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NAVIGATIONAL SAFETY OF INLAND WATERWAY TRANSPORT SYSTEM (IWTS) IN SARAWAK: RAJANG RIVER

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Abstract: Inland water transportation is regarded as one of the most effective ways for humanity to reduce its carbon footprint. The Sarawak Inland Water Transport System (IWTS) has become an essential tool for its residents due to its geographical location. They have access to basic facilities along the rivers' tributaries through their water transportation. Currently, undeveloped IWTS in the Rajang River has become a navigation safety issue depending on the type of vessel, with insufficient navigational aid installed in certain areas. The nature of the inadequacy of navigation safety can be daunting as it can lead to loss of life, damage to the environment, disruption of operations, injuries, and a long-term environmental impact, often causing severe consequences. This study assessed navigational safety on the Rajang River and recommended appropriate improvements based on the most recent specification requirements of the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) (IALA, 2009). The 3D area simulation of navigation marks will be developed using Sketch-Up Software based on satellite image data. The data was then analysed using Risk Assessment (Fuzzy-AHP technique) to propose the most appropriate aids for navigation and their placement. The proposal and design of aids in navigation for Tanjung Rajang River will increase safety and security for the shipping industry, increase turnaround time, and help maintain a zero-accident rate.

Keywords: IWTS, navigational safety, FAHP., 3D-simulation, aid to navigation.

Introduction

Background of the study area

Rajang River is located at latitude 2.385883 and longitude 112.618897 in Sarawak. The river flows through Borneo's northwest rises in the Iran Mountains and through Southwest to Kapit before approaching the westward course to the South China Sea. East Malaysia, particularly Sarawak, with over 30 rivers navigable by vessels of all sizes. The Rajang is the most significant river, with a total length of 306 miles. Its large, swampy delta includes Beruit Island, with a lighthouse at Sirik Point. In a region almost dependent on riverine transport, the Rajang River is navigable for 80 miles (130 km) to Sibu by oceangoing vessels and another 100 miles (160 km) by shallow-draft craft; small canoes can penetrate even farther into the otherwise inaccessible Iban country interior (Fong, 1996). The starting point for this research is from Iran Mountains 2.0833° N, 114.9167° E.

Due to many physical conditions, such as hilly terrain, land transit in Sabah and Sarawak is limited and available only in major towns. Most of the population in the Sibu area lives near the rivers' banks. Either coastal shipping or aviation services provide transportation between these two states. According to Priscoli *et al*. (1985), the Rajang River has about 306 miles, mainly for foreign ships up to 9 m draught anchorage at Tanjung Manis and 4 m Draught up to Sibu, the navigable channel for the Rajang River, approximately 5.8 m at the river bar. Logs are the most common cargo carried on Sarawak's major rivers. Rajang Port Authority has reportedly exported 2 million tonnes of logs and 500,000 tonnes of sawn timber in recent years. The bulk cargo is shipped to loading points in rafts or barges (Priscoli *et al*., 1985). There are many fundamental functions that the Rajang rivers serve, including the provision of clean water for the community and the improvement of the socio-economic status of the rural community, particularly those living along the river (Yassin *et al*., 2012).

Inland Waterway Transport System (IWTS)

The flow of the Rajang River, which runs through Brunei, Sabah, Sarawak, and Indonesia, improves freight and tourist accessibility. An inland waterway transportation system (IWTS) is complex and dynamic. Multiple factors make assessing navigational risk more challenging (Dobbins & Jenkins, 2011, Zhang *et al*., 2013). Additionally, while evaluating the navigational risk of an IWTS, there are difficulties since objective data is frequently lacking, and collecting it is costly and time-intensive, especially when considering human and managerial factors (Zhang *et al.,* 2016). One of the most extensively used ways for dealing with such a circumstance is fuzzy set theory, and several recent types of research have used it to undertake risk analysis (Chen *et al*., 2014; Zhang *et al*., 2016; Sahin & Yip, 2017; Xiang *et al*., 2017; Tseng & Cullinane, 2018; Wu *et al*., 2019).

Literature Review

Navigational Safety

Collisions are the most common type of inland waterway accident (Sulaiman, 2011.) Most ships that pass the route are unfit for the conditions (Uddin *et al*., 2017). Those who operate vessels either disregard the rules or lack adequate training and are unaware of the safety rules outlined in the 1976 Inland Shipping Ordinance. The water route has insufficient navigational buoys and markings for geographical features such as zigzags, narrows, and shallows (Wright, 2019). Moreover, this occurs due to a lack of vessel masters and crew training and adequate navigational aids along the waterway route. Likewise, due to a severe shortage of qualified vessel masters and crews, simple errors and avoidable circumstances continue to accumulate (Islam *et al*., 2021). Human error accounts for a high proportion of marine accidents, so the littoral states routinely review, consult, improve, and implement safety measures to improve navigational safety on congested waterways (Oei, 2001).

Till today, operations of most vessels are limited to daytime operations; they halt operations at night to prevent accidents since the vessels and navigation channels lack proper lighting systems to aid safe navigation (Solomon *et al*., 2021). Inland Waterway must consider improving the traditional navigation techniques as many of these marks cannot be identified by radar without enhanced reflectivity. This identification, relating radar data to the chart display, becomes extremely difficult for all mariners (Zhang *et al*., 2010). The Global Navigation Satellite System enables even greater accuracy using DGPS, GMDSS, and ECDIS. For hundreds of years, mariners relied on their faculties of sight and hearing to aid navigation. The long-term impact of traditional aids to navigation could be significant, as modern technology plays an increasing role (Zhang *et al*., 2010). Failure to correctly identify signs may cause navigational hazards and anxiety, and this can lead to a cause of marine accidents (Moon *et al*., 2018). Foreign ships and craft entering the Rajang River increased dramatically yearly.

