

A NOVEL MARITIME RISK ASSESSMENT MODEL OF WATERWAY TRANSPORTATION BASED ON TAKAGI-SUGENO FUZZY LOGIC: VIET NAM CASE STUDY

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Abstract. In this paper, we analyzed the safety assessment getting from the opinions of captains, pilots and navigators in Ganh Rai Bay. The results showed that the highest risk was caused by unsafe fishing ships and the most unsafe situation was generated by the crossing ships, wind and currents. The influence of human psychology factors was one of the most important factors, which caused the risk of collision. Based on fuzzy logic theory, we proposed risk assessment model which was tested in simulation and compared with the evaluation results of the Experts in Vietnam. The results showed the effectiveness of the novel maritime risk assessment model.

1. Introduction

Vietnam waterway is a complicated system affected by many factors such as ship performance, crew's quality, natural environment, management factors, etc. Waterway transportation accidents often lead to huge economic losses, casualties and environmental pollution. Therefore, it is important to evaluate the waterway transportation safety. In recent years, fault tree analysis method, fuzzy mathematics, optimization theory, artificial neural network and comprehensive safety assessment theory have been widely used in the analysis of these accidents [1-4]. There are several kinds of Representative risk assessment models in the field of maritime traffic, namely Waterway Risk Assessment Program of International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) (IWRAP) and Ports and Waterway Safety Assessment (PAWSA) of the United States Coast Guard (USCG). The IWRAP is a quantitative model and PAWSA is a qualitative model [5-6]. In 2010, two tools were recommended to International Maritime Organization (IMO) by IALA for ports and restricted waterways to use by national members. However, these models are not suitable to be applied in Vietnam. In this paper, we aim to give an overview of a quantifiable display of the scale of traffic danger between the designated ship and other ships in Vietnam waterway to develop the marine traffic assessment. Based on the statistical and analytical result, we have developed a fuzzy logic program based on the proposed model to evaluate the vulnerability of marine traffic in VungTau–Thi Vai channel.

The rest of the paper is organized as follows. Section 2 describes an overview of marine traffic on Vungtau zone. Section 3 presents the idea to build the model to assess the risk of collision of vessels while sailing in VungTau –Thi Vai channel based on Fuzzy logic in Matlab software, together with some conclusions in Section 4.

2. An overview of maritime waterway risk assessment model in Vung Tau Sea Port – Viet Nam

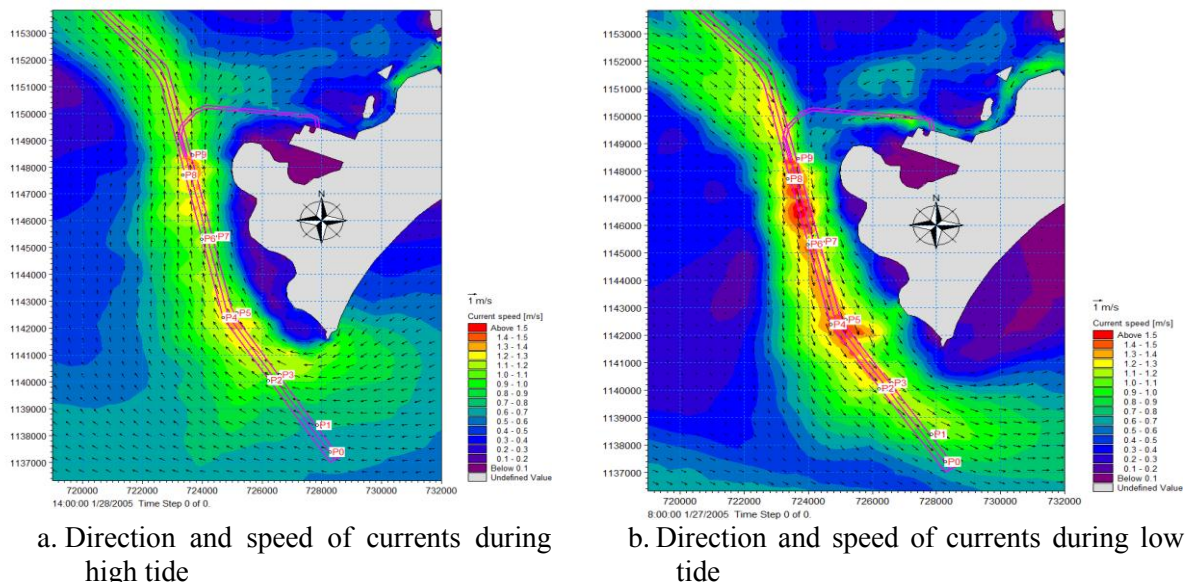
First of all, we analysed the causes of total 37 marine accidents happening in Vung Tau Sea Port, from 2007 to 2017—based on the maritime accident investigation report of Vung Tau Maritime Administration [7].

