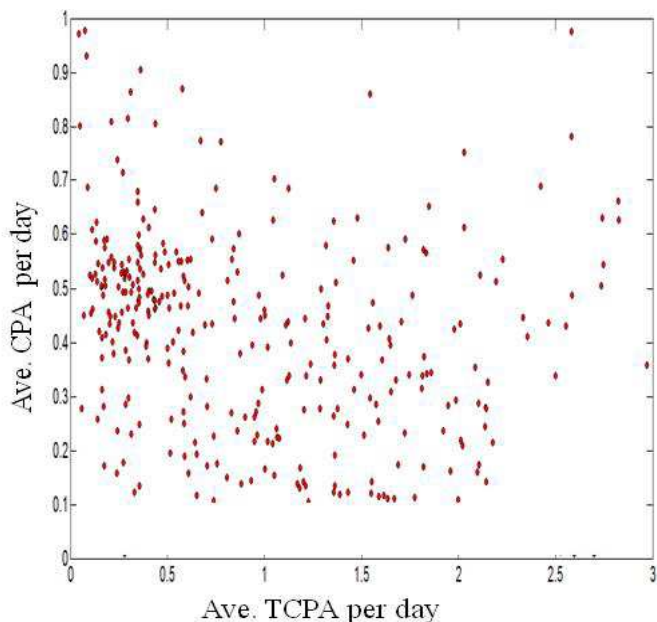


Fig. 5. Average CPA/ TCPA distribution on 13 May 2011 in Mokpo Waterway – Operating Rate 67% [own study]

CONCLUSIONS

This research purports to evaluate the maritime traffic characteristics and safety from the CPA/TCPA observation in waterway. All crossing vessels that are navigating within CPA 1 miles of Mokpo-Gu waterway are analyzed. The maritime traffic characteristics is represented by surveying the distribution of CPA as a function of TCPA. The average of CPA and TCPA was observed until the encountered ships pass safely each other after they come in a certain ship domain. As a consequence, the distribution of CPA as a function of TCPA gives a useful information for the special margin of waterway, maritime traffic pattern, and safety.

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STRESZCZENIE

Celem artykułu jest ocena ryzyka kolizji statków w funkcji zmiany wartości czasu do kolizji, a na tej podstawie oszacowanie charakterystyk determinujących ruch morski. Dane z radarów oraz systemu AIS zostały zarejestrowane w systemie VTS Mokpo w Korei. Przeanalizowano wszystkie przypadki przecinania się tras statków na podejściu do Mokpo-Gu w przypadku, gdy odległość minimalna (CPA) była mniejsza niż jedna mila morska. Charakterystyka ruchu morskiego opisana została poprzez wyznaczenie rozkładu wartości największego zbliżenia statków jako funkcji czasu do nadmiernego zbliżenia (TCPA). Dla pełnej jasności obliczono również współczynnik przepustowości drogi wodnej Mokpo. Opisano średnie wartości odległości największego zbliżenia oraz czasu do wystąpienia CPA bez względu na przekroczenia granic domeny obserwowanych statków. W konsekwencji wyznaczono rozkład wartości CPA jako funkcję TCPA, co okazuje się użyteczne dla oceny bezpieczeństwa ruchu morskiego.