Impressum

EDITORIAL OFFICE
Transactions on Maritime Science
Faculty of Maritime Studies
Ruđera Boškovića 37,
21000 Split, Croatia
www.toms.com.hr
office@toms.com.hr

PUBLISHER
Faculty of Maritime Studies
Ruđera Boškovića 37,
21000 Split, Croatia
office@pfst.hr

DESIGN
Offstudio, Zagreb, Croatia
Ana Banić Göttlicher and Maša Vukmanović

Abstracting/Indexing:
Web of Science (Emerging Sources Citation Index)
Scopus
Hrčak
Index Copernicus
TRID (the TRIS and ITRD database)
BMT | Marine Science and Technology
Google Scholar
Digitale Bibliothek Braunschweig
INSPEC

Published twice a year.
Printed on acid-free paper (print ISSN 1848-3305).
ToMS online (ISSN 1848-3313) offers free access
to all articles.
www.toms.com.hr

ToMS

Transactions on Maritime Science (ToMS) is a scientific journal with international peer review which publishes papers in the following areas:

~ Marine Engineering,
~ Navigation,
~ Safety Systems,
~ Marine Ecology,
~ Marine Fisheries,
~ Hydrography,
~ Marine Automation and Electronics,
~ Transportation and Modes of Transport,
~ Marine Information Systems,
~ Maritime Law,
~ Management of Marine Systems,
~ Marine Finance,
~ Bleeding Edge Technologies,
~ Multimodal Transport,
~ Psycho-Social and Legal Aspects of Long-Term Working Aboard.

The journal is published in English both as an open access journal, and as a classic paper journal (in limited editions).

ToMS aims at presenting major maritime research all over the world, particularly focusing on the Mediterranean area. Articles will be double-blind reviewed by three reviewers. ToMS also promotes scientific collaboration with talented students at a beginning of their scientific careers. These papers also undergo strict peer reviews. Furthermore, the Journal publishes short reviews on significant papers, book reviews and workshops in the fields of maritime science.

The views and opinions expressed in the papers are those of individual authors, and not necessarily those of the ToMS editors. Therefore, each author will take responsibility for his or her contribution as presented in the paper.

Publishing of the Journal is, in part, assisted by generous financial support from University of Split and Ministry of Science and Education.

All papers are checked by CrossCheck Powered by iThenticate

Contents

CONTRIBUTION

From Editor-in-Chief:

Ten Years with Full Sails

Igor Vujović

Dear Colleagues,

I am happy to inform you that the 20th issue of our Journal is out, which means we have been sailing the rough scientific publishing seas for a decade. Over the years, the Journal has been constantly upgraded. Our dedication was to internationalise the Journal. To achieve this meant increasing the number of members from different countries in our Editorial and Advisory Boards and more international reviewers, as well as obtaining ever higher-quality and attractive articles. It is worth reminding that the first volume contained 15 papers, and the current volume has 44 published papers. I am the second editor-in-chief. The first one, Ivica Kuzmanić, is still in the editorial team as our research integrity editor and chairman of the Ethical Committee. He was editor-in-chief for the first 15 issues.

Furthermore, the first issue was indexed in only two databases at the time. Thanks to our dedicated Journal staff and our article authors, we are currently indexed in the Web of Science Core Collection (WoSCC) and Scopus, among other respected indexing bases currently. In WoSCC, we are indexed in the Emerging Sources Citation Index (WSCI) base in the Marine Engineering category comprising 25 journals. The current Journal Citation Index (JCI) is 0.21. From five Scopus categories, ToMS is in quartile 3 in the following categories: Ocean Engineering, Law, and Automotive Engineering with ever-increasing Scientific Journal Rankings (SJR) of 0.2.

A lot has changed over a decade. Online publishing has been suppressing classic print. Therefore, some changes were necessary to keep pace with the current progress. Hence, we introduced the 'web-first' service. It was necessary since our publication rate is two issues per year, and some authors could not wait for a print edition for half a year. Our goal is to become a propulsive and fast-publishing online independent Journal with a print edition twice a year. Continuous online publishing is great for authors because a paper can be published as soon as it is accepted.

In addition, we took steps to renew and rejuvenate the editorial staff by introducing Associate Editors, who will use and maintain an Open Journal System (OJS), communicate with reviewers, and help promote the Journal further.

We are proud to announce a new issue. This issue covers both regular papers and the best papers from the International

Conference of Information & Communication Technology 2021 (ICICTM 2021). The information about the Conference can be found at: https://icictm.com.my/.

On behalf of the Journal, I am pleased to thank Dr. A. Nanthini Sridewi from the National Defence University of Malaysia for agreeing to become the Journal's Regional Editor from the 1st of January 2022. I am also pleased to thank Kindlein Wilson Junior (Brazil) for joining our team in this volume.

In keeping with our tradition and practice, in this issue we bring again a lyric poem in the Croatian Chakavian dialect, along with a video-audio clip and a translation in English. However, this time we will also take an opportunity of paying tribute to two great men who have forever and immeasurably indebted Croatian culture: the poet Pere Ljubić (Vrbanj on the island of Hvar 1900 – Zagreb 1952), one of the pioneers of lyric poetry in the Chakavian dialect (the first was Marko Marulić, father of the Croatian literature, back in the 15th Century) and Dinko Fio (Blato on the island of Korčula – Zagreb 2011), a renowned musicologist, singer, choir leader, conductor, composer, and music pedagogue. Ljubić's poem 'Naši Škoji' has been set to music by Dinko Fio, performed, among others, by klapa 'Kamen' from Split among many others, thereby making an anthological and memorable piece of the Croatian (Dalmatian) a capella singing. This type of singing is on the UNESCO intangible cultural heritage of mankind list.

I wish to thank all our reviewers for they responsible work. In this volume, 176 reviewers form 38 states (5 continents: Africa, North America and South America, Asia, and Europe) were involved in the peer review process. Except Croatia, the countries with the largest number of reviewers are: Malaysia, Turkey, Poland, and Spain. I greatly appreciate your contribution and time spent not only in assisting me in reaching my decision, but also enabling the author(s) to disseminate their work at the highest possible quality. Without the dedication of reviewers like you, it would be impossible to manage an efficient peer review process and maintain the high standards necessary for a successful journal. We hope you will help us realize our goal to improve both paper quality and visibility and that together we can make this journal stronger and recognizable, and sail safely to new challenges.

As this is a celebrating issue, I wish to thank all the current Advisory Board members, regional editors, Editorial Board members, as well as the former members for their help in developing this Journal for the past decade. I hope you will help us reach new goals of increasing impact factor, advancing in quartiles, and accepted in more indexation bases with even the highest reputation.

Best whishes
Editor – in - chief

Development and Experimental Investigation of a Marine Vessel Utilizing the Energy Ship Concept for Far Offshore Wind Energy Conversion

Mohd Najib Abdul Ghani Yolhamid, Mohd Norsyarizad Razali, M.N. Azzeri, Mohd Shukri Mohd Yusop, Ahmad Mujahid Ahmad Zaidi, Noh Zainal Abidin

The energy ship is a concept for offshore wind energy capture which has received very little attention until today. To this date, there had not been yet an experimental proof of concept. In order to tackle this issue, an experimental platform and data acquisition system has been developed. A 5.5m long sailing catamaran served as a platform equipped with a 240mm diameter water turbine. The energy ship platform has been tested several times in the actual river to investigate the workability of the platform and data acquisition system. Results show that energy ship platform can produced 500W electric power for a true wind speed of 10 knots.

KEY WORDS

~ Energy ship
~ Data acquisition system
~ Renewable energy

Universiti Pertahanan Nasional Malaysia, Kuala Lumpur, Malaysia

e-mail: najib@upnm.edu.my

doi: 10.7225/toms.v10.n02.001

Received on: 11.06.2021 / Revised on: 13.10.2021 / Accepted on: 17.10.2021 / Published: 21.10.2021

1. INTRODUCTION

Most of the wind energy resource is far out at sea. Unfortunately, it cannot be exploited with current wind energy technologies (grid-connected bottom-fixed or floating wind turbines) due to grid-connection cost, moorings and installation cost, and maintenance cost would be prohibitive. Therefore, there is a need to develop new wind energy technologies in order to enable harvesting the far-offshore wind energy resource.

A solution for this problem is using the energy ship concept which was been proposed by (R. Abd Jamil et. Al.,2019) with greater capacity factor acceding 80% due to optimizing weather forecast in order to maximizing the capacity factor. An energy ship is a ship driven by the wind using sails and equipped with a water turbine in order to convert the kinetic energy of the ship into electricity. Energy ships include an onboard energy storage system to store the produced energy. This concept is not new since it was first patented by (Salomon,1982). Note that he suggested hydrogen for energy storage. Since then, a few researchers have proposed designs of energy ships (Meller, 2007; Gizara,2007; Kim & Park, 2010; Pelz et. al.,2016; Gilloteaux & Babarit, 2017; Ouchi & Henzi, 2017; Babarit et. al.,2019; Babarit et. al.,2020) as in Figure 1.

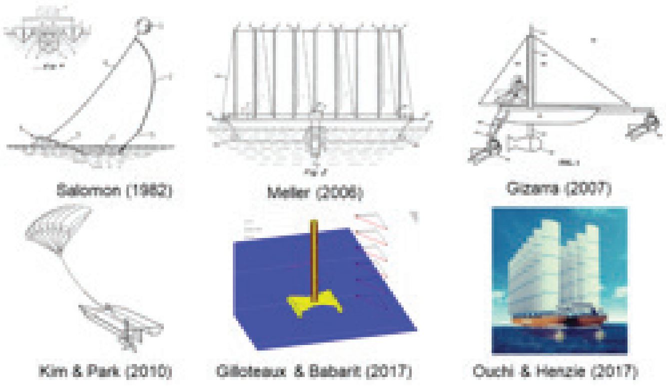


Figure 1.
Various design of energy ship.

Figure 2.
Picture of a hobie Cat Tiger Catamaran.

The hydro-generators are widely installed in sailing ship as the renewable energy mix provider to accommodate extra power demand for navigational lights, radio, and GPS. For fast sailing ship, the hydro-generator can produced high and stable electricity production as long as the ship is sailing.

The major difference between a sailing ship and an energy ship is the presence of a large water turbine underneath the ship. The main effect of the turbine is to generate an additional drag force. Energy production by the ship depends on the product of this force and the induced velocity in the disk swept by the rotor of the turbine. It has been shown in (Gilloteaux & Babarit, 2017; Babarit et. al., 2019) that optimizing the drag force and the induced velocity is key to maximize energy production. However, this hasn't been confirmed experimentally yet. Addressing this gap requires the development of an experimental platform, which is one of the aims of the present study. The second aim is to achieve an experimental proof-of-concept for the conversion of wind energy into electricity using the energy ship concept.

2. DESCRIPTIONS OF THE TEST PLATFORM

2.1. Hull and Sails

In this research, a used Hobie Cat Tiger sport catamaran as in Figure 2 is used as the basis for the test platform. Its length is 5.51 m. It is fitted with a Bermuda rig. The mainsail area is 17 m^2, the jib sail area is 3.45 m^2 and the spinnaker sail area is 19 m^2. This ship is normally operated by a crew of 2 people. Other main characteristics are given in Table 1.

Table 1.
Hobie Cat Tiger specification.

Specifications	
Crew	2-3
Length	5.51m
Beam	2.60m
Capacity	240kg
Weight	180kg
Draft w /Rudder Up	0.18m
Mast Length	9m
Mainsail Area	17m^2
Jib Sail Area	3.45m^2
Spinnaker Sail Area	19m^2
Hull Construction	Fiberglass/ foam Sandwich

2.2. Selection of the water turbine

In order to select the water turbine, an estimation of the power that can be absorbed by the platform for typical wind conditions if true wind speed W is 10 knots (approximately 5 m/s), true wind angle β=90° and ship velocity U=10 knots. The apparent wind speed and the apparent wind angle derive from the true wind speed W and the true wind angle β in Figure 3 as follows:

$$\begin{cases} V^2 = U^2 + W^2 + 2UW\cos\beta \\ W\sin\beta = V\sin\alpha \end{cases} \quad (1)$$

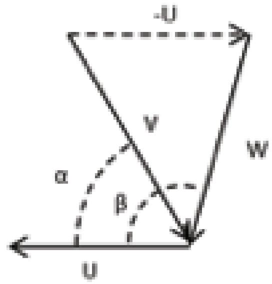


Figure 3.
Notattions and definitions for the true wind and apparent wind speeds and angles.

In the aforementioned conditions, the apparent wind velocity V is 14 knots and the apparent wind angle α is 45°. The thrust force delivered by the sails can be estimated using equation derived by (Babarit et. al.,2019):

$$T = \frac{1}{2}\rho_a A_s V^2 (C_L \sin\alpha - C_D \cos\alpha) \quad (2)$$

where ρ_a is the air density, A_s is the total sail area and C_L and C_D are the lift and drag coefficients of the rig. For a Bermuda rig, C_L is in the order of 1.5 and C_D is in the order of 0.5 (Charrier, 1979). Thus, the thrust force is in the order of 470 N. At equilibrium and without the water turbine, the thrust force is equal to the water resistance of the hull of the ship R_w. In a first approach, it is assumed that this water resistance is simply proportional to the square of the ship velocity:

$$R_w = r_w U^2 \quad (3)$$

As the thrust force is estimated to be 470 N, r_w is in the order of 18 N.s²/m².

When the water turbine is added, it creates an additional source of drag R_T. Therefore, the ship velocity will be smaller with the water turbine than without the water turbine. According to the momentum theory, the drag force can be written:

$$R_T = 2\rho_w A_T a(1-a) U^2 \quad (4)$$

Where $a \in [0, \frac{1}{2}]$ is the axial induction factor, ρ_w is the water density and A_T is the turbine disk area. The produced power can be written:

$$P_T = R_T (1-a) U \quad (5)$$

At equilibrium, the thrust force is equal to the water resistance plus the drag force from the water turbine:

$$T = R_W + R_T \quad (6)$$

Using Equations 1, 2 and 6 it leads to an equation relating the ship velocity to the water turbine drag:

$$\frac{1}{2}\rho_a A_s (U^2 + W^2 + 2UW\cos\beta)(C_L \sin\alpha - C_D \cos\alpha) = r_w U^2 + 2\rho_w A_T a(1-a) U^2 \quad (7)$$

Using equations 7 and 5 one can calculate the ship velocity and produced power as function of the axial induction factor. Results of such calculation are shown in Figure 4 for a true wind speed of 10 knots and a true wind angle of 90°. Note that in this calculation, it was assumed that the diameter of the water turbine is 240 mm. One can see that, as expected, the ship velocity reduces with increasing induction factor (because of increasing turbine drag force).

For the produced power, one can see that a maximum of approximately 500 W is obtained for an optimal induction factor of approximately 0.25. The corresponding turbine drag is approximately 200 N and the corresponding ship velocity is approximately 8 knots. Therefore, the cruising 600 hydrogenerator by Watt & Sea was selected as it matches well the requirements for the test platform. Indeed, this hydrogenerator has a nominal power of 600 W as shown in Figure 5. It can be fitted with a turbine of diameter 240 mm. For that turbine, it can deliver approximately 300 W electric power for 4 m/s ship velocity.

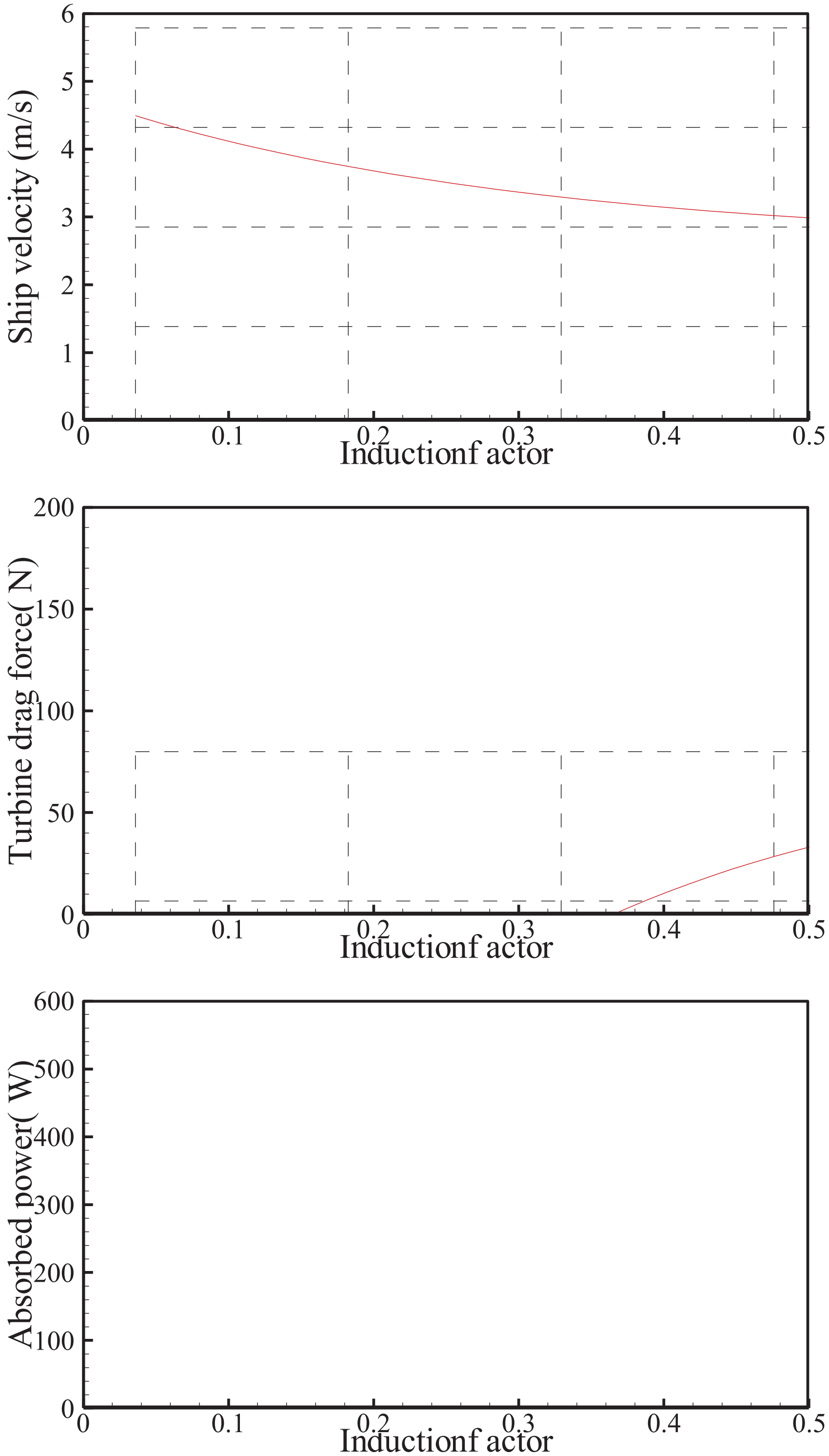


Figure 4.
Ship velocity, turbine drag force and absorber power as function of the induction factor for a true wind speed of 10 knots and a true wind angle of 90°.

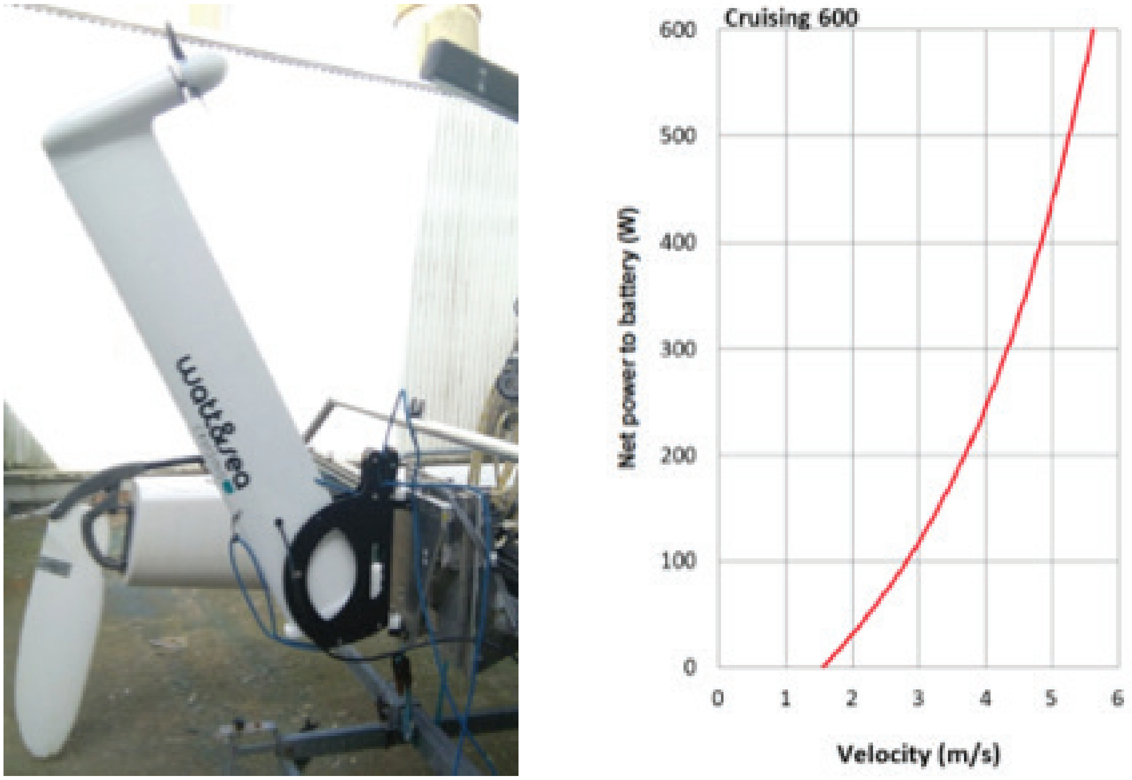


Figure 5.
Watt & Sea cruising 600 hydrogenerator.

2.3. Instrumentation

2.3.1 Ship Velocity, Heading and Motions

For measuring the ship velocity, ultrasonic speedo sensors from NKE Marine Electronics were selected. Model 90-60-479 was selected to provide speed measurement range in between 0.3 to 50 knots and provide resolution of two decimal points. Speed sensors were installed vertically under the port and starboard hull which were closed to the axis of the ship and installed in front of dagger board to achieve optimal performance. The installation can be visualized as described in Figure 6. The redundancy is needed for the case of failure or one of the hulls is flying on the air.

A BU-353S4-USB GPS was selected for measuring the geographic position of the ship with the horizontal position accuracy below than 2.5 meter. This sensor also allows the ship velocity over ground (speed over ground – SOG) and heading (course over ground – COG) to be measured through differentiation of the catamaran's positions. Sampling rate for the GPS is 1 Hz. Note that there can be differences between the velocity measurement from the speed sensors and the SOG ground depending on current.

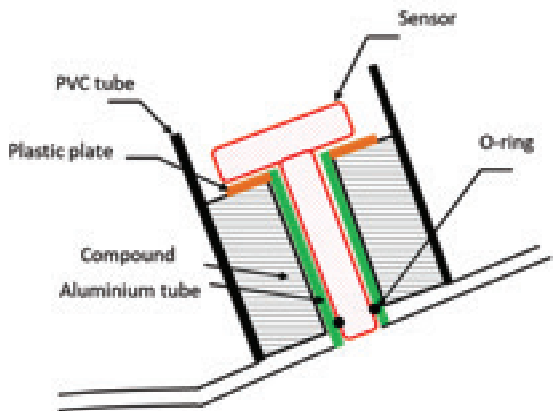


Figure 6.
Installation of speed sensor.

Motions of the ship were captured by BNO055IMU sensor at 100 Hz sampling rate. This sensor measured the heading, pitch and roll of the ship. IMU is calibrated for the best performance before conducting any test.

2.3.2. Wind Velocity and Direction Measurement

For measuring wind speed and direction, an anemometer model CV7-LCJ Capteurs was mounted at the top of the mast with additional position sensor from Honeywell. This position sensor is placed at the bottom of the mast for wind direction correction. The current designed allows the mast to be rotated at 90 degrees to the port and starboard respectively. Due to the angle limitation of current position sensor, an additional method is used to limit the rotation of the mast approximately 15 degrees to the port and starboard respectively by tying the mast to the sail rig adjuster on the port and starboard side of the ship.

2.3.3. Drag Force Sensor

One of the objective in the experiment is to investigate the effect of the drag force in order to maximise the energy production. So it requires that force to be measured. For that purpose, a dedicated balance has been designed. It is based on a set of three strain gauges which enables the drag force in the x direction as well as the moments in the y and z directions to be measured as shown in Figure 7. Load cell from HBM Z6 was selected for this task with triangular shape because of robustness and withstands extreme mechanical stress and aggressive media. For this purposes, 2 unit of load cell with maximum load 100 kg and 1 unit of load cell with maximum load 50N were selected. The balance is attached to the Hobie Cat Tiger at the center back of the platform. The load cells presented a linearity and hysteresis ideal for the test with error below 0.1% of the vertical and 0.4% horizontal for a full scale (200 N).

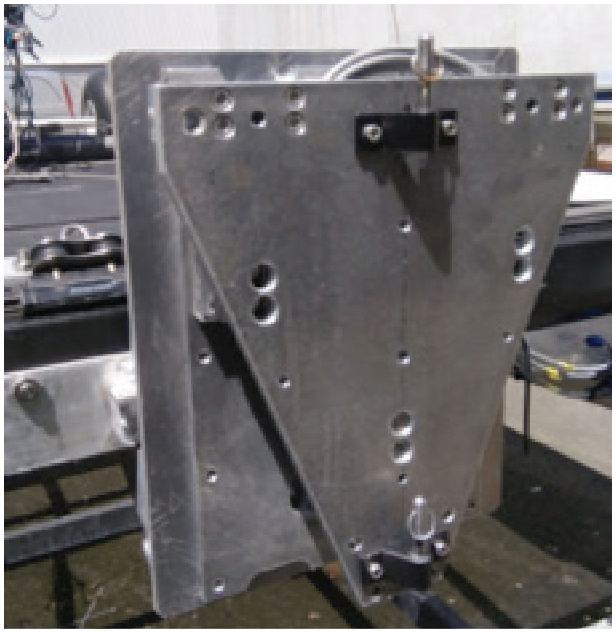


Figure 7.
Triangular load cell balance.

2.3.4. Hydrogenerator and Power Management System

For reasons explained above, a Watt & Sea Cruise 600 hydrogenerator was selected for the test platform. This type of hydrogenerator is designed to produce high performance output during cruising with low drag profile. Cruising hydrogenerator is light, robust, compact and easy to install. Delivered with 240 mm propeller, power converter regulator and lifting fastening bracket. There are three different sizes of propeller available which are 200mm, 240mm and 280mm. Increase the propeller size can generate more power at lower speed. As an example, a 240mm diameter propeller provides maximum using speed at 14 knots meanwhile propeller with larger diameter 280mm provides maximum using speed at 11 knots. Lower pitch will provide better acceleration and higher pitch will provide higher top speed. The hydrogenerator also comes with variable rotational speed control function (pitch control). For getting maximum performance the rotor speed must vary with wind speed.

The hydrogenerator is operated with a power management system consist of a power converter, a 24V Lithium battery, a dump load and an Arduino NANO microcontroller as shown in Figure 8. The 24V15Ah battery is selected due several reasons such as light weight (3kg), longest life, produced constant power, fast charging and safe. The dimension of the battery is 330mm in length, 96mm in width and 104mm in height. The alternating current electricity produced by the turbine is converted into direct current by the converter and stored into the 24 V Lithium battery. The converter also enables to control the water turbine (rotational velocity, drag force, power absorption) The system includes sensors for measuring the produced energy (current, voltage, power) and the turbine rotational velocity. When the battery is fully charged, the excess energy can be dissipated by the dump load.

Note that the battery included in the hydrogenerator system is also used for powering the anemometer, the data acquisition system and the wifi antenna using power over ethernet (PoE). The voltage is stepped down to 5V by using buck regulators.

The hydroelectric generator component specification and function are summarized in Table 2. Power management system is located at the starboard side of the hull. Some alteration and modification need to be made at the starboard hull of the catamaran to allow compartment with waterproof hatch to be installed. Waterproof hatch on the starboard hull of the catamaran is designed to locate a few items such as Lithium battery and also dump load resistor.

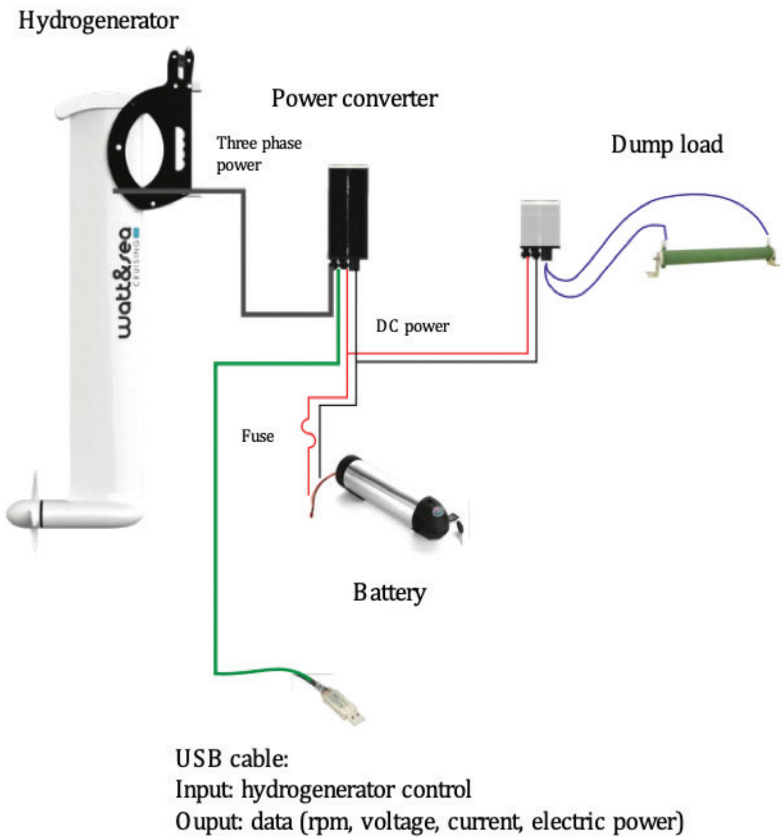


Figure 8.
Hydrogenerator and power management system.

Note that the battery included in the hydrogenerator system is also used for powering the anemometer, the data acquisition system and the wifi antenna using power over ethernet (PoE). The voltage is stepped down to 5V by using buck regulators.

The hydroelectric generator component specification and function are summarized in Table 2. Power management system is located at the starboard side of the hull. Some alteration and modification need to be made at the starboard hull of the catamaran to allow compartment with waterproof hatch to be installed. Waterproof hatch on the starboard hull of the catamaran is designed to locate a few items such as Lithium battery and also dump load resistor.

Table 2.
Hydrogenerator and power management system.

Item	Function
Hydrogenerator	Convert kinetic energy into electric energy
Converter	Convert 3 phase 40 voltage into 24V DC voltage
USB cable	As an interface to change the drag of the hydroelectric generator
Battery	Store the renewable energy and also act as a buffer
Dump load resistor	If the battery is in fully charged condition then the heat sink will be operated to discharge the energy

2.3.5. Data acquisition system and control

The data acquisition system is based on a Raspberry Pi 3. It is installed onboard in a Pelicase as in Figure 9. It is connected to the various system, sensors and transducers as illustrated in Figure 10. The sensors were selected to be wired connection. Waterproof pin connectors with IP68 standard were used for the connection. Several communication protocols such as NMEA 183, I^2C, ethernet and USB have been used in developing data acquisition system. As an example, GPS, anemometer and hydroelectric generator were connected using USB protocol meanwhile sensor such as IMU was connected using I^2C protocol.

Figure 9.
Data acquisition system in pelicase box.

The data acquisition system has been designed to record the measured data and store it in a CSV file. The overall recorded data is simplified as listed in Table 3. Data acquisition is start and stop by pressing the corresponding buttons located on the top of the pelicase box.

Moreover, the data acquisition system has been designed to enable the live data streaming through wifi. Thus, the data can be visualized live on a remote computer by an operator located on-land or on another boat. This feature has been developed to reduce the workload of the catamaran crew, as it is expected that they will be fully busy with the navigation and operation of the boat.

Table 3.
Data variable recorded.

Data	Sensor
Latitude	BU-353S4-USB GPS
Longitude	BU-353S4-USB GPS
Heading	BU-353S4-USB GPS / BNO055-IMU
Clock/ time	BU-353S4-USB GPS
Number of satellite	BU-353S4-USB GPS
Yaw	BNO055-IMU
Pitch	BNO055-IMU
Roll	BNO055-IMU
Heave	BNO055-IMU
Port hull speed	Speed sensor
Starboard hull speed	Speed sensor
Speed over ground	BU-353S4 USB GPS
Wind speed	CV7-C LCJ Capteurs anemometer
Wind direction	CV7-C LCJ Capteurs anemometer
Wind direction correction	Honeywell SMART Position Sensor
Hydrogenerator speed	Hydrogenerator
Battery , voltage	Hydrogenerator
Battery, current	Hydrogenerator
Dump load resistor, current	Resistor
Raspberry pi temperature	Raspberry Pi 3
Hydrogenerator drag	Strain gauges

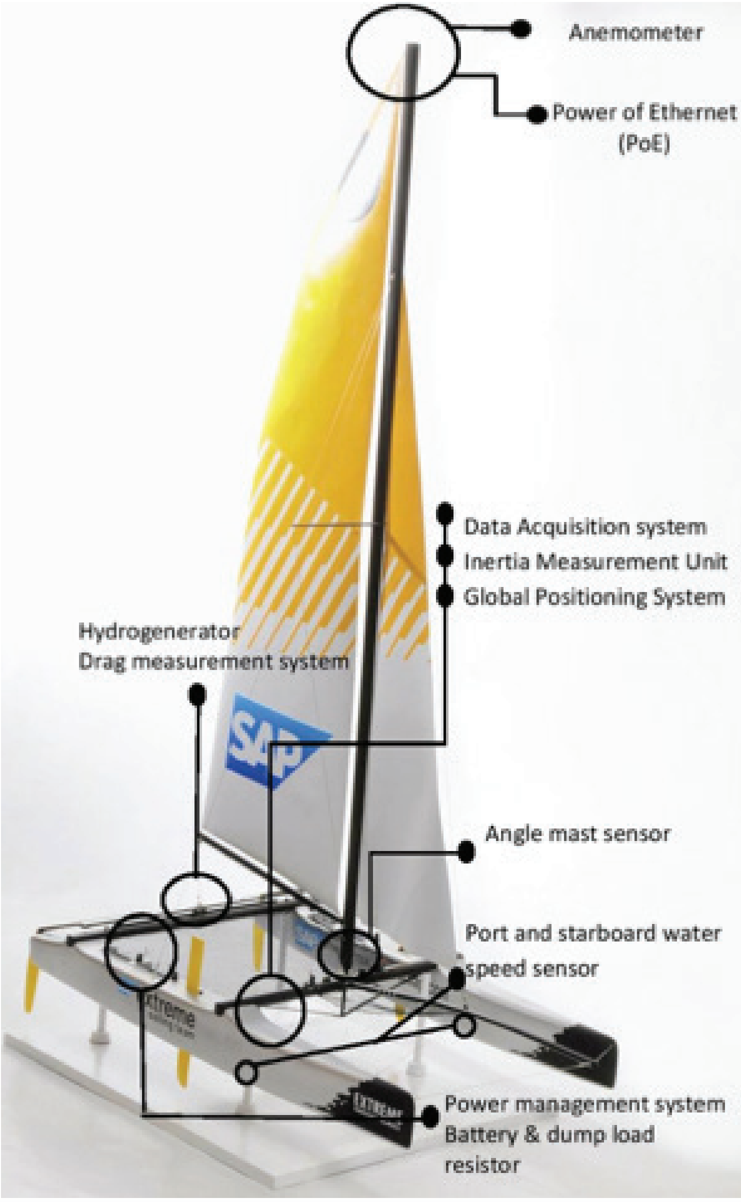


Figure 10.
Illustration of sensors location.

3. RESULT AND DISCUSSION

Four test was conducted to check the workability of the energy ship system and the platform as well as the data acquisition system and labelled as Run02, Run03 and Run04. A few results of trajectory of energy ship and speed can be visualised in Figure 11 and Figure 12. The trials were carried out in light wind conditions (1 to 7 m / s), without current. The control setting of the hydro generator was modified in order to study its effect on production energy. The hydro generator was controlled remotely, allowing the crew to focus on navigating the sailing ship.

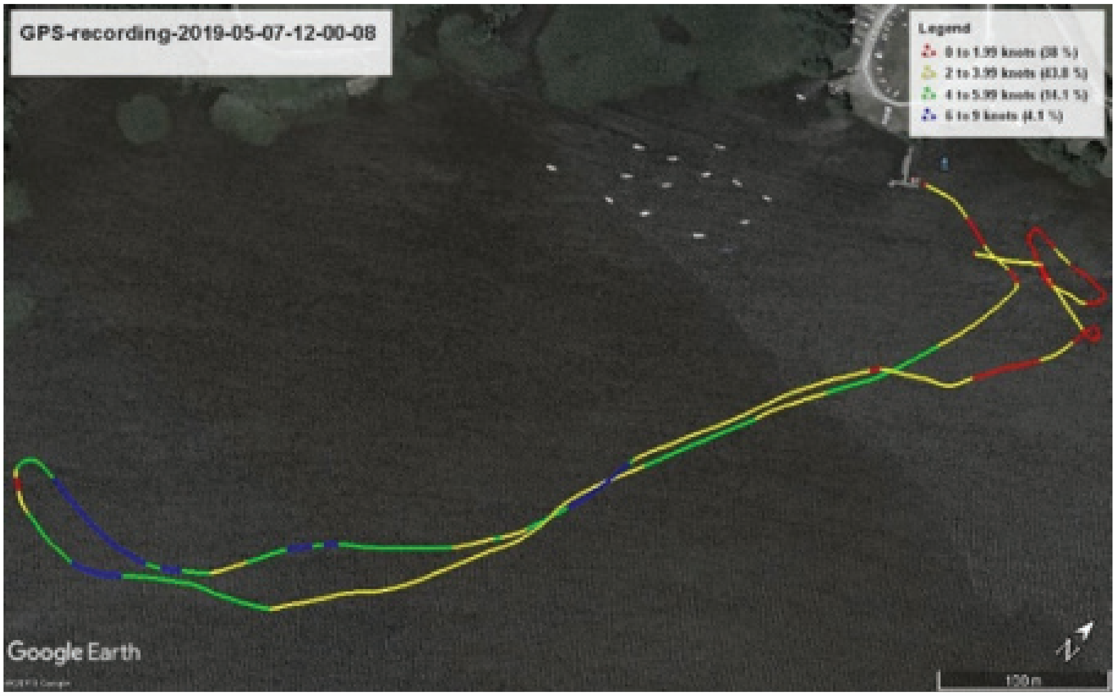
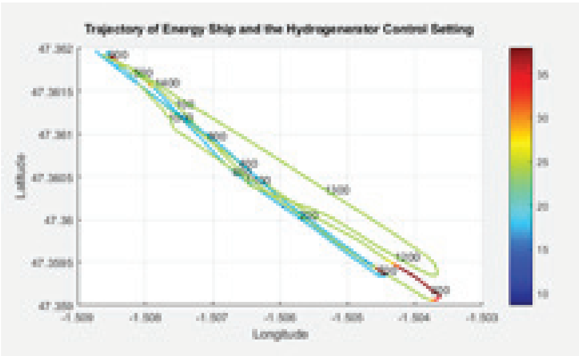


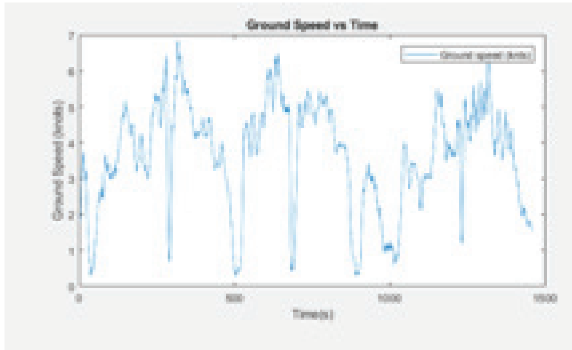
Figure 11.
Example of ship trajectory and speed measured during the trial. The colors indicate the speed of the sailing ship. Background and map image using Google Earth.

Figure 12.
Example of ship trajectory and speed measured during the trial. The colors indicate the speed of the sailing ship. Background and map image using Google Earth.