- 07 accidents happened due to force majeure (main engine or auxiliary engine failure),
- 11 accidents occurred because of the collision caused by the effects of currents and wind (about 30%).
- 7 accidents came about when ships change its directions (equal to 20%);
- 06 accidents were caused by parallel head-on situations or ship crossing;
- 03 accidents were caused by psychological factors of manoeuvre pilots (16%) including the distraction owing to the appearance of too many targets, hesitance due to language barrier.
- 03 accidents by over the speed limit or ship crossing affecting both ships.

From the statistics, it is necessary to analyse the influence of the above factors when developing a maritime risk assessment model in Vung Tau Sea port Viet Nam.

2.1. Current and Wind factors

Current factor: Based on the details of currents flowing at Vung Tau Seaport provided by Portcoast (given by Hydrodynamic Simulation Software - Mike 21, Denmark) [8]. The flow currents at seaport of Vung Tau Viet Nam are described in figure 1.



a. Direction and speed of currents during high tide

b. Direction and speed of currents during low tide

Figure 1: The synthesis of direction and speed of currents (simulation by using Hydrodynamic Simulation Software - Mike 21, Denmark)

According to the observation, it is (figure 1, a, b) showed that the currents in Vung Tau seaport are mostly tidal currents and directly affected by kinetic of ocean. Due to the differences in geographical features of the seabed in Vung Tau water area, vessels' navigation is in danger. Especially, the areas from buoy No1 to buoy No3, and buoy No7 to buoy No9 are affected by strong currents. In fact, among 11 accidents impacted by the current factor, there were 08 accidents occurring in Ganh Rai Gulf of Vung Tau (about 73%).

Wind factor: Based on the meteorological data observed by Vung Tau Hydro Meteorological station, Southern Regional Hydro Meteorological Center conducted a survey every hour over a seven-year period (2010-2017) and the wind frequency is indicated in Figure 2. Specifically, there are two wind directions (East and South West) influencing Vung Tau Seaport. It will be hazardous if ships sail on the channel when the wind intensity is at 4-7 m/s and currents flow in the same direction. In fact, among 11 collisions caused by the wind factor, there were 09 accidents at Ganh Rai Bay, Vung Tau (occupied 82%) influenced by both wind and current factors.

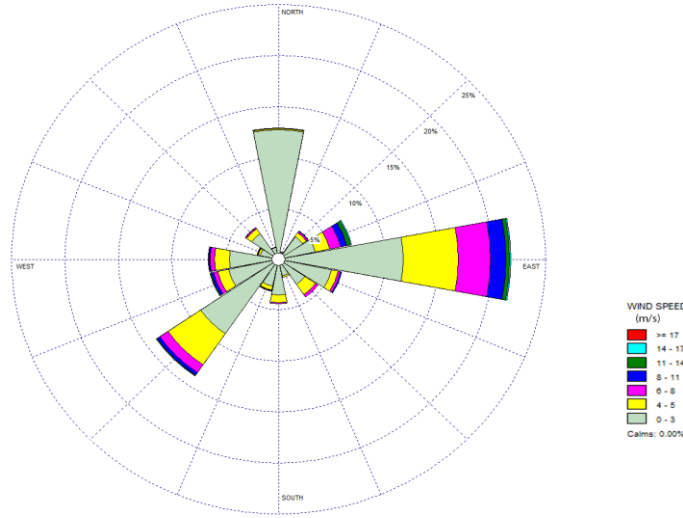


Figure 2. Wind speed observed from 2010 to 2017

2.2. Ship crossing and parallel head-on factors

According to the accident statistics within the last 10 years, 07 collision accidents (equal to 20%) happened on the channel when two ships were approaching head on. In fact, captains always felt worried even when two ships were in safe distance. There were 80% accidents coming from the captains' psychology. Also, some other reasons like the lack of understanding of maritime law, incomppliance of maritime safety regulation and management procedure (lack of understanding of Colreg 72; over speed, lack of knowledge or unable to update on the hydrometeorology, sea state, incomppliance of safety operations, etc.) made the sailors stressed out, which led to the shortage of confidence in ship maneuvering.