Although technology has advanced, such as e-navigation or autonomous vessel operation, losing traditional navigation aids will increase the risk of maritime accidents (Kim & Moon, 2018). Hence, it is required to have more enhancement and well maintenance to ensure the user’s safety. Additionally, shipping services increased (Yang & Chen, 2016; Moon *et al*., 2018).

Technique Application of Fuzzy Rules

Goguen first published an application technique on (fuzzy logic, 1967) and (Zadeh, 1978), which marked a turning point in dealing with uncertainty. Real-life circumstances are rarely precise and deterministic and thus cannot be precisely articulated. A comprehensive description of a simple system frequently necessitates far more specific data than a human could ever simultaneously identify, interpret, and comprehend (Zimmermann, 2010). Therefore, the concept of a fuzzy set provides a convenient starting point for developing a conceptual framework that is like the framework used in the case of standard sets in many ways but is more general and potentially has a much broader range of applicability, particularly in the fields of pattern classification and information processing (Goguen & Zadeh, 1967).

Research Purpose

Maritime academics and shipping industry organisations are concerned about the navigational safety of an IWTS. In the following section, a Fuzzy Analytical Hierarchy Process (FAHP) is provided to illustrate the applicability of AHP. and fuzzy rule basis for the navigational safety IWTS risk assessment. Even though the fuzzy rule bases and AHP are widely used in the shipping sector, it has not been applied in the Rajang River of IWTS for encounter risk management. Hence, the approach is used to assess the navigational risk of the Rajang River in a specific area, the Tanjung Rajang River, which is now uncertain.

The risk and safety assessment of the navigational environment is one of the heated topics in recent studies of the water transportation safety field. Many relevant research results have provided solid theoretical proof to related maritime supervision departments. They are helpful for the decision-making of maritime traffic safety management regulations. In recent years, ship transportation in coastal open waters has become increasingly busy. With the constant increase of traffic volume, the complication of ship routes in parts of the waters, and the influence of meteorological, hydrological, and geographical factors, the traffic accident rates in coastal open waters have increased dramatically.

Therefore, determining the navigational safety status in the inland waterway is vital to understanding the safety hazard daily plying the waterways. In addition, determination of the risk provides more precise decision-making corresponding to navigation safety by providing a suitable suggestion so as far as to reduce the accident in navigation. In addition, the traffic real-time observation data was obtained by A.I.S. and e-Nav, showing the ship type details. Ship type reflects vessels' degree of navigation risk to a certain extent. Different ships have different structures, properties, and goods; the loss arising from accidents differs.

Methodology

The research is separated into three primary stages, as shown in Figure 1, to quantify the problem and data: An evaluation based on the current issue, a general study, and the specific assessment required. The first stage is to study

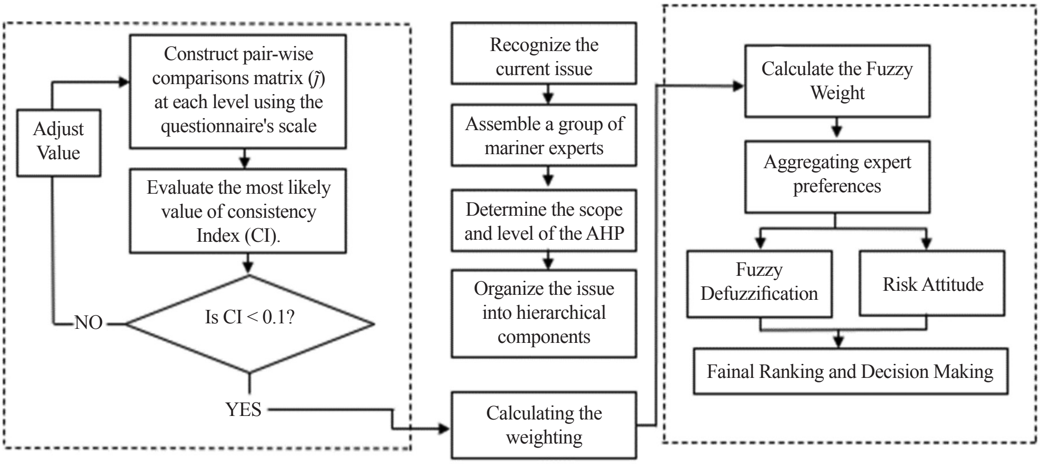

Figure 1: Research framework

the current issue within a particular area to gather relevant information about inland navigation on the Rajang River. The second step involves the development of a broad examination of the topics of interest. Develop the 3D environment using sketch-up software based on ENC and satellite images. As it is conducted on the Rajang River, data collection about the river includes classifying the type of vessel and determining navigation safety according to their risk and the availability of navigation aid. The third stage was devoted to evaluating the risk estimation on navigation safety in IWTS of Rajang River using Fuzzy-AHP.

Numerous variables influence the risk of navigational safety in the IWTS. The regulations for the periodic evaluation of the effectiveness of coastal navigation beacons state that "the navigation mark management agency is responsible for determining the navigation mark's service and technical levels, as well as its management and maintenance" (States & Accountability, 2020).