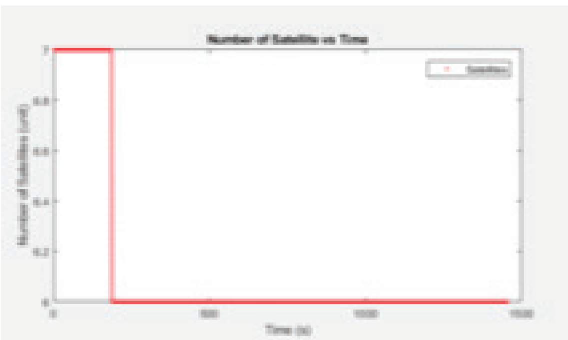
Sample of parameters recorded during the test by the data acquisition system can be visualized in Figure 13. Figure 13 (a) shows the ship trajectory with different hydrogenator control setting meanwhile Figure 13 (b) represents the ship speed during the testing which depended on the speed of the wind. Higher wind speed will produce higher ship speed. More number of satellites will produce more accurate data and this can be viewed in Figure 13 (c). Overall, seven satellite signals were captured during the testing. Figure 13 (d) shows the direction of the sailing ship which were in line the position of the ship that was mentioned earlier in 13 (a). Figure 13 (e) and (f) show the reading of hydrogenator power and battery voltage of the energy ship respectively that correlated with the wind speed. Other than that, Figure 13 (g) represents the corrected wind direction which was adjusted by mast angle sensor throughout the testing. The wind speed influences the speed of the ship and the electrical power production of the energy ship as shown in Figure 13 (h).



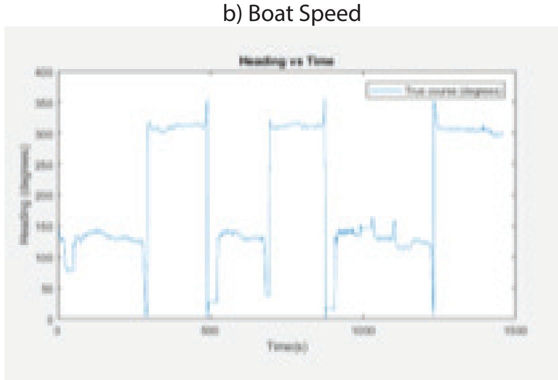
a) Longitude and Latitude



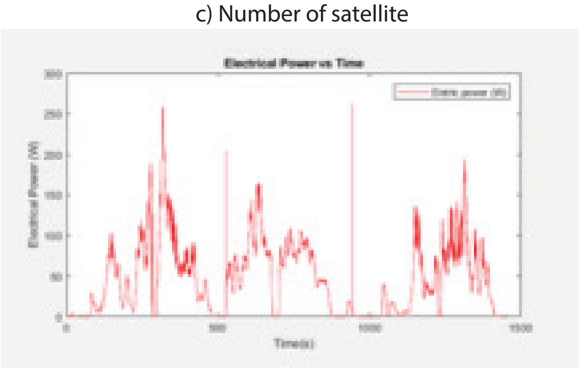
b) Boat Speed



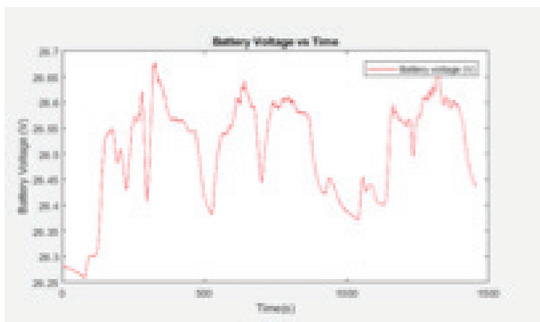
c) Number of satellite



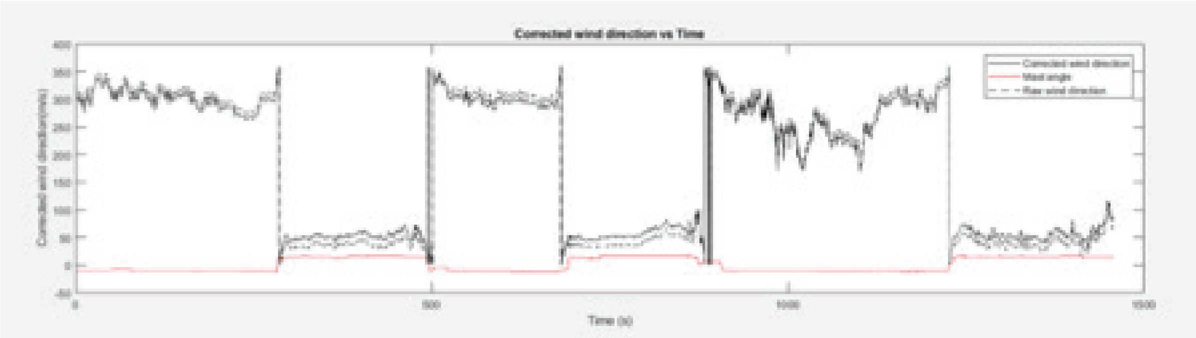
d) Heading



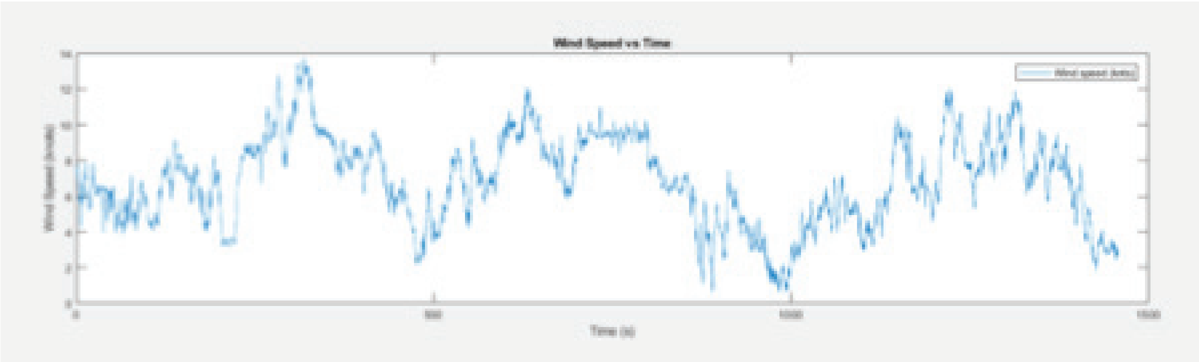
e) Hydrogenerator Power



f) Battery voltage



g) Wind direction



h) Wind speed

Figure 13.
Sample of parameters recorded by data acquisition system.

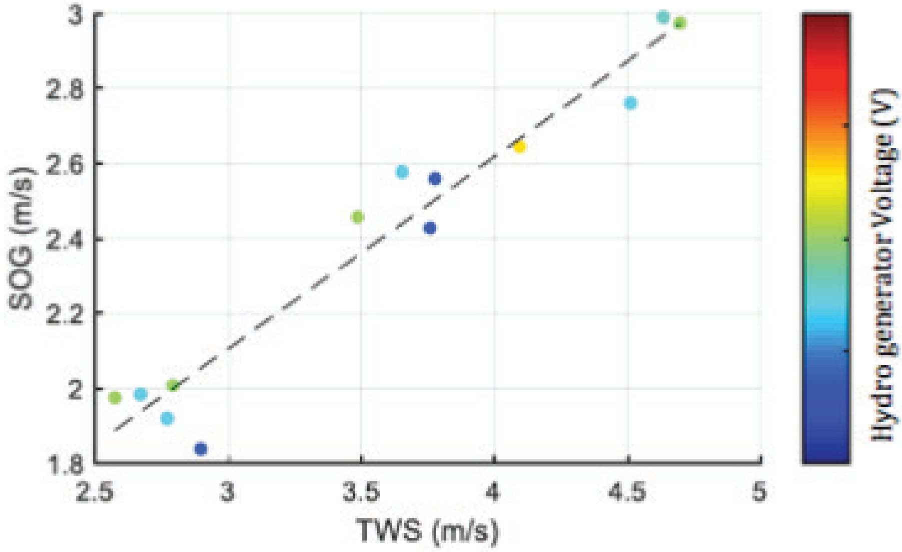


Figure 14.
(SOG) versus wind (TWS), with Hydro generator in operation (SOG ≈ 0.5110 X TWS + 0.5738).

Figure 14 represents the average speed of the energy ship in function of the average true wind speed and the voltage of the hydro generator. The average wind speed over the data ranges selected ranged between 2.5 and 5.0 m / s. Note that a good approximation of the ship's speed is half of the real wind when the hydro generator is in operation. The formula given in Figure 14 can be used to estimate the speed of a ship and subsequently estimate the electrical power produced by an energy ship as shown in Figure 5.

4. CONCLUSION

This trial campaign successfully demonstrates the principle of energy ship or wind powered vessel. The amount of power that can be produced by this prototype is about 600W for the true wind speed, 11 m/s. Results obtained prove that an energy ship concept is able to produce significant amount of energy. For future studies, the usage of control pitch propeller and bigger diameter of propeller are proposed to be investigated.

ACKNOWLEDGEMENT

Highest appreciation for Dr Aurelien Babarit for knowledge sharing and guidance, LHEAA, Ecole Central Nantes, Naval Group and National Defence University of Malaysia for the sponsorship my studies in ECN.

REFERENCES

Babarit, A., Clodic, G. and Gilloteaux J-C., 2019. A new energy system for sustainable methanol production from the far-offshore wind energy resource.

Babarit, A., et al., 2020. Validation experimentale du principe du voilierhydrolienne pour la recuperation de l'energie du vent en haute mer. Proceedings of 17emes Journees De L'hydrodynamique JH2020,Cherbourg, 24-26 November 2020.

Charrier, B., 1979. Etude theorique et experimental de l'effet Magnus destine a la propulsion des navires. PhD thesis, Universite de Paris VI. (In French).

Gilloteaux, J.-C. & Babarit, A., 2017. Preliminary Design of a Wind Driven Vessel Dedicated to Hydrogen Production. Volume 10: Ocean Renewable Energy. Available at: http://dx.doi.org/10.1115/omae2017-61408.

Gizara, A.R., 2007. Turbine integrated hydrofoil. Patent US2007/0046028A1.

Hydrodynamic in Advance Sailing Design, 1997. Twenty-First Symposium on Naval Hydrodynamics. Available at: http://dx.doi.org/10.17226/5870.

ITTC, 2014. General guidelines for uncertainty in resistance tests. ITTC-Recommended procedures 7.5-02-02-02.

Kim, J. & Park, C., 2010. Wind power generation with a parawing on ships, a proposal. Energy, 35(3), pp.1425–1432. Available at: http://dx.doi.org/10.1016/j.energy.2009.11.027.

Meller, M., 2006. Wind powered linear motion hydrogen production systems. Patent US7416918B2.

Ouchi, K. & Henzie, J., 2017. Hydrogen generation sailing ship: Conceptual design and feasibility study. OCEANS 2017 - Aberdeen. Available at: http://dx.doi.org/10.1109/oceanse.2017.8084808.

Pelz, P.F., Holl, M. & Platzer, M., 2016. Analytical method towards an optimal energetic and economical wind-energy converter. Energy, 94, pp.344–351. Available at: http://dx.doi.org/10.1016/j.energy.2015.10.128.

Roshamida, A.J. et al., 2019. Comparison of the capacity factor of stationary wind turbines and weather-routed energy ships in the far-offshore. EERA Deepwind 2019, Trondheim Norway.

Solomon, R.E., 1982. Process of converting wind energy to elemental hydrogen and apparatus therefor. US Patent 4335093A.

Risk Assessment of Wave Energy Converter At Kuantan Port, Pahang

Muhammad Asyraf Abdullah[a], Noh Zainal Abidin[b], Zulkifly Mat Radzi[b], Mohd Arif Ahmad[b], Vikneswaran Munikanan[a], Mohd Norsyarizad Razali[b], Neza Ismail[a]

Harvesting energy from ocean waves remains an untapped resource, and it is considered a new methodology in renewable energy, especially in Malaysia. This research is based on a project at Kuantan Port that used Wave Energy Converter (WEC) as a platform to generate energy from waves and convert it into electricity. The purpose of this research is to conduct a risk assessment before the execution of the project by referring to the International Organization for Standardization (ISO) 31000 and Risk Management Guidelines: Companion to AS/NZS 4360:2004. It started from risk identification and planned a mitigation way to reduce the grade of risk. These mitigations will be monitored throughout the project to avoid any accidents or harm during construction and installation in the future. The assessment will be using a qualitative analysis method that will gather all the possible risks that impact the project and propose the actions to mitigate the risk. The assessment will also consider the likelihood, seriousness, and weightage to determine the risk level. The risk assessment is divided into six clusters: project management, hydrography, mechanical, electrical, civil, and safety and security. After analysis, each cluster has given their feedback on the risk assessment and their cluster-s risk grade. This research has found that the risk grade is at grade C, which needs the risk assessment of this project to reduce the likelihood, seriousness, and required mitigation actions. Eventually, after the mitigation plan is applied to each risk, the grade of risk is reduced to N.

KEY WORDS

~ Renewable Energy
~ Wave Energy Converter
~ Risk Assessment
~ Risk Mitigation
~ Qualitative Analysis

a. National Defence University of Malaysia, Faculty of Engineering

e-mail: asyraf.abdullah93@gmail.com

b. National Defense University of Malaysia, Faculty of Science and Defense Technology

e-mail: zulkifly@upnm.edu.my

doi: 10.7225/toms.v10.n02.002

Received on: 11.06.2021 / Revised on: 29.07.2021 / Accepted on: 19.10.2021 / Published: 21.10.2021

1. INTRODUCTION

Renewable energy has emerged to become an integral option to replace traditional options, fossilized fuel. Ocean waves have been proved to evolve as a marine renewable energy source, and harvesting energy remains an untapped resource. It is still considered a new methodology in renewable energy, especially in Malaysia. It is estimated that harvesting energy from waves can supply approximately 1 and 1.5 times the world's consumption. However, most of this resource is currently technically unreachable or located remotely from the human community, and only 10% to 25% of electricity may be realistically generated from it (Ferro, 2006).

The marine renewable energy industry is about 10-15 years behind the wind renewable energy industry. The technology is still considered new, and there would be many obstacles within it, such as its predictability, manufacturability, installability, operability, survivability, reliability, and affordability (Mueller & Wallace, 2008).

Since the industry and technology are somewhat new, there will be many indecisions, thus creating risks. Risks can be described as the chance of something happening that will impact the objectives and often specified in terms of an event or circumstance and the consequences that may result from it (AS/NZS4360, 2004).

Risk assessment and analysis are applied as a vital decision support tool to predict all the uncertainties, anticipate the probable outcome, and establish guided mitigating procedures (Okoro et al., 2017). It can be commenced with variable degrees of detail and complexity, reliant on the purpose of the analysis, the availability and dependability of the information, and the resources existing. Analysis methods can be qualitative, quantitative, or combined, depending on the situations and planned use (BSI, 2018). Therefore, an adequate risk assessment is required to mitigate the risks that emerge from the uncertainties. The risk assessment flow consists of identifying risks, as well as analyzing, evaluating, and mitigating them.

This research is based on UPNM's project at Kuantan Port that has used Wave Energy Converter (WEC) as a platform to harvest energy from ocean waves and convert it into electricity. A risk assessment is conducted before the project's execution and will act as initial risk identification. It is then to be mitigated and then compared before and after the mitigation. The risk assessment is divided into six clusters: project management, hydrography, mechanical, electrical, civil, and security and safety. However, there have been limitations to this research. Considering the risk assessment is conducted before the project's execution, and the list of the risks is through brainstorming sessions between the team, there are maybe risks that are not listed and are not expected to happen. The newer risks will be updated and registered in the future.

2. METHODOLOGY

The qualitative analysis utilizes words to represent the potential outcome's Seriousness and the Likelihood that the outcome will occur. It may be used as a preliminary measure to identify risks that require a more thorough analysis. The analysis is suitable for decisions or where the numerical data or resources are inadequate for a quantitative analysis (AS/NZS4360, 2004).

The qualitative analysis assessment method is crucial to decide the significance of risks and identify which ones need to be treated before other risks. It relies on some computational and graphical tools (Keshk et al., 2018).

Using qualitative analysis allows for identifying the risk's priority, provides for the determination of areas of more considerable risk in a short time and without more significant expenditures, and the analysis is comparatively easy and inexpensive (Sung, 2015). Meanwhile, the drawback of using qualitative analysis is that it does not allow for allocating likelihoods and results by using numerical methods. The cost-benefit analysis is more difficult during the selection of mitigations (Sung, 2015).

A matrix of Seriousness and Likelihood can define the risk to decide the grading for each risk that will provide a ranking of the project risk exposure at the time of the assessment.

The term likelihood refers to the probability of something happening, whether defined, measured, or decided objectively or subjectively, qualitatively or quantitatively, or defined using general terms or mathematics (Standard, 2014). Seriousness is a term of the consequence of an event that will be affecting goals, can lead to a range of Seriousness, can be sure or unsure, and can have positive or negative effects on the plans. It can be expressed qualitatively or quantitatively, and initial consequences can heighten through knock-on effects (Standard, 2014).

For this research, the Likelihood and Seriousness rating for each risk is shown in Table 1 and Table 2, respectively.

Table 1.
Rating for Likelihood for each risk (AS/NZS4360, 2004).

Descriptive	Definition
High	It can be predicted to occur during the project
Medium	Not predicted to occur during the project
Low	Plausible but highly unlikely to occur during the project

Table 2.
Rating for Seriousness for each risk (AS/NZS4360, 2004).

Descriptive	Definition
Extreme	Most objectives cannot be accomplished
High	Some important objectives cannot be accomplished
Medium	Some objectives affected
Low	Slight effects that are easily mitigated

A rating of the risk rating is determined by the combination matrix of the rating level for Likelihood and Seriousness rating. The combination matrix is shown in Table 3.

Grading of the risk is identified by the combination of rating for Likelihood and Seriousness. The grade is rated from Grade A, B, C, D, and N. The grade is then weighted as numerical values to ease determining the grade for the project's overall risks and the mitigation actions that need to be taken. The weightage values are rated from 5, 4, 3, 2, and 1, respectively. The grade of the risk is shown in Table 4.

Table 3.
Combination matrix for grading of risk (AS/NZS4360, 2004).

	Seriousness				
		Low	Medium	High	Extreme
Likelihood	Low	N	D	C	A
	Medium	D	C	B	A
	High	C	B	A	A

Table 4.
Rating for the grade of the risk (AS/NZS4360, 2004).

Grade	Risk mitigation actions	Weighted
A	Mitigation actions, to decrease the Likelihood and Seriousness, to be identified and implemented as soon as the project commences as a priority	5
B	Mitigation actions, to decrease the Likelihood and Seriousness, to be identified and appropriate measures implemented during project execution	4
C	Mitigation actions, to decrease the Likelihood and Seriousness, to be identified and evaluated concerning costs for possible action if funds permit	3
D	To be noted – no action is needed unless grading increases over time	2
N	To be noted – no action is needed unless grading increases over time	1

3. RESULT AND ANALYSIS

For this research, there are six clusters involved in the project: Project Management Team, Hydrography Team, Mechanical Team, Electrical Team, Civil Team, and Security and Safety Team. Each cluster is assigned to one leader and a team consisting of five team members.

For the risk assessment, each team leader and their members are needed to determine the risks for their respective team, assess the impact of the risks to the project, give grading to the risks before mitigation is performed, determine the mitigation actions that need to be done to contain the risks, and give back the rating of grading of the risks after mitigation steps have occurred. The total grading of the project risks for each cluster is determined from the total grade average. Some of the risks from each cluster are shown in the tables below.

Table 5.
Risk on Project Management Team.

			BEFORE MITIGATION					AFTER MITIGATION			
ID	**DESCRIPTION OF RISK**	**IMPACT ON PROJECT**	**L**	**S**	**G**	**W**	**MITIGATION ACTIONS**	**L**	**S**	**G**	**W**
1	Hazards during construction and transportations at sea	Lead to worker accidents and injuries	M	M	C	3	Supplier responsibility in contract	L	L	N	1
2	Damage or theft to equipment and tools	Effects on the process of construction and installation	M	M	C	3	Supplier responsibility in contract	L	L	N	1
3	Natural disasters, e.g., Typhoon, Monsoon	The breakwater and ships nearby may be hit by the WEC platform	M	H	B	4	Dual safety design element	L	M	D	2
4	No ownership of the project after completion for operation and maintenance of WEC	No responsible parties to take over the project after completion	L	M	D	2	Obtaining specific agreement with KETSA on post-construction ownership and maintenance	L	L	N	1
5	Loose WEC platform may block the channel of Kuantan Port	Effect on Kuantan Port productivity in terms of number of ships coming alongside	L	M	D	2	The mooring chain design for WEC can withstand Extreme Wave Condition and hold the WEC as firm as possible. Besides, the location of WEC is outside the breakwater, not on the ship	L	L	N	1
		Project grade of risk before mitigation	**2.8**				**Project grade of risk after mitigation**	**1.2**			

Table 6.
Risk on Hydrography Team.

			BEFORE MITIGATION					AFTER MITIGATION			
ID	**DESCRIPTION OF RISK**	**IMPACT ON PROJECT**	**L**	**S**	**G**	**W**	**MITIGATION ACTIONS**	**L**	**S**	**G**	**W**
1	Validity and reliability of Oceanography Data Collected in terms of Depth, Wave Period, Wave Height, Current, Tide, Weather	The design of WEC will be affected and will not comply with the WEC specification requirement	M	M	C	3	The data collection and modeling have to be carried out by a qualified person and validated by Project Team – Team Leader is a Qualified Hydrographic Surveyor Category A	L	L	N	1
2	The quality and credibility of the hydrography surveyor standard	The data obtained is not reliable	L	M	D	2	The data collection and modelling have to be carried out by a qualified person and validated by Project Team – Validation has been carried out by Project Team Leader who is a Qualified Hydrographic Surveyor Category A	L	L	N	1
3	Calibration of instruments and measuring tools used	It will affect the reliability and accuracy of data collected	L	M	D	2	The equipment used is calibrated and function well before data collection. The accuracy standard is as follows: - Velocity Accuracy: 1% of measured value ± 0.5cm - Wave Height Accuracy: <1% of the measured value - Compass Accuracy: 2° - Pressure Accuracy: 0.5% of full scale - Temperature Accuracy: 0.1°C				
4	Suitability of WEC site location	Unable to obtain the required depth and wave characteristics for operation ability of WEC	L	M	D	2	Site suitability identification was made using modelling, carried out by the Meteorology Department and on-site data collection to confirm the modelling result. - Water depth range: 15.07m to 17.18m - Wave peak period range: 2.18s to 15.52s - Significant wave height range: 0.14m to 1.10m				
5	Disturbance to ecosystem	It will affect the ecosystem of surrounding areas (sea heritage)	L	M	D	2	Shall be assessed by research method	L	L	N	1
		Project grade of risk before mitigation	**2.2**				**Project grade of risk after mitigation**	**1.0**			

Table 7.
Risk on Mechanical Team.

			BEFORE MITIGATION					AFTER MITIGATION			
ID	**DESCRIPTION OF RISK**	**IMPACT ON PROJECT**	**L**	**S**	**G**	**W**	**MITIGATION ACTIONS**	**L**	**S**	**G**	**W**
1	The failure of mechanical parts to produce the required torque output to the motor	Unable to achieve the sufficient power output of WEC	L	L	N	1	The location's actual wave characteristics need to be finalized, and the overall system is to be designed according to the estimated output. Irregular wave conditions at sea should produce higher output compared to the theoretical calculations	L	L	N	1
2	The corrosion of WEC platform due to seawater condition	It will cause severe defects to the WEC hull plating, can cause the WEC to be capsized and sink	M	H	B	4	Layering and coating the WEC platform and the equipment with anti-rust paint and zinc anode	L	L	N	1
3	Mooring cable corroded and parted	Lead to mooring line breakage and harm to the ships and port nearby due to collision	M	E	A	5	Layering and coating the mooring line and the equipment with anti-rust paint and with a detailed mooring line analysis by an experienced industry partner	L	L	N	1
4	Instability of WEC and risk of capsize	Lead to WEC sink	L	H	C	3	HAT and SAT is to be carried out on installations to ensure that they are safe and meet the design requirements before commissioning	L	M	D	2
5	WEC unable to withstand to Extreme Wave Condition due to Monsoon or Typhoon	Broken and damaged WEC and can cause a collision to ships and port nearby	L	E	A	5	HAT and SAT are to be carried out on installations to ensure that they are safe and meet the design requirements. Stability analysis on the WEC by naval architect based on the extreme wave conditions analysis	L	M	D	2
		Project grade of risk before mitigation	**3.6**				**Project grade of risk after mitigation**	**1.4**			

Table 8.
Risk on Electrical Team.

			BEFORE MITIGATION					AFTER MITIGATION			
ID	**DESCRIPTION OF RISK**	**IMPACT ON PROJECT**	**L**	**S**	**G**	**W**	**MITIGATION ACTIONS**	**L**	**S**	**G**	**W**
1	The power generation system fails to generate the required output power	Unable to achieve the necessary power output and will need the power supply support from Kuantan Port	H	H	A	5	Hybrid with the solar panel which can provide an alternative power source. The power generator must be tested with a WEC prototype so that the output can be predicted and selection of a suitable size generator for the actual application made.	L	L	N	1
2	Motor generator wear and tear due to seawater condition	WEC unable to operate	L	E	A	5	Use a special casing of marine spec to avoid corrosion. IP65 Steel Enclosures, Electrical Enclosure Standard: IEC62208, IEC/EN/AS6052	L	L	N	1
3	The underwater cable is defective and disconnected	Lead to current leakage that harms the aquatic flora and fauna. Will interfere with the shipping route and port activities	L	E	A	5	Fabricate with a particular outer layer of cable which can sustain the impact with a maximum of 200MPa	L	L	N	1
4	Stator winding/ coil (motor) is defective	Unable to generate power	L	H	C	3	Ensure the generator spec according to marine use, which is 3 phase induction generators with compliance built to IEC 60034 international classification	L	L	N	1
5	Low insulation of the electrical system	Lead to current leakage and harm the life span of motor-generator	L	M	D	2	The design must follow the TNB requirement	L	L	N	1
		Project grade of risk before mitigation	**4.0**				**Project grade of risk after mitigation**	**1.0**			

Table 9.
Risk on Civil Team.

			BEFORE MITIGATION					AFTER MITIGATION			
ID	**DESCRIPTION OF RISK**	**IMPACT ON PROJECT**	**L**	**S**	**G**	**W**	**MITIGATION ACTIONS**	**L**	**S**	**G**	**W**
1	Unstable mounting of cable layout on the breakwater structure	The cable will deteriorate and be damaged, possibly lead to a current leakage	L	H	C	3	Testing and commissioning is to be carried out on installations to ensure that they are safe and meet the design requirement	L	L	N	1
2	Improper submarine cable mounting on the seabed	Unable to hold the position of submarine cable and lead the cable towards WEC. It will also increase tension and stress on the cable and lead to cable fracture	M	M	C	3	Provide suitable length to uphold the tension and stress during the design	L	L	N	1
3	Bad mounting of mooring block on the sea bed	Changes in the positioning of the anchor block will affect the operation of WEC, create tension force on the mooring cable, thus risking it being broken	L	H	C	3	Prepare expert's advice during the construction	L	L	N	1
4	WEC platform collide with the breakwater structure	WEC slamming to the breakwater structure and damaging the whole WEC platform, and the breakwater structure	L	H	C	3	Prepare enough buffer distance between the WEC platform and the breakwater structure	L	L	N	1
5	The location of the mooring block at the seabed is not suitable	Will affect the operation of WEC and be unable to achieve sufficient power output	L	M	D	2	Do a thorough investigation of the seabed surface before installation	L	L	N	1
		Project grade of risk before mitigation	**2.8**				**Project grade of risk after mitigation**	**1.0**			

Table 10.
Risk on Safety and Security Team.

ID	DESCRIPTION OF RISK	IMPACT ON PROJECT	BEFORE MITIGATION L	S	G	W	MITIGATION ACTIONS	AFTER MITIGATION L	S	G	W
1	Accident or emergency cases at the site area	Harm worker life during Installation and WEC operation	L	H	C	3	Apply the assistant of expertise OSHA Standard (for exp: Safety Officer)	L	L	N	1
2	Lack of security and safety system during WEC construction and operation	The WEC or integrated equipment can be stolen by theft or local people	M	H	B	4	Establish Site Office and Watchkeeper, Assistant by Maritime Agencies such as RMN, APMM, and Marine Police	L	L	N	1
3	Loss of accessories and equipment of WEC platform from theft	WEC unable to operate and generate the required power	L	H	C	3	Establish Site Office and Watchkeeper, Assistant by Maritime Agencies such as RMN, APMM, and Marine Police	L	L	N	1
4	Loss of accessories and equipment of battery house from theft	WEC unable to operate and generate the required power	L	H	C	3	Establish Site Office and Watchkeeper, Assistant by Kuantan Port security and equipped the battery house with CCTV	L	L	N	1
5	Risk of a collision on the WEC platform by ships in the areas	Effects on the safety of Kuantan Port route	L	E	A	5	Placement of specific lightings on WEC, usage of the particular colouring of the WEC buoy, giving notice to Mariners, establishing symbol in the Kuantan Nautical Chart, and making sure that the WEC is following Marine Department rules and regulation	L	M	D	2
		Project grade of risk before mitigation	**3.6**				**Project grade of risk after mitigation**	**1.2**			

The project grade of risk can be determined from and after the mitigation action occurs from the risks obtained from each cluster or team above. The summary of the project grade is shown in the tables below.

Table 11.
Project grade for each team before mitigation.

BEFORE MITIGATION		
No.	**Risk Group**	**Grade**
1.	Project Management	2.8
2.	Hydrography	2.2
3.	Mechanical	3.6
4.	Electrical	4.0
5.	Civil	2.8
6.	Safety and Security	3.6
Average Risk Grade		**3.17**

Table 12.
Project grade for each team after mitigation.

AFTER MITIGATION		
No.	**Risk Group**	**Grade**
1.	Project Management	1.2
2.	Hydrography	1.0
3.	Mechanical	1.4
4.	Electrical	1.0
5.	Civil	1.0
6.	Safety and Security	1.2
Average Risk Grade		**1.13**

The maximum grade of the risk before mitigation is allocated at grade 5, which represents mitigation actions, to reduce the Likelihood and Seriousness, to be identified and implemented as soon as the project commences as a priority. A benchmark of 2.5 is allocated after mitigation, half of the maximum grade of the risk. A set of a graph from before and after each group's mitigation action is shown in the figures below.

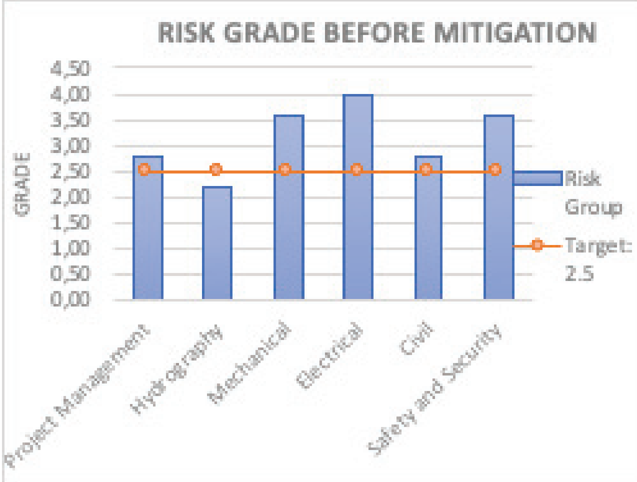


Figure 1.
Graph of risk grade before mitigation.

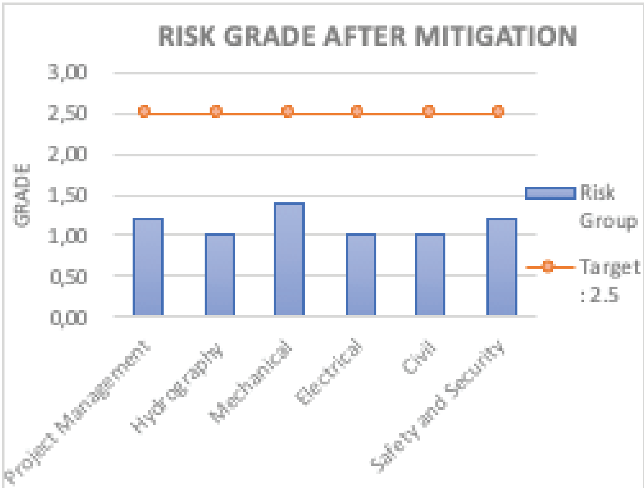


Figure 2.
Graph of risk grade after mitigation.

4. DISCUSSION

From the data obtained in the results and analysis, this research can concur that the risk is tolerable even before mitigation actions occur. Each team leader and their team members had given their feedback alongside the mitigation actions that need to be done to curb the risks.

By the project management team, the average project risk is graded at 2.8, which refers to Table 4, which is weighted at Grade C. It states that the mitigation actions decrease the Likelihood and Seriousness. It needs to be identified and its cost evaluated for possible action if funds permit. After mitigation action has been taken, the average project risk is graded at 1.2, and it is weighted at Grade N. It shows that no action is needed unless grading should increase over time.

For the hydrography team, the average project risk is graded at 2.2, as shown in Table 4, which is weighted at Grade D. It states that no action is needed unless grading is increasing over time. After mitigation action has been taken, the average project risk is graded at 1.0, and it is weighted at Grade N. It shows that no action is needed unless grading should increase over time.

By the mechanical team, the average project risk is graded at 3.6, as shown in Table 4, which is weighted at Grade B. It states that it needs to decrease the Likelihood and Seriousness to be identified, and appropriate actions need to be implemented during project execution. After mitigation action has been taken, the average project risk is graded at 1.4, and it is weighted at Grade N. It shows that no action is needed unless grading should increase over time.

By the electrical team, the average project risk is graded at 4.0, the highest amount of risk. As shown in Table 4, it is weighted at Grade B. It states that it needs to decrease the Likelihood and Seriousness, be identified, and appropriate actions need to be implemented during project execution. After mitigation action has been taken, the average project risk is graded at 1.0, and it is weighted at Grade N. It shows that no action is needed unless grading should increase over time.

By the Civil team, the average project risk is graded at 2.8, as shown in Table 4, which is weighted at Grade C. It states that the mitigation actions decrease the Likelihood and Seriousness, it needs to be identified and evaluated in terms of cost for possible action if funds permit. After mitigation action has been taken, the average project risk is graded at 1.0, and it is weighted at Grade N. It shows that no action is needed unless grading should increase over time.

Lastly, by Safety and Security Team, the average project risk is graded at 3.6, as shown in Table 4, which is weighted at Grade B. It states that it needs to decrease the Likelihood and Seriousness to be identified, and appropriate actions need to be implemented during project execution. After mitigation action has been taken, the average project risk is graded at 1.2, and it is weighted at Grade N. It shows that no action is needed unless grading should increase over time.

From the total project risk of the overall team, this project is graded at 3.17, which is shown Table 4. It is weighted at Grade C. It states that the mitigation actions decrease the Likelihood and Seriousness. It needs to be identified and evaluated in terms of cost for possible action if funds permit. After the mitigation action has been taken, the overall average project risk is graded at 1.13. It is weighted at Grade N. It shows that no action is needed unless grading should increase over time.

5. CONCLUSION

Risk assessment has proven as a necessity before executing this project. It has given a general presumption of the possible risks, and necessary action must be taken to control the risks. From the risk assessment, the project's total risk grade before mitigation is 3.17 at Grade C. The project's entire risk grade after mitigation is 1.13, which is at Grade N. The required allowable grade for the project should be less than 2.5, half of the maximum Grade A weighting at 5. In conclusion, this project is recommended to be carried out within Grade N of risk. All the mitigation procedures will be complied with, and no action is needed unless grading should increase over time.

ACKNOWLEDGEMENT

This paper is a part of the multidisciplinary research project of “Development of Optical Heave Buoy Wave Energy Converter (WEC) and is supported by the Ministry of Water, Land, and Natural Resources under grant H0001 – UPNM/2018/AAIBE-KETTHA/TK/1/P6. The authors would like to thank everyone involved directly or indirectly or who have in any way assisted in this paper's making.

REFERENCES

AS/NZS4360, 2004. Risk Management Guidelines Companion to AS/NZS 4360:2004. Nature, 428(6983), pp.592–592.

BSI, 2018. BS ISO 31000 - 2018 BSI Standards Publication Risk management — Guidelines. BSI Standards Publication, p.26.

Ferro, B.D., 2006. Wave and tidal energy. Refocus, 7(3), pp.46–48. Available at: http://dx.doi.org/10.1016/s1471-0846(06)70574-1.

Keshk, A.M., Maarouf, I. & Annany, Y., 2018. Special studies in management of construction project risks, risk concept, plan building, risk quantitative and

qualitative analysis, risk response strategies. Alexandria Engineering Journal, 57(4), pp.3179–3187. Available at:
http://dx.doi.org/10.1016/j.aej.2017.12.003.

Mueller, M. & Wallace, R., 2008. Enabling science and technology for marine renewable energy. Energy Policy, 36(12), pp.4376–4382. Available at:
http://dx.doi.org/10.1016/j.enpol.2008.09.035.

Okoro, U., Kolios, A. & Cui, L., 2017. Multi-criteria risk assessment approach for components risk ranking – The case study of an offshore wave energy converter. International Journal of Marine Energy, 17, pp.21–39. Available at:
http://dx.doi.org/10.1016/j.ijome.2016.12.001.

Standard, D. of M., (2014). Malaysian Standard 1525:2014.

Sung, S.H., 2015. Quantitative and Qualitative Approach for IT Risk Assessment. Asia-pacific Journal of Convergent Research Interchange, 1(1), pp.29–35. Available at:
http://dx.doi.org/10.21742/apjcri.2015.03.04.

Weight of Evidence Approach to Maritime Accident Risk Assessment Based on Bayesian Network Classifier

Ana Kuzmanić Skelin[a], Lea Vojković[b], Dani Mohović[c], Damir Zec[c]

Probabilistic maritime accident models based on Bayesian Networks are typically built upon the data available in accident records and the data obtained from human experts knowledge on accident. The drawback of such models is that they do not take explicitly into the account the knowledge on non-accidents as would be required in the probabilistic modelling of rare events. Consequently, these models have difficulties with delivering interpretation of influence of risk factors and providing sufficient confidence in the risk assessment scores. In this work, modelling and risk score interpretation, as two aspects of the probabilistic approach to complex maritime system risk assessment, are addressed. First, the maritime accident modelling is posed as a classification problem and the Bayesian network classifier that discriminates between accident and non-accident is developed which assesses state spaces of influence factors as the input features of the classifier. Maritime accident risk are identified as adversely influencing factors that contribute to the accident. Next, the weight of evidence approach to reasoning with Bayesian network classifier is developed for an objective quantitative estimation of the strength of factor influence, and a weighted strength of evidence is introduced. Qualitative interpretation of strength of evidence for individual accident influencing factor, inspired by Bayes factor, is defined. The efficiency of the developed approach is demonstrated within the context of collision of small passenger vessels and the results of collision risk assessments are given for the environmental settings typical in Croatian nautical tourism. According to the results obtained, recommendations for navigation safety during high density traffic have been distilled.

KEY WORDS

~ Maritime collision model
~ Probabilistic modelling
~ Bayesian Network classifier
~ Weight of evidence
~ Bayes factor
~ Probabilistic reasoning

a. University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia

e-mail: akuzmani@fesb.hr

b. University of Split, Faculty of Maritime Studies, Split, Croatia

e-mail: lvojkovic@pfst.hr

c. University of Rijeka, Faculty of Maritime Studies, Rijeka, Croatia

e-mail: dani.mohovic@pfri.uniri.hr

doi:10.7225/toms.v10.n02.w07

Received on: 06.05.2021 / Revised on: 12.07.2021/ Accepted on: 24.08.2021 / Published online: 26.08.2021

1. INTRODUCTION

The expanding character of Croatian nautical tourism has led to a tremendous increase in maritime traffic density, which, in turn, has raised concerns regarding the navigational safety in the Croatian part of the Adriatic Sea basin. The authorities of the Republic of Croatia have adopted a great number of laws, regulations, and orders in the field of navigational safety; however, further work is needed to assess the safety and minimize the risk of accidents due to novel conditions, (Ministry of Sea & Tourism, 2008). Some important directions towards safety assessment include the development of computational risk evaluation approaches and risk factor identification models in accordance with maritime safety analyses and the assessment process formalized by International Maritime Organization (IMO) into Formal Safety Assessment (FSA) guidelines. FSA is organized into five sets of tasks: 1) hazard identification (HAZID), 2) risk assessment, 3) identification of risk control options, 4) cost/benefit assessment, and 5) recommendations for risk control, (Kontovas & Psaraftis, 2009). Different aspects of human expertise, the maritime domain knowledge and modelling of complex events related to maritime accidents should be unified to support safety risk assessment of FSA, particularly the HAZID, thus contributing towards the ultimate goal of facilitating activities of stakeholders involved in maritime traffic regulation and management. Human knowledge and experience, as well as expert judgments, are the most important sources of information for the risk assessment inline to definitions of FSA.