2.3. Human's psychology factors

According to the random survey of 21 experienced people (07 managers; 10 pilots and 04 captains) in Vung Tau conducted in September 2017, the influence of human's psychology factors was one of the most important factors [9] leading to the risk of collision. Most experienced captains temporarily agreed that this factor is an important factor. However, it is really difficult to determine to what extent does this factor have an effect on marine accidents. Therefore, related to human's psychology, we need to systematically consider it as an uncertain one, which is also one significant finding of the review and analysis in the application area. Only three applications are found where uncertainty is quantified and qualitative assessments of uncertainties and/or biases are equally rare.

2.4. Risk assessment function

Based on the survey results, average values on the opinions of those surveyed; level of concentration / deviation of comments, the risk assessment function is as follows [9]:

$$K_{ra} = \sum_{i=1}^n \sum_{j=1}^m K_i f_j + P_{psy} \quad (1)$$

Where:

Coefficient K_{ra} is the overall of the risk assessment (safety level) of the vessels while navigating in Vung Tau sea zone. We have high risk of collision when the value of K_{ra} is small.

K_i are the corresponding coefficients of the above factors and $K f_j$ are the impact factors of safety level corresponding to the status of currents, wind, crossing situations and head on situation factors.

3. A novel maritime risk assessment model using Fuzzy logic

3.1. Current, wave and wind force

Mathematical of the currents: According to the actual survey and observation data [8] on the regime, direction and velocity of current at Vung Tau Sea Port, which is implemented by Portcoast - Port Engineering Consultant Joint Stock Company: October - November 2004 (rainy season); January 2005 (dry season); March 2009 (dry season) and June 2012 (rainy season), a two-dimensional current model can be computed [10] from (2) as below:

$$\begin{aligned} u_c &= V_c \cos(\beta_c - \psi_L - \psi_H) \\ v_c &= V_c \sin(\beta_c - \psi_L - \psi_H) \\ \tau_{\text{current}} &= [u_c, v_c, 0]^T \end{aligned} \quad (2)$$

Mathematical wave model introduced by Dang et al. [11] and modelled the wave surface construction and determined the wave height as equation (3):

$$\begin{aligned} \tau_{\text{wave}} = \zeta(x, y, t) &= \sum_{q=1}^N \sum_{r=1}^M \sqrt{2S(\omega_q, \psi_r) \Delta\omega \Delta\psi} \\ & * \sin(\omega_q t + \phi_{qr} - k_q (x \cos \psi_r + y \sin \psi_r)) \end{aligned} \quad (3)$$

The force of the wind (Dang et al., 2018) [11] in surge, sway, and yaw movement is illustrated according to wind forces regulations in Vietnam and is written as:

$$\begin{aligned} \tau_{\text{wind}} &= [X_{\text{wind}}, Y_{\text{wind}}, N_{\text{wind}}]^T \\ X_{\text{wind}} &= 0.5 C_X g_R \rho \omega V_R^2 A_T \\ Y_{\text{wind}} &= 0.5 C_Y g_R \rho \omega V_R^2 A_T \\ N_{\text{wind}} &= 0.5 C_N g_R \rho \omega V_R^2 A_L L \end{aligned} \quad (4)$$

3.2. Hydrodynamic interaction force

The linearized pressure difference $\Delta p(x_i, t)$ along the x -direction can be expressed by Bernoulli's theorem as the following equation [12]:

$$\Delta p(x_i, t) = -\rho \left\{ \frac{\partial}{\partial t} \int_{x_i}^{0.5L_i} \gamma_i(\xi_i, t) + U_i \gamma_i(x_i, t) \right\} \quad (5)$$

The lateral force $F_i(t)$ acting on the body can be obtained by the following equation.

$$F_i(t) = - \int_{-0.5L_i}^{0.5L_i} \Delta p(x_i, t) dx_i \quad (6)$$

$F_i(t)$ is the force per unit water depth in the two dimensional xy - plane.