The AHP is concerned with departure from consistency and its measurement and dependence within and between groups of elements in its structure; it has found the most widespread application in MCDM in planning, resource allocation, and conflict resolution. The AHP is a non-linear framework for performing deductive and inductive reasoning without using syllogisms in their simplest form. This is accomplished by considering multiple variables concurrently, allowing for dependence and feedback, and making numerical trade-offs to identify a synthesis or conclusion (Saaty & Vargas, 2006). The Fuzzy Analytic Hierarchy Process (FAHP) method has been used to assess the risk to navigation safety along the Inland Waterway in Rajang River. The target layer of the evaluation system is the risk of navigational safety. The main criteria layer is divided into Traffic Volume, Ship Traffic Condition, Navigational Condition, Waterway Configuration, and Maritime Accident Conditions. While in the sub-criteria layer, the related factors for the upper-level factors are refined further as follows: Deep Draft, Shallow Draft, Commercial Fishing Vessels and other boats, Hazard cargoes, Traffic Mix, Traffic Density, Ship Speed, Visibility, Wind, Current and Wave, Obstruction Condition, Aids to Navigation Condition, Channel Width, Water Complexity, Channel Depth, Channel Structure, Accident Frequency, Injuries to People, Property Damage and Hazardous Material Release. Moreover, the evaluation index forms a fuzzy nature; the weights are determined using the expert survey (Saaty, 1980).

Weighting the index based on FAHP

Following the establishment of the evaluation index system described previously, the FAHP approach was used to determine the weight of each index. The procedure is divided into the following steps:

(1) *Constructing a hierarchy*

Model the problem as a hierarchy. Then constructing a hierarchy by the relationship among each factor (Evaluation of the proportion of factors by a 9-point scale)

(2) *Construct the matrix of fuzzy complementary judgments*

To quantify the relative Importance of Triangular Fuzzy Numbers, fuzzy numbers a1, a2, and a3 are built for the original crisp value. Transfer the AHP-9-point scale to a triangular fuzzy number

Table 1: Pair-wise comparison (Satty, 1980)

A.H.P. 9-point scale	Positive Triangular Fuzzy Number	Reciprocal Triangular Fuzzy Number
Equal Importance	(1, 1, 1)	(1, 1, 1)
Intermediate Importance	(1, 2, 3)	(1/3, 1/2, 1)
Moderate Importance	(2, 3, 4)	(1/4, 1/3, 1/2)
Intermediate Importance	(3, 4, 5)	(1/5, 1/4, 1/3)
Strongly more Importance	(4, 5, 6)	(1/6, 1/5, 1/4)
Intermediate Importance	(5, 6, 7)	(1/7, 1/6, 1/5)
Very Strongly more Importance	(6, 7, 8)	(1/8, 1/7, 1/6)
Intermediate Importance	(7, 8, 9)	(1/9, 1/8, 1/7)
Extremely more Importance	(9, 9, 9)	(1/9, 1/9, 1/9)

A Model for Marine Expert Selection

(1) *Establish the fuzzy Positive Reciprocal Matrix and the total fuzzy judgment matrix*

According to (Buckley 1985), some experts evaluate the geometric mean of individual fuzzy positive Reciprocal Matrix to integrate into a fuzzy Reciprocal Matrix.

As a result, instead of using the original crisp value a_{ij} Create a fuzzy positive reciprocal matrix using fuzzy numbers $a_{ij} = (a_{ij}, a_{ijl,}, a_{ij}, a_{iju})$ Perform pair-wise comparison at each level of the hierarchy and create the fuzzy comparison matrix using fuzzy numbers. Firstly, A is a $n \; x \; n$ dimensional decision matrix.

$$\boldsymbol{A^k}= \begin{bmatrix} \mathbf{1} & \boldsymbol{a_{12}} & \cdots & \boldsymbol{a_{1(n-1)}} & \boldsymbol{a_n} \\ \boldsymbol{a_{21}} & \mathbf{1} & \cdots & \boldsymbol{a_{2(n-1)}} & \boldsymbol{a_{2n}} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \boldsymbol{a_{n1}} & \boldsymbol{a_{n2}} & \cdots & \boldsymbol{a_{n(n-1)}} & \boldsymbol{a_{nn}} \end{bmatrix}$$

A^{k} = The Fuzzy judgment matric of the kth tester

a_{ij} =, where I, j=1, 2……., n

a_{ij}= is a fuzzy number (l, m, u)

For reciprocal $A^{-1} = (i, m, u)^{-1} = \left(\frac{1}{u}, \frac{1}{n}, \frac{1}{l}\right)$

$a_{ij} = 1$ for $i = j$

(2) *Using the fuzzy geometric mean approach to calculate the weights*

Calculate the weights of criteria using the geometric mean method by following the steps

Fuzzy geometric mean value (r_i): $A_1 \otimes A_2 \otimes A_n$

$= (l_1, m_1, u_1) \otimes (l_2, m_2, U_2) \otimes (l_n, m_n, U_n) = (l_1 * l_2 * \ldots\ldots * ln,$

$m_1 * m_2 * \ldots\ldots * m_n, U_1 * U_2 * \ldots\ldots * U_n)^{\frac{1}{n}}$

When n is the number of criteria,

Hence, Fuzzy weights, w_i

$W_i = ri \otimes (r_1 \otimes r_2 \otimes r_n)^{-1}$.

$$u_A(x) = \begin{cases} 0 & if\ x \leq a \\ \dfrac{x-a}{b-a} & if\ a \leq x \leq b \\ \dfrac{c-x}{c-b} & b \leq x \leq c \\ 0 & x \geq C \end{cases}$$

$$w_i = \frac{l\ + m + u}{3}$$

$$\text{Normalised weights}=\frac{w_i}{\Sigma_n^{i-1} W_i}$$

(3) *Calculate consistency*

For pair-wise comparisons, calculate consistency across the consistency index (CI) and consistency ratio (CR). The AHP consistency test is represented in the equations below:

$$\lambda_{max} = \frac{1}{n}\Sigma_j^n = l\frac{Aw_i}{w_j}$$

$$\text{CI}=\frac{\lambda_{\max} - n}{n-1}$$

$$\text{CR}=\frac{CI}{RI}$$

The Development of Simulation Using Sketch Up

Figure 2, the digital chart with old navigational marks at Rajang River. The C-Map Software is used for digital charts. C-MAP offers various formats in its cartography products and services for lakes, beaches, and seas worldwide. The undeveloped IWTS in the Rajang River has become a navigation safety issue depending on the type of vessel, with insufficient navigational aid installed in certain areas.