The mapping of the domain knowledge domain about a risk assessment have become formalized through a volume of diverse scientific computational approaches, such as machine learning and uncertainty analysis. A number of approaches to qualitative and quantitative knowledge modelling have been investigated in maritime domain, but also other environmental modelling and safety assessments domains, as presented in recent literature surveys, (Huang, et al., 2020), (Chen, et al., 2019), (Lim, et al., 2018). Particularly applicable to maritime domain are Bayesian Networks (BNs), (Pearl, 1988), (Pearl, 2000), which have been recognized as an efficient mathematical tool for modelling maritime accidents. Namely, Bayesian Networks (BNs), (Pearl, 1988), (Pearl, 2000), are directed graphical models which provide framework for accident modelling and analysis by supporting the representation of dependencies and interactions of random variables involved in the probabilistic socio-technical system, where random variables are interpreted as causal factors involved in the maritime accident. BNs have been widely applied over the past years to assess a variety of accident types and scenarios, (Hänninen & Kujala, 2012), (Zhang, et al., 2013), (Zhang, et al., 2018), (Baksh, et al., 2018). From an in-depth review of the literature on maritime accident risk models based on Bayesian Network given in (Zhang & Thai, 2016) and (Chen, et al., 2019), it can be observed that the methodological framework required for qualitative and quantitative model development is well defined.

However, challenges are still encountered in the modelling stage and at the inference level, i.e. in the stage of model deployment. Several challenges can be highlighted. Maritime accidents are rare events for which real-world data provides incomplete and insufficient statistical information, leaving a burden of parameter initialization to maritime experts and data engineers involved in the model development. Next, an influence factor identification metric is not clearly defined with respect to quantitative data, thus leading to poor interpretation of model responses. In order to obtain an assessment of factors influencing the behaviour of complex maritime system, the Bayesian network, as an expert system framework founded in data mining and machine learning, should deliver interpretable quantitative and qualitative scores in an inference task.

Specifically, in a BN inference task, the aim is to come up with an assessment of identified hazard factors by their influence. Commonly used quantitative measures of influence are based on sensitivity analysis or one-at-a-time (OAT) analysis for each individual hazard factor, (Hänninen & Kujala, 2012), (Sotiralis, et al., 2016), where influences are calculated as the difference of hard evidence, i.e. as a difference of state values. The output of these analysis reveals the range of change of the target variable of a model - the larger the output change, the higher the influence to a factor is assigned. OAT influences are often expressed as probabilities or frequencies, which are hard to interpret due to rare event characteristics of accidents, while uncertainty-based concepts like likelihoods are rarely used because of difficulties with qualitative interpretation of likelihood values, (Trucco, et al., 2008), (Chen, et al., 2019). Moreover, such measures do not deliver the information on whether the influence factor contributes favourably or unfavourably to the accident occurrence; nor do they provide any qualitative scores. Qualitative scores used for interpretation of influence factors in maritime domain have been previously addressed in (Mazaheri, et al., 2016), using subjective, expert elicited weights based on the uncertainty of experts' knowledge. We are not aware of other advancements along this line of research, even though the availability of objective qualitative interpretation is important for a wider acceptance and practical deployment of the probabilistic analysis of maritime accidents.

In our paper, we have introduced the weight of evidence (WoE) approach, (Good, 1985), (Osteyee & Good, 1974), a likelihood-based approach, and we have derived the strength of evidence (SoE) as a quantitative measure that enables an interpretation of influence factors by means of qualitative categories, inspired by Bayes Factor, which are easily comprehensible to users of different backgrounds. The introduction of WoE and SoE is made possible by conceptualizing the Bayesian network model as a Bayesian network classifier. Bayesian Network classifier, (Friedman, et al., 1997), (Chan & Darwiche, 2002), (Bielza & Larrañaga, 2014), represents a decision function that distinguishes accident influencing factor state spaces into those which contribute to an increased chance of accident and those which contribute to a reduction of the chance of accident. This conceptualization importantly differs Bayesian Network classifier model from the common practice Bayesian Network models which do not take into account the non-accident scenarios and thus cannot assess model factors discriminatively with respect to their dual influence on the outcome.

This paper contributes to a current probabilistic maritime accident modelling and assessment methodology by defining the maritime accident model as a binary classifier, by introducing the likelihood based inference measure, and providing the grading scale for influence factor interpretation. The overview of the complete framework for risk assessment proposed in this paper is summarized in Fig.1. In the first phase, the BN classifier is structured and parametrized based on an expert elicitation and available data records. Credibility assessment is performed to verify the behaviour of the BN classifier. In the second phase inference is performed based on developed strength of evidence measure. Accordingly, the rest of the paper is organized as follows: in Section 2. a short theoretical background of Bayesian network is introduced, and accident formulation as a binary classification problem is defined. Next, the weight of evidence approach is developed. In section 3. the explication of model development and credibility assessment are given. The results of the approach are demonstrated in Section 4. The concluding remarks are given in Section 5.

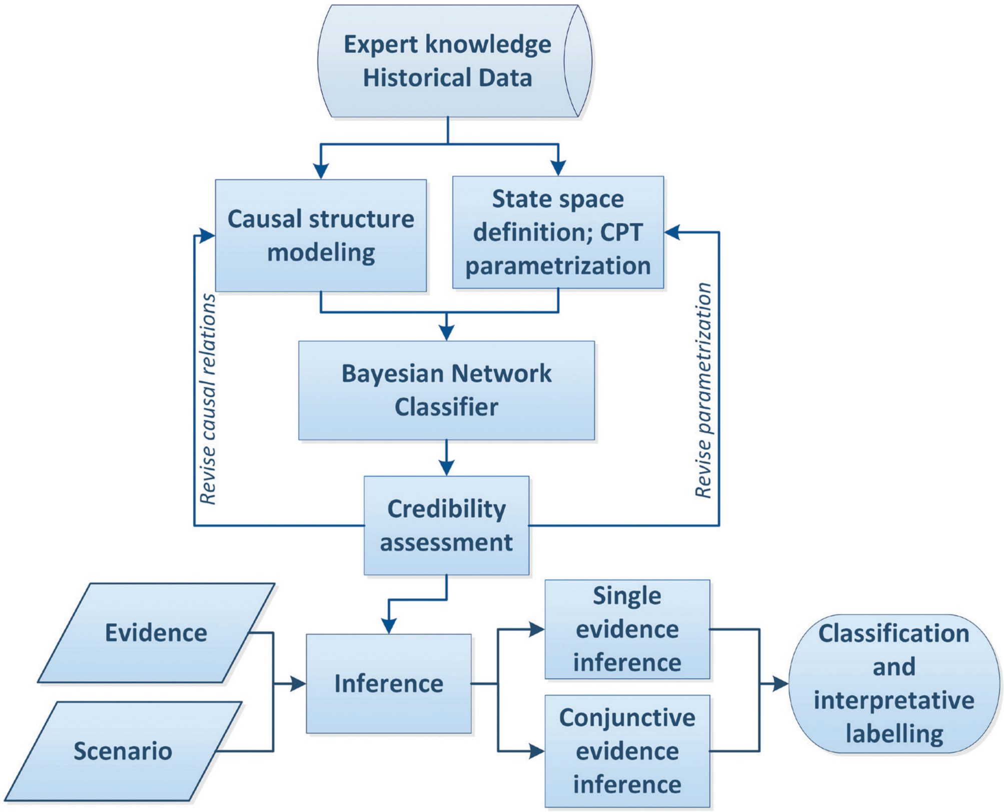


Figure 1.
The framework for influence factor assessment based on Bayesian Network classifier.

2. BAYESIAN NETWORK

Bayesian network, (Pearl, 1988), (Jensen & Nielsen, 2007), (Darwiche, 2014), offers a unified modelling framework that compensates for insufficiency of statistical information and uncertainty of expert knowledge and is thus able to encode sparse data and different aspects of experts' knowledge and beliefs about the maritime accidents. Bayesian network is formally defined as triplet (V, G, Θ). V denotes a set of n random variables $V = \{V_1, V_2, \ldots, V_N\}$, G is a directed acyclic graph whose nodes are members of V connected in such a way that each variable is conditionally independent of its non-descendants given its parents. Each directed edge represents a conditional dependence between parent-child node pair. Let the parents of $Vi \in V$ in G be denoted by $\pi(Vi)$; let Θ denote the set of local conditional probability distributions $\Theta = \{P(V_i | \pi(V_i)), V_i \in V\}$. Given (V, G, Θ), BN provides a joint probability distribution over the set of V as multiplication of a set of conditional probabilities:

$$P(V) = \Pi_{V_i \in V} P(V_i | \pi(V_i)) \quad (1)$$

A set of variables V is organized into three types of nodes: observable nodes, intermediary node, and target nodes, while variable dependencies are described with three causal classes: causal chain, common effect, and common cause, (Pearl, 2000). Observable nodes are nodes for which statistical data or strong knowledge is available, such as weather conditions, availability of technical equipment and similar. Intermediary nodes are unobservable or partly observable nodes, such as human factors, human related factors, technical related factors, etc., for which the experts' beliefs or limited historic data is available. The observable and intermediary nodes both form the set of influence nodes, and will be denoted by $X = \{ X_1, X_2, ..., X_n \}$, $n = N - 1, X \subset V$. The remaining variable from the set $V \setminus X$ is a target node, representing maritime accident decision node, and will be denoted as Y throughout the paper.

The process of development of Bayesian network is organized into tasks: domain knowledge is acquired, relevant hazard factors to constitute the set of variables V are identified and causally connected, and probabilities and conditional probabilities are assigned. An iterative process is required during the model development. Multiple revisions of associations that form the G and check of values in Θ are performed. Both qualitative and quantitative *BN* development follows good practice guidelines for BNs in safety and reliability analysis domains. The interested reader is referred to (Chen & Pollino, 2012), (Marcot & Penman, 2019), (Sigurdsson, et al., 2001).

2.1. Accident Formulation as a Binary Classification and Context Definition

Maritime accident BN models are typically built upon data available in accident records and data elicited from human expert knowledge of accident scenario. A drawback of approaches based on accident records and knowledge of accidents is that they do not take into account non-accidents, because there is not such data, (Stornes, 2015), and thus cannot provide sufficient confidence in estimating influencing factors. This point has been discussed concisely from a methodological viewpoint in (Øvergård,2015) In our paper we take on an approach that seeks to include the non-accident data as well through expert elicited data on non-accident. Therefore, we pose the accident modelling as a binary classification problem where two targeted states are "accident occurring" and "accident non-occurring". A modification of common approach is made at the point of data collection from experts, where the expert knowledge elicitation is made for accident and non-accident cases.

Since the BN framework supports the definition of probabilities as degrees of belief, the probabilities represented as the degree of belief are used to define probabilities of events that occur rarely or have not yet occurred. This way, non-accidents, for which no real-world data exists, can be defined by experts. Often applied frequentists definition of probability requires an event to have occurred enough times to allow the collection of accountable information which in this case is not possible as maritime accident is a rare event.

We seek the approach, the one that exploits the fact that experts can define non-accidents scenario and propose beliefs as inputs to BN accordingly. In our work, the risk assessment model reflects current navigational situation scenario in which a maritime accident is a rare event, thus the focus is on the modelling of the current state-of-the-environment of the small ship in navigation under collision risk. The model is conceptualized in such a way as to include all factors believed to have the ability to cause an accident, but also to reduce the chance of accident; and it is parametrized in such a way as to include both data, where available, and expert knowledge of the accident and expert knowledge and belief for non-accident scenarios.

Variables $X = \{ X_1, X_2, \dots, X_n \}$ and variable states x^i_j, $i \in [1,..,n]$, $j \in [2,..,m]$, known as influence factors, encode structurally and parametrically the likelihood of occurrence or non-occurrence of an accident Y in accordance to data and expert elicitation. The accident variable Y has two states, y and $\bar{y}$, that correspond to "accident" and "non-accident", respectively. Whenever a random variable X takes on a state value $x = e$, it is called an evidence. Given a *BN*, for which the prior probability distribution of the target node defines the probability threshold $h_0 = \frac{P(y = y_0)}{P(\bar{y} = \bar{y}_0)}$, there exists a classification function $F^{BN}(x)$ that assigns labels $\{0, 1\}$ to influence factors x by evaluating likelihood of accident occurrence given the evidence, based on the weight of evidence, (Osteyee & Good, 1974), as follows:

$$F^{BN}(x=e) = \begin{cases} 0 \text{ if } \frac{P(y|x=e)}{P(\bar{y}|x=e)} > h_0 \\ 1 \text{ if } \frac{P(y|x=e)}{P(\bar{y}|x=e)} < h_0 \end{cases} \tag{2}$$

The classification labels have a semantic interpretation. A factor x is "accident contributing" or has an "adverse influence" if $F^{BN}(x) = 0$, or factor x is "accident preventing", or has a "beneficial influence", if $F^{BN}(x) = 1$. When $\frac{P(y | x = e)}{P(\bar{y} | x = e)} = h_0$ the factor is on a decision boundary and its individual influence is neutral. Influence factors, labelled 0, are causative and will be denoted x, while those labelled 1, are preventive, and will be denoted $\bar{x}$. Classifier concept enables reasoning with BN, and it is extended further by the analysis of weight of evidence to allow grading of P(y|x=e) and P($\bar{y}$|x=e) according to the strength of the response of the target variable. Details are developed in the Subsection 2.2.

Maritime collision context definition

The development of BN classifier that would generalize over a spectrum of environments would not be feasible due to specificity and uncertainty inherent to diversity of possible scenarios; therefore, it is required to constrain the context of risks assessment in terms of the accident type and the environment. The model development and the approach to risk assessment is exemplified on maritime collision as an accident type being of the most interest to Croatian nautical tourism safety assessment due to high severity of consequences, though the approach and methodology can be generalized to other maritime accident types. Of interest in this paper are small passenger ships in non-linear coastal navigation, having a length of below 70 meters with maximum allowed capacity of 250 persons. The safety risk of these vessel types carrying passengers on a commercial basis might occur in particular during the tourist season, when the density of the sea traffic is considerably increasing. Safety concerns are further accentuated by the fact that coexisting risk factors, such as technical, human, and environmental parameters could possibly contribute to an unfavourable event, collision being the most severe in terms of harm for human lives and assets.

2.2. Weight of Evidence Approach to Reasoning With Bayesian Network Classifier and Interpretation

Not every evidence x has an equally strong impact on the target node. The strength of the impact of evidence on the target can be quantitatively measured by the adaptation of Irvine J. Good's weight of evidence approach, (Good, 1985), (Osteyee & Good, 1974). The discriminative model formulation allows, not only for classification, but for testing of the strength of evidence with respect to two competing hypotheses, H_1 and H_2.

The weight of evidence is the difference in information about x provided by H_1 compared to H_2, (Osteyee & Good, 1974):

$$WoE\,(H_1/H_2:x) = I\,(x:H_1) - I\,(x:H_2)$$

$$WoE(H_1/H_2:x) = \log\frac{P(x|H_1)}{P(x)} - \log\frac{P(x|H_2)}{P(x)} = \log\frac{P(x|H_1)}{P(x|H_2)} \tag{3}$$

The weight of evidence, as the log likelihood of the evidence given the two hypotheses, is further developed according to the Bayes theorem:

$$WoE(H_1/H_2:x) = \log\frac{P(H_1|x)}{P(H_2|x)} - \log\frac{P(H_1)}{P(H_2)} \tag{4}$$

$WoE\,(H_1 \,\backslash H_2 : x)$ in Eq.(3) can be positive or negative. The positive *WoE* means that hypothesis H_1 is supported by x, while negative *WoE* indicates support of x to H_2. Classifier function in Eq. (2) evaluates these properties of Eq.(4) and assigns labels to evidence accordingly. Besides classification, we are interested in measuring the strength with which the evidence x contributes to the hypothesis. Now, we take that H_1 is an accident (or non-accident) hypothesis, which competes with the baseline case hypothesis, H_2. In this case, it is taken that prior probabilities of the two hypotheses are equally probable, which eliminates the second term of Eq. (4). Therefore, the strength of evidence for H_1 against H_2 is measured as the absolute value of the first term in Eq. (4):

$$SoE(H_1/H_2:x) = \left|\log\frac{P(H_1|x)}{P(H_2|x)}\right| \tag{5}$$

The strength of evidence as the log ratio of $P\,(H_1|\,x)$ and $P\,(H_2|\,x)$ is a measure of relative change. Since $P\,(H_1|\,x)$ and $P\,(H_2|\,x)$are close values (relatively small changes are expected), the log ratio of the two conditional probabilities can be approximated with a percent change. Therefore, we define $SoE(H_1 \,\backslash H_2 : x)$ as the percent change as follows:

$$\%SoE(H_1/H_2:x) = \left|\frac{P(H_1|x) - P(H_2|x)}{P(H_2|x)}\right| \tag{6}$$

Causal reasoning with probabilistic models depends on interpretations of the results of WoE by means of $F^{BN}\,(x{=}e)$ and $SoE(H_1 \,\backslash H_2 : x)$. Standard grading of evidence into categories used for interpretation of the *WoE* are derived from Bayes Factor (*BF*) scales, and are transformed as 10log (*BF*), (Jeffreys, 1998), (Kass & Raftery, 1995). Absolute values of *BF* and its interpretations are shown in Table 1. Adaptations of scales of *WoE* are not uncommon, (Kass & Raftery, 1995). In our paper the modification is made to the first two grading categories whose role in general applications is to eliminate irrelevant evidence. To accommodate the expert elicitation and Bayes network classifier parametrization process, through which insensitive and irrelevant factors have already been eliminated, the ranges of the first two categories have been adapted to the application, and therefore changed from (0 to 5) and (5 to 10) to $[0,1\rangle$ and $[1,10\rangle$. The proposed interpretation of the importance of influence factors for the classification system in our paper is given in Table 2.

Using the interpretative categories proposed in Table 2, influence factors, either causative, x, or preventive, $\overline{x}$, can be verbally labelled. Causative influence factors are interpreted with respect to their influence to cause the accident, while preventive influence factors are interpreted with respect to their potential to prevent accident.

Table 1.
Linguistic interpretation of value categories of the weight of evidence (from (Jeffreys, 1998), (Kass & Raftery, 1995)).

Evidence against the null hypothesis	Bayes factor (BF)	WoE=10 log(BF)
Anecdotal evidence	1 to 3.2	0 to 5
Substantial evidence	3.2 to 10	5 to 10
Strong evidence	10 to 100	10 to 20
Decisive evidence	>100	>20

Table 2.
Interpretative categories of influence factor based on percent change obtained by %SoE.

Classification of influence factor	Interpretation of relative influence on the target variable (accident/non-accident)	SoE [%]
weak influence factor	its influence on the target variable is not critical	0 - 0.9
substantial influence factor	its influence on the target variable is significant	1 - 9.9
strong influence factor	its influence on the target variable is very significant	10 - 19.9
extremely strong influence factor	its influence on the target variable is critical	>20

Using the interpretative categories proposed in Table 2, influence factors, either causative, x, or preventive, $\overline{x}$, can be verbally labelled. Causative influence factors are interpreted with respect to their influence to cause the accident, while preventive influence factors are interpreted with respect to their potential to prevent the accident.

3. STRUCTURING AND PARAMETRIZATION OF THE BASELINE BAYESIAN NETWORK CLASSIFIER FOR COLLISION

A first line in BN construction is the definition of general hazard types for maritime accidents and their relevant factors. To identify general hazards for collision, a review of the existing knowledge in literature has been made, while institutional database information has been collected and interviews with maritime experts have been held in order to define specific local hazard conditions, extract relevant factor states, and establish causal relations among factors. Hazard factors, in maritime accidents, may be directly observable (weather, equipment, wind), but also many factors are unobservable due to their intrinsically unobservable nature (e.g. human error, personal condition, etc.) or the lack of indications of presence or absence of such factors. Some factors may be partially observable (e.g. safety culture). These factors are intermediary nodes of the causal network. Relevant factors are identified with the help of existing literature on maritime accidents from (Hänninen & Kujala, 2012) and (Mazaheri, et al., 2016), and adapted for collision context analysed in this paper. The compilation of identified factors helps the construction of causal relations and the formation of the causal system encoded with the network topology. In our approach, the network topology growth is initialized at target node 'Collison' and parental nodes are added using the rules of the previously mentioned three causal classes, where interpretation of direction of arrow from node Vi to Vj is that belief in Vi implies expectation in Vj, (Jensen & Nielsen, 2007). Addition of the first level causal nodes: "Give-way", "Communication with other ship", "Loss of control of other ship" and "Traffic distribution" is based on a minimal theory-based model deduced from COLREG rules, (Cockcroft & Lameijer, 2003), and from collision avoidance strategies in an interaction during a critical encounter situation, (Chauvin, et al., 2013), (Chauvin & Lardjane, 2008). Next, each of the first-level parental nodes are further explained and related to their own parental nodes, thus embedding further influence factors from the preselected factor list. In a similar manner, the network is grown until observable independent factors are reached.

It should be noted that development involves refinement of structure through adding the omitted factors and removing irrelevant factors and their relations through collaboration with domain experts. Fig. 2. shows resulting causal influence network of the maritime collision, its nodes and dependence structure. In the subsequent step, state spaces of each factor are defined. For example, tiredness is an influence factor, and it has two states: present or not present; availability or nonavailability of the technical equipment are separate aspects for technical factors; wind force has multiple states, etc. Next, conditional probability distributions of each factor given its parents are assessed and its adjustments are performed, in a top-down manner, from the causal nodes to the effect node. Conditional probabilities are assigned based on expert's beliefs, national weather reports, local maritime databases, and the existing literature. The final parametrisation of the state space is based on a consensus elicitation of expert knowledge, (Hassall, et al., 2019), (Zhang & Thai, 2016). The description of each factor, their state spaces and sources of data, are given in the Appendix.

Local coherence checking is conducted during this stepwise parametrisation of nodes using sensitivity analysis, (Kjærulff & Gaag, 2000), implemented in GeNIe/SMILE, (BayesFusion, 2020), and the parameter calibrations are performed accordingly. The model encapsulates the collective domain knowledge of the expert group participants and their understanding of safety problem of the maritime collision risk, thereby representing the baseline model.

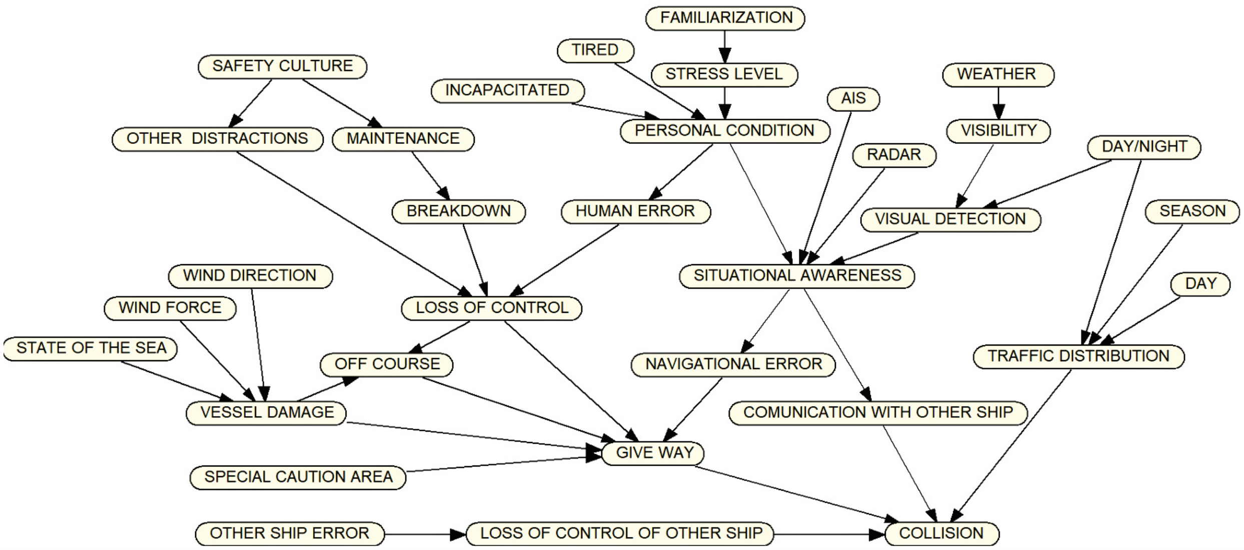


Figure 2.
The causal influence network for maritime collision.

An individual ship involvement in a collision accident is modelled, as such models are underrepresented in scientific literature, (Ozturk & Cicek, 2019). Most of the proposed collision models are built from the point of view of two ships involved. While increasing the complexity of the Bayesian Network and accompanying computational complexity, such models do not yield the gain in information on influential risk factors for individual ship, as they do not address interactions of variables of complex and large Bayesian Networks. We believe that the behaviour of individual ship should be well developed and understood prior to modelling a collision as a two-party event. It should be noted that in our model an influence of another ship is not neglected, yet its contribution is represented as a simplified sub-network comprised of chain "Other ship error" → "Loss of control".

3.1. Credibility of the Baseline Bayesian Network Classifier Model

A common final stage of any classification model development, before its deployment, is the assessment of its accuracy based on the real-world data. When data-driven assessment is not feasible, i.e., when there is no data to confront the developed model with the credibility of the model is assessed. Credibility verifies that underlying assumptions and properties of the model are satisfied. Monotonicity is the property that should be exhibited by expert knowledge based Bayesian networks, thus, a way to evaluate credibility of the developed BN classifier model is the verification of monotonicity, (Pianosi, et al., 2014), (Gaag, et al., 2004). Monotonic behaviour is incorporated into a model through qualitative influences at the development stage. Violation of monotonicity can occur despite engineering efforts to carefully encode knowledge and it can exist even after sensitivity tests were performed, (Plajner & Vomlel, 2017), (Pianosi, et al., 2014). A fundamental monotonic behaviour is observed when the increase in values of parental variables produce the increase in corresponding values for the child variables. For example, let X_i be the parent of Y. Let the parental influence factors x and $\bar{x}$ be the causative and preventive, respectively; and let child nodes' states y and $\bar{y}$ correspond to "accident" and "non-accident". Whenever y takes on a value 1, it represents an evidence that accident occurs, and at the same time $\bar{y}$ becomes 0. Let this be denoted as Y_{acc}. Likewise, whenever $\bar{y}$ takes on a value 1, it represents an evidence that accident does not occur, and at the same time y becomes 0. Let this be denoted as $Y_{non\text{-}acc}$. The exemplary parental conditional probabilities are given in Table 1. Due to monotonicity constraint, it should hold for every parental node that $P(x \mid Y_{acc}) \geq P(\bar{x} \mid Y_{acc})$ and $P(\bar{x} \mid Y_{non\text{-}acc}) \geq P(x \mid Y_{non\text{-}acc})$. Any parent-child nodes (i.e. effect-cause nodes) should respect these relations locally. Using a bottom up approach, from the target node backward to root nodes, the whole network is checked locally for monotonic behaviour.

Table 3.
Example of the conditional probability table of parent-child nodes.

	collision :: yes	collision :: no
influence factor :: preventive	$P(\bar{x} \mid Y_{acc})$	$P(\bar{x} \mid Y_{non\text{-}acc})$
influence factor :: causative	$P(x \mid Y_{acc})$	$P(x \mid Y_{non\text{-}acc})$

Also, the global monotonicity test can be performed with monotone likelihood ratio test (MLR), (Mukhopadhyay, 2000), a measure similar to odds ratio, which, unlike the odds ratio, assumes a causal relation of the influence factor and the outcome:

$$MLR = \frac{\dfrac{P(\bar{x} \mid Y_{acc})}{P(\bar{x} \mid Y_{acc}) + P(\bar{x} \mid Y_{non\text{-}acc})}}{\dfrac{P(x \mid Y_{acc})}{P(x \mid Y_{acc}) + P(x \mid Y_{non\text{-}acc})}} \tag{7}$$

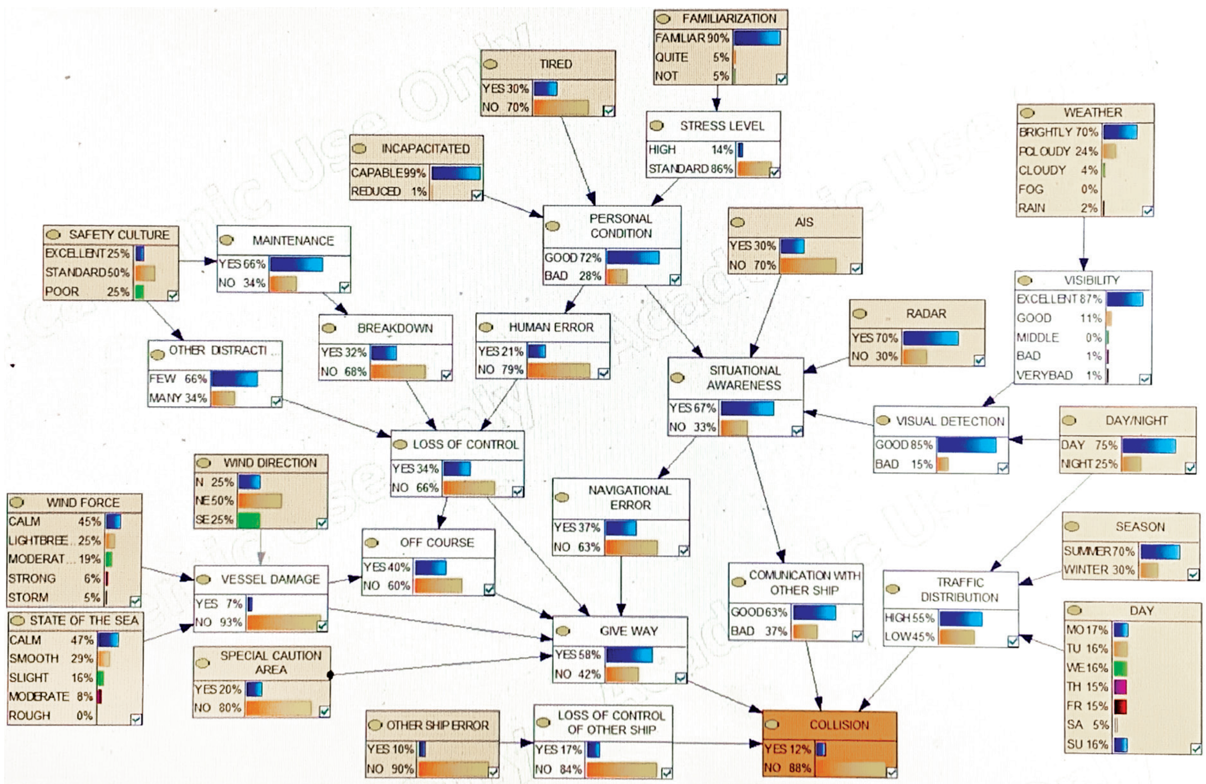


Figure 3.
Baseline model inference (developed and tested using GeNIe/SMILE, (BayesFusion, 2020) and pyAgrum, (Gonzales, et al., 2017)).

MLR indicates how much more likely is it that a collision will occur when preventive influence factor is present compared to when causative influence factor is present. Due to monotonicity, it should hold that MLR ≤ 1, which indicates that when a random variable takes a preventive state, the likelihood of accident is lower than (or equal to) the likelihood of accident when the same random variable takes on a causative state. When any of tested links does not obey monotonicity suggested by expert, it informs us that an intervention in conditional probability tables is required. In this case, non-monotonic influence factor should be optimized and recalibrated using the sensitivity analysis.

The inference results of credibility tested baseline Bayesian Network classifier show that the likelihood of collision occurrence is 12%, compared to the likelihood of 88%, that collision will not occur under baseline state of the world situation (Fig.3.). This implicates that substantial belief is held by experts against the collision occurrence in the baseline situation, given encoded uncertainty about the state of the world. The GeNIe/SMILE, (BayesFusion, 2020), is used for the development and Phyton library pyAgrum, (Gonzales, et al., 2017), for inferences. Belief updates in the network are based on Lazy propagation algorithm, (Madsen & Jensen, 1999).

4. RESULTS OF INFERENCE WITH BAYESIAN NETWORK CLASSIFIER

Evidence analysis based on the weight of evidence approach delivers two pieces of information: classification of causative and preventive influence factors, and their strength of influence (SoE) with interpretative categories. Below, the results of single evidence inference analysis and conjunctive evidence inference analysis will be presented.

Single evidence inference results are presented in Table. 4. Influences based on the SoE metric and the colour coding refer to the interpretation system proposed in Table 2. Collision risks are identified as collision contributing, adversely influencing factors, termed causative influence factors. The proposed method identifies accident preventing contributors as well. The left-side column presents the strengths of causative influence factors, and the right-side column presents the influence factors that have a collision preventing potential.

Several extremely strong single risk factors identified are poor communication with other vessel, lack of situational awareness, loss of control of other ship, failing to comply with a give way, human error, loss of control, and poor personal condition. According to the SoE scoring, poor communication with other vessel raises the relative likelihood of collision by 28.6%, and its influence is estimated as a critical risk. The communication between vessels has been identified as one of the most influential factors in other studies of risks in navigational situations involving small passenger vessels and pleasure craft in high density area, (Øvergård, et al., 2020). The lack of situational awareness raises a relative likelihood of collision by 25.7% and is assessed as critical risk. This is in accordance with common maritime safety knowledge and many documented accidents. USCG accident database indicates that the lack of situational awareness is the causal factor in 60% of all accident causes, (Baker & McCafferty, 2005). Next, the factor contributing critically to accidence occurrence is a poor personal condition, which is in direct causal relation to situational awareness and an immediately preceding parent of human error. Needless to accentuate, human related factors are credited as the major cause of accidents. Among strong preventive influences, compliance with give way regulations and the communication with other vessel are sharing the first place, followed by low traffic density, no navigational error, staying in control of vessel, winter season and being on the navigational course. In the preventive factors class list of Table 4, no extremely strong preventive influence factors are identified, which is the expected result of the classifier, considering that it has been organized and developed to reflect the normal collision-free state of navigation under the risk of collision.

In the interpretation of BN classifier inference results, one should be aware that evidence influence measured by the strength of evidence might not be the same as the importance of evidence. Namely, in the interpretation of inference scores provided by the strength of evidence, the proximity of the evidence node to the target node can be considered. It is known that nodes proximal to the target node of causally conceptualized networks are more strongly affecting the target node, (Hänninen & Kujala, 2012), and the influence of evidence on the target node attenuates with the propagation length between these nodes, (Yuan & Druzdzel, 2007). A simple propagation length weighting, that balances out the influence of adjacency of nodes, is introduced to perform ranking of influence factors, where propagation length is measured with the depth of graph, (Yuan & Druzdzel, 2007). Propagation length weight we is defined as the ratio of minimal number of edges traversed from evidence to target node, and maximal number of edges traversed from the deepest node. In our model, the maximal depth is 7, as counted from "Familiarization" to "Collision". So, for example, for the "Human error" variable, the propagation length weight is $w_e = 3/7$.

Table 4.
Classification of causative and preventive influence factors, their influence strengths and interpretative categories (red: extremely strong influence; orange: strong influence; green: substantial influence; yellow: weak influence. See Table 2.)

causative influence factors	SoE (%)	preventive influence factors	SoE (%)
COMUNICATION WITH OTHER VESSEL::POOR	28.6322	GIVE WAY::YES	16.6576
SITUATIONAL AWARENESS::NO	25.7142	COMMUNICATION WITH OTHER VESSEL::GOOD	16.6576
LOSS OF CONTROL OF OTHER SHIP::YES	24.5791	TRAFFIC DENSITY.::LOW	13.0642
GIVE WAY::NO	23.2998	SITUATIONAL AWARENESS::YES	12.9394
HUMAN ERROR::YES	21.0030	NAVIGATIONAL ERROR::NO	11.0112
LOSS OF CONTROL::YES	20.7900	LOSS OF CONTROL::NO	10.8181
PERSONAL CONDITION::POOR	20.4178	SEASON::WINTER	10.7047
NAVIGATIONAL ERROR::YES	18.9269	OFF COURSE::NO	10.3557
INCAPACITATED::REDUCED	17.5977	DAY/NIGHT TIME::NIGHT	7.8712
OTHER SHIP ERROR::YES	17.2202	PERSONAL CONDITION::GOOD	7.7834
OFF COURSE::YES	15.4193	HUMAN ERROR::NO	6.2625
VESSEL DAMAGE::YES	15.2623	LOSS OF CONTROL OF OTHER SHIP::NO	4.8567
TRAFFIC DENSITY::HIGH	10.6247	TIRED::NO	3.1742
WIND FORCE::STORM	9.2608	AIS::YES	2.1032
STRESS LEVEL::HIGH	8.5240	RADAR::YES	2.0824
TIRED::YES	7.4072	DAY::{FRI,SAT}	1.9855
FAMILIARIZATION::NOT	6.0461	OTHER SHIP ERROR::NO	1.9131
RADAR::NO	4.8596	OTHER DISTRACTIONS::FEW	1.604
SEASON::SUMMER	4.5881	SAFETY CULTURE::EXCELLENT	1.5752
VISIBILITY::VERY POOR	4.3718	BREAKDOWN::NO	1.5287
WEATHER::RAIN	4.0371	STRESS LEVEL::STANDARD	1.3874
BREAKDOWN::YES	3.2586	MAINTENANCE::YES	1.26
OTHER DISTRACTIONS::MANY	3.1493	VESSEL DAMAGE::NO	1.0682
SAFETY CULTURE::POOR	2.7765	WIND FORCE::CALM	1.0682
DAY/NIGHT TIME::DAY	2.6240	VISUAL DETECTION::GOOD	0.4173
MAINTENANCE::NO	2.4740	FAMILIARIZATION::FAMILIAR	0.3962
VISUAL DETECTION::POOR	2.3348	SPECIAL CAUTION AREA::NO	0.3902
SPECIAL CAUTION AREA::YES	1.5621	INCAPACITATED::CAPABLE	0.1775
AIS::NO	0.9017	SEA STATE::CALM	0.17
SEA STATE::MODERATE	0.8098	VISIBILITY::EXCELLENT	0.0822
DAY::{MO,TU,WE,TH,SU}	0.4967	WEATHER::BRIGHT	0.0822
WIND DIRECTION::NE	0.0002	WIND DIRECTION::SE	0.0002

Figure 4.
Importance ranking based on propagation length weighted SoE.

According to the ranking based on weighted SoE, extremely strong and the strong causative, as well as the strong preventive influencing factors, are obtained and shown in Fig 4. It yields that the extremely strong causative influencing non-adjacent factors are poor personal condition, human error, lack of situational awareness, and a loss of control. This reasoning is supported by the results of preventive factor ranking, where good situational awareness is the highest ranked preventive factor. Previous studies and experience have recognized contribution of these human related factors and a lack of situational awareness in the collision causation, and in particular in the collision causation of small passenger vessels that are not obligated to carry a radar and/or AIS.

The influences of the observable risks and preventive factors, often called indicators, for an individual ship are extracted in Table 5. Among observable factors, strong risk for collision is a reduced psychophysical condition of the person responsible for watchkeeping. This is embodied in an 'incapacitated::reduced' factor whose name is adopted from (Hänninen & Kujala, 2012). With regard to assessment of influences of technical equipment, the results show that not being equipped with a radar presents a higher risk of collision that not being equipped with AIS. Not having a radar increases relative risk of collision by almost 5%, and not being equipped with AIS raises relative risk by nearly 1%. Also, the results show that being equipped with a radar or AIS, individually contribute preventively by reducing the likelihood of collision by around 2% (factor influences are not necessarily additive). Among environmental factors, the summer season is ranked as a substantial causative factor, while the winter season is ranked as a factor with strong preventing potential. This implies the importance of the investigation of traffic density which is in direct relation to season.