The theory for the two dimensional perturbation method introduced in [12] and the force which is non-dimensionalization are presented as follows:

$$F = 0.5 \rho B_0 T_0 V_p^2 C_\gamma \quad (7)$$

Where F is the lateral force, corresponding to $F_i(t)$, ρ is the water density, B_0 is the beam of the own ship, T_0 is the mean draught of the own ship, V_p is the velocity of the ‘parallel’ ship.

3.3. Fuzzy human psychology factor

Our fuzzy rules are using the same rules as in [13] in order to design a Takagi - Sugeno fuzzy logic with a compact rule base. The rule notation form within B_k^i is a binary variable that determines the consequence of the rule and is given as follows:

$$R_i : \text{If } \hat{e}_1 \text{ is } A_{k1}^i \dots \text{and } \hat{e}_n \text{ is } A_{kn}^i \text{ then } u_{fk} \text{ is } B_k^i,$$

Where $A_{k1}^i, A_{k2}^i, \dots, A_{kn}^i$ and B_k^i are fuzzy sets. The influence of human psychology factors based on Takagi-Sugeno fuzzy logic is set up in equation (2) and the fuzzy output can be expressed as bellows

$$K_{psy} = \frac{\sum_{i=1}^h \theta_k^{-i} [\prod_{j=1}^n \mu_{A_{kj}^i}(\hat{e}_j)]}{\sum_{i=1}^h [\prod_{j=1}^n \mu_{A_{kj}^i}(\hat{e}_j)]} = \theta_k^T \varphi_k(\hat{e}) \quad (8)$$

$\mu_{A_{kj}^i}(\hat{e}_j)$ is the fuzzy membership function (input database shall be based on the survey table of Maritime Accident Investigation Conclusions of Vung Tau Maritime Administration from 2007 to 2017 [8]), h is the total number of If-Then rules, θ_k^{-i} is the point at which $\mu_{B_k^i}(\theta_k^{-i}) = 1$ and $\varphi_k(\hat{e}) = [\varphi_k^1, \varphi_k^2, \dots, \varphi_k^h]^T \in R^h$ is the fuzzy basis vector with φ_k^i defined as:

$$\varphi_k^i(\hat{e}) = \frac{\prod_{j=1}^n \mu_{A_{kj}^i}(\hat{e}_j)}{\sum_{i=1}^h [\prod_{j=1}^n \mu_{A_{kj}^i}(\hat{e}_j)]} \quad (9)$$