On Sketch-up, a risk assessment module for navigational safety was developed to sketch three-dimensional sites. Based on Figure 3, the sketch-up of the 3-D site modelling will develop by using satellite image data. By assigning the necessary real-time information during the sketch-up of the 3-D site modelling, the real-time risk assessment for navigational aids is completed.

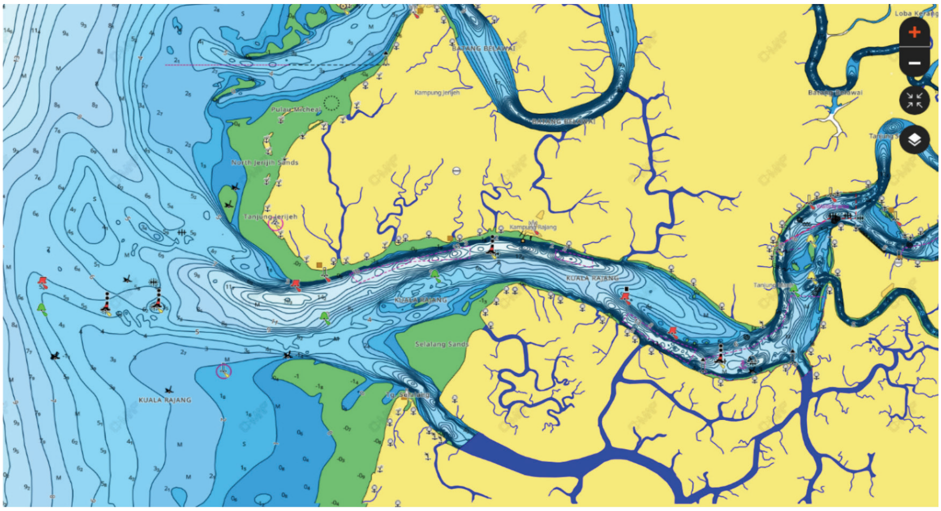

Figure 2: Digital chart with old navigational mark at Rajang River

Source: www.c-map.com

Figure 3: Rajang River using satellite image data
Source: www.c-map.com

Results and Discussion

This bar chart shows the distribution of arrival vessels by type in the Tanjung Rajang River. The traffic movement is according to the type of vessel in Tanjung Rajang River. Table 2 contains data for the year 2020 collected from e-Nav (real-time A.I.S. observation data). Cargo Ship shows the highest number of vessels than any other type of vessel. The highest number of vessels in December depends on the different types of vessels, whereas April has shown the lowest number due to the influence of Covid-19. The summary is tabulated. For both years, the number of vessels was recorded monthly. The data collected every month showed that the type of vessel was nearly approaching in each category.

Figure 4 shows the monthly ship type of the vessel plying in the selected area, Tanjung Manis, Rajang River. There are 13 types: Cargo Ship, Fishing Vessel, Law Enforcement, Other-Container Vessel, Passenger Vessel, Pilot, Pleasure Craft, Search or Rescue Boat, Speed Boat, Tanker, Towing, and Tugboat. Based on the frequency analysis, the highest value is cargo ship at 40.4%, whereas the Pilot vessel has the lowest percentage value at 0.1%. The value shows the vessel navigating the inland waterway in the Rajang River. Based on the traffic real-time tabulated data in Table 2, Laura (I.M.O.: 9700665, Call Sign: V7JP9) is a bulk carrier, the largest vessel with its beam of 31 m, Draught of 7.2 m, and LOA 199.9 m navigate in the Inland Waterways of Rajang River. The vessel

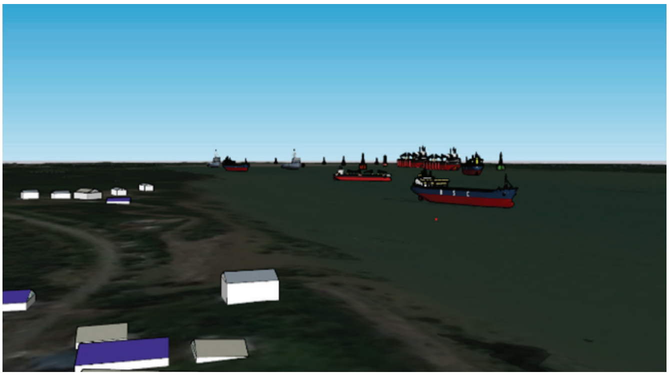

Figure 4: Rajang River using sketch-up of the 3-D site modelling
Source: www.c-map.com