Table 5.
Classification of causative and preventive observable influence factors and SoE categories.

observable risk factors	SoE (%)	observable preventive factors	SoE (%)
INCAPACITATED::REDUCED	17.5977	SEASON::WINTER	10.7047
WIND FORCE::STORM	9.2608	DAY/NIGHT TIME::NIGHT	7.8712
TIRED::YES	7.4072	TIRED::NO	3.1742
FAMILARIZATION::NOT	6.0461	AIS::YES	2.1032
RADAR::NO	4.8596	RADAR::YES	2.0824
SEASON::SUMMER	4.5881	DAY::{FRI,SAT}	1.9855
WEATHER::RAIN	4.0371	OTHER SHIP ERROR::NO	1.9131
SAFETY CULTURE::POOR	2.7765	SAFETY CULTURE::EXCELLENT	1.5752
DAY/NIGHT TIME::DAY	2.6240	STRESS LEVEL::STANDARD	1.3874
SPECIAL CAUTION AREA::YES	1.5621	WIND FORCE::CALM	1.0682
AIS::NO	0.9017	FAMILIARIZATION::FAMIL.	0.3962
SEA STATE::MODERATE	0.8098	SPECIAL CAUTION AREA::NO	0.3902
DAY::{MO,TU,WE,TH,SU}	0.4967	INCAPACITATED::CAPABLE	0.1775
WIND DIRECTION::NE	0.0002	WEATHER::BRIGHT	0.0822

The great increase in traffic density during the tourist season has raised particular concerns about the navigational safety of small tourist passenger vessels, and the assessment of the influence of traffic density on the collision causation is one of the main interests that have spurred the risk assessment approach development described in this work. According to the results, the high traffic density rises the relative likelihood of collision by 10%. Additional confirmation that traffic density in general is a strong factor is given by the observation in the results that the low traffic density has a preventive potential. Therefore, to gain a more in-depth understanding of the influence of high traffic density, a conjunctive evidence analysis is performed, with an aim to identify the co-occurring risks. The influence of the conjunction of high traffic density and all other factors on accident occurrence is given in Table.6.

Conjunctive evidence analysis results reveal that during the high maritime traffic density, the number and the strength of co-occurring causative influence factors have risen, while the number of preventive factors has been reduced, but also strengthened. Human error is a novel extremely strong risk factor when co-occurring during the high traffic density, as can be revealed through comparison of difference of single risks factors and those risks factors arising through co-occurrence analysis (from comparison of data between Table 4 and Table 6). Extremely strong factors, both causative and preventive, are the communication with other vessels and give way, which accentuates the important influential character of these factors, preceding immediately the occurrence of collision. Among observable risk factor, incapacitation, i.e. reduced psychophysical ability, is heightened, and its influence is interpreted as an extremely strong collision risk (Table 6). Also, stormy wind, often occurring suddenly during high traffic tourist season, and tiredness become very significant risk factors. No observable preventive factor can be extracted, which means that prevention cannot be focused on any indicator factor but on an unobservable, intermediary once. Again, to compensate for adjacency of these nodes to targeted collision node, the ranking is performed based on propagation length weighted SoE, and shown in Fig. 5. The propagation length weighted SoE reveals that human related factors are most prominent collision contributing factors. Among preventive factors, the good situational awareness is accentuated as a very significant preventive factor during high traffic density.

Table 6.
Classification of causative and preventive influence factors and their SoE based interpretative categories for the assessment of collision during high maritime traffic density period.

causative influence factors	SoE (%)	preventive influence factors	SoE (%)
COMUNICATION WITH OTHER VESSEL::POOR	43.0723	GIVE WAY::YES	24.642
SITUATIONAL AWARENESS::NO	38.9043	COMUNICATION WITH OTHER VESSEL::GOOD	24.642
HUMAN ERROR::YES	34.89	SITUATIONAL AWARENESS::YES	19.1552
GIVE WAY::NO	34.5448	NAVIGATIONAL E.::NO	16.312
LOSS OF CONTROL::YES	30.8289	PERSONAL CONDITION::GOOD	11.5343
PERSONAL CONDITION::POOR	30.3519	OFF COURSE::NO	6.3415
NAVIGATIONAL ERROR::YES	28.5373	LOSS OF CONTROL::NO	5.2939
LOSS OF CONTROL OF OTHER SHIP::YES	26.9525		
INCAPACITATED::REDUCED	26.1628		
OFF COURSE::YES	22.8674	observable risk factors	SoE (%)
VESSEL DAMAGE::YES	22.6119	INCAPACITATED::REDUCED	26,1628
OTHER SHIP ERROR::YES	18.8907	WIND FORCE::STORM	13,7905
WIND FORCE::STORM	13.7905	TIRED::YES	11,0279
STRESS LEVEL::HIGH	12.6865	FAMILARIZATION::NOT	9,269
TIRED::YES	11.0279	RADAR::NO	7,1763
FAMILIARIZATION::NOT	9.269	WEATHER::RAIN	6,0426
VISUAL DETECTION::POOR	7.3986	SAFETY CULTURE::POOR	4,1296
RADAR::NO	7.1763	SPECIAL CAUTION AREA::YES	2,3353
VISIBILITY::VERY POOR	6.5486	AIS::NO	1,358
WEATHER::RAIN	6.0426	SEA STATE::MODERATE	0,9797
BREAKDOWN::YES	4.8493	WIND DIRECTION::NE	0,2261
OTHER D.::MANY	4.6873		
SAFETY CULTURE::POOR	4.1296		
MAINTENANCE::NO	3.688		
SPECIAL CAUTION AREA::YES	2.3353		
AIS::NO	1.358		
SEA STATE::MODERATE	0.9797		
WIND DIRECTION::NE	0.2261		

According to the results obtained, the following recommendations for safety improvement during high traffic density can be distilled:

- Human related factors, their effects on situational awareness and the navigational error require special attention. In particular, the situational awareness and proper adjustment of navigational course are very significant in preventing unwanted hazard situations.
- The first line of intervention during high maritime traffic density is the prevention of the incapacitation and tiredness. Adequate cognitive and physical responses from the responsible seafarer importantly prevent the occurrence of accident through human error as the extremely strong influence factor identified by the developed approach.
- When in close encounter situation during high traffic density, both the knowledge on regulations for a give way and

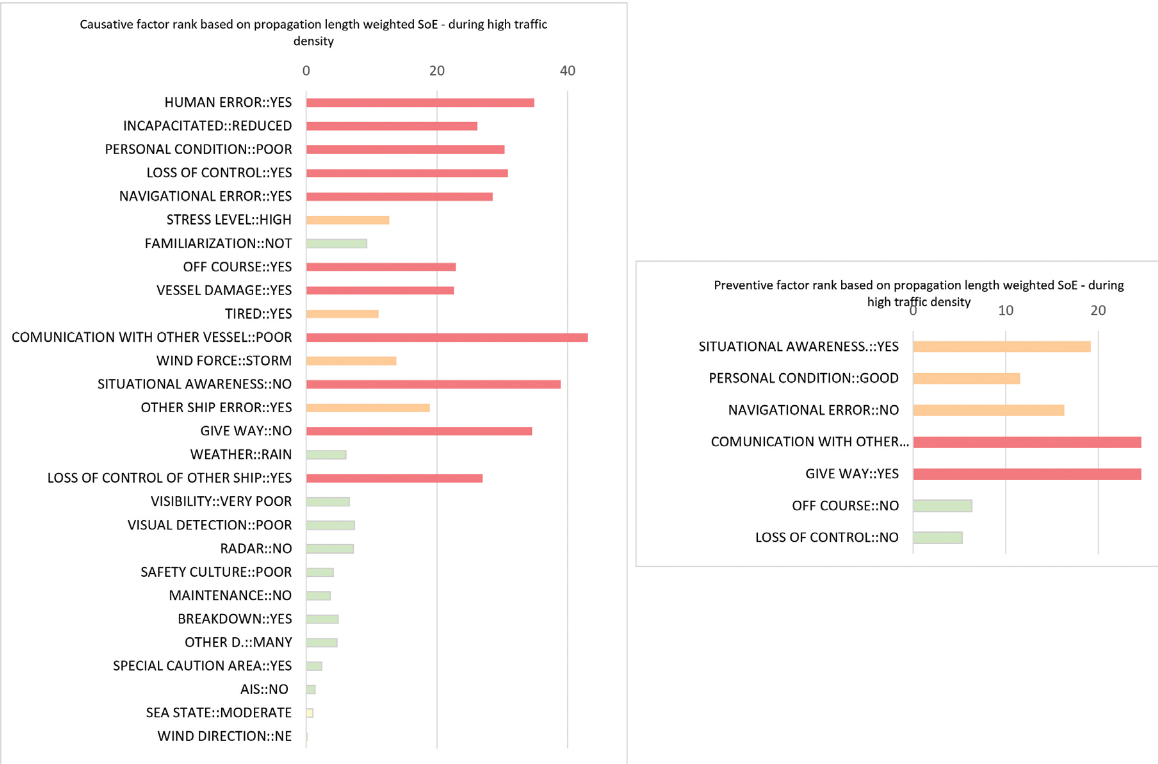


Figure 5.
Importance ranking of co-occurring collision influencing factors during high maritime traffic density based on propagation length weighted SoE.

the communication with other vessels, are critically important for the prevention of a collision within the analysed context.

5. CONCLUSION

Due to rare event characteristic of maritime accidents, the lack of data hinder the development of risk assessment models based on nowadays modern machine learning based models, and the Bayesian Network models has proven to be a good alternative solution that can embody sparse data, expertise, and experience in the maritime domain. However, when these probabilistic models of maritime accidents are put into work, the question of how to interpret the inference results and make it available to a wider group of interested experts without requiring the background knowledge in probabilistic methodology arises. The two aspects, modelling and interpretative reasoning, have been addressed in this paper. First, the Bayesian framework is exploited to develop a probabilistic causal model of maritime accident based on conceptual formulation of a causal network as a Bayesian Network classifier. The major strength of binary formulation of model outcomes lies in the possibility of introduction of weighting of evidence based on outcome hypothesis likelihood ratios. Along this line, the strength of evidence measure is derived and grading of results into influential categories is proposed. Thus, the strength of influence of the state space (influence factors) on the collision occurrence can be interpreted semantically without a background knowledge.

Though the complete framework is showcased for the modelling and the assessment of risks of collision for small vessels in navigation in the Adriatic, generalization can be made to other accident types in the maritime domain. The results of identified risks and preventive factors are obtained through the analysis of the conjunctive effect of factors and ultimately presented as the safety guarding recommendations in the scenario of navigation in high traffic density. Some recommendations obtained from the developed system are very intuitive to human reasoning, others are not as obvious, and become comprehensible and noticeable only when organized into a hierarchically structured influence diagram and after being quantitively evaluated. Therefore, the developed approach contributes to the focused reasoning required for an intervention development under the given scenario. Similarly, any scenario can be imposed within the defined state space of the assessed accident.

It is important to mention the limitations that impact the results. The incomplete, insufficient, and scarce data is the universal problem for maritime risk assessment. It affects both the model development and the model validation. Consequently, it affects the inference results. The attention should be drawn to the uncertainty of network structure and the node parameters of the proposed model which represent the causal contributors to an accident. The network structure uncertainty should be investigated in future work. The maritime risk assessment obtained with the proposed weight of evidence approach and the recommendations distilled from the results should be viewed within the scope and limitations of the model. For a more in-depth overview on limitations of BNs in maritime accident domain, the interested reader is referred to (Hänninen, 2014).

Distances of the evidence nodes and target note play an important role in influence ranking for estimation of interventional priorities, but not in the classification of causative and preventive influences. According to (Yuan & Druzdzel, 2007), propagation length values are highly network dependant. Thus, an interesting direction of future work would be to investigate optimal values of the importance ranking based on propagation length, where not only risks are assessed, but interventional priorities are to be estimated as well. Also, in the future work, situational awareness should be researched in more detail as it is a very significant accident influencing factor that is affected by both human factors and technical equipment. More complex situational awareness subnetwork, that would accentuate the interplay of human factors and technical equipment, could yield a novel insight into its contributions to the occurrence of maritime accident, but also its potential for their prevention.

REFERENCES

Baker, C.C. et al., 2005. Accident Database Review of Human-Element Concerns: What Do The Results Mean For Classification? Human Factors In Ship Design, Safety & Operation. Available at: http://dx.doi.org/10.3940/rina.hf.2005.11.

Baksh, A.-A. et al., 2018. Marine transportation risk assessment using Bayesian Network: Application to Arctic waters. Ocean Engineering, 159, pp.422–436. Available at: http://dx.doi.org/10.1016/j.oceaneng.2018.04.024.

BayesFusion, L., 2020. Pittsburgh, USA. Available at: www.bayesfusion.com.

Bielza, C. & Larrañaga, P., 2014. Discrete Bayesian Network Classifiers. ACM Computing Surveys, 47(1), pp.1–43. Available at: http://dx.doi.org/10.1145/2576868.

Chan, H. & Darwiche, A., 2002. Reasoning about bayesian network classifiers. Proceedings of the 19th Conference on Uncertainty in Artificial Intelligence (UAI2003), Acapulco, Mexico, Morgan Kaufmann, pp. 107-115.

Chauvin, C. & Lardjane, S., 2008. Decision making and strategies in an interaction situation: Collision avoidance at sea. Transportation Research Part F: Traffic Psychology and Behaviour, 11(4), pp.259–269. Available at: http://dx.doi.org/10.1016/j.trf.2008.01.001.

Chauvin, C. et al., 2013. Human and organisational factors in maritime accidents: Analysis of collisions at sea using the HFACS. Accident Analysis & Prevention, 59, pp.26–37. Available at: http://dx.doi.org/10.1016/j.aap.2013.05.006.

Chen, P. et al., 2019. Probabilistic risk analysis for ship-ship collision: State-of-the-art. Safety Science, 117, pp.108–122. Available at: http://dx.doi.org/10.1016/j.ssci.2019.04.014.

Chen, P., Mou, J. & van Gelder, P.H.A.J.M., 2019. Integration of individual encounter information into causation probability modelling of ship collision accidents. Safety Science, 120, pp.636–651. Available at: http://dx.doi.org/10.1016/j.ssci.2019.08.008.

Chen, S.H. & Pollino, C.A., 2012. Good practice in Bayesian network modelling. Environmental Modelling & Software, 37, pp.134–145. Available at: http://dx.doi.org/10.1016/j.envsoft.2012.03.012.

Cockcroft, A. N. & Lameijer, J. N. F., 2003. Guide to the collision avoidance rules. 6th ed. Oxford: Butterworth-Heinemann.

Darwiche, A., 2009. Modeling and Reasoning with Bayesian Networks. Cambridge university press.

Friedman, N., Geiger, D. & Goldszmidt, M., 1997. Bayesian Network Classifiers. Machine Learning, 29(2/3), pp.131–163. Available at: http://dx.doi.org/10.1023/a:1007465528199.

Gaag, L. C. v. d., Bodlaender, H. L. & Feelders, A., 2004. Monotonicity in Bayesian networks. Proceedings of the 20th conference on Uncertainty in artificial intelligence, July 7-11, Banff, Canada, AUAI Press, pp. 569-576.

Goerlandt, F. & Montewka, J., 2015. Maritime transportation risk analysis: Review and analysis in light of some foundational issues. Reliability Engineering & System Safety, 138, pp.115–134. Available at: http://dx.doi.org/10.1016/j.ress.2015.01.025.

Gonzales, C., Torti, L. & Wuillemin, P.-H., 2017. aGrUM: A Graphical Universal Model Framework. Lecture Notes in Computer Science, pp.171–177. Available at: http://dx.doi.org/10.1007/978-3-319-60045-1_20.

Good, I. J., 1985. Weight of evidence: A brief survey. Bayesian statistics 2: Proceedings of the Second Valencia International Meeting, September 6-10, Amsterdam, pp. 249-269. Elsevier.

Hänninen, M. & Kujala, P., 2012. Influences of variables on ship collision probability in a Bayesian belief network model. Reliability Engineering & System Safety, 102, pp.27–40. Available at: http://dx.doi.org/10.1016/j.ress.2012.02.008.

Hänninen, M., 2014. Bayesian networks for maritime traffic accident prevention: Benefits and challenges. Accident Analysis & Prevention, 73, pp.305–312. Available at: http://dx.doi.org/10.1016/j.aap.2014.09.017.

Hassall, K.L. et al., 2019. Facilitating the elicitation of beliefs for use in Bayesian Belief modelling. Environmental Modelling & Software, 122, p.104539. Available at: http://dx.doi.org/10.1016/j.envsoft.2019.104539.

Huang, Y. et al., 2020. Ship collision avoidance methods: State-of-the-art. Safety Science, 121, pp.451–473. Available at: http://dx.doi.org/10.1016/j.ssci.2019.09.018.

Jeffreys, H., 1998. Theory of probability. 3rd reprint ed. Oxford: Oxford University Press.

Jensen, F. V. & Nielsen, T. D., 2007. Bayesian Networks and Decision Diagrams. Springer-Verlag New York.

Kass, R.E. & Raftery, A.E., 1995. Bayes Factors. Journal of the American Statistical Association, 90(430), pp.773–795. Available at: http://dx.doi.org/10.1080/01621459.1995.10476572.

Kjærulff, U. & Gaag, L. C. v. d., 2000. Making Sensitivity Analysis Computationally Efficient. Proceedings of the Sixteenth Conference on Uncertainty in Artificial Intelligence (UAI2000), June 30 - July 3, Stanford, USA, pp. 317-325.

Kontovas, C.A. & Psaraftis, H.N., 2009. Formal Safety Assessment: A Critical Review. Marine Technology and SNAME News, 46(01), pp.45–59. Available at: http://dx.doi.org/10.5957/mtsn.2009.46.1.45.

Lim, G.J. et al., 2018. Models and computational algorithms for maritime risk analysis: a review. Annals of Operations Research, 271(2), pp.765–786. Available at: http://dx.doi.org/10.1007/s10479-018-2768-4.

Madsen, A.L. & Jensen, F.V., 1999. Lazy propagation: A junction tree inference algorithm based on lazy evaluation. Artificial Intelligence, 113(1-2), pp.203–245. Available at: http://dx.doi.org/10.1016/s0004-3702(99)00062-4.

Marcot, B.G. & Penman, T.D., 2019. Advances in Bayesian network modelling: Integration of modelling technologies. Environmental Modelling & Software, 111, pp.386–393. Available at: http://dx.doi.org/10.1016/j.envsoft.2018.09.016.

Mazaheri, A., Montewka, J. & Kujala, P., 2016. Towards an evidence-based probabilistic risk model for ship-grounding accidents. Safety Science, 86, pp.195–210. Available at: http://dx.doi.org/10.1016/j.ssci.2016.03.002.

Ministry of Sea, T. a. I. & Tourism, M. o., 2008. Nautical tourism development strategy of the Republic of Croatia 2009–2019.[Online] Available at: mmpi.gov.hr/UserDocsImages/arhiva/Strategija%20razvoja%20nautickog%20turizma%20ENGL%201.pdf.

Mukhopadhyay, N., 2020. Probability and Statistical Inference. Available at: http://dx.doi.org/10.1201/9780429258336.

Osteyee, D. B. & Good, I. J., 1974. Information, weight of evidence, the singularity between probability measures and signal detection (Lecture Notes in Mathematics), Springer-Verlag Berlin Heidelberg.

Øvergård, K. I., 2015. Human Error: Causality and the Confusion of Normative and Descriptive Accounts of Human Performance. In K. I. Fostervold, S. Å. K. Johnsen, L. Rydstedt and R. G. Watten (Eds.) Creating Sustainable Work Environments, (pp. C5-6, C5-10). Lysaker, Norway: Norwegian society for ergonomics and human factors. Available at: https://openarchive.usn.no/usn-xmlui/handle/11250/2486731.

Øvergård, K.I., Tannum, M.S. & Haavardtun, P., 2020. Observation and assessment of crossing situations between pleasure craft and a small passenger ferry. WMU Journal of Maritime Affairs, 19(3), pp.337–355. Available at: http://dx.doi.org/10.1007/s13437-020-00211-1.

Ozturk, U. & Cicek, K., 2019. Individual collision risk assessment in ship navigation: A systematic literature review. Ocean Engineering, 180, pp.130–143. Available at: http://dx.doi.org/10.1016/j.oceaneng.2019.03.042.

Pearl, J., 1988. Probabilistic Reasoning in Intelligent Systems: Networks of Plausible Inference. San Francisco, CA,United States: Morgan Kaufmann.

Pearl, J., 2000. Causality: Models, Reasoning, and Inference. 2nd Ed. ed. Cambridge, UK: Cambridge University Press.

Pianosi, F. et al., 2016. Sensitivity analysis of environmental models: A systematic review with practical workflow. Environmental Modelling & Software, 79, pp.214–232. Available at: http://dx.doi.org/10.1016/j.envsoft.2016.02.008.

Plajner, M. & Vomlel, J., 2017. Monotonicity in Bayesian Networks for Computerized Adaptive Testing. Symbolic and Quantitative Approaches to Reasoning with Uncertainty, pp.125–134. Available at: http://dx.doi.org/10.1007/978-3-319-61581-3_12.

Rausand, M. & Høyland, A., 2003. System Reliability Theory: Models, Statistical Methods, and Applications. 2nd Ed., Wiley.

Sigurdsson, J.H., Walls, L.A. & Quigley, J.L., 2001. Bayesian belief nets for managing expert judgement and modelling reliability. Quality and Reliability Engineering International, 17(3), pp.181–190. Available at: http://dx.doi.org/10.1002/qre.410.

Sotiralis, P. et al., 2016. Incorporation of human factors into ship collision risk models focusing on human centred design aspects. Reliability Engineering & System Safety, 156, pp.210–227. Available at: http://dx.doi.org/10.1016/j.ress.2016.08.007.

Stornes, P., 2015. Risk influencing factors in maritime accidents : An exploratory statistical analysis of the Norwegian Maritime Authority incident database. [Online] Available at: https://samforsk.brage.unit.no/samforsk-xmlui/handle/11250/2360509.

Trucco, P. et al., 2008. A Bayesian Belief Network modelling of organisational factors in risk analysis: A case study in maritime transportation. Reliability Engineering & System Safety, 93(6), pp.845–856. Available at: http://dx.doi.org/10.1016/j.ress.2007.03.035.

Yuan, C. & Druzdzel, M.J., 2006. Importance sampling algorithms for Bayesian networks: Principles and performance. Mathematical and Computer Modelling, 43(9-10), pp.1189–1207. Available at: http://dx.doi.org/10.1016/j.mcm.2005.05.020.

Zhang, D. et al., 2013. Incorporation of formal safety assessment and Bayesian network in navigational risk estimation of the Yangtze River. Reliability Engineering & System Safety, 118, pp.93–105. Available at: http://dx.doi.org/10.1016/j.ress.2013.04.006.

Zhang, G. & Thai, V.V., 2016. Expert elicitation and Bayesian Network modeling for shipping accidents: A literature review. Safety Science, 87, pp.53–62. Available at: http://dx.doi.org/10.1016/j.ssci.2016.03.019.

Zhang, J. et al., 2018. Quantitative assessment of collision risk influence factors in the Tianjin port. Safety Science, 110, pp.363–371. Available at: http://dx.doi.org/10.1016/j.ssci.2018.05.002.

APPENDIX

Variables	Description	State	Data source
Daytime	Statistical number of maritime accidents during the day or night. In the case of passenger cruise ships, the risk of a maritime accident is higher during the day, since the observed ships are more active during the day.	day/night	MMPI [1]
Season	Indicates whether the marine casualty occurred in summer or winter. The summer period is period from April 1 to October 31.	summer/winter	MMPI
Day	Refers to the relationship between the probability of a maritime accident and the day of the week.	7	MMPI
Weather	Describes a meteorological condition during a maritime accident	4	MMPI
Sea state	Refers to the state of the sea at the time of the maritime accident	5	MMPI
Wind force	Refers to the wind force at the time of the maritime accident	6	MMPI
Wind direction	Refers to the wind direction at the time of the maritime accident	3	MMPI
Visibility	Refers to the visibility at the time of the maritime accident	5	MMPI
Traffic distribution	The ratio of the total number of vessels and the area of the observed area, where the term vessel includes ships, yachts and boats	low/high	MMPI1[2]
Visual detection	Refers to the visibility from the bridge which is conditioned by the design and arrangement of the windows on the bridge, the wipers on the windows, the salt on the windows, etc. The variable also refers to the visibility conditioned by the intensity of the sunlight.	good/bad	expert
Tired	Refers to the condition of the person operating the ship.	yes/no	DNV1[3],expert
Familiarization	Refers to the experience of a person operating a ship sailing a certain area.	yes/no	DNV[4],expert
Stress level	Refers to how much stress the person operating the ship is exposed to.	yes/no	DNV,expert
Incapacitated	Refers to the mental ability of the person operating the ship. Disability can occur due to effects of alcohol, illness, drug abuse, or some medications.	yes/no	DNV,expert
Other distractions	Refers to the exposure of the person operating the ship to other distractions, such as mobile devices, the presence of other people on the bridge, problematic situations on the ship that may distract him from navigation tasks.	yes/no	DNV, expert
Situational awareness	Refers to a person's ability to construct a mental model based on the present status, and make projections into the future environment, both onboard and around	yes/no	DNV, expert
Personal condition	Refers to the mental and physical condition of the person operating the ship.	good/bad	expert

1. *MMPI, data obtained per request from the databases of The Ministry of Maritime Affairs, Transport and Infrastructure of the Republic of Croatia, https://mmpi.gov.hr/*
2. *MMPI1, Available at.: https://mmpi.gov.hr/UserDocsImages/arhiva/MMPI%20-%20South%20Adriatic%20v.3.1%2022-12_14.pdf*
3. *DNV1, Det Norske Veritas, Formal safety assessment of Electronic Chart Display and Information System (ECDIS). Technical report. DNV; 2006.*
4. *DNV, Det Norske Varitas, Formal safety assessment – large passenger ships, technical report, DNV, 2003*

Communication with other vessel	Refers to successful communication with another ship in the event of collision courses or during navigation through narrow channels	good/bad	expert
Safety culture	- possible lack of crew and human resources on board, poor financial situation of the company that owns the ship, frequent changes of crew due to dissatisfaction with working conditions - working hours, i.e. the possibility for seafarers to work in shifts that can result in increased fatigue and reduced quality of health. - non-compliance with safety protocols, poor awareness of the crew about maritime safety.	high/standard/bad	DNV,expert
Give way	Refers to taking proper actions to avoid collisions in accordance with the "Pravilnik o sigurnosti pomorske plovidbe u unutarnjim morskim vodama i teritorijalnom moru Republike Hrvatske te načinu i uvjetima obavljanja nadzora i upravljanja pomorskim prometom.",(Croatian Maritime Law,2013)[5]	yes/no	expert
Maintenance	Refers to the maintenance of technical systems, ship hull and ship systems in general.	good/bad	expert
AIS	Refers to correct use of the automatic identification system on board	yes/no	expert
Radar	Refers to the correct use of the radar on a ship	yes/no	expert
Vessel damage	Refers to all damage to the ship regardless of cause and effect.	yes/no	expert
Special caution area	Refers to areas of special danger specific to the observation area. Areas of special caution defined according to the Maritime-Navigation Study of the Split, Ploče and Dubrovnik navigable areas are: Splitska vrata, Drvenički kanal, Viški kanal, Šoltanski kanal, Pakleni otoci and Pakleni kanal, Prilaz Gradskoj luci, areas of seaplane navigation, areas of the outer edges of the islands.	yes/no	expert
Loss of control	Refers to the loss of control of a ship due to a technical malfunction or due to human error during which nothing can stop the ship from moving towards danger.	yes/no	DNV, expert
Breakdown	Refers to a technical failure on board, regardless of the cause and effect of the failure.	yes/no	DNV, expert
Human error	Refers to intolerant activity or deviation from normal behaviour whose boundaries are defined by the system.	yes/no	DNV, expert
Navigational error	Refers to errors in navigating the sea, i.e. in determining the position of the ship, control and supervision of its movement.	yes/no	DNV, expert
Off course	Refers to a group of causes that lead to the ship being unable to navigate at the planned course.	yes/no	DNV, expert
Loss of control of other ship	Refers to the loss of control of another ship due to a technical or human error, or the influence of external factors.	yes/no	expert
Other ship error	Refers to human errors on another ship (navigation errors, handling errors, etc.)	yes/no	expert

5. *Croatian Maritime Law, 2013., Available at: https://narodne-novine.nn.hr/clanci/sluzbeni/2013_06_79_1640.html*

Application of GIS: Maritime Accident Analysis in Malaysian Waters Using Kernel Density Function

Sarah Isnan, Nur Hazimah Nordin, Ainul Rahman, Afiqah Rosly, Adenen Aziz, Zulkifly M. R., Abu Zarim, Muhammad Syafiq Bin Mohd Abu

Statistics from the Marine Department in Malaysian Territorial waters has shown an increase in maritime accidents. The data of maritime accidents, including latitude and longitude of the locations, are analysed using Geographical Information System with Kernel Density function. This is to visualise, locate and identify the high-risk location of maritime accidents in Malaysian waters. Using the GIS analysis, the findings suggest that the data of the high-risk maritime location is at Malacca Straits. The results showed that GIS analysis is a useful tool to analyse maritime accidents data and can be used as a guidance for navigators to plan their passage in order to avoid maritime accidents.

KEY WORDS

~ Geographical Information System
~ Kernel density
~ Maritime accidents
~ Malacca straits
~ Malaysian water
~ Spatial analysis

Universiti Pertahanan Nasional Malaysia, Kuala Lumpur, Malaysia

e-mail: sarahmohdisnan@gmail.com

doi: 10.7225/toms.v10.n02.004

Received on: 20.05.2021 / Revised on: 20.08.2021 / Accepted on: 01.09.2021 / Published: 21.10.2021

1. INTRODUCTION

Maritime traffic has been used as a way to transport goods for over 3,000 years and this industry has developed rapidly to avoid maritime accidents that could cause damages to the ship and goods, pollution, and even deaths. Maritime accidents are divided into three categories: those resulting in very serious causalities, serious causalities, and less serious causalities (IMO, 2008). It is a global issue and numerous research has been done in studying their patterns, trends, and consequences.

According to the United Nations Convention on the Law of the Sea, Internal Waters are the sea areas on the landward side of the baselines, while the sea areas comprising the territorial sea, exclusive economic zone, and continental shelf lie on the seaward side of the baselines. For security and enforcement by the Malaysian Coast Guard, Malaysian waters include internal waters, territorial sea, continental shelf, and an exclusive economic zone. Malaysian water areas span over approximately 500,000 km^2.

According to the Ministry of Transport (2019), more than 55,000 ships enter main ports in Malaysia annually, such as the West Port and North Port at Port Klang, Port of Tanjung Pelepas, Penang Port, and Port of Bintulu. This high-density traffic and the high number of ships entering the main ports in Malaysia have made Malaysia one of the competitors in the maritime industry. However, it also affects the safety of Malaysian waters (Asnida & Wahab, n.d.). Hence, a study of maritime accidents is crucial to warn navigators of heavy traffic in certain areas, especially in Malacca Straits.

2. LITERATURE REVIEW

Most of the scholars focused on the analysis of the maritime accidents data using GIS such as Huang et al., (2013), Acharya et al., (2017) and Zhang et al., (2020). Both Huang et al., (2013) and Acharya et al., (2017) used Buffer analysis to study distribution of maritime accidents. On the other hand, Zhang et al., (2020) used Kernel Density analysis to study distribution patterns of maritime accidents worldwide. Ugurlu et al., (2012) and Sigua & Aguilar (2003) created a new database of ship accidents using GIS. Dobbins and Abkowitz (2010) simulated ship routes using GIS in order to analyse ship traffic in the US waters.

Based on the literature review, most of the researchers have used GIS to analyse maritime accidents, but they have only emphasised general global maritime accidents in certain areas. However, no research on GIS analysis has been done in Malaysian waters. Hence, this research is important to visualise and map out the trends of maritime accidents in Malaysian waters. This will help in future coastal planning and safety management, as well as decision making.

3. METHODOLOGY

3.1. Spatial Analysis in GIS

In GIS, spatial data that contains attributes can be visualised in a map to predict an incident by an interactive method. Different layers of maps which contain different spatial data and attributes could be combined to produce a single map. The spatial analysis is a tool in ArcGIS which is able to visualise and model the spatial data geographically. In addition, the output can be explored to predict any upcoming situation. This analysis is powerful in assessing the topographical suitability of different purposes, making predictions of output, and analyse and interpret the changes occurring based on the results produced, so that users can solve the problem efficiently (Esri, 2018).

3.2. Kernel Density Analysis

Geographic information system is a computer system designed to capture, query, analyse, and display geospatial data (K.T Chang, 2019). Kernel density analysis is one of the tools in GIS that is used for hot spot analysis. This method analyses location and spatial extent of incidents accurately. Statistically, Kernel density technique is a better hot spot identifier than the cluster analysis techniques (Shahrabi and Pelot, 2009). Kernel density method generalises incident occurrences over the entire study area, while hot spot techniques provide statistical summaries for the incidents (Shahrabi and Pelot, 2009). This method calculates densities in all locations, whereas other hot spot analysis defines the boundary of hot spot areas arbitrarily (Shahrabi and Pelot, 2009). Kernel density method creates a continuous surface to represent density variability over the entire study area, not just in certain cluster, as is the case with other hot spot techniques (Shahrabi and Pelot, 2009).

The estimation for new coordinates at a point (m,n) is shown in Figure 1. The predicted density at a new (x,y) location is determined by the following formula:

$$Density = \frac{1}{(radius)^2} \sum_{i=1}^{n} [\frac{3}{\pi} . pop_i \left(1 - \left(\left(\frac{dist_i}{radius} \right)^2 \right)^2 \right] \text{, For distance}_i < \text{radius}$$

where:

- i = 1,…,n are the input points. Only include points in the sum if they are within the radius distance of the (x,y) location
- pop_i is the population field value of point i, which is an optional parameter
- $dist_i$ is the distance between point i and the (x,y) location

Figure 1.
Formula to Estimate Density for Points Surface (Spurr and Silverman, 1988).

3.3. Study Area

The study area focuses on Malaysian waters. Data from the Marine Department consists of four different years of accident (2016 to 2019), types of vessels, type of accidents, longitude and latitude of location of accidents. The data is then processed in ArcMap, which shows the latitude and longitude of each accident. Subsequently, the map is analysed using GIS Kernel Density Analysis to predict the vulnerable area of maritime accidents in order to improve safety management planning.

The raw data that was received from the Marine Department of Malaysia has undergone quality checking to ensure accurate attributes and spatial data. After that, the latitude and longitude are converted into radian format, so that the GIS will be able to map and visualise the data in an interactive map. The work process of the research is shown in Figure 2.

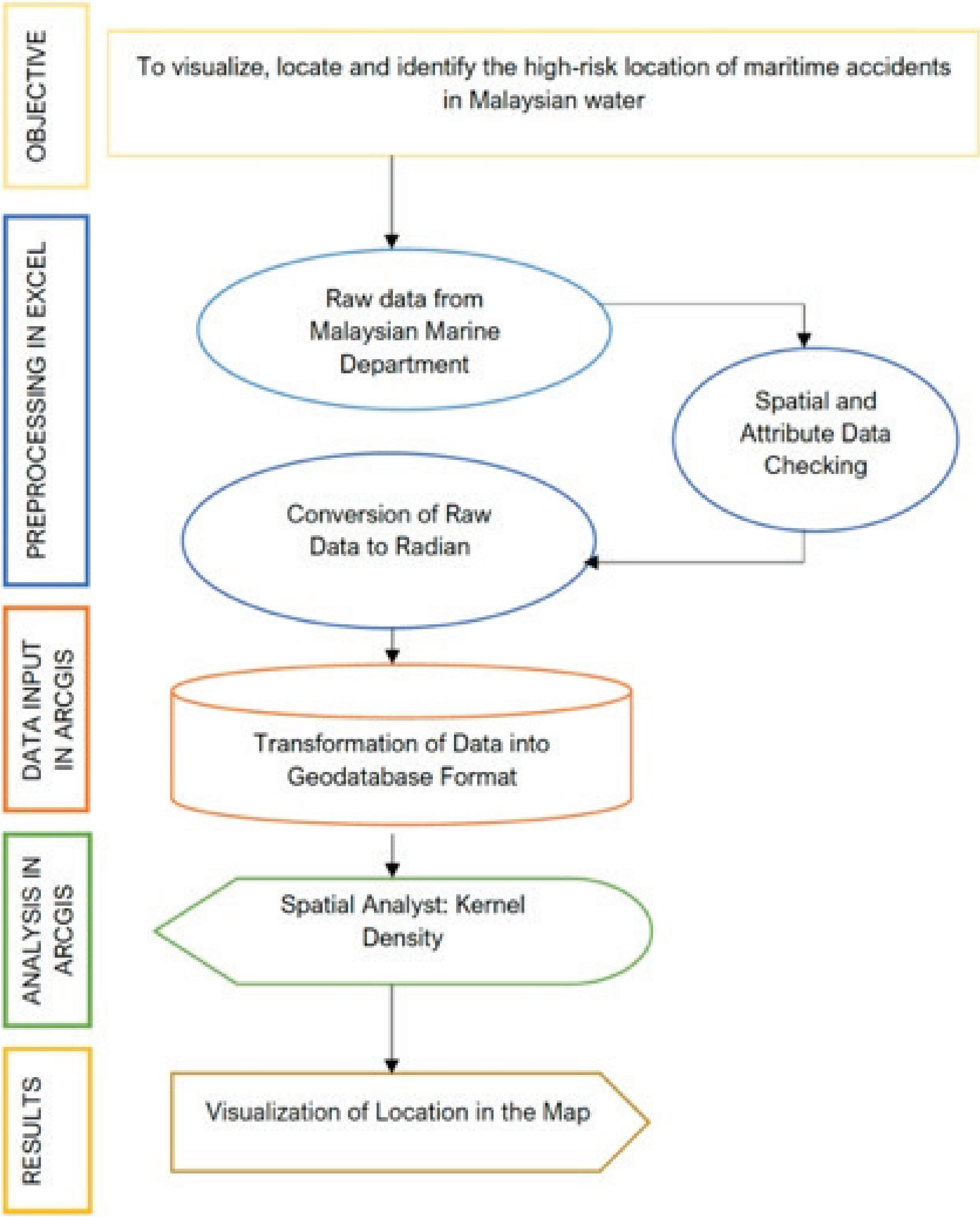


Figure 2.
Research Work Process.

4. RESULTS AND DISCUSSIONS

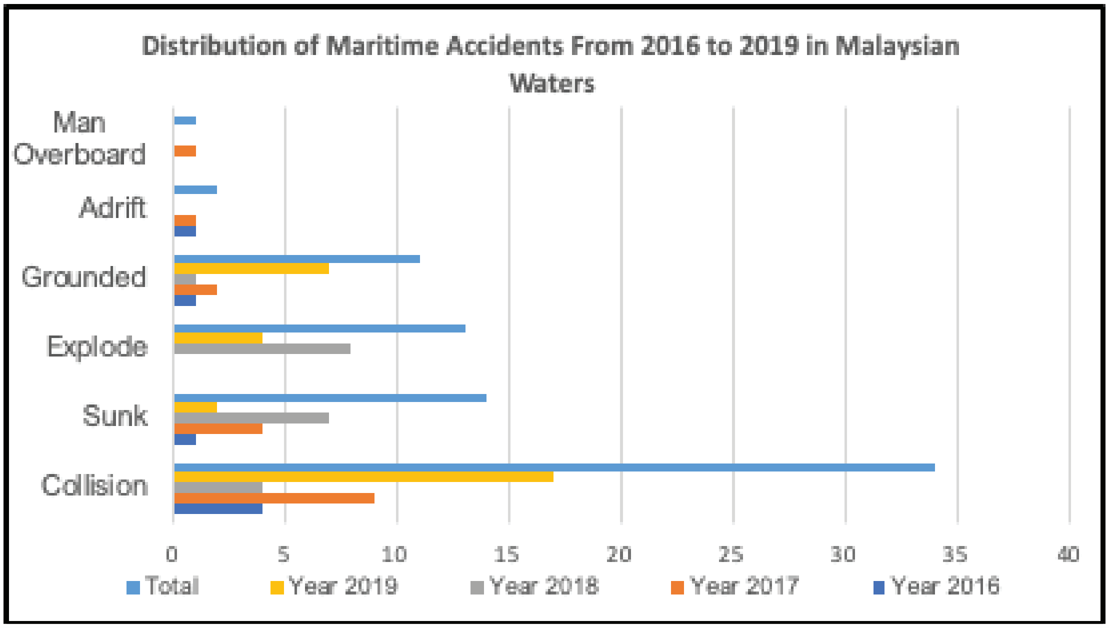


Figure 3.
Distribution of Maritime Accidents From 2016 to 2019 in Malaysian Waters.