3.4. Maritime risk assessment model on Matlab Simulink

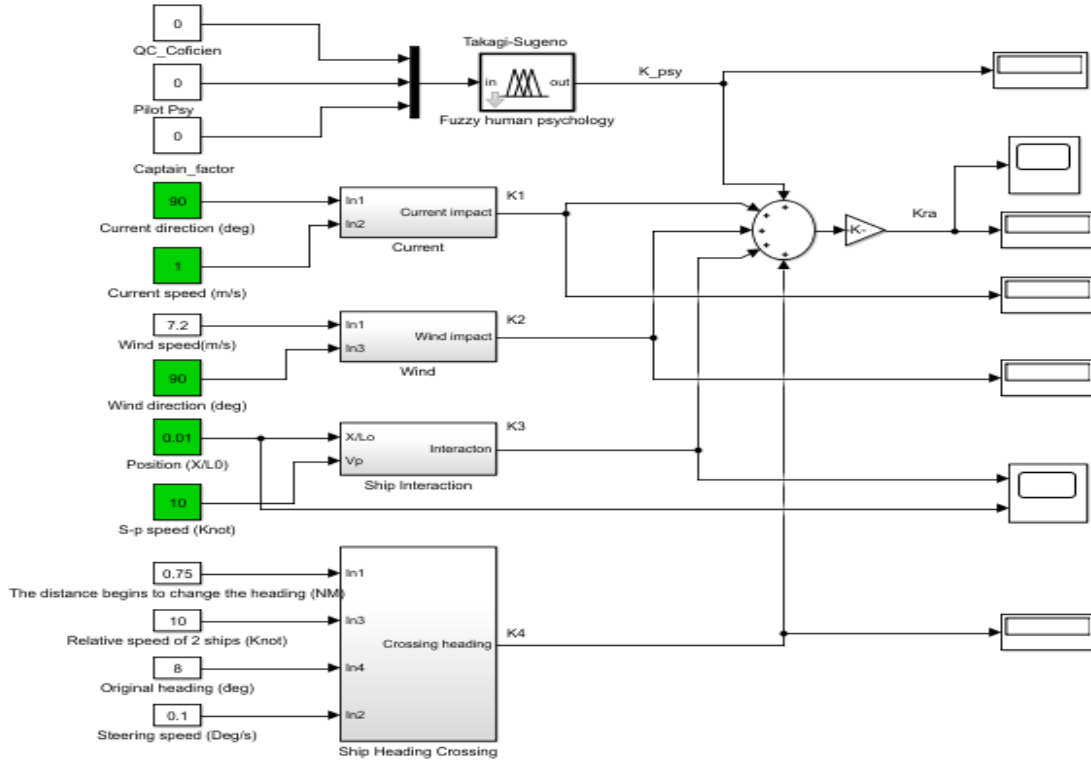


Figure 3. General block diagram of maritime risk assessment model on Matlab Simulink

From the equation (1), (2), (3) (4), (7), we build the Maritime Risk Assessment Model based on Takagi-Sugeno Fuzzy designed in Matlab and to be presented in figure 3, and 3 inputs of fuzzy set are defined in figure 4 including Abilities / Capabilities of Captain; Failure to comply with the Rules for the Prevention of Collisions at Sea (Colreg 72), and The fault of the Pilot.

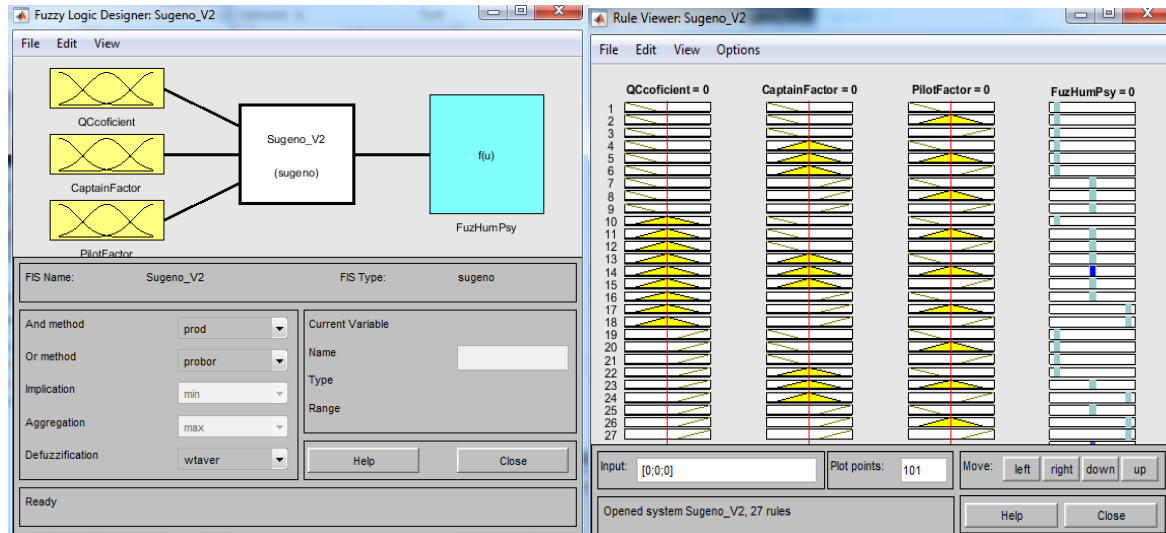


Figure 4. Sugeno fuzzy sets with 3 inputs that characterize the human psychology of a total of 27 rules

3.5. Simulation results

We test the software from 10 different cases with dissimilar equations and coefficients to take into account the inflow element, the thresholds of danger are taken by experts. Specifically, the results of measurement, observation and use of Danish Mike 21 Software calculate the maximum flow velocity during ebb tide as 1.4 m/s and ebb tide as 1.52 m/s. The effect of the ship in the situation where the trains are running in the direct direction, judging by the train's LOA, about the beam distance between the two ships at the time of passage on the canal and the relative speed between the two ships (divided by 5 levels from -2 to +2).