Table 2: Overview of type of vessel in 2020

2020	Cargo Ship	Fishing Vessel	Law Enforcement	Other-Container Vessel	Passenger Vessel	Pilot	Pleasure Craft	Search/ Rescue Boat	Speed Boat	Tanker	Towing	Tugboat	Total
Jan	57	15	5	7	0	0	9	1	10	31	1	27	163
Feb	55	26	0	6	0	0	10	0	1	17	0	20	135
March	57	6	0	8	0	0	10	0	5	37	2	17	142
April	33	6	0	8	0	0	2	0	4	15	2	3	73
May	49	12	0	4	0	0	8	0	2	21	1	15	112
June	46	7	0	5	0	0	7	0	1	20	0	30	116
July	60	12	0	7	0	0	18	0	2	18	0	33	150
Aug	54	20	0	4	1	0	19	0	8	37	1	21	165
Sep	56	8	0	12	3	0	18	0	7	30	0	14	148
Oct	60	13	0	6	0	0	23	0	4	23	0	21	150
Nov	63	6	0	5	1	2	16	0	8	24	1	18	144
Dec	93	10	0	7	0	0	18	0	11	22	4	27	192
Total	683.0	141.0	5.0	79.0	5.0	2.0	158.0	1.0	63.0	295.0	12.0	246.0	**1690**
Mean	56.9	11.8	0.4	6.6	0.4	0.2	13.2	0.1	5.3	24.6	1.0	20.5	
Median	56.5	11.0	0.0	6.5	0.0	0.0	13.0	0.0	4.5	22.5	1.0	20.5	
Standard Deviation	13.3	5.9	1.4	2.1	0.9	0.6	6.0	0.3	3.3	7.2	1.2	7.8	
Percentage	40.4%	8.3%	0.3%	4.7%	0.3%	0.1%	9.3%	0.1%	3.7%	17.5%	0.7%	14.6%	

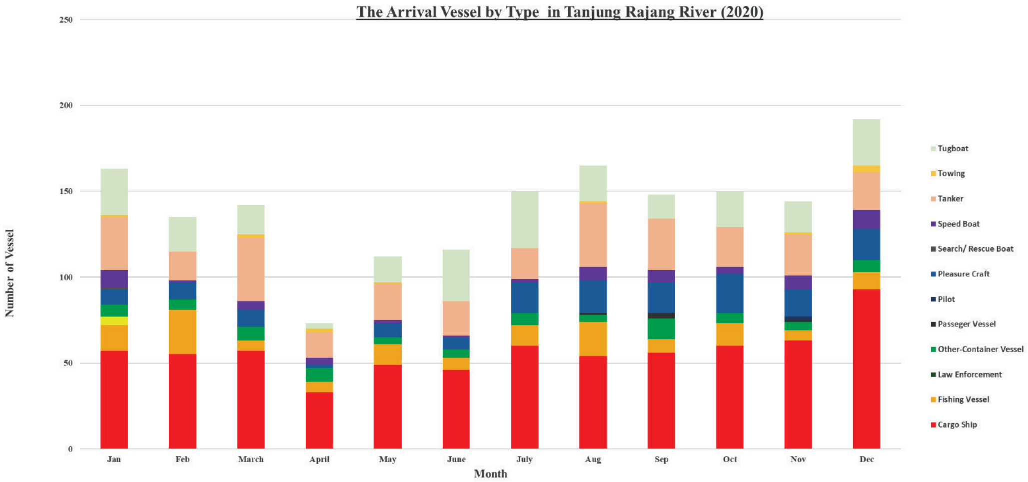

Figure 5: Bar graph of arrival vessels by type in Tanjung Rajang River by month in 2020 and the number of vessels

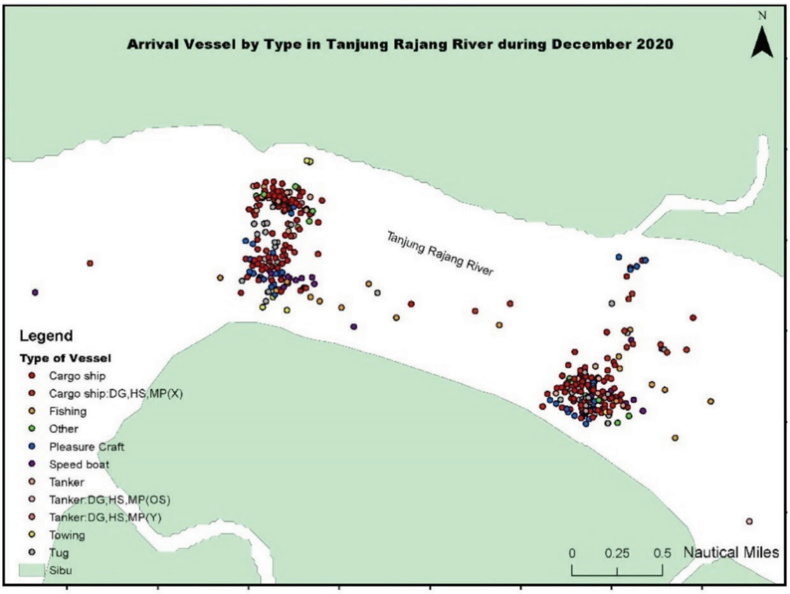

Figure 6: Tabulate Real-time arrival vessel by type data in QGIS in Tanjung Rajang River during December 2020

mainly operates throughout the day due to a lack of adequate aid to navigation throughout the river. Julaihi (2020) stated that the AtoN initiative would enhance the security of the shipping industry, particularly cargo vessels and enforcement, by establishing a safer trip environment and more systematic navigation regulations, resulting in faster turnaround times and zero maritime accidents. In addition, this will help in systematic the in and out of the ship, especially during night-time, thus enhancing the efficiency of the water traffic at Rajang River," he explained (Julaihi, 2020). Therefore, it was essential to upgrade, digitise and expand the number of buoys and beacons and install leading lights towards and within the port of Rajang River to increase navigation safety under IALA's latest specification requirements.