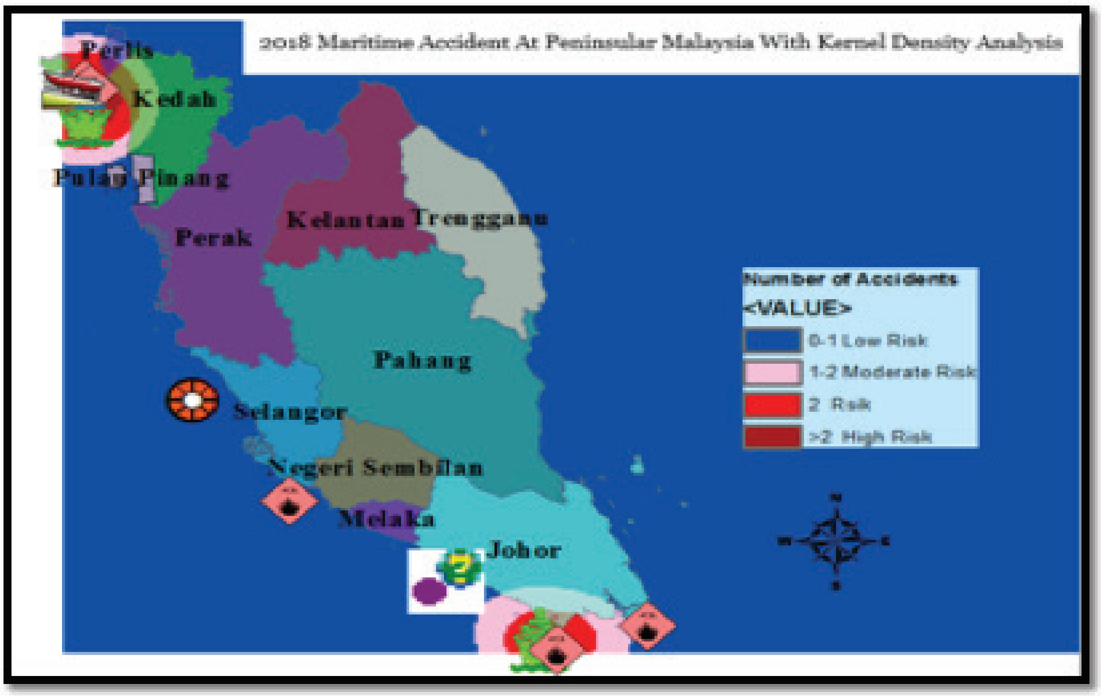


Figure 4.
2018 Maritime Accident at Peninsular Malaysia with Kernel Density Analysis.

Figure 3 shows the distribution of maritime accidents from 2016 to 2019 in Malaysian Waters. The types of maritime accidents that occurred from 2016 to 2019 in Malaysian Waters were man overboard, adrift, grounding, explosion, sunk and vessel collision. As can be seen in the graph, the highest number of accidents occurring in 2016 was vessel collision, and the lowest man overboard. The most frequent accidents occurring in 2017 were vessel collisions, while the rarest were man overboard and adrift. In 2018, the majority of accidents were related to vessel explosion, and the lowest were adrift and man overboard. The highest number of accidents occurring in 2019 was vessel collision, while the lowest was man overboard and adrift. According to Ezequiel and Marin (2014), even with advanced technologies and management, any type of maritime accident, such as collision, explosion, and sinking can happen.

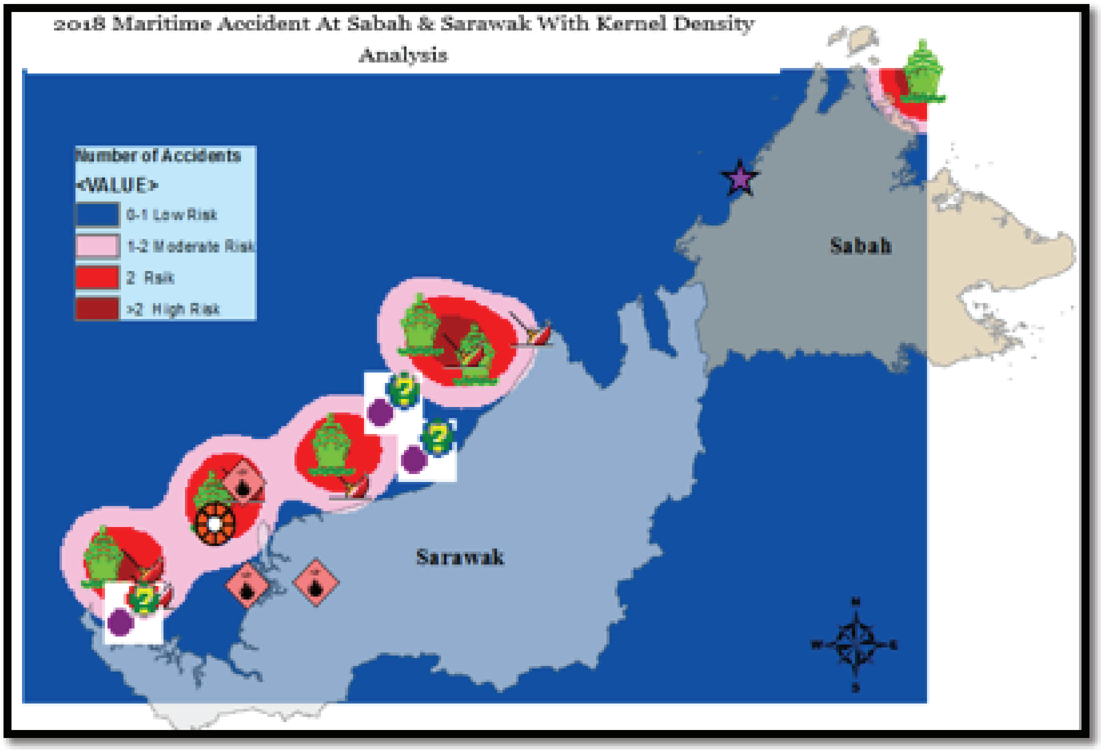


Figure 5.
2018 Maritime accident at Sabah & Sarawak with Kernel Density analysis.

Figures 4 and 5 show maritime accidents in Malaysia during the year 2018, after Kernel Density analysis was done. The high occurrence of accidents is reported at Singapore Straits and Sarawak territorial sea. The result of Kernel Density function analysis has produced different types of contour to indicate the highest to the lowest risk of accidents. Firstly, the dark blue label indicates the lowest or low-risk area of accidents. Next, the label that is pink in colour indicates moderate risk area of accidents. The red label indicates the areas that are categorised as risky. Finally, the high-risk area is highlighted with a darker red colour. More than 100,000 ships navigate through the Straits of Malacca annually. It has a high traffic density as it is the shortest route for vessels from the Middle East to China (Abdul Wahab, 2017). One of the possible causes of accidents at Malacca Straits is the restricted visibility due to haze caused by forest and bush fires in Sumatra. This has affected the safe navigation through the waterways, and it remains a threat to mariners even today.

Other than that, groundings are also one of the frequent accidents along the Straits. With the shallow seafloor along the Singapore Straits being the most notorious for groundings, some ships get stuck while navigating along the stretches of the Malacca Straits (Ahmad, 2014). On top of that, ships that are not adequately maintained or are suffering mechanical problems contribute to the risk of accidents. A power or steering failure while navigating busy or challenging waters can quickly turn into a severe situation (Fadzlon, n.d.).

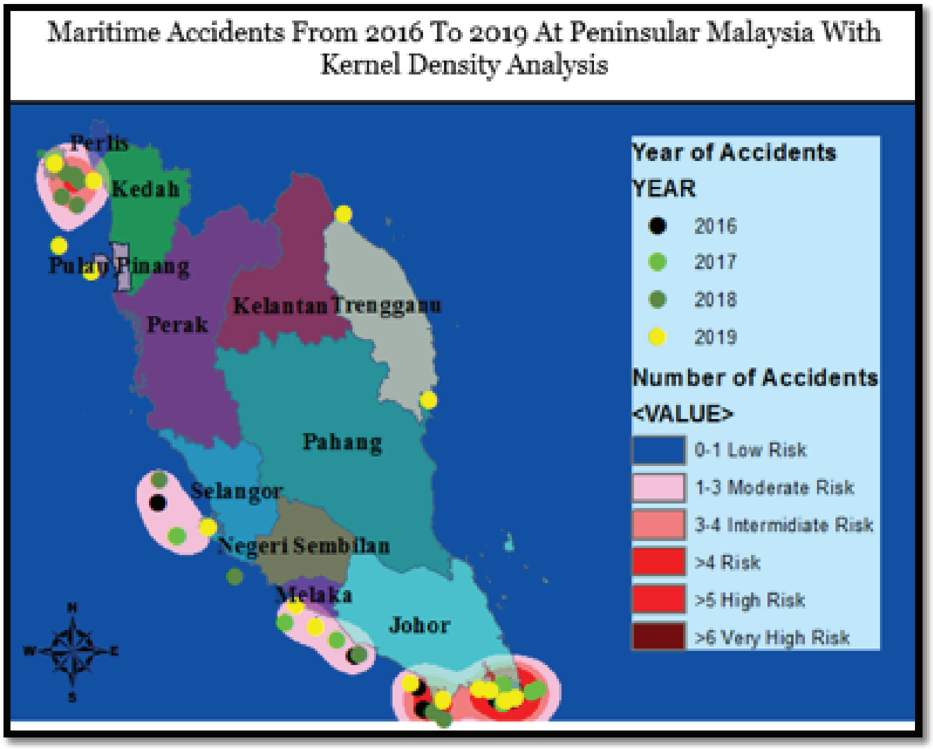


Figure 6.
Maritime Accidents from 2016 to 2019 at Peninsular Malaysia with Kernel Density analysis.

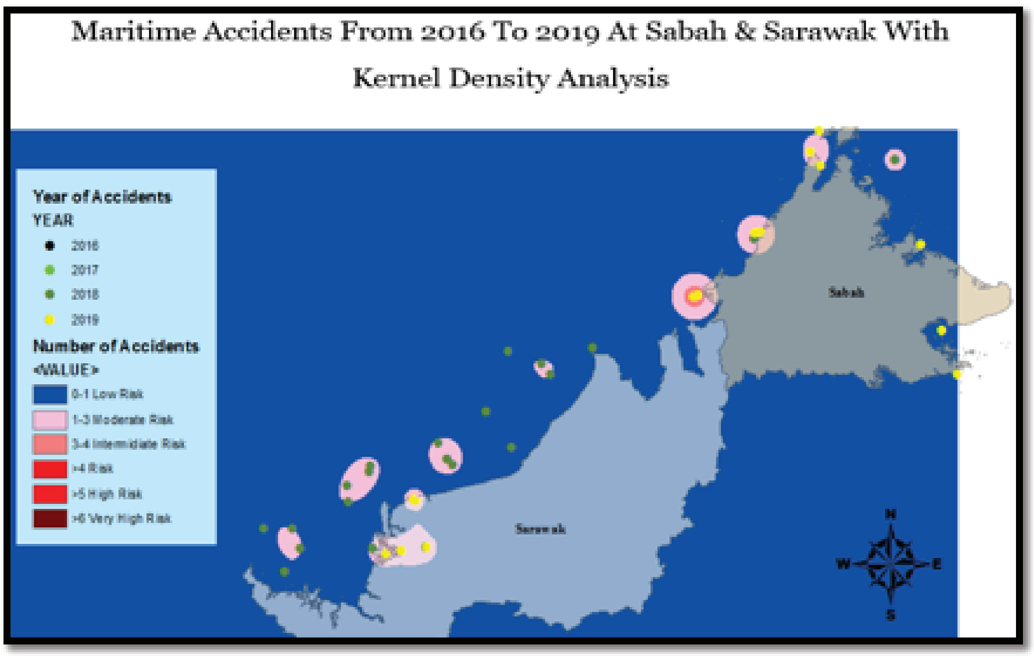


Figure 7.
Maritime accidents from 2016 to 2019 at Sabah & Sarawak with Kernel Density analysis.

Figure 6 and 7 show Kernel Density analysis of maritime accidents in Malaysia from the year 2016 to 2019. Relationship of types of colour to the frequency of accidents is categorised in Table 1.

Table 1.
Relationship of colour on the map with frequency of accidents.

Contour on the Maps	Category of Location	Frequency of Accidents
Blue	Low risk	<1
Pink	Moderate	2
Light Red	Intermediate	3
Red	Risk	4
Dark Red	High Risk	5
Very Dark Red	Very High Risk	>6

Based on Kernel Density Analysis, high risk and very high-risk locations are at Straits of Malacca and Singapore Straits. In addition, the Straits' most difficult conditions lie between Horsburgh Lighthouse and One Fathom Bank Lighthouse, about 217 miles away. Moderate risk is recorded for this area. The remaining 500 miles are more accessible to the sea. As masters are free to plan their course, the apparent trend is to use the shortest route. This means that many ships draw the same courses that cause them to overtake the narrow limits of the lane. Although the implementation of Traffic Separation Schemes (TSS) has considerably assisted traffic management, with different types of vessels travelling at different speeds and crews, there is still a risk of collision and grounding (Fadzlon, n.d.).

In Kedah waters, kernel density analysis detects intermediate risk and moderate risk area of maritime accidents. This is because vessels seldom cross this area. Based on the analysis, maritime accidents at Sarawak and Sabah are moderate to low. Navigators seldom cross this waterway as they usually use Malacca Straits, being the shortest route to cross from the Middle East to China (Abdul Wahab, 2017).

5. CONCLUSION

Kernel Density analysis function in ArcMap is able to produce an output of map with the analysis of dense maritime accidents location. Geographical Information System is able to produce output of the pointed location of maritime accidents and analysis of the highest and lowest number of the accidents. From this research, any agencies or government may be able to improve the safety on sea by surveying the location that has high a number of accidents and avoiding them. Navigators also need to be extra careful when navigating through the Straits of Malacca.

For the recommendation of future research, the researcher suggests adding details of the location of maritime accidents information on the ArcMap. Details such as water depth, navigation equipment like buoys and lighthouses, tidal stream and current, as well as location of anchorage, could be added so that the ArcMap will be more helpful to navigators in planning their passage to avoid maritime accidents.

REFERENCES

Abdul Wahab, N., 2021. Maritime Transport Safety in Malaysia. Unescap. Available at: https://www.unescap.org/sites/default/files/%28Session%203%29%20Malaysia_Maritime%20transport%20safety.pdf, accessed on: 1 March 2021.

Acharya, T.D., Yoo, K.W. & Lee, D.H., 2017. GIS-based Spatio-temporal Analysis of Marine Accidents Database in the Coastal Zone of Korea. Journal of Coastal Research, 79, pp.114–118. Available at: http://dx.doi.org/10.2112/si79-024.1.

Dobbins, J.P. & Abkowitz, M., 2010. Use of Advanced Information Technologies for Marine Accident Data Analysis Visualization and Quality Control. Journal of Transportation Safety & Security, 2(1), pp.1–13. Available at: http://dx.doi.org/10.1080/19439960903560312.

Ezequiel, J. and Marin, M., 2014. Induced Maritime Accidents, July 2014.

Huang, D.-Z., Hu, H. & Li, Y.-Z., 2013. Spatial Analysis of Maritime Accidents Using the Geographic Information System. Transportation Research Record: Journal of the Transportation Research Board, 2326(1), pp.39–44. Available at: http://dx.doi.org/10.3141/2326-06.

Sigua, R. and Aguilar, G., 2003. Maritime incident analysis using GIS, Journal of the Eastern Asia Society for Transportation Studies, 5(11), pp. 778–793.

Ugurlu, O., Yildirim, U. and Yuksekyildiz, E., 2012. Marine accident analysis with GIS, NAV International Conference on Ship and Shipping Research.

Zhang, Y. et al., 2021. Spatial patterns and characteristics of global maritime accidents. Reliability Engineering & System Safety, 206, p.107310. Available at: http://dx.doi.org/10.1016/j.ress.2020.107310.

Creation of Ship Navigation Data Using Simulation Technology in Training Module

Zulkifly Bin Mat Radzi[a], Tang Jut Weng[b], Md Hafize Md Eusoff[b], Sarah Isnan[b], Adenen Aziz[b]

All ships need navigation data to ensure they stay on track during course-changing maneuvers. Navigation data are usually obtained by shipyards while conducting turning trials at sea. The aim of this research was to generate navigation data for warships, such as the Leander Class Frigate (LCF). The research was conducted using the Ship Bridge Simulator (SBS) simulation technology at the Maritime Centre of the National Defence University of Malaysia (NDUM). Turning trials were conducted at various speeds, rudder angels, and heading changes. Distance to new course, advance and transfer have been tabulated for LCF navigation data. Navigation experts validated the data by nautical chart plotting. The data were found to be highly reliable for the training module. The research was successfully conducted and generated LCF navigation data. The navigation data collected are highly accurate and effective for the naval cadet navigation training module at the NDUM. The SBS software is highly suitable for turning trials and navigation data generation.

KEY WORDS

~ Navigation data
~ Turning trial
~ Simulation technology
~ Ship bridge simulator
~ Training module

a. MAREC, National Defence University of Malaysia
e-mail: zulkifly@upnm.edu.my
b. Universiti Pertahanan Nasional Malaysia, Kuala Lumpur, Malaysia
e-mail: hafize@upnm.edu.my

doi: 10.7225/toms.v10.n02.w03

Received on: 20.05.2021/ Revised on: 18.06.2021/ Accepted on: 06.07.2021/ Published online: 16.07.2021

1. INTRODUCTION

Maritime transportation is essential for the commercial sector, especially for a maritime nation. The international rules and regulations for ships at sea are coordinated by the International Maritime Organisation (IMO) and required to be observed by all ships at sea (Cockcroft, 2004). Although a variety of instruments can be used for navigation purposes, vessels need accurate navigation data to maintain navigation safety. In order to train naval cadets in navigation safety, the National Defence University Malaysia (NDUM) had procured a full-mission Ship Bridge Simulator (SBS) from Kongsberg, Norway in 2015 (Zulkifly, 2016). Thereafter, a training module known as the LAKSANA Module was developed to improve professional competencies of naval cadets. The LAKSANA Module contains psychomotor and affective curriculum for naval cadets' assessment. However, the LAKSANA Module has yet to establish the navigation data for different types of ships in the SBS. Therefore, the objective of this research was to generate ship navigation data for Leander Class Frigates (LCF) using SBS simulation technology at the NDUM Maritime Centre.

Ships need navigation data to ensure they stay on track during course-changing maneuvers (Hirano, 1980). The captain is required to procure such data prior to setting sail. Without navigation data the captain would not be able to maneuver his vessel precisely when changing course (Drachev, 2012), increasing the risk of collision or even grounding at sea. Figure 1 shows the turning circle of a ship and the terms used in navigation practice.

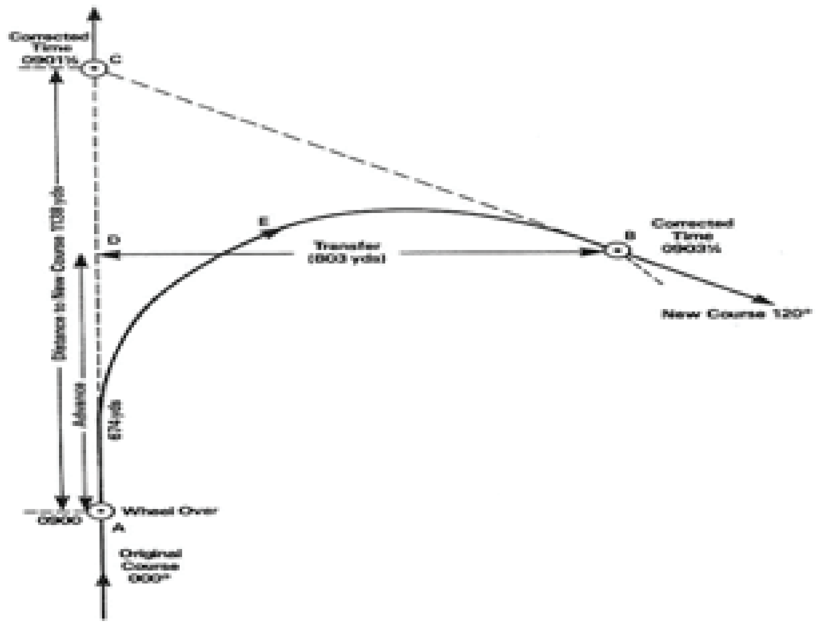


Figure 1.
Ship's turning circle and navigation terms used in navigation practice.
(Admiralty Manual of Navigation Volume 1, BR45, 1987).

- Distance to New Course (AC) is the distance from the wheel over position to the point of intersection of the original course and the new course of a ship.
- Advance (AD) is the distance a ship has advanced in the direction of the original course and on completion of a turn measured from a wheel over position.
- Transfer (DB) is the distance of a ship's transfer in a direction at an angle from the original course to the new course.

Figure 2 shows heading change from 351° to 114° required to enter the Lumut harbor. Point A is the start of the turn at wheel over position and Point B is the start of the new course. Point C is the point of intersection of the original course and the new course. The distance between points A and C is distance to new course (DNC), between points A and D the advance (ADV) and between points B and D the transfer (TRANS). Nautical chart plots are based on the navigation data of His Majesty's Ship (KD) HANG TUAH from Table 1.

The NDUM SBS was built based on a Royal Malaysian Navy (RMN) training vessel used for naval cadet navigation training. The SBS build-up depicts a ship bridge with windows, fitted with navigation equipment such as the wheel, throttle, radar, electronic chart, communication equipment, ship's data board and the captain's chair. The navigation equipment was integrated using computer software capable of displaying the view of ports, straits and coastal areas. Jyotsna Pandey (2016) said that mathematical models could be used in computer software to generate ship navigation data with great accuracy. Figure 3 is an illustration of the SBS at the NDUM Maritime Centre acquired in 2015 from Kongsberg, Norway.

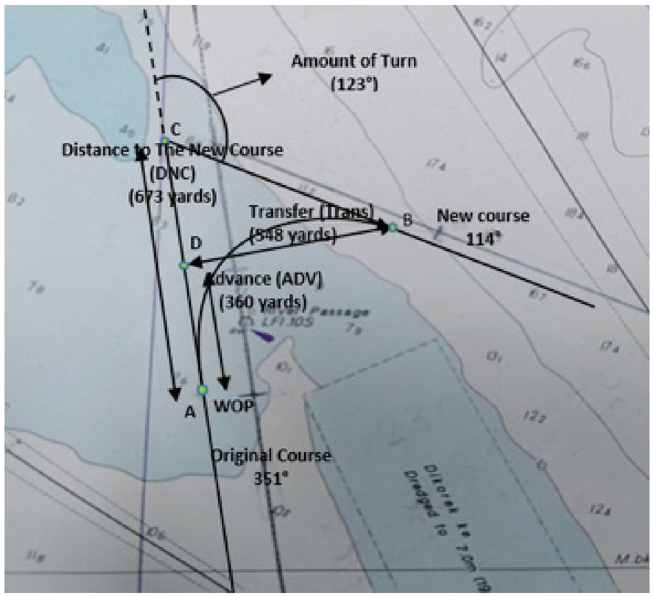


Figure 2.
Ship's navigation data drawn on nautical chart.

Table 1.
Extract from KD HANG TUAH navigation data.

Speed	Rudder Angle	Angle of Turn	ADV (cable)	TRANS (cable)	DNC (cable)
10 knots	20°	123°	360 yards (1.8)	548 yards (2.8)	673 yards (3.4)

Figure 3.
The SBS at Maritime Centre, UPNM (Zulkifly, 2016).

The LAKSANA Module was developed based on SBS capabilities that can be used to assess the levels of the psychomotor and affective domains, as well as the competencies of naval cadets. The seven levels of the psychomotor domain are: perception, set, guided response, mechanism, complex overt response, adaptation and origination. The five levels of the affective domain are: receiving phenomena, responding to phenomena, valuing, value organisation and value internalisation. A simulator is an effective navigation training tool for the development of psychomotor and affective domains in naval cadets (Zulkifly, 2016). The SBS can adapt, slow down, fast track or repeat scenarios depending on the performance of individual trainees. Naval cadets are required to undergo navigation training that will enable them to enter or leave the harbor, deal with man overboard recovery situations, pilot to anchorage, execute fleet maneuvering exercises and evolutions at sea using the SBS. The professional conduct of the LAKSANA Module requires the navigation data of the vessel used in the training module to be developed.

2. METHODOLOGY

A simulation technique that uses a mathematical model is an effective method for predicting a vessel's maneuvering ability (Etter, 2013). The goal of this research was to generate navigation data for the LCF, to be used by naval cadets in their navigation training module. The primary data will be generated using the ship's turning circle trials conducted at the SBS. The LCF model will be used for the turning trials due to the similarity of the maneuvering capabilities of the LCF and the KD HANG TUAH. Navigation data generated have been validated by former RMN ship commanding officers who are serving as lecturers at the NDUM. Analysis was conducted through comparison with the KD HANG TUAH navigation data, serving as secondary data. Navigation data collected from the turning trials conducted in the SBS are transformed into a table and graph for final analysis.

3. RESULTS AND ANALYSIS

Navigation data have been validated through interviews with three navigation experts. All three respondents are former commanding officers of RMN ships who have conducted turning trials of their vessels. They said that officers of the watch and commanding officers need navigation data as a reference, to familiarize themselves with the turning capabilities of their vessel. Navigation data are normally acquired through the turning trials of the vessel conducted by the shipyard. However, turning trials need to be repeated for verification purposes by a ship's commanding officer. External factors, such as ocean currents, tidal streams and the wind need to be considered to determine the accuracy of navigation data. These external factor predictions are extracted from tide tables and nautical charts.

The exact maneuvering capability of a vessel cannot be determined without accurate navigation data. The SBS used in LCF turning trials is appropriate because naval cadets need to be trained onboard a frigate class warship. Naval cadets are required to use a frigate's DNC, TRANS and ADV accurately during the LAKSANA Module training to avoid grounding and collision of ships at sea.

Navigation data generated through LCF turning trial simulation, which produced various DNC, ADV and TRANS, are recorded in Table 2. Table 2 suggests that the bigger the rudder angle used, the shorter the transfer, advance and distance to new course, since a vessel's turning circle is smaller when a greater rudder angle is used.

Table 2.
LCF navigation data recorded at SBS at the speed of 10 knots.

Rudder Angle	Change of Heading SBS											
	45˚			60˚			90˚			120˚		
	DNC	ADV	TRANS	DNC	ADV	TRANS	DNC	ADV	TRANS	DNC	ADV	TRANS
10°	475 (2.4)	722 (3.6)	241 (1.2)	590 (3.0)	820 (4.1)	395 (2.0)	909 (4.5)	909 (4.5)	745 (3.7)	1449 (7.2)	778 (3.9)	1166 (5.8)
15°	366 (1.8)	574 (2.9)	207 (1.0)	462 (2.3)	670 (3.4)	359 (1.8)	709 (3.5)	709				
(3.5)	610 (3.1)	1129 (5.6)	635 (3.2)	859 (4.3)								
20°	345 (1.7)	503 (2.5)	159 (0.8)	416 (2.1)	586 (2.9)	290 (1.5)	650 (3.3)	650 (3.3)	547 (2.7)	1004 (5.0)	541 (2.7)	798 (4.0)

Note: DNC, ADV and TRANS are measured in yards (cable)

In Figure 4, LCF's course in the SBS simulation was plotted for 000°, speed of 10 knots and a 15° rudder angle. The DNC is measured from A to C, ADV from A to D and TRANS from B to D to generate LCF navigation data. Turning trials have been conducted at various rudder angles and heading changes, as shown in Table 2.

Meanwhile, the reliability of the navigation data obtained during the LCF turning trials was checked by second year undergraduate students of Maritime Technology (BSc. MarTech). Navigation data reliability was verified through the use of the data in practical exercises in the LAKSANA Module. The navigation data were plotted by students showing LCF DNC, ADV and TRANS on the nautical chart. The LCF navigation data were found to be highly accurate when used by students in the LAKSANA Module. Navigation experts have conducted a qualitative analysis of the LCF navigation data and confirmed that the data could be used to train naval cadets in pilotage, man overboard recovery and fleet maneuvering exercises. Navigation experts recommended that the data be used by naval cadets in the LAKSANA Module. BSc. MarTech students agreed that the LCF navigation data were reliable for accurate plotting on the nautical chart and pilotage exercises at the SBS. Navigation data were found to be an effective tool for improving the navigational competencies of naval cadets before undergoing industrial training onboard RMN ships.

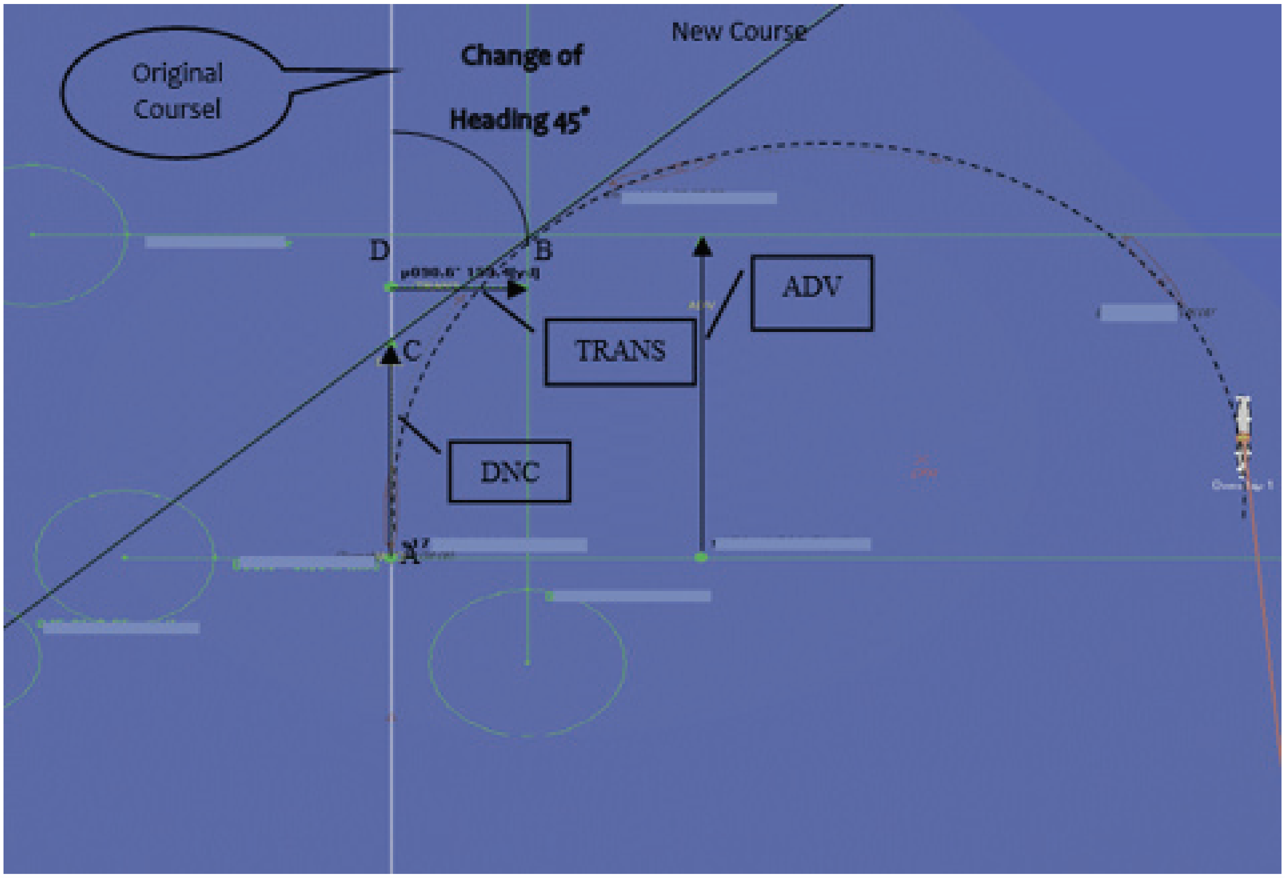


Figure 4.
LCF turning trail course at the SBS.

4. CONCLUSION

This research has successfully generated LCF navigation data for the LAKSANA Module. The SBS was found to be suitable for the creation of navigation data to be used in the pilotage training of naval cadets. The creation of LCF navigation data had a huge impact on the development of competencies that naval cadets need to make a headway in the navy. SBS software simulation was found to be suitable for conducting turning trials and generating a vessel's navigation data. Navigation experts from the ranks of former RMN ship commanding officers, who are NDUM lecturers, have validated the LCF navigation data and confirmed their suitability for the LAKSANA Module. The reliability assessment done by BSc, MarTech students confirmed that the navigation data are highly accurate for measuring LCF's DNC, ADV and TRANS. Hence, this research is a contribution in the field of creation of vessel navigation data using SBS simulation technology at the NDUM Maritime Centre.

REFERENCES

Cockcroft, F., 2004. Seamanship and Nautical Knowledge. Glasgow: Brown, Son & Ferguson.Ltd.

Drachev, V., 2012. Calculating Wheel-Over Point. Asia-Pacific Journal of Marine Science & Education, 2(1).

Etter, P., 2013. Underwater Acoustic Modeling and Simulation. USA: CRC Press.

Greswell, J.W & Greswell, J.D., 2018. Research Design Qualitative, Quantitative and Mixed Method 5th Ed. USA: Saga Publication.

Hebbs, R., 2017. Naval Science III. Annapolis: Naval Institute Press.

Hirano, M.T., 1980. Ship Turning Trajectory in Regular Wave. Trans. Tokyo: Jpn. Soc. Nav. Archit. 60.

Jyotsna Pandey, K.H., 2016. Study on Turning Maneuver of Catamaran Surface Vessel with a Combined. Conference on Control Applications in Marine Systems, Trandheim, Norway: IFAC CAMS 2016, pp. 446-451.

Ministry of Defence, UK, 1983. Admiralty Manual of Seamanship, BR67 Vol 3. London: Her Majesty's Stationery Office.

Ministry of Defence, UK, 1987. Admiralty Manual of Navigation, BR45 Vol 1. London: Her Majesty's Stationery Office.

Ministry of Defence, Malaysia, 2019. Defence White Paper, Kuala Lumpur: MoD Malaysia.

National Security Council, Malaysia, 2019. National Security Policy, Putrajaya: NSC, Malaysia.

Stravridis, J., 2010. Command at Sea. 6th ed. Annapolis: United States Naval Institute.

Tanaka, Y., 2018. The International Law of the Sea, 3rd ed. Cambridge: Cambridge University Press.

Zulkifly, M.R., 2016. Module Psikomotor dan Afektif Menggunakan Teknologi Simulator. Kuala Lumpur: UPNM.

Impact of Spoofing of Navigation Systems on Maritime Situational Awareness

Andrej Androjna, Marko Perkovič

The development of contemporary navigation and positioning systems have significantly improved reliability and speeds in maritime navigation. At the same time, the vulnerabilities of these systems to cyber threats represent a remarkable issue to the safety of navigation. Therefore, the maritime community has raised the question of cybersecurity of navigation systems in recent years. This paper aims to analyse the vulnerabilities of the Global Navigation Satellite System (GNSS), Electronic Chart Display Information System (ECDIS) and Automatic Identification System (AIS). The concepts of these systems were developed at a time when cybersecurity issues have not been among the top priorities. Open broadcasts, the absence of or limited existence of data encryption and authentication can be considered as their primary security weaknesses. Therefore, these systems are vulnerable to cyber-attacks. The GPS as the data source of a ship's position can relatively easily be jammed and/or spoofed, increasing the vulnerabilities of ECDIS and AIS. A systematic literature review was conducted for this article, supplemented by a SWOT analysis of the AIS service and particular case studies of recent cyber-attacks on these systems. The analysis of selected case studies confirmed that these systems could easily be spoofed and become a subject of data manipulation with significant consequences for the safety of navigation. The paper provides conclusions and recommendations highlighting the necessity for the users to be aware of the vulnerabilities of modern navigation systems.

KEY WORDS
~ Cybersecurity
~ Jamming
~ Spoofing
~ Safety of navigation
~ Shipboard navigation systems

University of Ljubljana, Faculty of Maritime Studies and Transport, Portorož, Slovenia

e-mail: andrej.androjna@fpp.uni-lj.si

doi: 10.7225/toms.v10.n02.w08

Received on: 11.06.2021/ Revised on: 14.08.2021/ Accepted on: 22.08.2021/ Published online: 23.09.2021

1. INTRODUCTION

Maritime cybersecurity represents one of the most important segments of maritime security policy in general. Today's maritime industry is highly dependent on digitalisation. Modern digital systems are used in many segments of the maritime sector, including port authorities, national maritime administrations, maritime traffic management systems, shipping companies, and vessel monitoring and management systems.

The trend towards digitisation and integration of systems is largely present in the maritime sector. Most of the ship navigation, communication and control systems are integrated and use the Internet for successful operation (Middleton, 2014; Chybowski et al., 2019; Dobryakova et al., 2018). Modern information technologies, together with digitalisation and integration trends, have significantly accelerated and improved the processes of management, safety and control in the maritime sector. However, it is important to emphasise that these technologies are vulnerable to cyber-attacks. The number of these attacks shows a trend of significant growth. Cyber-attacks in the maritime industry have increased by 900% between 2017 and 2019 (Marine Insight, 2020).

As the International Maritime Organization (IMO) gives great importance to maritime security issues, it has adopted resolution MSC.428 (98) "Marine Cyber Risk Management in

Security Management System (SMS)" (IMO, 2017) and "Guidelines on Cyber Risk Management (MSC-FAL 1/Circ.3) (IMO, 2017a)." The adoption of these documents enabled the revision of the provisions of the International Safety Management Code (ISM). The ISM contains cyber risks and recommendations to protect ships and ship systems from cyber-attacks (IMO, 2018). The new provisions of the ISM Code entered into force on 1 January 2021.

Based on the IMO's suggestion, the International Electrotechnical Commission (IEC) has developed the standard 63.154 to ensure the technical aspects to increase cyber resilience. This standard contains general requirements, test methods and required test results with the aim of increasing the level of cybersecurity of maritime navigation and communication systems (IEC, 2019).

At the regional level, the cybersecurity efforts of the European Union (EU) should be highlighted. The EU has taken significant steps to raise the level of cybersecurity in a number of sectors, including the maritime sector. In the maritime sector, the ''EU Maritime Security Strategy'' (EU, 2014), ''2018 Revised Action Plan'' (EU, 2018) and ''Progress Reports'' (EU, 2016; EU, 2017b; EU, 2020) are worth mentioning. The EU Maritime Security Strategy is the EU's umbrella document for maritime cybersecurity issues, while the Action Plan defines measures and Progress Reports shows the implementation of these measures in the maritime sector on an annual basis.

States and professional associations in the maritime sector are also involved in addressing the cybersecurity issue. States develop national cyber and information security strategies (Danish Maritime Cybersecurity Unit, 2018), while professional associations conduct research and situation assessments to define the risk of cyber threats in the maritime sector (BIMCO, 2020).

Thus, it can be said that a regulatory framework, technical and operational mechanisms, and implementation tools have been developed at global, regional and national levels. This framework identifies problems, analyses risks, monitors trends and defines measures to reduce the risks of cyber threats in the maritime sector. It is important to stress that analyses and trends show that significant steps have not yet been taken to increase the level of cybersecurity on ships, i.e. their essential navigation and communication devices are vulnerable to cyber-attacks.

There is no single classification of the types of cyber threats. Jones et al. state that the general and broad spectrum of these threats to the maritime sector includes business disruption, financial loss, damage to reputation, damage to goods and the environment, incident response costs, and fines or legal issues (Jones et al., 2012). Caponi and Belmont specify such threats, which may include manipulation of passenger lists, illegal shipments, breach of sensitive cargo shipments, intentional engine failures, vessel shutdowns, or other manipulation of onboard control systems (Caponi & Belmont, 2015). Over the past decade, cyberattacks have been recorded against almost all segments of the maritime sector. Ships, shore-based offices, seaports, terminals and supply chains are exposed to cyber threats (Androjna & Twrdy, 2020). It should also be noted that the IMO being affected by a cyber-attack at the end of last year was no exception (Knowler, 2020).

This paper analyses cyber threats to ship navigation and communication systems. These systems have significant weaknesses in terms of their exposure to cyber threats. According to BIMCO research, positioning systems, navigation systems, propulsion control systems, and surveillance systems are vulnerable to cyber threats (BIMCO, 2017).

Problems related to cyber threats to onboard navigation systems can be observed at two levels. One level of the problem represents the connection of the Shipboard Integrated Navigational System (INS) to the Internet. In the research conducted by Svilicic et al. (Svilicic, 2019) and Hareide et al. (Hareide, 2018), a higher level of cyber-attack threat was observed when the INS is connected to the Internet, i.e. when it is operating in online mode. The second level of the problem is related to the technical characteristics of the INS device. At the time of their commissioning, security was not the imperative as it is today (Kessler, 2020). Therefore, some of today's navigational devices can be relatively easily disrupted with relatively simple, inexpensive, and easily accessible devices.