Table 1. Summary of simulation results and forecast of risk of ship collision by Matlab - Simulink

| Case | Own ship | | | Parallel ship | | | Distance (NM) | horizontal distance (NM) | Original heading | Degree of heading change(°/s) | Current (Knot) | Wind Level | K3 | K4 | Kpsy | Kra | Result test |
|--------|----------|----|------|---------------|------|------|---------------|--------------------------|------------------|-------------------------------|----------------|------------|----|----|------|-------|-------------|
| | Lp | Bp | Vp | Lo | Bo | Vo | | | | | | | | | | | |
| Case 1 | 199.9 | 32 | 10.9 | 190 | 32.3 | 6.8 | | 0.16 | | | 3.5 | 4 - 0 | 0 | 0 | 0 | 1.2 | Safe |
| Case 2 | 199.9 | 32 | 10 | 172.2 | 28 | 11.5 | 1 | | 8 | 0.08 | 0 | 4 - 45 | 0 | 0 | 0 | 0.6 | Safe |
| Case 3 | 199.9 | 32 | 10 | 125 | 22 | 8 | 0.5 | | 5 | | 0 | 4 - 60 | 0 | 0 | 0 | 0.3 | Safe |
| Case 4 | 335 | 42 | 12.7 | 99 | 18 | 6.9 | 0.5 | | 12 | | 2.7 | 4 - 0 | 0 | 0 | 0 | 0.7 | Safe |
| Case 5 | 208 | 30 | 7.2 | 207.4 | 29 | 6.4 | | 0.3 | | | 2.5 | 4 - 10 | 0 | 0 | 0 | 1,067 | Safe |
| Case 6 | 172.1 | 27 | 8.7 | 207.4 | 29 | 11.4 | | 0.3 | | | 2.7 | 4 - 30 | 0 | 0 | 0 | 1 | Safe |
| Case | 335 | 42 | 12.7 | 207.4 | 29 | 10.5 | 1.5 | | 10 | 0.13 | 2.7 | 4 - 0 | 0 | 0 | 0 | 0.76 | Safe |

| 7 | 4 | | | | | | 10 | 67 | | | | | | |
|---------|-------|----|------|-------|------|------|-------|------|-------|---|----|-----|-----------|----------|
| Case 8 | 172.1 | 27 | 10.7 | 177 | 28 | 11.6 | 0.4 | 2.7 | 4 - 0 | 0 | 0 | 1.2 | Safe | |
| Case 9 | 172.7 | 27 | 10.9 | 225 | 32.3 | 12.1 | 0.34 | 2.5 | 4 - 0 | 0 | 0 | 1.2 | Safe | |
| Case 10 | 180 | 30 | 10 | 151.1 | 25.6 | 7.5 | <0.05 | 1.75 | 4 | 2 | -2 | -2 | 0.53 3 | Accident |

The simulation results are showed in Table 1,

- $Kra > 1$ (case 1, case 5, case 6, case 8, case 9): two ships are in safety condition.
- $0 < Kra < 1$ (case 2, case 3, case 4, case 7): Two ships are at risk of collision (but within safe range)
- $Kra < 0$ (case 10): Two ships can meet with an accident because the captain's psychology is in the worst state.

4. Conclusion

From the results of the safety assessment survey getting from the opinions of captains, pilots and navigators in Ganh Rai Bay, we have already found out the suitable safety assessment impact factors considering all internal and external elements of vessels based on our questionnaires and simulation experiments in Matlab software. The collection of the impact factors on the “safety level” consists of current, wind, crossing situations, head-on situations and human psychology factor. We have built a Maritime Risk Assessment Model based on Takagi-Sugeno Fuzzy to evaluate the vulnerability of traffic in Vung Tau – Thi Vai Channel, Vietnam. The proposed model is tested in simulation and compared with the evaluation results of the Experts and accident statistics from Vung Tau Port Authority, the findings are basically similar and they prove the correctness of the proposed model.

5. References

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