Table 3: List of vessel names with her I.M.O., call sign, type of vessel, L.O.A., beam, and draught at Rajang River in 2020

Vessel Name, I.M.O., Call Sign	Type of Vessel	LOA (m)	Beam (m)	Draught (m)
Laura (I.M.O.: 9700665, Call Sign: V7JP9)	Generic: Cargo Detailed: Bulk Carrier	199.9	32	7.2
Mirabella (I.M.O.: 9145889, Call Sign: E5U3348)	Generic: Cargo Detailed: Bulk Carrier	189.8	31	10.7
MV Brave (I.M.O.: 9181027, Call Sign: 3FOP9)	Generic: Other Detailed: Bulk Carrier	189.8	31	6.6
Ocean Princess (I.M.O.: 9245196, Call Sign: VRXR8)	Generic: Cargo Detailed: Bulk Carrier	192	32	6.9

Table 4: The weighted index and the quantitative standard of each factor. Owning limited time and resources, the weightage of this research is adjusted and referred to by (Chen *et al*., 2014) findings as they have done similar research on the Yangtze River in China

Risk Assessment for Navigational Safety		Quantitative Standard	Weight	CI	CR	%
1. Traffic Volume	Deep Draft	The daily number of large vessels (%)	0.1617	0.0119	0.0106	16.17
	Shallow Draft	The daily number of small vessels (%)	0.1894			
	Commercial fishing vessels and other boats	The percentage of commercial fishing vessels and other vessels that operate on a daily (%)	0.3169			
	Hazard cargoes	The percentage of vessels carrying hazardous commodities per day (%)	0.2160			
2. Ship Traffic Conditions	Traffic Mix	The average number of vessels each day	0.1996	0.0012	0.0140	18.94
	Traffic Density	Smoothness level: Score (0~10)	0.4459			
	Ship Speed	Percentage of over-speeding ships every day (%)	0.3545			

3. Navigational Conditions	Visibility	The number of days per year when visibility is less than 0.54 nm	0.2501	0.0143	0.0127	31.69
	Wind	The number of days per year when there has been a wind greater than 6 grade (strong breeze)	0.1197			
	Current and Wave	Crosscurrent velocity (m/s)	0.1917			
	Obstruction Condition	The distance between the channel's centreline and the end of the channel (m)	0.1575			
	Aids to Navigation	Score (0~10)	0.2810			
4. Waterway Configuration	Channel Width	The length of the largest ship/the channel's narrowest width	0.2570	0.0168	0.0187	21.6
	Waterway Complexity	The number of traffic-related particular points within a channel / the channel's length	0.2518			
	Channel Depth	Channel depth (m)	0.3369			
	Channel Structure	Score (0~10)	0.1544			
5. Accident Condition	Accident Frequency	Annual accident frequency average	0.2430	0.0104	0.0115	11.6
	Injuries to people	The number of people injured	0.4731			
	Property damage	Economic losses	0.1073			
	Hazardous material release	Pollution degree: score (0~10)	0.1766			

The weight assigned to each element also significantly impacts the risk assessment results. The weight index was calculated using the Fuzzy technique and the Analytic Hierarchical Process (AHP) approach to ensure the accuracy and acceptability of the evaluation results based on a relevant project from the Rajang Port Authorities. The expert questionnaire was compiled and distributed to 30 expert mariners from Rajang Port Authorities, Merchant Navy Sarawak, Tanjung Manis Integrated Port, Marine Department, and some related departments throughout the project. All questionnaires were returned. The judgment matrix based on the AHP technique was constructed after considering all the experts' opinions and suggestions. The weight of each factor was computed using Microsoft Excel and passed the consistency check. The detailed computation process was omitted from this section.

The risk assessment method would be useless if all the values of the contributing factors of aids to navigation risk were manually input or determined. As a result, a risk assessment module for navigational safety was created on Sketch-up to sketch a Three-dimensional site. The real-time risk assessment for aids to navigation is accomplished by allocating the required real-time information during the sketch-up of 3-D site modelling. In addition, the system will be enhanced with specific external databases and expert experience information. The data can be updated according to the set targets and assessment circumstances. The crucial real-time information was extracted in this module to determine the value of the factors in the created index system. Then the FAHP model was conducted to perform the risk assessment for the chosen navigation aid along the IWTS in Rajang River. The results may reflect the real-time danger level of the channel's aids to navigation, which may provide additional assistance to aids to navigation administrators and be valuable in improving navigation service and ship navigation safety.

Corresponding to Table 5, Navigational Condition (0.2789) at first ranking based on the result, while the second rank is Waterway Configuration (0.2198). The third rank is Ship Traffic Condition (0.1821), followed by Traffic Volume (0.1807) at the fourth rank. The fifth rank or the last is Maritime Accident Conditions (0.1385). This shows how important Navigational Conditions are in Navigational Safety.

Table 6 shows that Deep Draft (0.3332) is ranked top based on results, whereas Commercial Fishing Vessels and Other Boats is ranked second (0.2488). The third rank is Shallow Draft (0.2290), followed by Hazard Cargoes (0.1890). This demonstrates how Deep Draft reflects a high volume of traffic.

According to Table 7, Traffic Density comes in the top place (0.4082). This demonstrates that Traffic Density influences the Ship Traffic Condition during rush hour. The Ship Speed (0.3826) comes in second place. Traffic Mix (0.2091) is in third place.