Recent cyber-attacks on ships show that GPS, ECDIS and AIS are particularly vulnerable to these attacks. In this paper, we analyse the vulnerabilities of these systems. In general, these systems may be exposed to cyber threats related to jamming and spoofing.

Jamming is an intentional or unintentional interference (Kjerstad, 2016) of a radio frequency signal. Unintentional disruptions can be the result of various reasons, such as adverse weather conditions or equipment malfunctions, but they do not fall into the group of cyber threats because they are not caused intentionally. From a cyber-security perspective, particular attention is paid to intentional jamming, which is an intentional transmission of signals. GNSS is vulnerable to jamming. Cases of GNSS jamming are recorded in different parts of the world. From the point of view of navigation safety, it is essential to note that navigation systems sound an alarm when they detect jammers (Androjna et al., 2020). Spoofing is a more sophisticated method of cyber-attacks (Kjerstad, 2016) of intentionally creating false signals that can cause GNSS, ECDIS and AIS malfunctions. In most cases, spoofing is more difficult to detect than jamming. Jamming and spoofing of navigation systems can lead to data manipulation and modification, insertion of malicious content and fake data, hijacking, availability disruption, bandwidth usurpation.

The article consists of four sections. Section 2 describes the methodology. Section 3 provides a literature review on the main features of GNSS, ECDIS and AIS and their vulnerabilities to spoofing, examples and analysis of significant spoofing events. Section 4 discusses the results and provides some recommendations and conclusions.

2. METHODS

A literature review on spoofing of navigation systems on maritime situational awareness was conducted. It was followed by a comprehensive, explicit, reproducible, and idiosyncratic implicit method of data collection and structured following documented guidelines (Tranfield, Denyer & Smart, 2003; Grant & Booth, 2009; Milner, 2014). This method consists of ten steps congregated into three phases. The first phase focused on defining a review question to guide the search: "What are the effects of AIS spoofing in the maritime domain?" The second phase identified the appropriate time frame for documents to be included from relevant research databases such as Scopus, Web of Science, Science Direct, Google Scholar and open sources. "Spoofing" and "jamming" were identified as search keywords to be reviewed. After refining the selection to identify relevant documents, over 49 documents (21 articles, 18 peer-reviewed journal articles, and 10 reports from specialised agencies) were included, covering the mentioned area in the period from 2019 to 2020. In the third phase, we report our findings from the literature review.

The specific aspect of AIS / GPS spoofing is reinforced by the SWOT analysis in section 3.1.3 and by the case study analysis in section 3.3 from the Faculty of Maritime Studies and Transport, University of Ljubljana, regarding a particular AIS spoofing event near Elba Island in late 2019 (Androjna et al., 2021). As part of the research, AIS data were first obtained through cooperation with the Slovenian Maritime Administration, which is stored at MARES regional data exchange programme. Additional AIS day data were subsequently obtained from the Italian Coastguard. With these archive data, the strength of signals received at the AIS BS on the island of Elba was analysed, and a navigation scenario of the affected area created using the application AIS Network Data Client, played in two different VTS applications Navi-Harbor (Wärtsilä) and Pelagus (Elman). The spoofing data AIS analysis was then displayed on ECDIS and RADAR applications via the ship tracking simulator Navi Trainer Pro (Wärtsilä). Finally, a traffic density map (TDM) was created by using the European Marine Observation and Data Network (EMODnet) method (EMSA, 2019) and ship positioning data from terrestrial and S-AIS data sources, maritime infrastructure, and the SafeSeaNet Ecosystem Graphical Interface (SEG) application.

3. RESULTS

This chapter analyses the GNSS, ECDIS and AIS challenges connected with cyber threats to maritime navigation. It presents findings on their vulnerabilities, which will predominantly come from their technical performances. A basic description of these systems, basic technical and operational requirements, and liabilities to spoofing will be provided. The analysis of selected cyber-attacks to these systems confirmed their liability to cyber threats that may lead to a decrease in the level of safety of navigation and result in particular economic and even significant geopolitical consequences.

3.1. Vulnerabilities of GNSS, ECDIS and AIS to cyber threats

3.1.1. Vulnerabilities of GNSS

GNSS is designed to provide a continuous positioning service that measures time and speed for an unlimited number of users (Kjerstad, 2016). The best-known system in operational use is the US GPS (GPS/Navstar), which was developed as a military system with the option for civilian users.

The term GNSS refers to space-based systems such as the US GPS, Russian Global Navigation Satellite System (GLONASS), European Galileo System, Chinese BeiDou, Indian Navigation Indian Constellation (NavIC), Japanese Quasi-Zenith Satellite System (QZSS) (Androjna et al., 2020), and satellite navigation systems developed in future. The term GNSS is often colloquially replaced by the term GPS as it is widely used worldwide.

According to the International Convention for Safety of Life at Sea (SOLAS) Regulation V/19.2.1.6, all ships, irrespective of size, shall have a receiver for a GNSS or a terrestrial radio navigation system or other means suitable for use at all times throughout the intended voyage to establish and update the ship's position by automatic means (IMO, 2020). Due to SOLAS requirements, simplicity of use and high reliability, GNSS receivers now have an extensive application on ships and are a significant source of position fixing and timing.

GNSS is vulnerable to jamming, spoofing, meaconing (INTERTANKO, 2019) and blocking. GNSS jamming is the deliberate transmission of signals on frequencies used by GNSS to prevent receivers from locking onto authentic GNSS Signals (Androjna et al., 2020). Jamming can be done with relatively simple, inexpensive, and commercially available radio transmitters that send signals on almost the same frequency as the satellites (Kjerstad, 2016). It is important to note that there is unintended jamming due to space weather conditions. Cases of GNSS jamming have been reported in different parts of the world, usually in some crisis areas and during military activities such as electronic warfare exercises (Kjerstad, 2016).

Unlike jamming, GNSS spoofing is a more demanding and sophisticated method of cyber-attack that requires sophisticated equipment and a higher level of technical knowledge for its implementation (Kjerstad, 2016). GNSS spoofing broadcasts a false GNSS signal or a rebroadcast of accurate signals acquired at a different location or time (INTERTANKO, 2019). Spoofing can result in false position indication or timing. In GNSS spoofing, the transmission of a false signal is synchronised with an actual signal. Since the false signal is stronger than the real one, the GNSS receiver follows this false signal. Technically, GNSS spoofing is easier to implement by rebroadcasting than by broadcasting a false signal (INTERTANKO, 2019). A significant problem associated with GNSS jamming and spoofing is that GNSS is linked to onboard navigation and communication systems and is the only source of position and time for these systems. This means that the position and time error of the GNSS receiver is transferred to other connected equipment, which can cause an additional problem in the safe conduct of maritime navigation.

3.1.2. Vulnerabilities of ECDIS

ECDIS is an advanced navigation information system (Weintrit, 2009) that provides a continuous display of vessel position using the official Electronic Navigational Charts (ENC). ECDIS allows the display of all information required for safe navigation and must support a full range of navigational functions. As an information system, ECDIS goes far beyond the pictorial display of nautical charts on a computer screen (Hecht et al., 2017). The legal requirements for ECDIS are defined in the SOLAS Convention. Regulation V/19.2.10 of the SOLAS Convention requires ECDIS to be carried on certain types of SOLAS ships engaged on international voyages (IMO, 2020). In addition, ECDIS must be certified in accordance with SOLAS Regulation V/18 and IMO Resolutions A.817(19), MSC.64(67), MSC.86(70), and MSC.232(82), comply with the IMO performance standards and type approved by the Administration. This means that ECDIS must have type approval and test procedures developed by IEC 61.174 and IEC 62.288 standards and based on the IMO and International Hydrographic Organization (IHO) requirements before installation on the ship (Hecht et al., 2017). According to SOLAS requirements, ENC, which is used in ECDIS, must be official (issued by the national hydrographic office), up-to-date and compliant with the relevant IHO standards and specifications.

In order to comply with the IMO requirements for a permanent indication of vessel's position and other navigation functions, ECDIS should be linked to the appropriate sensors. These sensors can be divided into mandatory and optional. According to the IMO Resolution MSC.232(82), mandatory ECDIS sensors are a continuous position source (GNSS), a gyrocompass (or a heading transmission device), and a speed and distance measuring device (Thornton, 2016). All other sensors are optional. In practice, ECDIS is usually connected with various sensors, such as backup mandatory sensors, echo sounder, AIS, anemometer, radar (including ARPA).

In principle, there are three groups of ECDIS vulnerabilities. These are vulnerabilities of ENC data, then vulnerabilities of the mandatory and optional ECDIS sensors, and vulnerabilities of ECDIS as a computer-based system. ECDIS displays the official ENCs in human-readable System Electronic Navigational Chart (SENC) format. With the goal of preventing data manipulation and unauthorised use of the official ENCs and their updates, IHO Standard S-63 (IHO Data Protection Scheme) was developed. This standard provides a method to protect ENC data based on an encryption algorithm that provides piracy protection, selective access and authentication of ENC data (IHO, 2020). The application of this standard allows the end-users (vessels) to have authorised access to the official, up-to-date and protected ENC data while providing ENC manufacturers with protection against unauthorised access, modification, or manipulation of the data. The application of the Data protection scheme eliminates or significantly reduces the vulnerabilities of ENC data and enables its secure transfer via USB or the Internet from the manufacturer to the end-user. ECDIS mandatory and optional sensors of particular interest in cybersecurity are the vulnerabilities of the GNSS and AIS. In the event of a cyber-attack on the GNSS and/or AIS, these sensors will provide inaccurate information to ECDIS. The third group of vulnerabilities relates to ECDIS as a computer-based system. According to BIMCO, a malware attack on ECDIS installed onboard a newbuilding paperless bulk carrier is a reported case of a malware attack. ECDIS failure was not identified as a cyber-issue by the responsible crew members. This incident, in which ECDIS was infected with a virus, caused a significant delay to a voyage and high delay-related and repair costs (BIMCO, 2020a). ECDIS vulnerabilities, especially in paperless vessels, can lead to severe consequences ranging from navigational safety to marine pollution or geopolitical threats.

3.1.3. Vulnerabilities of AIS

The AIS is a communication system that enables automatic and continuous data exchange between ship and shore. The system was developed in collaboration among the IMO, International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), International Telecommunication Union (ITU) and International Electrotechnical Commission (IEC) (IALA, 2016). According to SOLAS regulation V/19.2.4, all ships of 300 GT and more engaged in international voyages and cargo ships of 500 GT and more not engaged in international voyages and passenger ships, irrespective of their size, shall be equipped with AIS (IMO, 2020). The European Union and national authorities have also developed obligations related to AIS for certain types of non-SOLAS vessels (i.e. fishing and recreational vessels) (Kjerstad, 2016). The international, regional, and national requirements and the ease and practicality of use greatly expand the range of users of AIS.

At the beginning of its development, the AIS was designed as a device to exchange identification information between ship and shore. The broader applications became apparent very quickly so that today the use of AIS is significantly expanded compared to the past, ranging from use for vessel collision avoidance, identification purposes, the safety of navigation, maritime security, traffic monitoring, prediction and analysis, search and rescue, monitoring of fishing activities, ecological concerns and scientific purposes (Natale et al., 2015; Eriksen et al., 2018; Ramin et al., 2020; Sciancalepore et al., 2021).

The AIS transceivers consist of a VHF transmitter, two VHF Time Division Multiple Access (TDMA) receivers, a VHF Digital Selective Calling (DSC) receiver, a positioning module (GNSS) and other sensors connected via standard marine electronic communication links (Caprolu et al., 2020). From a technical point of view, the AIS transmits and receives standardised messages on two dedicated VHF channels 87B and 88B (AIS 1 and AIS 2) using the self-organised TDMA protocol (SOTDMA), where the unit of time (one minute) is divided into time slots of equal length of 26.7 ms, allowing a nominal AIS capability of 2,250 messages per minute and per one dedicated AIS channel (IALA, 2016). The basic requirement for using the SOTDMA protocol is the synchronisation of the time slots of AIS stations, which is achieved by a highly accurate standard time reference provided by the GNSS (ITU, 2014). The AIS messages are standardised by type and content and divided into four groups with corresponding nominal reporting intervals depending on the type of AIS stations, message group, navigational status, speed, and course change (IALA, 2016). The existing AIS protocol provides standardised, simple, accurate and fast data exchange between different types of mobile (shipborne) AIS stations (AIS Class A and AIS Class B, AIS SART, MOB-AIS, EPIRB-AIS and AIS and SAR aircraft) and fixed AIS stations (AIS Base Stations, AIS repeaters, and AIS Aids to Navigation - AtoNs). The AIS service has numerous advantages and, of course, disadvantages.

Based on these facts, the SWOT analysis (Piercy & Giles,1989) of the AIS service is described in Table 1.

Table 1.
SWOT analysis of AIS service.

Strengths	**Weaknesses**
1. Anti - collision aids to navigation. 2. Enhanced MSA. 3. SAR aid. 4. Safety aids to navigation – AtoN. 5. Marine environmental pollution monitoring and control.	1. Possible errors in navigation data may cause a CPA alarm to be raised. 2. Malicious attack on AIS service may generate unrealistic MSA. 3. Possible generation of false distress signals for MOB. 4. Generation of one or more fake buoys at critical locations. 5. Malicious attack on the AIS service with ship spoofing.
Opportunities	**Threats**
1. If navigational data is appropriately used, the risk of collision can be reduced. 2. AIS provides increased MSA that enables effective response to emergencies such as search and rescue (SAR). It may help to identify trends or improvements in the provision of services to enhance the safety of navigation. 3. If SAR data are not corrupted in some way, the cost of operating SAR can be reduced, helping rescuers locate survivors. 4. AIS can increase the safety of navigation in a particular sea area. 5. S-AIS can detect ship oil spills in the open sea.	1. Potential spoofing can mislead the OOW in making a collision decision. 2. Potential spoofing of ships may mislead national authorities regarding maritime surveillance. 3. Potential AIS SART spoofing can trigger SART alerts to mislead victims into navigating to hostile and attacker-controlled sea areas. 4. AtoN spoofing can mislead the OOW in navigation, resulting in incorrect manoeuvres at critical locations with heavy shipping traffic or in coastal navigation (e.g., shoals). 5. Potential ship spoofing by attackers can falsify information to blame another ship for oil spills.

From the SWOT analyses, the advantages of AIS service can easily become disadvantages if the service is exposed to a malicious attack. Opportunities can lead to increased Maritime Situational Awareness, the safety of navigation, environmental protection, and efficiency of SAR operations. At the same time, since AIS service is a nonsecure and open broadcasting system, it can be exposed to external threats such as spoofing.

All types of AIS stations are vulnerable to spoofing, hijacking and availability disruption based on software or radiofrequency threats (Balduzzi et al., 2014). Vulnerabilities of AIS arise primarily from its technical performance as AIS is an open broadcasting system with no security features. The data sent by the transponders are not encrypted and do not have authentication, integrity checking, and confidentiality features (Goudossis & Katsikas, 2018; Caprolu et al., 2020). Therefore, there are risks for malicious transmissions and data manipulations (IALA, 2016).

So far, some methods have been proposed to mitigate AIS risks of spoofing. The proposal of a protected AIS software that uses the technique of public-key cryptography provides an authentication and message integrity service (Kessler, 2020). Another proposal is the secure AIS application protocol based on encryption and authentication of transmission using a certification mechanism applicable in AIS class A and B stations (Aziz et al., 2020). This proposal has been further extended by introducing Auth-AIS, which allows the authentication of AIS messages (Sciancalepore et al., 2021). The maritime certificateless identity-based public-key cryptography method provides on-demand authentication, message integrity, and confidentiality of AIS data (Goudossis & Katsikas, 2018; Goudossis & Katsikas, 2020). All these proposals are based on cryptographic methods that enable the encryption of AIS messages. They are also backwards compatible and allow interoperability with existing AIS devices that do not use the modified software or hardware (Androjna et al., 2021).

3.2. Selected case studies of GNSS spoofing

The last few years have been remarkable in many ways. Although the coronavirus pandemic disrupted worldwide operations, some global trends, such as our increasing reliance on GNSS, have continued unabated (Buesnel, 2020). In recent years, there have been several disruptive incidents that have caused a stir in the shipping industry, as shown in Table 2.

Table 2.
An overview of some GNSS spoofing events that affected maritime traffic between the years 2018 and 2020.

Location and Date	Spoofing Incidents Description
Ten global locations connected to one of the superpower states, 2016-2019	9,883 suspected spoofing incidents.
Point Reyes in northern California, 2019	Ships thousands of miles at sea mysteriously reported GPS positions in ring patterns off the coast of San Francisco.
Eastern Mediterranean and the Red Sea, 2019	Signal interference, loss of erratic AIS/GPS signals.
Strait of Hormuz, 07/2019	A British oil tanker, Stena Impero, was seized by Iranian forces after the ship was spoofed into changing course into Iranian waters.
Ningbo (China) - Nampo (Democratic People's Republic of Korea), 07-11/2019	The M/V Fu Xing 12 manipulated its identity by employing two AIS on board and using four different ship names to disguise its operations in delivering illegal coal and other resources.
Port of Shanghai, 2018-2019	Fake signals caused ships to appear to be moving in ring patterns at short intervals.
Ponce De Leon Inlet, Florida, 2020	Four visual AtoNs appeared on the map based on fake AIS messages.
Elba Island, 03/12/2019	Deliberate spoofing of the vast number of artificial AIS targets temporarily affected the navigation of ships.
Galapagos, 07/2020	One of the world's largest fleets of fishing nations misreported its location (approximately 10,000 km from its observed location) to conceal illegal fishing activities in the exclusive economic zone (EEZ) around the Galápagos Islands.

From Table 2, it can be concluded that the original purpose of AIS spoofing to this day is to conceal illegal fishing and other illegal activities at sea, including ship spoofing and AIS hijacking. There was also an example of AtoNs spoofing at Ponce De Le-on Inlet. In recent years, we have seen GNSS spoofing as part of defence development in a civilian scenario. The AIS spoofing has been deliberately used for electronic warfare and to disguise military activities such as the situation in the Eastern Mediterranean and Red Sea (Androjna et al., 2021). Another example in 2017 is the incident at Gelendzhik Airport, where at least 20 ships near the Black Sea Novorossiysk Commercial Sea Port reported that their AIS tracks falsely indicated their position as Gelendzhik Airport, about 32 km inland. Many ships were involved, and all of the ships' tracking systems placed them in the same nonsensical position. This led to the speculation that it could be attributed to one of the tests of satellite spoofing technology by one of the space superpower states, whether as part of their electronic warfare arsenal or simply an anti-drone measure to protect very important persons (Androjna et al., 2020).

A practical example of geopolitical and geo-economic competition is the July 2019 detention of a British oil tanker, Stena Impero, which was seized by Iranian forces after her GPS used in the AIS message was tricked (spoofed) into changing her course to Iranian waters, as seen in Figure 1. As a result, the ship, cargo, and crew had become more than pawns in a geopolitical war (Bockmann, 2019). This incident could have been avoided if navigators were aware of the possibility of AIS spoofing and the potential impact on the MSA. They should never rely on a single source of information and should double-check data provided by AIS.

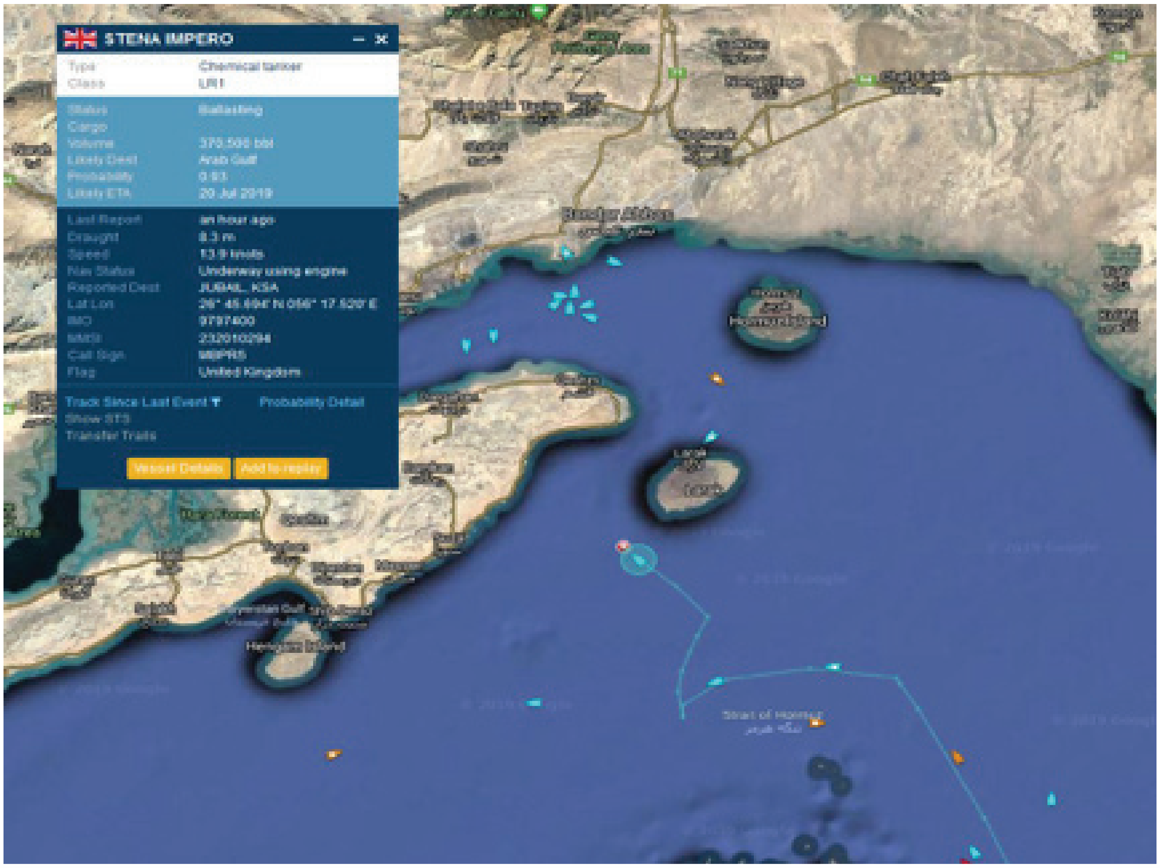


Figure 1.
Stena Impero veered off course (Source: ClipperData, 2019).

At the same time, a mysterious new electronic device has emerged in China that spoofs AIS signals in ways experts have never seen before. There have been reports of several spoofing incidents discovered in over 20 coastal areas and ports that have been ongoing for months. Unlike “traditional” spoofing, GNSS signals were grouped into large circles, later referred to as “crop circles”, with the signals moving to the same position, resulting in a confusing traffic situation for ship pilots (Inside GNSS, 2019). Bergman (2019) observed that the locations of the “spoofing circles” were oil terminals. The timing of the spoofing, imposition of the US sanctions on the purchase of Iranian oil, and observations by others that Iranian oil was entering China suggest that some spoofing was being used to conceal these transactions.

Another example of spoofing was observed in July 2020 when one of the world’s top fishing fleets was accused of misreporting its location to conceal illegal fishing activities in the EEZ around the Galápagos Islands. The ships reported via AIS a location in New Zealand that was about 10,000 km from their observed location. In fact, they may have penetrated deep into the Galápagos EEZ, where illegal fishing has occurred, as shown in Figure 2 (Buesnel, 2020; HawkEye360, 2020). This kind of disappearance is just one of many ways criminals use location spoofing of a GNSS dependent system to support their nefarious activities.

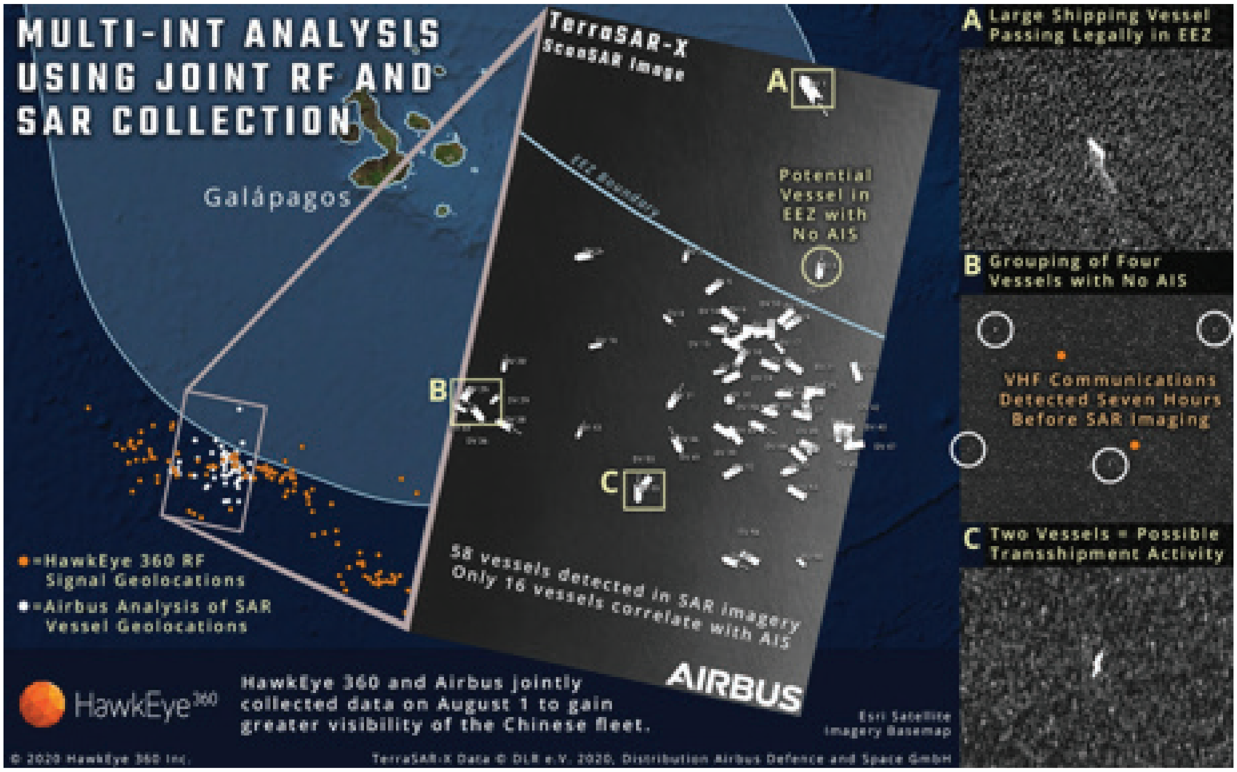


Figure 2.
Vessels disappearance from AIS tracking, the Galápagos Islands (Source: HawkEye360, 2020).

3.3. AIS spoofing event near Elba Island – case study

In December 2019, a ship-spoofing situation occurred at an Italian AIS base station near Elba Island, which the European Maritime Safety Agency noticed. During the first Italian Coast Guard investigation, 870 different ships were displayed at two different times (13:13 and 13:28) with a duration of 3 min in the first transmission and 2 min in the second. All tracks appeared in an area of 28 × 21 nautical miles between the islands of Elba and Corsica with different routes and speeds, which made it impossible to monitor the maritime traffic in this area and affected the real ship transmissions.

At the Faculty of Maritime Studies and Transport, University of Ljubljana, we thoroughly investigated the situation to support

EMSA's analysis and found 3,742 fake vessels (861 false tracks with MMSI 24480XXXX), which together generated 5,133 messages. Using the European Marine Observation and Data Network method, a traffic density map was created using vessel's position data collected from terrestrial and satellite AIS data sources, maritime infrastructure and the SafeSeaNet Ecosystem Graphical Interface application. As shown in Figure 3, vessel density was up to 45 vessels/km2 (Androjna et al., 2020).

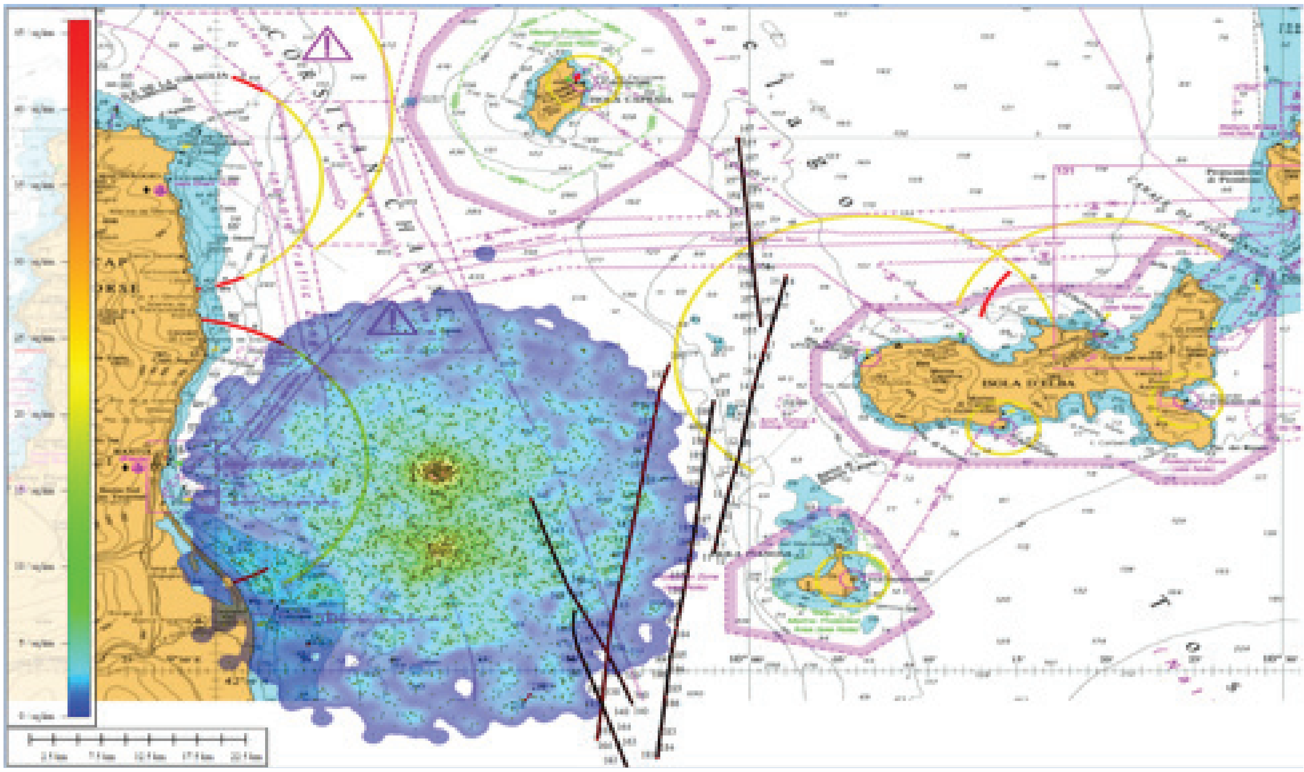


Figure 3.
AIS spoofing—shipping density near Island of Elba (Screenshot of Global Mapper, Admiralty Raster Chart background) (Source: Androjna et al., 2020, 2021).

AIS data was initially obtained by working with the Slovenian Maritime Administration, Italian Coastguard, MarineTraffic and VesselFinder. The archive data were again streamed using AIS Network Data Client application and fed into two different VTS applications Navi-Harbor (Wärtsilä) and Pelagus (Elman). The spoofing data AIS in the affected area is displayed in ECDIS and RADAR applications via the vessel tracking handling simulator Navi-Trainer Pro (Wärtsilä). A traffic density map was then constructed using vessel positioning data from the terrestrial and S-AIS data sources, maritime infrastructure, and the SafeSeaNet Ecosystem Graphical Interface application. We found that seven ships were in a spoofing cloud and that the broadcast system was congested. Thousands of AIS received streams (95% signal processing load) caused significant MSA degradation, as shown in Figure 4 (Androjna et al., 2021). They were identified as Dutch flag naval units, artificially generated, with different identification codes, positions, routes and speeds.

There were 3 AIS bursts, and "all" vessels were identified as passenger ships (AIS Type 60) 90 meters long and 24 meters wide, with no draft or destination information. Possible candidates for this AIS spoofing event include vessels with MMSI 999999999, which is quite common around AIS and often associated with naval vessels, MMSI 312320000, an individual fishery that assumed the identity of vessel scrapped in 2016, and MMSI 367309390. The obtained data indicate that a spoofing algorithm was run with automatically incrementing MMSI numbers. In our case study, it was not possible to determine the reasons for spoofing and the location of the sender that generated the false signals (Androjna et al., 2021).

The simulation of the spoofing event shows a potential impact on navigation safety. Ships in a spoofing cloud were on a collision course with more than a dozen other spoofed fake M/Vs, as shown in Figure 5.

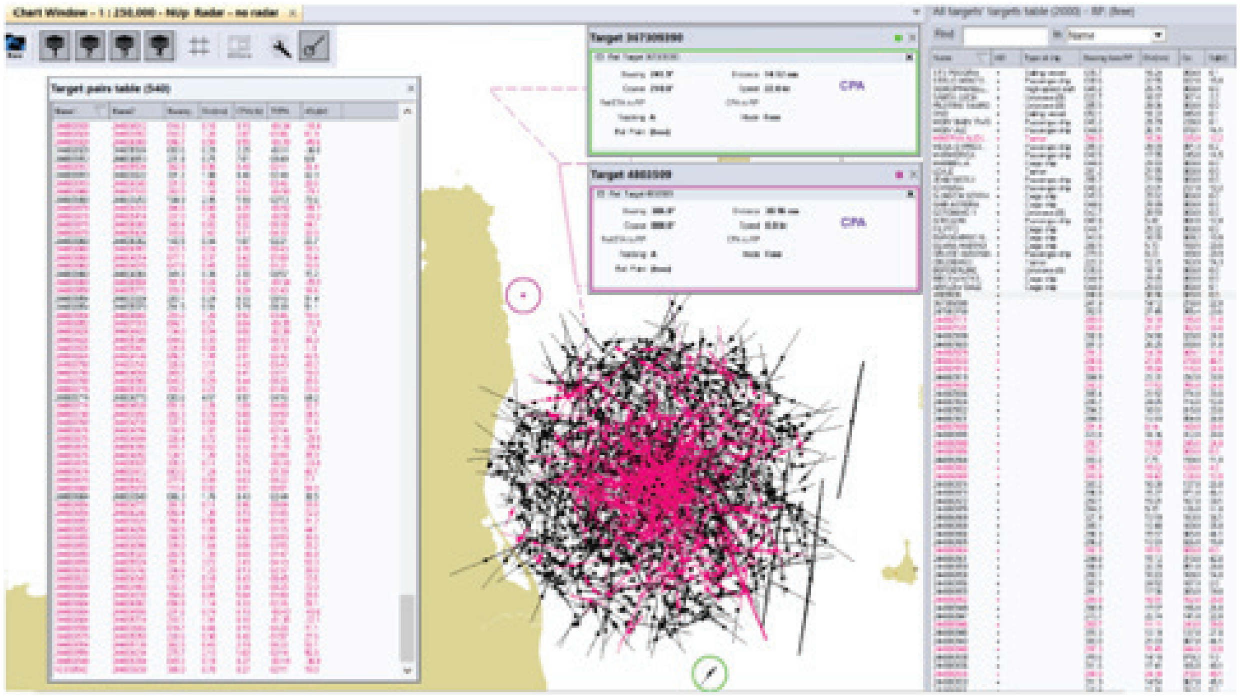


Figure 4.
VTS system overload tested by Navi-Harbor (Wärtsilä) application.

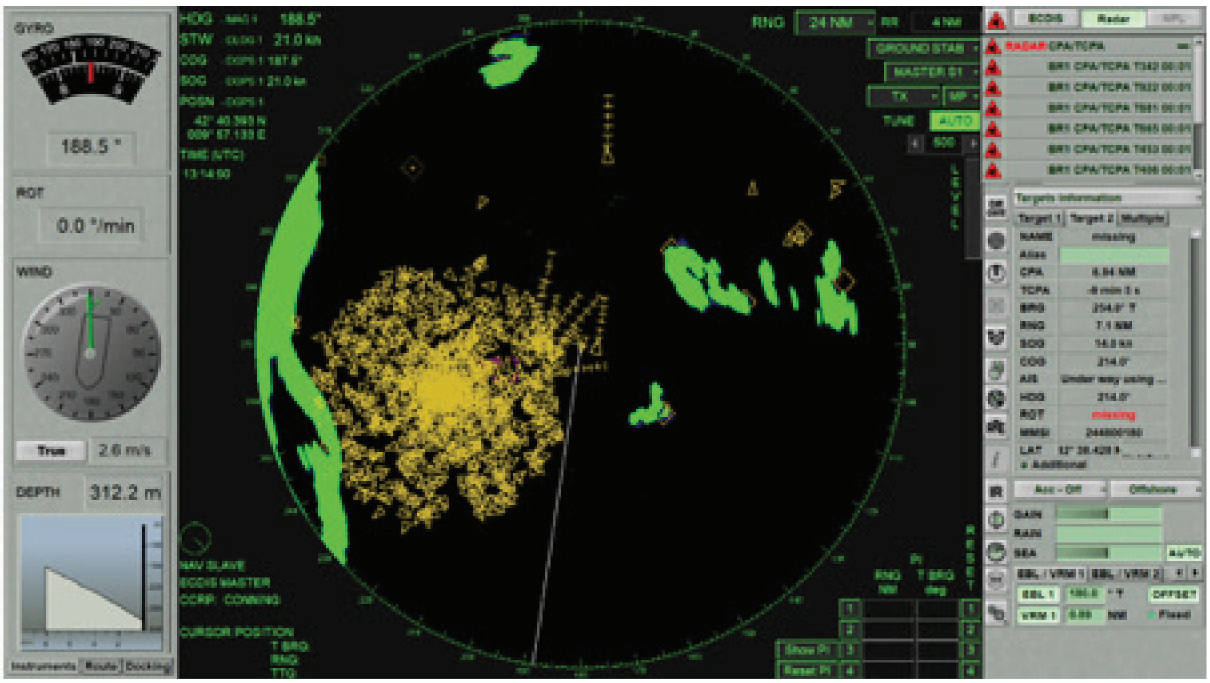


Figure 5.
Collision course with the number of ships (Screenshot of Navi-RADAR 4000 ECDIS MFD, Navi-Trainer Professional 5000 Simulator, Wärtsilä) (Source: Androjna et al., 2021).

Consequently, a relatively large number of collision alerts appear, which may lead to an inappropriate OOW decision. In this situation, an experienced OOW will use a "raw" radar image without the AIS data support and enhance the sharp visual lookout. Fortunately, AIS spoofing event occurred during the day and in a favourable navigation area. Had it occurred at night and in a dense traffic sea area hazardous to navigation, navigation safety could have had severe consequences. Therefore, OOWs need to be aware of AIS spoofing and the potential impact on MSA.

4. CONCLUSIONS/DISCUSSION

In this article, the importance of cybersecurity is presented. GNSS spoofing has been an issue in defence for many years and is now beginning to affect shipping. As more devices and autonomous systems rely on GNSS, even more systems may be vulnerable to spoofing attacks. The maritime industry and shipping are not immune to such cyber-attacks. There will be many new cyber vulnerabilities in the future through which systems can be attacked if they are not adequately protected. Our analysis has shown that spoofing events like the one originating near the Island of Elba can affect ship security. Such a large number of ships appearing on ECDIS screen is primarily a technical problem that clearly creates a false scenario. In this mass of data, a vessel can be overlooked, so it is essential to use other means of safe navigation at the same time. If both AIS and GNSS, on which accurate positioning is based, are subject to spoofing, it may be unsafe to rely solely on ECDIS and its additional overlays. GNSS signals are essential for safe and efficient navigation. They are an integral part of maritime navigation, and their degradation threatens safety at sea.

Given the impact of digital technologies on maintaining seaworthiness, a robust defence against jamming and spoofing is required, i.e. a global cybersecurity framework. The maritime industry must stay ahead of the curve, so manufacturers must ensure the reliability, resilience, and function of multisensor systems for security and liability reasons. Confidentiality, authentication and message integrity of AIS data should remain preserved based on cryptographic data techniques and methods. Unfortunately, the cryptographic methods proposed by the scientific community have not been applied in practice. Therefore, AIS existing protocol is still unencrypted and vulnerable to cyber threats.This paper identifies the GNSS, ECDIS and AIS vulnerabilities that impact maritime security and recommends that the maritime community implement a robust cybersecurity system and use encrypted signals to protect against spoofing and other maritime cyber threats.

CONFLICT OF INTEREST: The authors declare no conflict of interest.

REFERENCES

Androjna, A. et al., 2020. Assessing Cyber Challenges of Maritime Navigation. Journal of Marine Science and Engineering, 8(10), p.776. Available at: http://dx.doi.org/10.3390/jmse8100776.