Based on Table 8, Aids to Navigation Condition (0.2759) is ranked highest, while visibility is ranked second (0.2418). Current and Wave is ranked third, and Obstruction Condition is ranked fourth (0.1642). The wind is ranked fifth (0.1252). This exemplifies how important navigational aids are.

Table 9 shows that Channel Depth (0.3369) is ranked top based on results. This shows how Channel Depth affects Water Configuration. The Channel Width is ranked second (0.2541). The third rank is Water Complexity (0.2327), followed by Channel Structure (0.1790).

Table 10 shows that Hazardous Material Release (0.4498) is ranked top based on results. This shows that Hazardous Material Release contributor to Maritime Accident Conditions. Injuries to People is ranked second (0.4164), whereas the third rank is Accident Frequency (0.2762). Damage Property is ranked fourth (0.1214).

As illustrated in Figure 6, the overall danger level associated with navigational safety in the Rajang River is moderate (score: 0.20). The primary dangers are posed by Navigational conditions, classified as high risk, with a score of 0.20. From the fuzzy inputs, it was observed that the user thought Traffic Volume and Waterway Configuration are two of the second highest-priority criteria along with

Table 5: FAHP using geometric mean method results for ranking main goal navigational safety

	Traffic Volume	**Ship Traffic Condition**	**Navigational Condition**	**Waterway Configuration**	**Maritime Accident Conditions**
Result	0.1807	0.1821	0.2789	0.2198	0.1385
Ranking	4	3	1	2	5

Table 6: FAHP using geometric mean method results for ranking traffic volume

Traffic Volume	**Deep Draft**	**Shallow Draft**	**Commercial Fishing Vessels and other boats**	**Hazard Cargoes**
Result	0.3332	0.2290	0.2488	0.1890
Ranking	1	3	2	4

Table 7: FAHP using geometric mean method results for ranking ship traffic condition

Ship Traffic Condition	Traffic Mix	Traffic Density	Ship Speed
Result	0.2091	0.4082	0.3826
Ranking	3	1	2

Table 8: FAHP using geometric mean method results for ranking navigational condition

Navigational Condition	Visibility	Wind	Current and Wave	Obstruction Condition	Aids to Navigation Condition
Result	0.2418	0.1252	0.1930	0.1642	0.2759
Ranking	2	5	3	4	1

Table 9: FAHP using geometric mean method results for ranking water configuration

Waterway Configuration	Channel Width	Waterway Complexity	Channel Depth	Channel Structure
Result	0.2541	0.2327	0.3369	0.1790
Ranking	2	3	1	4

Table 10: FAHP using geometric mean method results for ranking maritime accident condition

Maritime Accident Condition	Accident Frequency	Injuries to People	Property Damage	Hazardous Material Release
Result	0.2762	0.4164	0.1214	0.4498
Ranking	3	2	4	1

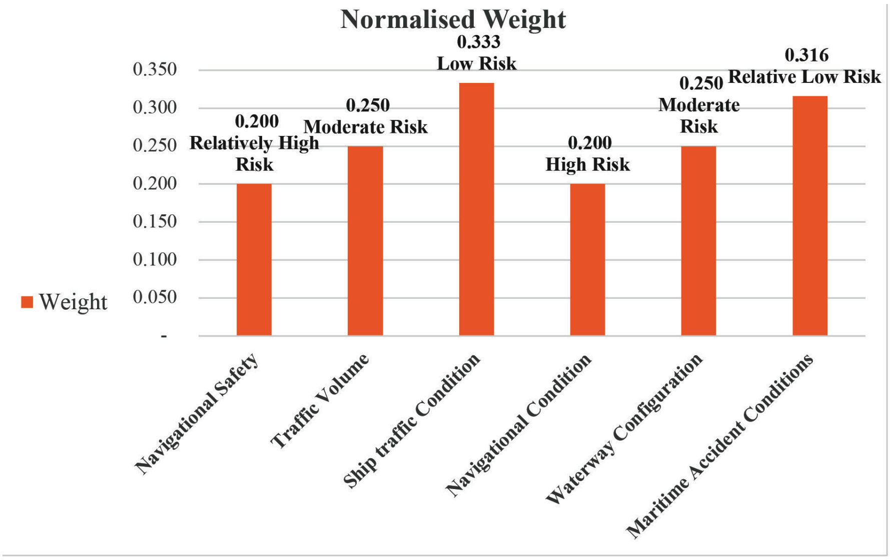

Figure 7: Ranking risk condition of navigational safety using normalised weight in IWTS
(Note: 0~0.2=" High Risk; 0.2~0.3= "Relative High Risk; 0.3~0.4= "Moderate Risk"; 0.4~0.45= "Relative Low Risk; 0.45~0.5 = "Low Risk")

Navigational Condition. For this reason, the criterion Navigational Condition is given the highest weight, and the alternative with the highest score on the Navigational Condition criterion is the best. The vessels in the IWTS are diverse, with strong wind and obstruction conditions. As the Navigational Condition is also among the user's top priorities, it is chosen as the most important one in every comparison, except when compared with Traffic Volume and Waterway Configuration. Thus, this is known as a close second in criterion weight.

Then the user ranks the criteria Maritime Accident Condition. So, this criterion comes a third of the criterion weight. Nevertheless, the effect of linguistic terms and corresponding fuzzy numbers were seen. The user has thought Maritime Accident Condition is Relatively Important. For this reason, this criterion comes in third but in a distant third. This affects the result, as we see that even though Navigational Condition has the lowest score in normalised weight, which is 0.2 in the criterion, it still has gained the highest Importance to the risk in navigational safety. Lastly, the ship traffic condition recorded has low significance and, therefore, has less impact on the final score.