Androjna, A. & Twrdy, E., 2020. Cyber Threats to Maritime Critical Infrastructure. In: ČALETA, Denis (ur.), POWERS, James F. (ur.). Cyber terrorism and extremism as threat to critical infrastructure protection. E-ed. Ljubljana: Ministry of Defense, Republic of Slovenia: Institute for Corporative Security Studies; Tampa: Joint Special Operations University. Available at: https://dk.mors.si/Reader/Cyber_Terrorism_and_Extremism.html.

Androjna, A. et al., 2021. AIS Data Vulnerability Indicated by a Spoofing Case-Study. Applied Sciences. 2021, 11, 5015. Available at: https://doi.org/10.3390/app11115015.

Aziz, A. et al., 2020. SecureAIS - Securing Pairwise Vessels Communications. 2020 IEEE Conference on Communications and Network Security (CNS). Available at: http://dx.doi.org/10.1109/cns48642.2020.9162320.

Balduzzi, M., Pasta, A. & Wilhoit, K., 2014. A security evaluation of AIS automated identification system. Proceedings of the 30th Annual Computer Security Applications Conference. Available at: http://dx.doi.org/10.1145/2664243.2664257.

Bergman, B., 2019. Systematic GPS Manipulation Occurring at Chinese Oil Terminals and Government Installations. Available at: https://skytruth.org/2019/12/systematic-gps-manipulation-occuring-at-chinese-oil-terminals-and-government-installations/, accessed on: 10 May 2021.

BIMCO, 2017. IHS-BIMCO-Survey-Findings—Story in Numbers. Available at: https://cybersail.org/wp-content/uploads/2017/02/IHS-BIMCO-Survey-Findings.pdf, accessed on: 25 April 2021.

BIMCO, 2020. Safety at Sea and BIMCO cybersecurity white paper—IHS Markit 2020 Cyber Security Survey. Available at: https://ihsmarkit.com/info/0819/cyber-security-survey.html?utm_medium =website&utmsource=sas-news-article-1&utm_campaign=cyber-security-whitepaper, accessed on: 24 April 2021.

BIMCO, 2020a. The Guidelines on Cyber Security Onboard Ships, Version 4. Available at: https://www.bimco.org/about-us-and-our-members/publications/the-guidelines-on-cyber-security-onboard-ships, accessed on: 18 May 2021

Bockmann, M., 2019. Seized UK Tanker Likely "Spoofed' by Iran. Available online: https://lloydslist.maritimeintelligence.informa.com/LL1128820/Seized-UK-tanker-likely-spoofed-by-Iran, accessed on: 22 May 2021.

Buesnel, G., 2020. Thousands of GMDSS jamming and spoofing incidents reported in 2020. Available at: https://www.linkedin.com/pulse/thousands-gnss-jamming-spoofing-incidents-reported-2020-guy-buesnel/, accessed on: 1 February 2021.

Caponi, S.L. and Belmont, K.B., 2015. Maritime Cybersecurity: A Growing Threat Goes Unanswered. Intellectual Property & Technology Law Journal, 27(1), p.16.

Caprolu, M. et al., 2020. Vessels Cybersecurity: Issues, Challenges, and the Road Ahead. IEEE Communications Magazine, 58(6), pp.90–96. Available at: http://dx.doi.org/10.1109/mcom.001.1900632.

Chybowski, L., Gawdzińska, K. & Laskowski, R., 2019. Assessing the Unreliability of Systems during the Early Operation Period of a Ship—A Case Study. Journal of Marine Science and Engineering, 7(7), p. 213. Available at: http://dx.doi.org/10.3390/jmse7070213.

ClipperData. ClipperData July 19, 2019 - the vessel took an abrupt turn north.

Danish Maritime Cybersecurity Unit, 2018. Cyber and Information Security Strategy for the Maritime Sector 2019–2022. Available at: https://www.dma.dk/Documents/Publikationer/Cyber%20and%20Information %20Security%20Strategy%20for%20the%20Maritime%20Sector.pdf, accessed on: 24 April 2021.

Dobryakova, L.A., Lemieszewski, L.S. & Ochin, E.F., 2018. GNSS Spoofing Detection Using Static or Rotating Single-Antenna of a Static or Moving Victim. IEEE Access, 6, pp.79074–79081. Available at: http://dx.doi.org/10.1109/access.2018.2879718.

EMSA, 2019. Traffic Density Mapping Service - Methodology. Ref. Ares (2019)4005069 - 24/06/2019. Available at: http://www.emsa.europa.eu/related-projects/tdms.html, accessed on: 28 April 2021.

Eriksen, T., Greidanus, H. & Delaney, C., 2018. Metrics and provider-based results for completeness and temporal resolution of satellite-based AIS services. Marine Policy, 93, pp.80–92. Available at: http://dx.doi.org/10.1016/j.marpol.2018.03.028.

EU, 2014. Council of the EU. European Union Maritime Security Strategy. 11205/14, Brussels. 24 June 2014. Available at: http://register.consilium.europa.eu/doc/srv?l=EN&f=ST%2011205%202014%20INIT, accessed on: 24 April 2021.

EU, 2016. European Commission; High Representative. On the implementation of the EU Maritime Security Strategy Action Plan. Joint Staff Working Document SWD(2016)217 Final. Available at: https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/docs/body/swd-2016-217_en.pdf, accessed on: 24 April 2020.

EU, 2017. European Commission; High Representative. Second report on the implementation of the EU Maritime Security Strategy Action Plan. Joint Staff Working Document SWD(2017)238 Final. Available at: https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/swd-2017-238_en.pdf, accessed on: 24 April 2021.

EU, 2018. Council of the EU. Revised European Union Maritime Security Strategy (EUMSS) Action Plan. Annex to 10494/18, Brussels. 26 June 2018. Available at: https://data.consilium.europa.eu/doc/document/ST-10494-2018-INIT/en/pdf, accessed on: 24 April 2021.

EU, 2020. European Commission; High Representative. Report on the implementation of the revised EU maritime security strategy action plan. In Joint Staff Working Document; European Commission: Brussels, Belgium, 2020; in draft.

Goudosis, A. & Katsikas, S., 2020. Secure AIS with Identity-Based Authentication and Encryption. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, 14(2), pp.287–298. Available at: http://dx.doi.org/10.12716/1001.14.02.03.

Goudossis, A. & Katsikas, S.K., 2018. Towards a secure automatic identification system (AIS). Journal of Marine Science and Technology, 24(2), pp.410–423. Available at: http://dx.doi.org/10.1007/s00773-018-0561-3.

Hareide, O.S. et al., 2018. Enhancing Navigator Competence by Demonstrating Maritime Cyber Security. Journal of Navigation, 71(5), pp.1025–1039. Available at: http://dx.doi.org/10.1017/s037346331 8000164.

HawkEye360, 2020. Chinese Fishing Fleet Encroaches on the Galapagos Islands: HawkEye360 Monitors the Fleet for Suspicious Behavior and Potential Illegal Fishing. Available at: https://www.he360.com/insight/potential-illegal-fishing-seen-from-space/, accessed on: 30 May 2021.

Hecht, H., Berking, B., Jonas, M. & Woster, M., 2017. The Electronic Chart Fundamentals, functions, data and other essentials, A Textbook for ECDIS Use and Training 4th Edition, The Netherlands, Geomares Publishing.

IALA, 2016. IALA Guideline - An overview of AIS, Edition 2.0. Availabe at: https://www.navcen.uscg.gov/pdf/IALA_Guideline_1082_An_Overview_of_AIS.pdf, accessed on 14 May 2021.

IEC, 2019. International Electrotechnical Commission. Maritime Navigation and Radiocommunication Equipment and Systems-Cybersecurity-General Requirements, Methods of Testing and Required Test. Results; IEC 63154 ED1; IEC, Geneva, Switzerland.

IHO, 2020. IHO Data Protection Scheme, Edition 1.2.1, Monaco.

IMO, 2017. IMO Resolution MSC.428 (98). Available at: http://www.imo.org/en/OurWork/Security/Guide _to_Maritime_Security/Documents/Resolution%20MSC.428(98).pdf, accessed on 24 April 2021.

IMO, 2017a. Guidelines on Cyber Risk Management. Maritime Safety Committee: 2017, MSC-FAL (1/Circ.3). pp. 1–6. Available at: http://www.imo.org/en/OurWork/Security/Guide_to_Maritime_Security /Documents/MSCFAL.1Circ.3%20%20Guidelines%20On%20Maritime%20Cyber%20Risk%20Management%20(Secretariat).pdf, accessed on: 24 April 2021.

IMO, 2018. ISM. International Safety Management Code; IMO Publishing: London, UK, 2018.

IMO, 2020. The International Convention for Safety of Life at Sea (Consolidated edition 2020); IMO Publishing, London, UK, 2020; pp. 15/34-15/35. ISBN: 9789280116908.

Inside GNSS, 2019. Sinister Spoofing in Shanghai. Available at: https://insidegnss.com/sinister-spoofing-in-shanghai/#:~:text=Someone%20has%20updated%2019th%20century,experts%20have%20never %20seen%20before, accessed on: 10 May 2021.

INTERTANKO, 2019. Jamming and Spoofing of Global Navigation Satellite Systems (GNSS). Available at https://www.maritimeglobalsecurity.org/media/1043/2019-jamming-spoofing-of-gnss.pdf, accessed on: 24 April 2021.

ITU, 2014. ITU-R M.2287-0. Automatic identification system VHF data link loading.

Jones, K.D., Tam, K. & Papadaki, M., 2012. Threats and Impacts in Maritime Cyber Security. Engineering & Technology Reference, 1(1). Available at: http://dx.doi.org/10.1049/etr.2015.0123.

Kessler, G.C., 2020. Protected AIS: A Demonstration of Capability Scheme to Provide Authentication and Message Integrity. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, 14(2), pp.279–286. Available at: http://dx.doi.org/10.12716/1001.14.02.02.

Kjerstad, N., 2016. Electronic and Acoustic Navigation Systems, Alesund, Norway, Norvegian Institute of Science and Technology, ISBN: 978-82-92186-57-2.

Marine Insight, 2020. Maritime Cyber-Attacks Increase by 900% in Three Years. Available at: https://www.marineinsight.com/shipping-news/maritime-cyber-attacks-increase-by-900-in-three-years/#, accessed on: 24 April 2021.

Middleton, A., 2014. Hide and Seek: Managing Automatic Identification System Vulnerabilities: Proceedings of the Marine Safety and Security Council, Coast Guard. Journal of safety and security at sea, 71(4).

Natale, F. et al., 2015. Mapping Fishing Effort through AIS Data G. Tserpes, ed. PLOS ONE, 10(6), p.e0130746. Available at: http://dx.doi.org/10.1371/journal.pone.0130746.

Piercy, N. & Giles, W., 1989. Making SWOT Analysis Work. Marketing Intelligence & Planning, 7(5/6), pp.5–7. Available at: http://dx.doi.org/10.1108/eum0000000001042.

Ramin, A., Mustaffa, M. & Ahmad, S., 2020. Prediction of Marine Traffic Density Using Different Time Series Model From AIS data of Port Klang and Straits of Malacca. Transactions on Maritime Science, 9(2). Available at: http://dx.doi.org/10.7225/toms.v09.n02.006.

Sciancalepore, S. et al., 2021. Auth-AIS: Secure, Flexible, and Backward-Compatible Authentication of Vessels AIS Broadcasts. IEEE Transactions on Dependable and Secure Computing, pp.1–1. Available at:
http://dx.doi.org/10.1109/tdsc.2021.3069428.

Svilicic et al., 2019. A Study on Cyber Security Threats in a Shipboard Integrated Navigational System. Journal of Marine Science and Engineering, 7(10), p.364. Available at:
http://dx.doi.org/10.3390/jmse7100364.

Thornton, P., 2016. The ECDIS Manual, Reformatted 1st edition, Scotland, Witherby Publishing Group.

Weintrit, A., 2010. The Electronic Chart Display and Information System (ECDIS): An Operational Handbook, Poland, Gdynia Maritime University.

Acoustic Approach to Determining Seabed Substrates Distribution at Mandi Darah Island, Sabah

Mohd Shukri Mohd Yusop[a], Mohd Norsyarizad Razali[a], Nazirah Md Tarmizi[b], Mohd Najib Abdul Ghani Yolhamid[a], M. N. Azzeri[a], Ainul Husna Abdul Rahman[a]

Marine ecosystems and natural habitat play the important role of the Earth's life support system. They significantly contribute to economies and food safety and help preserve ecological processes. However, the devastation of the marine ecosystem in Malaysia due to the human factor and climate change is quite alarming. Therefore, spatial marine information, especially on the distribution of seabed substrates and habitat mapping, are of utmost importance for marine ecosystem management and conservation. Traditionally, seabed substrate and habitat mapping were classified based on direct observation techniques such as photography, video, sampling, coring and scuba diving. These techniques are often limited due to water clarity and weather conditions and only suitable for smaller scale surveys. In this study, we employed an acoustic approach using the RoxAnn Acoustic Ground Discrimination System (AGDS) with a high-frequency single-beam echo sounder to examine the distribution of seabed substrate at the Mandi Darah Island, Sabah. The acoustic signals recorded by AGDS are translated into hardness and roughness indices which are then used to identify the unique characteristics of the recorded seabed types. The analysis has shown that fifteen types of substrates, ranging from silt to rough/some seagrass, have been identified and classified. The findings demonstrated that the acoustic method was a better alternative for seabed substrate determination than the conventional direct observation techniques in terms of cost and time spent, especially in large scale surveys. The seabed substrate dataset from this study could be used as baseline information for the better management and conservation of the marine ecosystem.

KEY WORDS

~ Seabed substrate
~ Acoustic signal
~ RoxAnn GD-X
~ Mandi Darah island
~ Single beam
~ Habitat mapping

a. Universiti Pertahanan Nasional Malaysia, Kuala Lumpur, Malaysia

e-mail: mohd.shukri@upnm.edu.my

b. Universiti Teknologi MARA, Perlis, Malaysia

e-mail: nazir230@uitm.edu.my

doi: 10.7225/toms.v10.n02.007

Received on: 28.06.2021/ Revised on: 13.10.2021/ Accepted on: 19.10.2021/ Published: 21.10.2021

1. INTRODUCTION

Approximately 71% of our planet is covered by oceans and seas which contribute to major natural and economic resources of the world. Marine ecosystem and natural habitat play the important role of the Earth's life support system. They significantly contribute to economies and food safety and help preserve ecological processes. However, marine biodiversity and ecosystem are at risk. Marine habitats are lost, coral reefs devastated, the seas polluted and fish resources depleted (Fakiris et al., 2019). Coral reefs are important ecological and economic resources in a number of countries, including Malaysia. They are important ecosystems for marine life, protect the coast from stronger waves and serve as a source of income to millions of people. In Malaysia, coral reefs cover almost 4,006 square km, are a habitat for more than 700 fish species (Marine and coastal biodiversity, 2015). The average living coral numbers in Malaysia have dropped to 41.32% and have been declining since 2015 (Reef Check Malaysia, 2020). Therefore, an effort to protect and preserve the marine ecosystem is crucial for the sustainability of marine life. However, the viable and effective preservation and protection of the marine ecosystem greatly depend on sufficient information on the spatial extent, geographical range and ecological characteristics of the resource or habitat of interest. Thus, the need to accurately determine seafloor characteristics and map habitat is evident in marine spatial planning, management and conservation of marine biodiversity and the ecosystem (Herkül et al., 2017). Other than that, accurate information on seafloor topography and seabed composition are likewise important for marine engineering, pipe or cable laying, marine geological studies, as well as naval operations, especially those involving submarines and mine warfare (Baker & Harris, 2012; Coiras et al., 2007; Hasan et al., 2014).

Traditionally, information on seafloor types and marine habitats were determined based on direct observation techniques such as photography, video, sampling, coring, or scuba diving (Biondo & Bartholomä, 2017). While direct observation techniques are suitable for seabed description, they are subject to individual expert interpretations which may differ from one another. Direct observation techniques also depend on water transparency and weather conditions and are time consuming (Schimel et al., 2010). Technological advancements made possible the application of the indirect method that uses the remote sensing approach for habitat mapping purposes (Hamana & Komatsu, 2016). The remote sensing approach to habitat mapping can be divided into two distinct types, namely, optical remote sensing which uses the electromagnetic spectrum to capture an image from an airborne platform or satellite, and acoustic remote sensing which uses an acoustic sensor attached to a surface vessel for marine mapping. Optical satellite remote sensing devices commonly used for marine habitat mapping are Landsat (Hossain et al., 2016), ALOS (Mustapha et al., 2014), and high resolution satellite imagery, such as Quickbird and World View 2 (Conti et al., 2020; Garcia et al., 2015; Papakonstantinou et al., 2017). Although optical remote sensing is highly efficient for mapping larger areas, it is limited to shallow waters due to the light attenuation in the water column. This method can usually make measurements up to the maximum depth of 30m, provided the local conditions are favorable and the sea is calm (Jawak et al., 2015; Lecours et al., 2018). On the contrary, the acoustic method has no restrictions with respect to water depth and clarity (Tajam & Mokhtar, 2019; Hamana & Komatsu, 2016). An acoustic system, such as a single beam echo sounder (SBES), sidescan sonar (SSS), and multibeam echo sounder (MBES) has become an option, as it is capable of overcoming the setbacks of direct observation techniques (Alevizos et al., 2015). Therefore, this study will employ a single beam acoustic system to examine the distribution of seabed substrate at the Mandi Darah Island. The seabed substrate map based on acoustic data will also be used as a preliminary study for site suitability selection for the proposed installation of the Wave Energy Converter (WEC) system.

2. MATERIALS AND METHOD

2.1. Study Area Description

The study was conducted at the Mandi Darah Island (Figure 1) which is 240 km from Kota Kinabalu. The Mandi Darah Island is a small island located (06° 55' 59" N, 117° 20' 19" E) 60 km from Kudat, Sabah Malaysia. The island has the surface of only 2.5 km^2, with the highest peak approximately 529 meters above sea level (Monaliza & Samsur, 2011). This island is one of the islands belonging to the Tun Mustapha Park - a Kudat-Banggi Priority Conservation Area. This area is known for the presence of migratory species, large and diverse coastal and marine ecosystems, as well as productive fishing grounds (Sabah Parks, 2017). There are an estimated 35 houses on the island, populated by the Ubian tribes who work as fishermen (Suadik et al., 2018).

2.2. Data Collection

The survey period was May 26 - June 15, 2018 and covered approximately 11.7 square kilometers. The data were obtained from a single beam echo sounder, while the back scatter data were processed using the RoxAnn GD-X unit manufactured by Sonavision Ltd UK throughout the survey. Since the study area was in shallow water, a single beam echo sounder was operated at the frequency of 200kHz, while a Fugro Marinestar 9205 GNSS Receiver was used for accurate positioning.

2.2.1. RoxAnn GD-X

RoxAnn GD-X is commonly used for marine environmental monitoring and habitat mapping (Brown et al., 2005; Rukavina, 2001) and apart from depth measurement, it can also classify seabed types owing to its built-in acoustic seabed classification function (Che Hassan, 2014). Generally, the RoxAnn acquisition

Figure 1.
Location of study area around the Mandi Darah Island (Google earth, 2021).

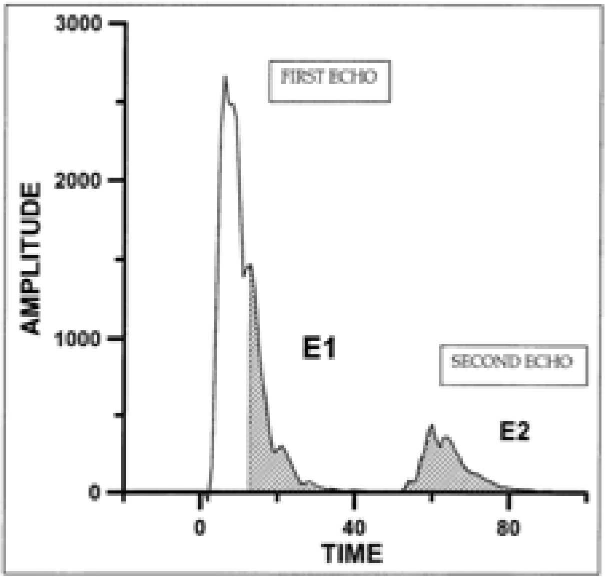


Figure 2.
Acoustic signal processing of the reflection of the first and second echo from the bottom, recorded by the RoxAnn system; the shaded area is integrated to form two indices E1 and E2 (Hamilton, 2001).

software selects two distinct echoes, E1 and E2, that are reflected from the seabed (Foster-Smith & Sotheran, 2003). The E1 is a decaying echo after the initial peak and mostly used to determine the roughness of the ground surface, while the second echo, E2, reflects twice from the seabed and is thus strongly affected by seabed hardness (Figure 2).

A complete AGDS incorporates the input of real time, geo-referenced survey and all valid E1 and E2 signals collected and sent to the computer for further processing using the RoxMap Scientific software. The acquired acoustic signatures, consisting of the roughness index (E1) and the hardness index (E2), are plotted against each other based on the predefined RoxAnn library known as the RoxAnn Square, by referring to Yap (2017) as in Figure 3. The RoxAnn Square uses colored boxes where the x axis represents the index of hardness (E2) and the y axis the index of roughness (E1). All the data in the box correspond to a particular substrate type, based on the roughness and hardness indices. Substrates such as rock and gravel, generate high E1 and E2 values, whereas the muddy substrate has low E1 and E2 values since it absorbs the sound from the echo sounder due to its flatness (Cholwek et al., 2000). The data from RoxAnn were also combined with the GPS position, depth and time for further processing using the geographical information system (GIS) to produce substrate maps.

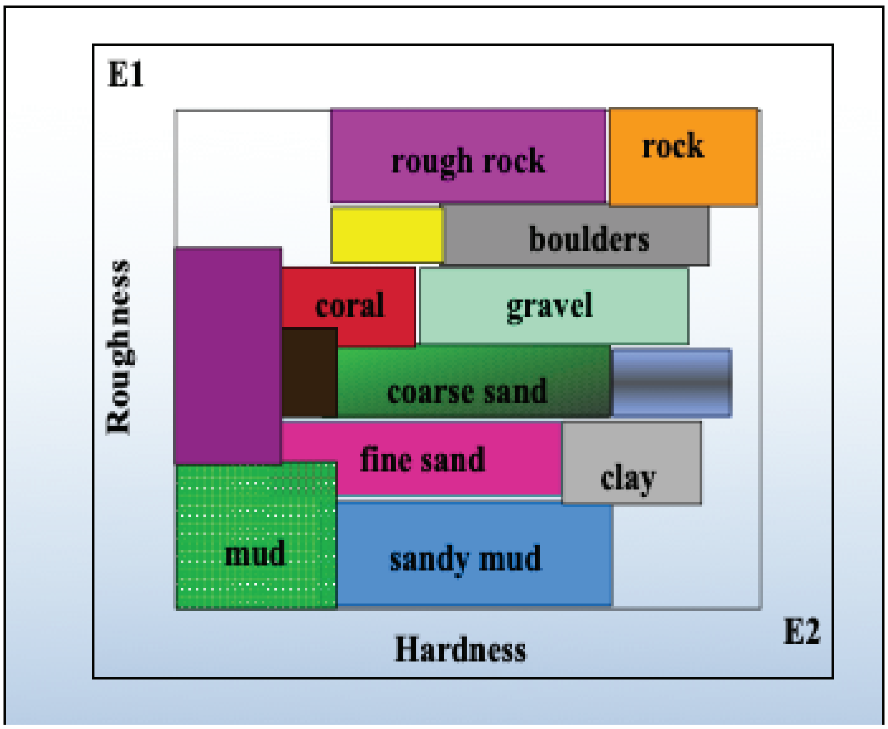


Figure 3.
RoxSquare calibration color box showing different substrates obtained using E1 and E2 echoes (Yap,2017).

2.2.2. AGDS Survey Methodology

In general, the AGDS works on the principle that when an acoustic wave emitted by an echo sounder is reflected off the seabed, it is attenuated by the properties of the reflecting surfaces (Chivers et al., 1990). The AGDS is better used to differentiate between various seabed habitats, because some of the substrate features could give different acoustic reflections. For instance, the coral substrate has medium range roughness (E1) and hardness (E2) values, while the substrates of rocks and gravel generates high E1 and E2 values (Tajam and Mokhtar, 2019). Prior to data collection, the RoxAnn system was calibrated to synchronise all system components where substrate conditions were known. An initial calibration on mud was performed in the vicinity of the Mandi Darah Island jetty. Upon completion of the initial calibration on mud, the AGDS was ready to be trained on multiple coral/non-coral substrates within the surveyed area.

The purpose of this calibration was to configure a scale that would cover all possible substrates, from very soft substrates, such as mud, to extremely hard substrates, such as bedrock found within the survey area. This procedure also required a diver to mark the substrate of interest with rope and a marker buoy. The survey vessel then proceeded to the selected location of the substrate of interest to record the acoustic signature. The recorded acoustic signals were stored in the RoxSquare library. 15 types of substrate, consisting of coral and non-coral substrates, were trained and identified prior to the beginning of the survey. During the survey run, the data-logging software RoxMap Scientific was used for data acquisition. The survey tracks were well-spaced between each other. The vessel sailed at the average speed of 4–5 knots, parallel to the island. The recorded data were then processed using the Surfer 15 software to produce a seabed substrate map. Three stages of processing were involved in the Surfer 15 processing. The first stage required the filtering of spikes in the raw data, caused by echo interference due to shallowness and hard substrates, such as corals. The second stage involved the importation of data variables for x, y and substrate classes, while the third stage involved spatial interpolation using the point kriging method, with a 35 meter resolution spacing to obtain an interpolation map for the substrate's distribution.

3. RESULTS AND DISCUSSION

A total of 34,206 signals from the RoxAnn were recorded with the high frequency echo sounder in the survey period. Figure 4 shows a trackline with different colours representing seabed substrate variations in the survey area. 15 types of substrate have been identified in the survey area, as shown in

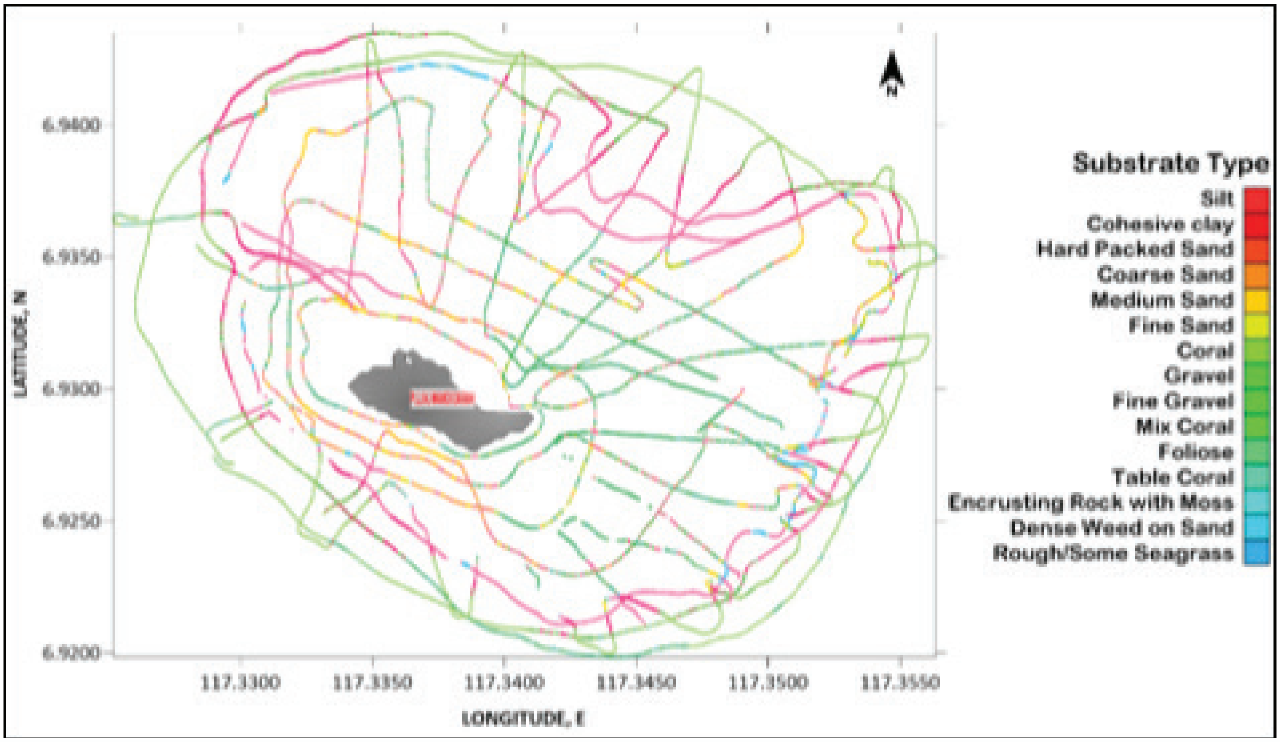


Figure 4.
Trackline of the 2D AGDS survey carried out at the Mandi Darah Island.

Table 1. The results from the data obtained show that gravel was the most dominant substrate, covering 47,656.33m² (39.95%) of the study area, followed by hard-packed sand (30,891.86m², i.e. 25.90%), fine gravel (15,851.52m², i.e.13.29%) and cohesive clay (11,837.30 km², i.e. 9.92%). Meanwhile, dense weed on sand and silt represented a minute portion of the substrates, with less than 3m² or 0.002% of total signal coverage, followed by fine sand 84.55m² (0.07%) and coral 313.12m² (0.26%).

The depth, determined by RoxAnn, varies between 2 and 23 m, as shown in the bathymetry map in Figure 5. The depth is bigger in the west of the island and shallower in the east. Some shallow water areas in the east of the island surfaced during low tides.

Table 1.
Substrate percentages determined at the Mandi Darah Island.

Number of Signal and Coverage of All Substrate					
CODE	**SUBSTRATE**	**NO OF SIGNAL**	**% OF SIGNAL**	**COVERAGE m²**	**% OF COVERAGE**
1	Rough/Some Seagrass	1,391	4.07	1,980.88	1.66
2	Dense Weed on Sand	14	0.04	2.46	0.00
3	Encrusting Rock with Mosses	1,540	4.50	1,354.81	1.14
4	Table Coral	1,503	4.39	2,794.53	2.34
5	Foliose	2,210	6.46	2,330.66	1.95
6	Mix Coral	2,131	6.23	1,842.65	1.54
7	Fine gravel	3,486	10.19	15,851.52	13.29
8	Gravel	5,714	16.70	47,656.33	39.95
9	Coral	893	2.61	313.12	0.26
10	Fine Sand	163	0.48	84.55	0.07
11	Medium Sand	2,903	8.49	734.45	0.62
12	Coarse Sand	1,962	5.74	1,619.27	1.36
13	Hard Packed Sand	8,638	25.25	30,891.86	25.90
14	Cohesive Clay	1,647	4.81	11,837.30	9.92
15	Silt	11	0.03	1.69	0.00
	TOTAL	**34,206**	**100.00**	**119,296.06**	**100.00**

The 3D interpolation map, showing the distribution of seabed substrates around the Mandi Darah island (Figure 6), was produced using the Surfer 15 software. Observations show that there aren't many corals around the island. They are mostly scattered to the south and east in the gravel dominant area, with a small percentage of coral found to the west of the island mostly covered in sandy substrate. This can perhaps be attributed to the area being a route commonly used by boats from the islands to reach Banggi and Kudat, which might have affected coral growth. It is also exposed to waves and currents stronger than on the other, calmer side of the island, resulting in high turbulence and sedimentation to the west of the island. These conditions could affect coral growth and abundance (Lirman et al., 2003).

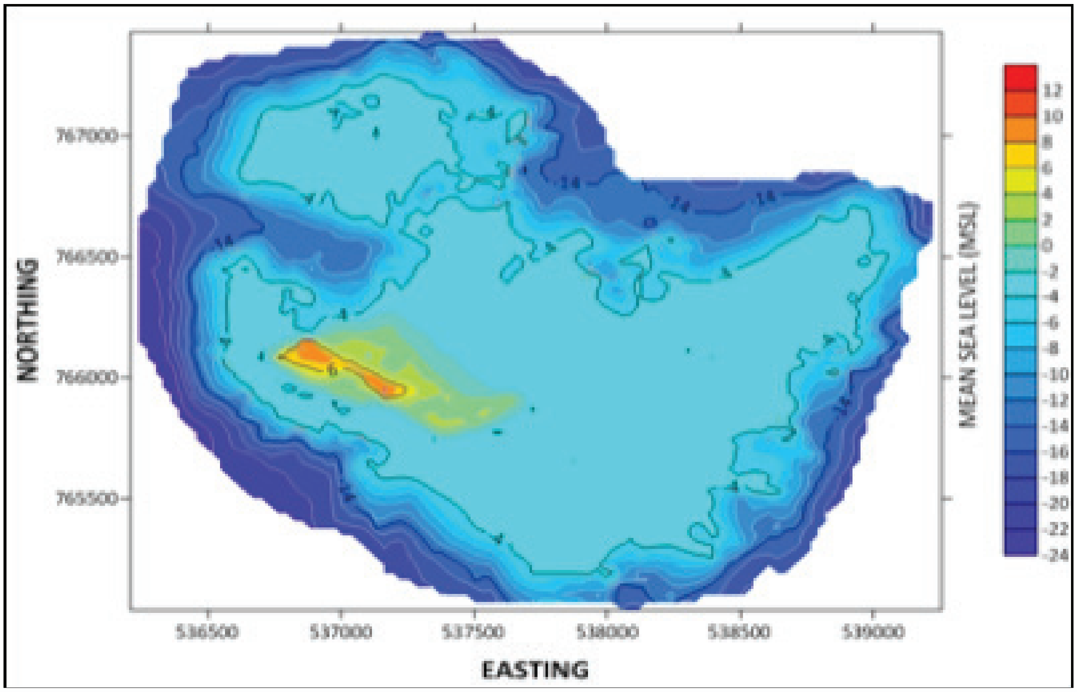


Figure 5.
Bathymetry map showing water depths around the Mandi Darah Island.

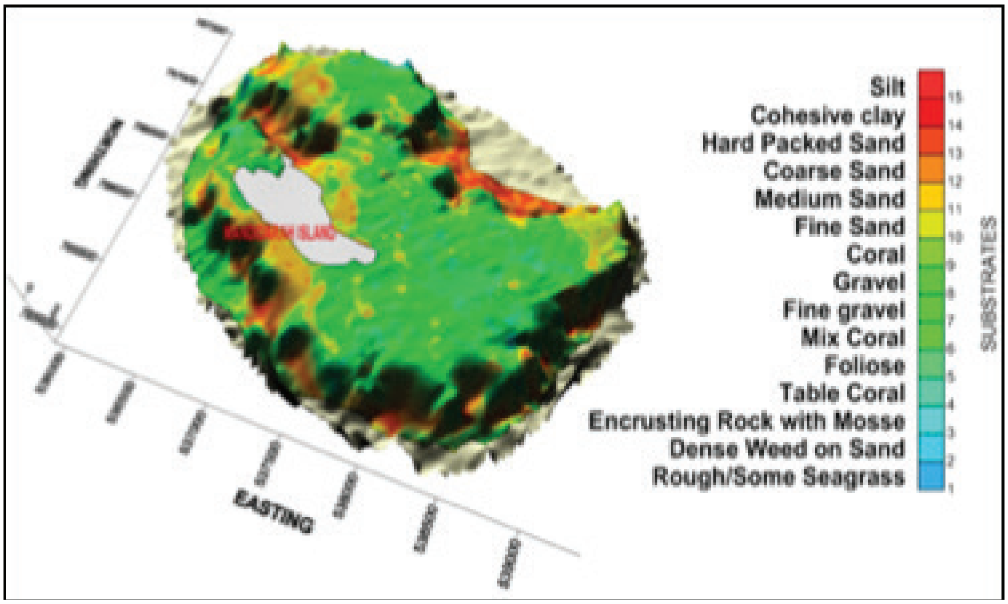


Figure 6.
3D interpolation map showing substrate distribution around the Mandi Darah Island.

The acoustic approach described in this paper is suitable for seabed substrate mapping in moderately clear waters, such as those surrounding the Mandi Darah Island. The traditional scuba diving approach to direct measurement and visual survey remains one of the most dependable survey methods for gathering seafloor information. Yet, this traditional method is highly risky for the diver, not cost-efficient, cumbersome, and impractical for producing maps covering larger areas. Acoustic methods using echo sounders would be more practical for mapping wide areas, as they take less time and require less manpower than the traditional scuba diving approach (Abdullah et al., 2016). In contrast, the satellite remote sensing approach is capable of covering a larger area in less time. Albeit, although this is an advantage, satellite remote sensing only works in shallow and clear waters, as the light decreases within the water column. Heavy clouds common in the equatorial region such as Malaysia are a serious problem for satellite remote sensing and often hampered data collection. In addition, due to the territorial and radiometric resolution of satellite visuals, this methodology also has restrictions with respect to the identification of particulars of a tiny, dispersed or low-populated seafloor habitat (Komatsu, 2003). In this instance, the acoustic approach is more suitable for substrate mapping in Malaysian waters.

4. CONCLUSION

This study has successfully explored the seabed substrate of the Mandi Darah Island, using RoxAnn GD-X and high-frequency single-beam echo sounder. The acoustic data obtained were color coded to represent the variations of the seabed substrate characteristic for the study area. A total of 15 types of substrate have been identified and classified, ranging from silt to rough/some seagrass. The application of the acoustic approach in this study has demonstrated its capability to identify seabed substrates at low cost and in a relatively small area. For further research, this method could become an alternative to and complement the traditional methods that use direct observation techniques, such as video, scuba diving, etc. The acoustic technique also has the advantage of facilitating the rapid surveying of turbid waters. Although the acoustic approach gives good results, since this study employed AGDS with a single-beam echo sounder, an interpolation between survey lines is required, as it frequently resulted in the misclassification of seabed substrates. Future studies should therefore use a multi-beam echo sounder capable of full seafloor coverage for seabed substrate mapping.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support received from the National Defence University of Malaysia and the Ministry of Energy and Natural Resources for a part of its multidisciplinary research grant (UPNM/2018/AAIBE-KETTHA/TK/1/P2), as well as to Geohydrocean Services Sdn. Bhd. for technical advice and data collection at the site.

REFERENCES

Abdullah, A. L. et al., 2016. Conservation of pulau payar marine park and optical remote sensing models. Kemanusiaan, 23, pp. 79–107.

Baker, E.K. & Harris, P.T., 2012. Habitat Mapping and Marine Management. Seafloor Geomorphology as Benthic Habitat, pp.23–38. Available at: http://dx.doi.org/10.1016/b978-0-12-385140-6.00002-5.

Biondo, M. & Bartholomä, A., 2017. A multivariate analytical method to characterize sediment attributes from high-frequency acoustic backscatter and ground-truthing data (Jade Bay, German North Sea coast). Continental Shelf Research, 138, pp.65–80. Available at: http://dx.doi.org/10.1016/j.csr.2016.12.011.

Brown, C.J. et al., 2005. Mapping seabed habitats in the Firth of Lorn off the west coast of Scotland: evaluation and comparison of habitat maps produced using the acoustic ground-discrimination system, RoxAnn, and sidescan sonar. ICES Journal of Marine Science, 62(4), pp.790–802. Available at: http://dx.doi.org/10.1016/j.icesjms.2004.10.008.

Coiras, E., Myers, V. & Evans, B., 2007. Reliable Seabed Characterization for MCM Operations. OCEANS 2007. Available at: http://dx.doi.org/10.1109/oceans.2007.4449126.

Conti, L.A., Torres da Mota, G. & Barcellos, R.L., 2020. High-resolution optical remote sensing for coastal benthic habitat mapping: A case study of the Suape Estuarine-Bay, Pernambuco, Brazil. Ocean & Coastal Management, 193, p.105205. Available at: http://dx.doi.org/10.1016/j.ocecoaman.2020.105205.

Fakiris, E. et al., 2019. Multi-Frequency, Multi-Sonar Mapping of Shallow Habitats—Efficacy and Management Implications in the National Marine Park of Zakynthos, Greece. Remote Sensing, 11(4), p.461. Available at: http://dx.doi.org/10.3390/rs11040461.

Foster-Smith, R.L. & Sotheran, I.S., 2003. Mapping marine benthic biotopes using acoustic ground discrimination systems. International Journal of Remote Sensing, 24(13), pp.2761–2784. Available at: http://dx.doi.org/10.1080/0143116031000066323a.