To determine the absolute weights assigned to each element and the comparative scores assigned to a few user-selected criteria in Rajang River. Moreover, the uses of FAHP obtain some crisp inputs and a set of fuzzy linguistic values from the expert mariner that denote relative importance measures for each possible pair of these factors, as determined by the user. These values are used to calculate the Rajang River's Inland Waterway Transport System's final score, which measures its suitability for the given inputs. Additionally, the channel is frequented by small vessels or high-speed craft that navigate excessively during bad weather, resulting in poor visibility (Kray, 1973; Wright, 2017).

Hence, the obstruction condition was not noted. All these factors contribute to a high-risk level. However, the channel characteristics, navigation aids, and navigational environment are all favourable for ship navigation, reducing navigation risk to a certain extent. In a nutshell, the IWTS overall risk level is high risk. Based on the above evaluation results, the following risk control recommendations were made for the IWTS in Rajang River:

- Streamlining ship navigation directions, admonishing, and guiding small and commercial fishing vessels to adhere to the laws.
- Notifying overspeeding ships promptly to maintain a safe speed.
- Placing safe water markings or leading lines in areas of high ship flux to guide ships safely through this area.
- Making full use of visual and radio aids to create one comprehensive navigation aid system that provides accurate and timely navigation information and warnings to ships.
- The results have been evaluated and authorised by a mariner expert frequently using IWTS.

Additionally, the risk assessment can be modified in real-time to align with the selected targets and assessment contexts.

Conclusion

This research aims to achieve all the objectives by proposing suitable aids to navigation (AtoN) and configuration based on the IALA standard (IALA, 2009). This research started by recognising the problems of IWTS in Rajang River (Tanjung Rajang River) by applying the FAHP to an IWTS based on a hierarchical model in terms of navigational safety risk. The developed approach, which incorporates a fuzzy rule base and AHP, highlights relevant qualitative and quantitative criteria, describes the use of a rule-based transformation technique to convert quantitative criteria into qualitative criteria, and addresses synthesis to achieve at main criteria of risk estimation. Once the risk of navigation safety is completed, this research develops a three-dimensional area simulation

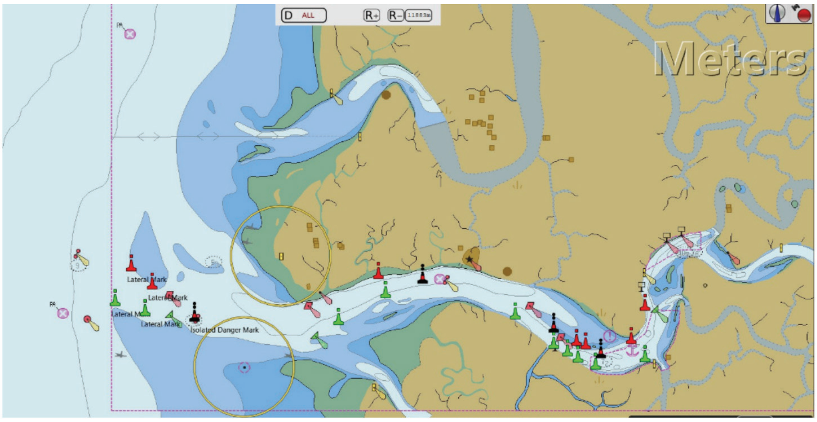

Figure 8: Placement of new navigational aids in Rajang River

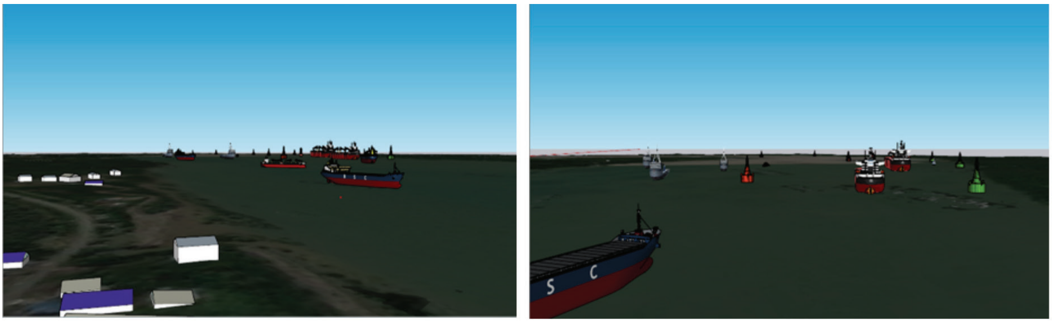

Figure 9: 3D modelling placement of new navigation in Rajang River by using the Sketch-Up

using Sketch-Up based on Google Earth Pro and a topography map. These steps have been achieved and led this research to a conclusion.

In addition, a real-time risk assessment module based on a constructed index system and a FAHP model was completed to enhance the risk level of navigational safety. Compared to the traditional method of assessing the risk of aids to navigation, real-time risk assessment for aids to navigation using FAHP on a three-dimensional simulation system platform for aids to navigation can provide real-time, more scientific, and comprehensive results for the selected targets. Furthermore, the risk in navigational safety would be updated in real-time when the targets and assessment environments changed. Additionally, the assessment results were authorised by an expert mariner following practical use in the IWTS in the Rajang River.

In conclusion, this research is beneficial. The main goal is to design a three-dimension area simulation that might help the state government to plan further to improve the navigational safety of IWTS in Rajang River by expanding the number of aids to navigation effectively to serve the local and international shipping communities resulting in zero marine accidents. The proposed method has practical implications and application prospects in the maintenance field.

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