Garcia, R. et al., 2015. A Method to Analyze the Potential of Optical Remote Sensing for Benthic Habitat Mapping. Remote Sensing, 7(10), pp.13157–13189. Available at: http://dx.doi.org/10.3390/rs71013157.

Hamana, M. & Komatsu, T., 2016. Real-Time Classification of Seagrass Meadows on Flat Bottom with Bathymetric Data Measured by a Narrow Multibeam Sonar System. Remote Sensing, 8(2), p.96. Available at: http://dx.doi.org/10.3390/rs8020096.

Hamilton, L.J., 2001. Acoustic seabed classification systems. DSTO Technical Note DSTO-TN-0401.66. Available at: http://www.dsto.defence.gov.au/corporate/reports/DSTO-TN-0401.pdf.

Che Hasan, R. et al., 2014. Integrating Multibeam Backscatter Angular Response, Mosaic and Bathymetry Data for Benthic Habitat Mapping S. Thrush, ed. PLoS ONE, 9(5), p.e97339. Available at:
http://dx.doi.org/10.1371/journal.pone.0097339.

Herkül, K., Peterson, A. & Paekivi, S., 2017. Applying multibeam sonar and mathematical modeling for mapping seabed substrate and biota of offshore shallows. Estuarine, Coastal and Shelf Science, 192, pp.57–71. Available at:
http://dx.doi.org/10.1016/j.ecss.2017.04.026.

Hossain, M.S. et al., 2016. Marine and human habitat mapping for the Coral Triangle Initiative region of Sabah using Landsat and Google Earth imagery. Marine Policy, 72, pp.176–191. Available at:
http://dx.doi.org/10.1016/j.marpol.2016.07.003.

Jawak, S.D., Vadlamani, S.S. & Luis, A.J., 2015. A Synoptic Review on Deriving Bathymetry Information Using Remote Sensing Technologies: Models, Methods and Comparisons. Advances in Remote Sensing, 04(02), pp.147–162. Available at:
http://dx.doi.org/10.4236/ars.2015.42013.

Biondo, M. & Bartholomä, A., 2017. A multivariate analytical method to characterize sediment attributes from high-frequency acoustic backscatter and ground-truthing data (Jade Bay, German North Sea coast). Continental Shelf Research, 138, pp.65–80. Available at:
http://dx.doi.org/10.1016/j.csr.2016.12.011.

Lirman, D. et al., 2003. Coral communities of Biscayne Bay, Florida and adjacent offshore areas: diversity, abundance, distribution, and environmental correlates. Aquatic Conservation: Marine and Freshwater Ecosystems, 13(2), pp.121–135. Available at:
http://dx.doi.org/10.1002/aqc.552.

Monaliza, M.D., & Samsur, M., 2011. Toxicity and Toxin Properties Study of Puffer Fish Collected from Sabah Waters. Health and the Environment Journal, 2(1), pp. 14–17.

Marine and Coastal Biodiversity, 2015. Marine and coastal biodiversity offsets. Available at: https://www.mybis.gov.my/art/6.

Mustapha, M. A., Lihan, T., & Khalid, L. I., 2014. Coral reef and associated habitat mapping using ALOS satellite imagery. Sains Malaysiana, 43(9), pp. 1363–1371.

Papakonstantinou, A., Stamati, C. & Topouzelis, K., 2020. Comparison of True-Color and Multispectral Unmanned Aerial Systems Imagery for Marine Habitat Mapping Using Object-Based Image Analysis. Remote Sensing, 12(3), p.554. Available at:
http://dx.doi.org/10.3390/rs12030554.

Reef Check Malaysia., 2020. 2020 Status of Coral Reefs. p.128.

Rukavina, N., 2001. Mapping and monitoring contaminated-sediment geometry and stability. The Science of The Total Environment, 266(1-3), pp.33–39. Available at:
http://dx.doi.org/10.1016/s0048-9697(00)00738-5.

Sabah Parks., (2017). Tun Mustapha Park. The Official Website of the Board of Trustees of the Sabah Parks.

Schimel, A.C.G. et al., 2010. Quantitative experimental comparison of single-beam, sidescan, and multibeam benthic habitat maps. ICES Journal of Marine Science, 67(8), pp.1766–1779. Available at:
http://dx.doi.org/10.1093/icesjms/fsq102.

Suadik, M. et al., 2018. Sumber semula jadi dan kepentingannya terhadap sosioekonomi komuniti pesisir Pantai Timur Sabah. Jurnal Kinabalu, 21, pp. 1–19.

Tajam, J., & Mokhtar, M., 2019. Marine Habitat Distribution and Substrate Composition of Dangli Group of Islands, Langkawi UNESCO Global Geopark, Kedah, Malaysia. International Journal of Oceans and Oceanography, 13(1), pp. 37–56.

Yap, K., 2017. An Attempt Using Hydro-Acoustic Approach for Rapid Coral Reef Mapping in Malaysia.

A Study into the Development of a Light Weight Smart Life Buoy Prototype (LWSLB)

Suresh Thanakodi, Muhamad Lazim Talib, Syarifah Aishah Syed Ali, Norshahriah Abdul Wahab, Amalina Farhi Ahmad, Norshaheeda Mohd Noor, Muhammad Izham Bin Ahmad Zahari, Mohd Arif Ahmad

Life Buoy, also known as a life preserver, is a crucial safety tool on board any marine ships. The most common and conventional lifesaver is operated manually to save people from drowning, yet this method poses a risk for both the victim and rescuer. Hence, with the help of current technology, a smart lifebuoy has been developed, whereby the rescuer just operates the lifebuoy using remote control. Yet, the existing smart life buoy system has been found heavy and hard to be operated, especially for women, children, and other people with disabilities.This paper focuses on the development of a lightweight smart life buoy system and its characteristics. Arduino Uno R3, Arduino Nano, DC motor 775, Transmitter and Receiver kit were the main components used in the development of the lightweight smart life buoy system (LWSLB). The developed LWSLB system was tested at the National Defence University of Malaysia' swimming pool due to Covid-19 lockdown, and data such as speed, range of remote connection and battery endurance were obtained. It has been found out that the developed LWSLB weighs just 3.5kg overall compared to Brand S which weighs 13.75kg. However, in terms of speed, Brand S proves to be faster at 4.17m/s compared to LWSLB which exhibits a speed of 1.25m/s.

KEY WORDS

~ Lifebuoy
~ Remote-control
~ Arduino
~ Drowning

Universiti Pertahanan Nasional Malaysia, Kuala Lumpur, Malaysia

e-mail: suresh@upnm.edu.my

doi: 10.7225/toms.v10.n02.008

Received on: 28.06.2021/ Revised on: 10.10.2021/ Accepted on: 13.10.2021/ Published: 21.10.2021

1. INTRODUCTION

Globally, drowning is rather common (Zhu, Jiang, Li and Chen, 2015) and, according to the World Health Organization (WHO), drowning fatalities are a neglected public health issue, ranked as the third most frequent cause of unintentional death by injury (Nyitrai, Edwards and Dwyer, 2019). Unintentional drowning occurs in diverse locations such as lakes, rivers, and coastlines (Celia et al., 2018). It also happens in various weather conditions and affects both adults and children (Celia et al., 2018). Generally, drowning is referred to as the process of submersion or immersion in liquid to experience respiratory impairment (Zhu, Jiang, Li and Chen, 2015). Therefore, flotation has become a device that plays an important role in saving lives.

Personal flotation devices and life preservers, such as lifebuoys, have been used on various watercraft for many years during emergencies (Mitev, 2020). For example, a lifebuoy may be released from the watercraft into the water towards the person overboard during a man overboard (MOB) situation in which a person has unintentionally fallen out of the watercraft and into the surrounding water (Mitev, 2020). Once the lifebuoy has been launched into the water towards the person overboard, the lifebuoy is hopefully within the reach of the person overboard; if not, it is often more difficult to rescue the person overboard (Mitev, 2020).

In the current era, lifebuoy can be categorized into two types known as manual lifebuoy and smart lifebuoy. The manual lifebuoy is a conventional one, such as the lifebuoy ring that is a doughnut-shaped (Collins, 2017). The utilization of manual life buoy seems to be practical when the victim is not far from the rescuer's place. This is because manual lifebuoy can only reach the victims according to the strength of the rescuer who is throwing the ring and in certain drowning situations, at least one person may have to descend into the water with the life ring to rescue the victim (Mitev, 2020). For man overboard situations, a person needs to guide the lifebuoy towards the overboard man as it is usually not accurate when the lifebuoy is thrown towards the victim (Mitev, 2020) However, the scenario can be challenging and risky for the rescuer, even with good swimming skills during bad weather or in a rocky place.

As a life-saving alternative, the introduction of technology to lifebuoy has given birth to a smart lifebuoy. It can be best presented as a remote-control, mostly U-shaped lifebuoy (Collins, 2017). Smart lifebuoys are able to reach the far victim by utilizing remote-control thumb-stick that can be conducted by the rescuer (Collins, 2017). This technology avoids the danger and risk for the rescuer from descending into the water to save the victim. However, the existing smart lifebuoy system has been found too heavy and hard to be operated, especially for women, children, and other people with disabilities. Hence, this may jeopardize the rescue mission during an emergency of man overboard situations. Therefore, there is a high niche for the development of a lightweight remote-control lifebuoy system.

For the purpose of this paper the researcher has used Arduino technology for the development of a light-weight life buoy prototype. Arduino is open-source software for designing and programming electronics (Badamasi, 2014). There are plenty of advantages in using Arduino, such as the components consisting of a small circuit which reduces the size of the prototype (Varesano, 2011), affordable cost (Watelectronics, 2021), user-friendly (Varesano, 2011), facilitating multiple input and output. Unfortunately, it is not a waterproof device, therefore, the developed Arduino circuit has to be placed in a waterproof casing to ensure the board and electronics components' safety from exposure to water.

In this research work the developed LWSLB uses remote-control technology. Remote-control technology is a wireless power transmission system that includes a transmitter and a receiver for the signal transmission and receiving process (Terada, Shinoda and Yamamoto, 2014). The transmitter consists of a power transmission unit for powering the transmitter, as well as a communication module (Terada, Shinoda and Yamamoto, 2014). On the other hand, the receiver unit on the smart lifebuoy is able to receive signals from the transmitter unit using a power receiving unit (Terada, Shinoda and Yamamoto, 2014). The received data signal then enables the water pump to turn on as the water pump acts as the thruster for the buoy. The thrust happens through the pull and pushes mechanism, whereby the water pump pulls the water inwards and pushes it out in another outlet with pressure, producing the thrust needed for the buoy, while turning left or right according to the rescuer's signal from the remote controller.

Based on practicality, the remote-control life buoy device is more efficient to be used in rescuing a drowning person. It reduces the risk of the rescuer from also turning to be a victim. Observation also concludes that remote-control lifebuoy may shorten the time for a rescue operation, and it is also user friendly to be conducted by anyone from shore or on board a ship. Generally, remote-controlled lifebuoy or also known as smart lifebuoy stands a better chance of saving people's life compared to conventional lifebuoy.

2. METHODOLOGY

Figure 1 summarizes the overall process in accomplishing the research work. The prototype designing process has been carried out based on a literature review by focusing on the weight reduction of the existing remote-controlled lifebuoy. For this research work, two different working prototype models have been developed and analyzed. Both of the developed LWSLB use Arduino technology as a mainboard. Components such as Arduino Nano, L298N driver, transmitter, receiver board, motor, and 12V Lithium Polymer battery, have been selected and utilized on both prototypes.

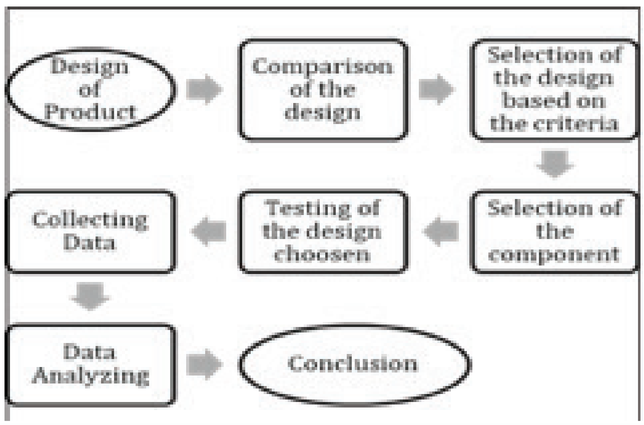


Figure 1.
Flowchart of procedure.

Both developed LWSLB have been later tested and their functionality verified in the swimming pool located in the National Defence University of Malaysia due to the Covid-19 Movement Control Order. The best-designed prototype has then been determined and its performances described in terms of speed, loading weight, battery endurance, and range for the remote-control connection. Further enhancing the analysis, the obtained data have been compared with the industrial existing smart lifebuoy. As a final process, conclusions have been drawn based on the research objectives and findings from the experiment.

2.1. Design Constructed

Figure 2 shows Prototype X, developed from kickboard, polyvinyl chloride (PVC) pipe, rubber hose, and electronic components. In this prototype, the Arduino board and electronics components have been located on the left side of the white coloured PVC pipe to ensure the electronics components sealed from contact with water. The thrust for Prototype X is achieved through the differences in water pressure created by the water pump through a water inlet rubber hose under the PVC pipe and water outlet at the upper rubber hose.

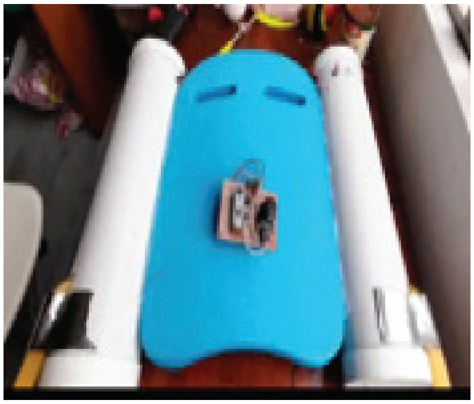


Figure 2.
Prototype X.

Figure 3 shows the second design, constructed using similar materials and the same electronic boards and components, but with an addition of used mineral bottles. In this design, the Arduino board and electronic components were secured inside the mineral bottles to prevent contact with water. All the openings in the bottle were sealed using a water-resistant sealant. In comparison with the previous design, the thrust for Prototype Y generated through water pressure pushed out from both ends of PVC using the 775-motor controlled by the L298N motor driver. The 12V 775 DC Motor has a speed of 2200 rotation per minute (rpm) and a torque of 350g-cm at a maximum efficiency. The 775 DC motor has been chosen due to its characteristics of high speed (torque).

Figure 3.
Prototype Y.

2.2. Comparison Between Design and Speed Characterization

In comparison to Prototype Y, Prototype Y has been found to be heavier as the design uses bigger PVC pipes on both sides of the kickboard to host the electronic components. The electronic components in Prototype X are located inside of one of the PVC pipes, which causes instability for the overall lightweight smart life buoy system, compared to Prototype Y. This is due to the design of Prototype Y which houses the electronic components in a bottle at the front, balancing and distributing the weight between the left and right side accordingly. Furthermore, the Prototype Y exhibits more ergonomic design which enables the user to easily hop on to during the rescue mission. Hence, with all due considerations and comparisons between the two designs, Prototype Y has been found to be better and is therefore used throughout the experiment for the characterization process.

In order to obtain the speed and average speed for Prototype Y, the formulae below have been used in this experimental work, whereas the results are discussed in Section 3.3.

$$\text{Speed,v} = \frac{\text{distance,d}}{\text{time,t}}$$

$$\text{Average speed} = \frac{(\text{Speed for 10m+Speed for 25m+Speed for 50m})}{3}$$

2.3. Remote Control Construction

Figure 4 shows the schematic diagram constructed using Proteus 8 application for the transmitter and receiver module of the smart lifebuoy system. The diagram consists of Arduino uno R3, Arduino nano, switch, motor, and power supply. Figure 4 clearly depicts the separation between the transmitter and receiver module, whereby many components attached to the receiver are compared to the transmitter.

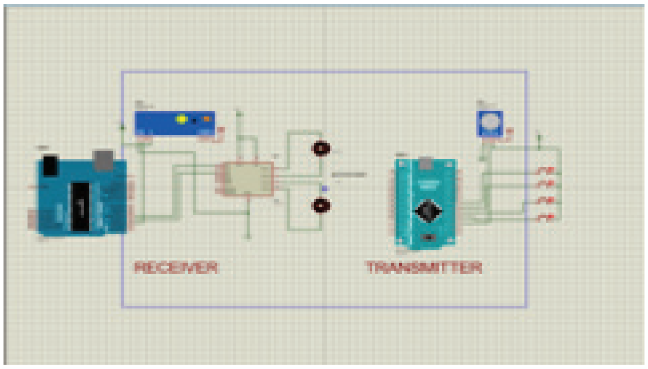


Figure 4.
Schematic Diagram of Remote-Control for LWSLB.

The transmitter's simple design is due to the functionality of a basic remote control in order to facilitate its use and to create user-friendly features for the rescuer. On the other hand, the receiver module, located on the lifebuoy, consists of other relevant components such as switch, motor, power supply and etc. The coding for the operation of the lifebuoy system has been carried out using Arduino software platform known as Arduino Integrated Development Environment (IDE) and uploaded to the board via computing order to facilitate the USB connection.

3. RESULTS

3.1. Comparison Between Types of Life Buoy System

Table 1 summarizes the comparison between the types of lifebuoys currently in existence and in the market usage. The manual life buoy (life ring) and the developed Prototype Y can be categorized as light weight lifebuoy compared to the existing smart life buoy. Light weight lifebuoy enables the rescuer to dispatch it faster during an emergency and this may indirectly help the survivability of the victim. On the other hand, the existing smart lifebuoy (Brand S) and the developed Prototype Y exhibit more ability compared to the life-ring in terms of rescuing range. The smart life buoy rescuing range has been determined by the range of remote-control connection, while the manual life buoy (life ring) is based on the rescuer's muscle strength.

Table 1.
Types of Life Buoy in Comparison.

Characteristics	Manual Life Buoy (Life Ring)	Existing Smart Life Buoy (Brand S)	Developed Light Weight Smart Life Buoy (LWSLB) (Prototype Y)
Weight	Light (2.5kg – 4.3kg)	Heavy (13.75kg)	Light (3.50kg)
Rescuing Range	Based on human's strength	Based on a range of remote-control connection	Based on a range of remote-control connection
Provided Support System	NIL	Allows the victim rest on the lifebuoy	Allows the victim rest on the lifebuoy
Accuracy to Reach Victims	Less accurate for long-range distance victim & depends on the environmental factors too	Able to reach the victim at any conditions	Able to reach the victim at any conditions
Risk Assessment	Both to the victim and the rescuer	Victim only	Victim only

In addition to the rescuing range factor, the accuracy of lifebuoy in reaching the victim is also crucial, whereby the smart lifebuoy is able to reach the victim accurately in any weather conditions as it is remotely controlled and uses the motor technology to manoeuvre towards the victim. While the manual life buoy has many challenges in reaching the victim, as it does not have any maneuvering capabilities and is easily affected by the water current directions. This may result in high possibilities of losing the victim and in such condition requires the rescuer's direct involvement by descending into water for the rescuing purposes. Hence, utilizing smart life buoy system, reduces the risk of losing a number of lives compared to the manual life buoy, whereby both the victim and the rescuers are at a risk of drowning.

3.2. Cost Comparison Between Smart Life Buoy System

Table 2 summarizes the detailed cost incurred for the development of a lightweight smart lifebuoy system (Prototype Y). The detailed components, with a total cost for the current smart life buoy available in the market (Brand S), is impossible to present since this research work is a self-funded work and the cost to obtain it quite high. Overall cost of Brand S is estimated to be at € 2,795.56, while the developed Prototype Y costs around € 47.60. Yet, it is expected that this cost might increase by 20% if Prototype Y is to be commercialized as there will be an aesthetic upliftment, especially in replacement of mineral water bottle housing the electronic boards. In terms of money, Prototype Y looks promising and affordable for any normal fisheries ship to own it, while Brand S is for a high-end user. However, further analysis carried out on the Prototype Y performance and comparison between Brand S has also been presented in the next section.

Table 2.
Cost Comparison between Brand S and Prototype Y.

Brand / Apparatus	Qty.	Existing Smart Life Buoy System (Brand S)	Developed LWSLB (Prototype Y)
12V Motor 775 for Water Pumping	2		€ 12.42
Arduino Uno R3	1		€ 4.95
Arduino Nano	1		€ 3.00
L298N Motor Driver	1		€ 1.43
Transmitter and Receiver Module Kit	1		€ 1.22
Li-Po Battery 12V 4200mah	1		€ 17.59
9V Battery	1		€ 1.01
Kickboard	1		€ 3.08
PVC Pipe with Elbow	-		€ 2.28
Mineral Bottle	2		€ 0.62
Total Cost		**€ 2,795.56**	**€ 47.60**

3.3. Characterization of Performance on Developed LWSLB (Prototype Y)

Table 3 summarizes the test results for average speed characterization of Prototype Y. The characterization test was conducted at the National Defence University of Malaysia's swimming pool due to the Covid-19's Movement Control Order. The swimming pool has a maximum length of 50 meter with a depth of 2 meters and the tests have been repeated thrice for each length range. The average speed for each test range have then been averaged out by using the formula discussed in Section 2.2. While for the speed test there is no specific apparatus, the basic Galileo's formula, as stated in Section 2.2, has been used, helping to obtain the speed attained by Prototype Y.

Table 3.
Results on Average Speed Obtained by Prototype Y.

Range	Time Taken	Speed
10m	7.81 s	1.28 m/s
25m	20.16 s	1.24 m/s
50m	40.65 s	1.23 m/s
Average Speed	1.25 m/s	

Therefore, using this technique the rest speed tests have been obtained by varying the distance travelled by Prototype Y and duration (time) taken using a stopwatch. As the observation made from Table 3 shows, there is a slight reduction in speed from Prototype Y as the distance increases. One of the reasons causing such scenario would be human error in obtaining the time taken since it is manually done, using a stopwatch. This is due to the longer distance the Prototype Y travels: the human mind become less alert and comfortable with the situation, hence there is a slight delay between the eyes and hand coordination using the stopwatch in gathering the data for time.

Another possible reason for the situation might be due to motor thrust in the first ten (10) metres that accelerates before reaching its normal speed and this is caused by high current during the start-up of the motor. Both error factors have been mitigated in this experiment by averaging out the speed with various distance, resulted in average speed of 1.25ms-1 for the developed Prototype Y. The average speed, as shown in Table 3, has been obtained by using the average formula discussed in section 2.2.

Table 4 summarizes the results obtained from various criteria of life buoy such as its weight, speed, and load carrier. For smart life buoy, three (3) important criteria were experimented upon: battery endurance, range of remote-control connections, and the life buoy speed. The performance comparison between the developed Prototype Y against the current lifebuoy in the market has also been presented in Table 4. Certainly, a manual life buoy, light in weight and able to lift up to 200kg of load, but highly dependent on the life-savers skill and rescuing experiences, hence increases the risk of losing life of both the victim and rescuers.

Table 4.
Performance Comparison of Various Life Buoy.

Brand / Characteristics	Manual Life Buoy (Life Ring)	Existing Smart Life Buoy (Brand S)	Developed Light Weight Smart Life Buoy (Prototype Y)
Weight	2.5kg – 4.3kg	13.75kg	3.5kg
Speed	Based on human strength	4.17m/s	1.25m/s
Load Carrier	200kg	200kg	100kg
Battery Endurance	N/A	30 minutes	12 minutes
Range of Remote-Control Connection	N/A	300 meters	50 meters

The developed Prototype Y weights 3.5kg and manages to reduce the smart life buoy weight by 74.5% in comparison to Brand S, the existing in the current market. However, the marketed Brand S smart life buoy has a higher speed and longer battery endurance compared to Prototype Y. This is due to the utilized number of motors, type of motor and battery used in Brand S compared to Prototype Y. The type of motor and their number plays a major role in creating the thrust, resulting in speed, while a higher capacity battery is able to supply power for a longer duration of time. Brand S is propelled by two (2) electric motors to power up its turbine, while prototype Y uses only one motor to create the water pressure necessary for its thrust.

In designing Prototype Y, the reduction of weight and cost were the major consideration, hence, with the budgeted cost, small power type of motor have been used in order to reduce the weight, as well as a smaller capacity battery. This explains the reason behind the poor performance of Prototype Y compared to Brand S in terms of speed and duration of battery usage. Brand S has nearly 83.3% advantages compared to Prototype Y in terms of remote connectivity. The ability for a longer range of remote connectivity depends highly on the technology used, whereby Brand S uses Bluetooth 4.2 and Wi-Fi technology, increasing the range for its remote connection, while Prototype Y uses Arduino Radio Frequency (RF) transmitter and receiver module. Monetary factor also plays a vital role in the development of Prototype Y. Although there are some disadvantages of the developed prototype in comparison to Brand S, Prototype Y has succeeded in becoming a lightweight smart lifebuoy and could possibly be used in short range rescue missions.

4. CONCLUSION

In conclusion, the introduction of smart lifebuoy technology complements the usage of manual lifebuoy and has clearly exhibited more advantages, mainly in reducing the risks of losing life during search and rescue operations. Prototype Y has been successfully developed to become a fully functional lightweight smart life buoy system; however, with a reduced performance in comparison to the product currently existing in the international market. The developed prototype can be used in s short-range rescue mission with an affordable price for everyone to own it. On the other hand, improvements can be made towards the number of motors utilized and types of motors for gaining a higher speed life buoy system. In addition, using a higher capacity Lithium Polymer (LiPo) battery can extend the functional duration of the life buoy and it is also recommended to use a broader kickboard to increase the ability to carry higher loads. All things considered, the objective of this paper has been achieved by presenting the development and characterization of the lightweight smart life buoy system (Prototype Y).

REFERENCES

Allied Components, 2016. 14 Essential Electronic Components and their Functions. Available at: https://www.alliedcomponents.com/blog/essential-electronic-components-functions, accessed on: 12 January 2021.

Badamasi, Y.A., 2014. The working principle of an Arduino. 2014 11th International Conference on Electronics, Computer and Computation (ICECCO). Available at: http://dx.doi.org/10.1109/icecco.2014.6997578.

Collins, A., 2017. U-SAFE: This Remote Controlled Life Buoy is super fast in saving lives. Available at: https://factschronicle.com/u-safe-this-remote-controlled-life-buoy-is-super-fast-in-saving-lives-4619.html, accessed on: 24 January 2021.

ElProCus, 2019. Water Pump: Working principle, Types and Their Applications. Available at: https://www.elprocus.com/water-pump-types-and-applications, accessed on: 12 January 2021.

GrandOcean, 2020. Lifebuoy Ring, Life Float Ring Manufacturer. Available at: https://www.grandoceanmarine.com/marine-safety-equipments/life-float-life-buoy/, accessed on: 12 January 2021.

Kumar, A., 2020. Difference Between Centrifugal pump and Reciprocating pump. Available at: https://learnmechanical.com/difference-between-centrifugal-pump-and-reciprocating-pump, accessed on: 12 June 2020.

Lin, Y.-N. et al., 2020. Development and verification of a smart remote control system for home appliances. Computers & Electrical Engineering, 88, p.106889. Available at: http://dx.doi.org/10.1016/j.compeleceng.2020.106889.

Mitev, G., 2020. Autonomous Lifebuoy. US20200148320A1.

Nyitrai, N., Edwards, S. & O'Dwyer, N., 2019. Drowning Prevention: Define and Then Gather Evidence or Gather Evidence to Define? International Journal of Aquatic Research and Education, 10(4). Available at: http://dx.doi.org/10.25035/ijare.10.04.01.

Ridden, P., 2019. Remote-controlled lifebuoy propels itself to save troubled swimmers. Available at: https://newatlas.com/dolphin-oceanalpha-remote-electric-lifebuoy/60586/, accessed on: 12 June 2020.

Seguin, C. et al., 2018. Unmanned aerial vehicles (drones) to prevent drowning. Resuscitation, 127, pp.63–67. Available at: http://dx.doi.org/10.1016/j.resuscitation.2018.04.005.

Terada, T., Shinoda, H. and Yamamoto, K., 2014. Wireless power transmission system, transmitter, and receiver. US8892033B2.

Varesano, F., 2011. What is Arduino, Why we choose it, what can we do with it? Available at: http://www.varesano.net/blog/fabio/, accessed on: 12 January 2021.

Watelectronics, 2021. Arduino Technology Architecture and its Applications. Available at: https://www.watelectronics.com/arduino-technology-architecture-and-applications/, accessed on: 12 January 2021.

Zhu, Y., Jiang, X., Li, H. and Chen, J., 2015. Mortality among drowning rescuers in China, 2013: a review of 225 rescue incidents from the press. BMC Public Health, 15(631).

Heavy Metal Content Analysis and Toxicity Assessment of Oil-Based Drilling Mud using Zebrafish Embryos

Nanthini Sridewi, Siti Nurbariah, Syahida Ahmad

Aim: Used oil-based drilling muds (OBDMs) are toxic to marine organisms due to the fluid's complex chemical nature. The illegal dumping of used OBDMs is still rampant in many parts of the world despite of the stringent laws and regulations pertaining to its disposal. To date, study of the assessment of heavy metal content in used OBDMs from the Malaysian oil and gas industry has been limited. Furthermore, the study of the toxic effect of OBDMs using a zebrafish embryo model has never been reported before. Therefore, in this research, the used oil-based drilling muds (OBDMs) were analyzed for their heavy metal content and toxicity against Zebrafish embryos. *Methods*: Used OBDMs were collected from an Anchor Handling Tug Supply (AHTS) vessel mud tank from Kemaman, Terengganu. The heavy metal content in the mud was analyzed using ICP-AES. Zebrafish embryos were exposed to OBDMs of varying concentrations (i.e., 0.25 mg/ml, 0.125 mg/ml, 0.06 mg/ml, 0.03 mg/ml, 0.015 mg/ml, 0.0076 mg/ml, 0.0034 mg/ml and 0.0019 mg/ml). The toxicity and teratogenicity of the mud on zebrafish embryos were assessed every 24 hours, for 96 hours, using endpoints like embryo mortality, heart rate and hatching rate. *Results*: The heavy metal content of used OBDMs had the highest concentration of barium (Ba) 2360 ppm, followed by lead (Pb) 120 ppm, zinc (Zn) 104 ppm, arsenic (As) 9 ppm, and chromium (Cr) 16 ppm, with cadmium (Cd) concentration of less than 1 ppm being the lowest. The Ba (2360 mg/L) concentration in the OBDM sample exceeded the concentration of Ba in normal marine sediment reported to be around 2000 mg/L. The 96 h LC_{50} of the OBDM in zebrafish embryos was reported to be 0.005 mg/mL (5 ppm). Zebrafish embryos that were exposed to high concentrations of OBDMs exhibited a lower hatching rate and reduced heart rate than the control group. *Conclusion*: The findings of this study are indicative of the highly toxic nature of used OBDMs and its dosage-dependent teratogenicity effects on zebrafish embryo. Knowledge of the potential environmental impacts of OBDMs released into the marine environment can be the basis for prudent decision-making that will help minimize environmental damage.

KEY WORDS

~ Oil-based drilling muds
~ Heavy metal
~ Toxicity
~ Zebrafish embryo
~ Embryotoxicity
~ Teratogenicity

Universiti Pertahanan Nasional Malaysia, Kuala Lumpur, Malaysia

e-mail: nanthini@upnm.edu.my

doi: 10.7225/toms.v10.n02.w06

Received on: 20.05.2021 / Revised on: 06.06.2021 / Accepted on: 06.07.2021/ Published online: 28.08.2021

1. INTRODUCTION

The process of oil and liquefied natural gas production involves several major processes, such as exploration, well development, production, and site abandonment (Doric and Dimovski, 2018). During well development, drilling fluid is circulated in the borehole to facilitate a cost-effective and efficient drilling operation (Gandhi and Sarkar, 2016).

There are three main categories of drilling fluids, i.e. water-based muds that can be dispersed and non-dispersed, non-aqueous muds, usually called oil-based muds, and synthetic-based muds (Seyedmohammadi, 2017). These drilling muds are continuously circulated between the well and the platform through a riser pipe. Mud is used to maintain pressure and wall stability, as an agent that cools and lubricates the drill bit and to carry rock drill cuttings generated during the drilling process away from the cutting head to the platform (Ahmed et al., 2020; Hossain and Islam, 2018).

Environmental problems associated with complex drilling fluids in general, and oil-based drilling mud (OBDM) in particular, are among the major concerns of communities worldwide (Gamal et al., 2019). The discharge of hole fluid or cuttings generated with OBDMs is not permitted in most offshore-drilling areas (Cordes et al., 2016; Kark et al., 2015). All such drilled cuttings and waste fluids are processed and shipped to shore for disposal. However, the risks of unregulated offshore disposal or accidental spillage is still a major concern, especially in areas outside national jurisdiction (Sharif et al., 2017).

The awareness of high heavy metal content of OBDMs and the fact that they bioconcentrate and biomagnify across the food chain emphasize the importance of extrapolating the toxicity of OBDMs to humans. Although laboratory studies on rodents can be a reliable tool for this purpose, they are often expensive and involve ethical concerns. A better alternative to rodents as model organisms in toxicological studies are adult and embryonic zebrafish.

Embryos in particular have the added advantage that their developmental stages can be observed directly due to the transparent nature of the eggs (Chahardehi et al., 2020). Furthermore, as zebrafish and humans have 70% of the DNA in common, this organism is more suitable for the extrapolation of toxicity in humans (Chanika et al., 2019).

To date, though various studies on OBDM toxicity have been conducted on fish, crustaceans and mollusks, no studies have been conducted on adult zebrafish or their embryos. Therefore, in this study, we attempted to evaluate median lethal concentrations (LC50), as well as potential developmental and teratogenic effects of the OBDM on zebrafish embryos, using samples collected from an Anchor Handling Tug Supply (AHTS) vessel mud tank from Kemaman, Terengganu, Malaysia. The heavy metal content of the used OBM sample was also analyzed.

2. MATERIALS AND METHOD

2.1. Sample Acquisition

The used OBDM samples were collected from the mud tank of an AHTS vessel, from the oil field at Kemaman, Terengganu, Malaysia. The jack-up rig has a drilling depth capacity of 30,000 feet and can operate at water depths of up to 400 feet. Drilling mud samples were collected using a grab sampler and transferred into high-density polyethylene bags. The samples were preserved in an icebox before being transported to the laboratory for further analyses.

2.2. Heavy Metal Analysis of the Used OBDM Medium

The used OBDM samples were subjected to acid digestion using a combination of sulphuric acid (H2SO4) and nitric acid (HNO3) at a 3:1 ratio. The analysis of arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb) and zinc (Zn) content was conducted using Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) according to USEPA 6010B.

2.3. Serial Dilution of Used OBDM

A solvent of H2SO4: HNO3 mixed at a 3:1 ratio (4 ml) was combined with 6 ml of Danio-SprintM Embryo Media (0.1% DMSO) and regulated to pH 7.2. The mixture was used to prepare a stock solution of the used OBDM samples with the final concentration of 5mg/ml. The stock solution was serially diluted with Danio-SprintM Embryo Media to obtain a series of concentrations ranging from 0.25 mg/ml, 0.125 mg/ml, 0.06 mg/ml, 0.03 mg/ml, 0.015 mg/ml, 0.0076 mg/ml and 0.0034 mg/ml to 0.0019 mg/ml.

2.4. Used OBDM Toxicity Testing Using Zebrafish Embryos

Zebrafish embryos were purchased from Danio Assay Laboratories Sdn. Bhd. The zebrafish embryotoxicity test was carried out in keeping with Zhu et al. (2008). Embryo viability was checked under a stereomicroscope to make sure they are in the pharyngula stage [24 hpf (hours post-fertilization)]. Only healthy embryos were selected and transferred into a 96-well plate. The embryo media in each well was replaced with 100 μL of fresh Danio-SprintM Embryo Media followed by the addition of 100μL of the pre-prepared serial dilution of the sample. The treated embryo plates were incubated at 28±2°C and observed under an inverted stereomicroscope under 100x magnification, every 24 hours for 96 hours. Toxicity endpoint was determined through the assessment of mortality, heartrate and hatching rates. The LC50 value was calculated using probit analysis to compare the survival of treated embryos with the control group.

3. RESULTS AND DISCUSSION

3.1. Heavy Metal Content in Used OBDM

The heavy metal content of used drilling mud largely depends on the type of drilling mud used, as well as on the geological factors of the oil shale deposits. The OBDM sample in this study contains a remarkably high concentration of Ba (2360 mg/L) [Table 1], exceeding the concentration of Ba in normal marine sediment, reported to be around 2000 mg/L (Neff, 2008).

Table 1.
Concentration of heavy metals in the used OBDM sample.

Heavy Metal	Limit of Reporting (LOR)	Concentration (mg/L)
Arsenic	1	9
Barium	5	2360
Cadmium	1	<1
Chromium	1	16
Lead	1	120
Zinc	1	104

A similar observation was made in many previous studies, regardless of the type of drilling mud tested. The source of Ba is Barite ($BaSO_4$), which is often added to drilling muds as a weighting agent to counteract pressure in geological formations being drilled, preventing a blowout (Alfa et al., 2019; Neff, 2008). Lead (120 mg/L) and zinc (104 mg/L) concentrations are approximately 10x higher than the average content of these metals in uncontaminated marine sediment which has the lead and zinc content of (10–33 ppm) and (27–88 ppm) respectively. The bioconcentration of these heavy metals poses a serious threat to marine organisms due to their persistent nature and bioavailability.

3.2. Toxicity Assessment of Used OBDM Using Zebrafish

The embryotoxicity effects of OBDM samples in the first 96 hrs. of zebrafish development revealed significant toxicity of the samples even at low sample concentrations. As sample concentrations increased, the survival of zebrafish embryos decreased, reaching 100% mortality at OBDM concentration of 0.125 mg/mL after 96 hrs. of exposure (Table 2).

Table 2.
The mortality rate of zebrafish embryos after 96 hrs. of exposure to varying OBDM concentrations.

OBDM Concentration (mg/mL)	Mortality Rate (%)
0.125	100
0.06	91.67
0.03	83.33
0.015	66.67
0.0076	50
0.0034	33.33
0.0019	16.67
Control (EM with 0.2% DMSO)	8.33

The LC_{50} value of OBDM in zebrafish embryos was found to be 0.005 mg/mL (5 ppm). This OBDM toxicity for zebrafish embryos is comparable to that of hydroquinone (4.40±0.33 ppm) and mercuric chloride (0.27 ppm) as reported in literature (Ahmad et al., 2020). The hatching rate of zebrafish larvae was observed between 48 hpf - 96 hpf (Figure 1). Embryos in the control group had the hatching rate of over 80%. As OBDM concentrations increased, decreasing embryo hatching rates were observed. No hatching was observed at the OBDM concentration of 0.125 mg/ml, corresponding to 100% embryo mortality.

Besides, no premature or delayed hatching was observed in either the control or test groups. Zebrafish mortality occurred in the embryonic stage and hatched larvae survived 96 hrs. of exposure to varying OBDM concentrations.

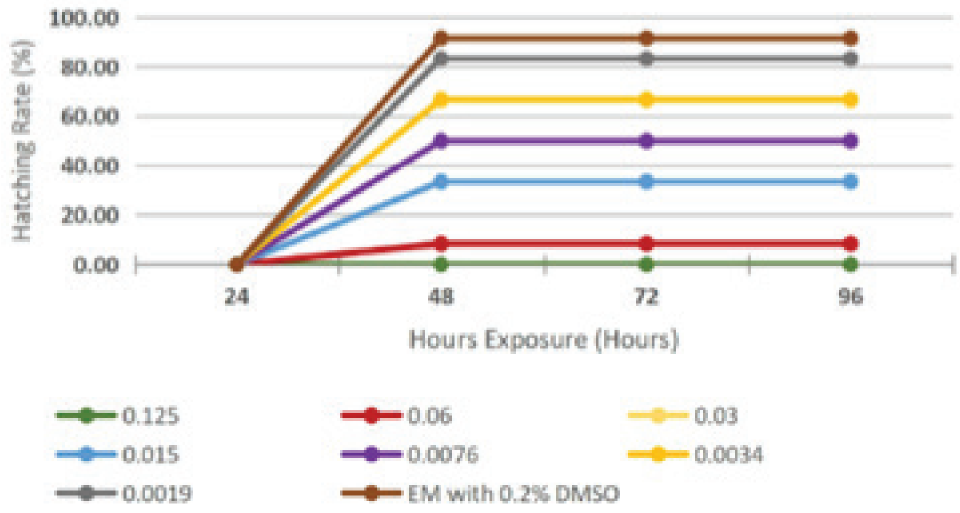


Figure 1.
Effect of varying OBDM sample concentrations on the hatching rate of zebrafish larvae over a 96-hour exposure period.

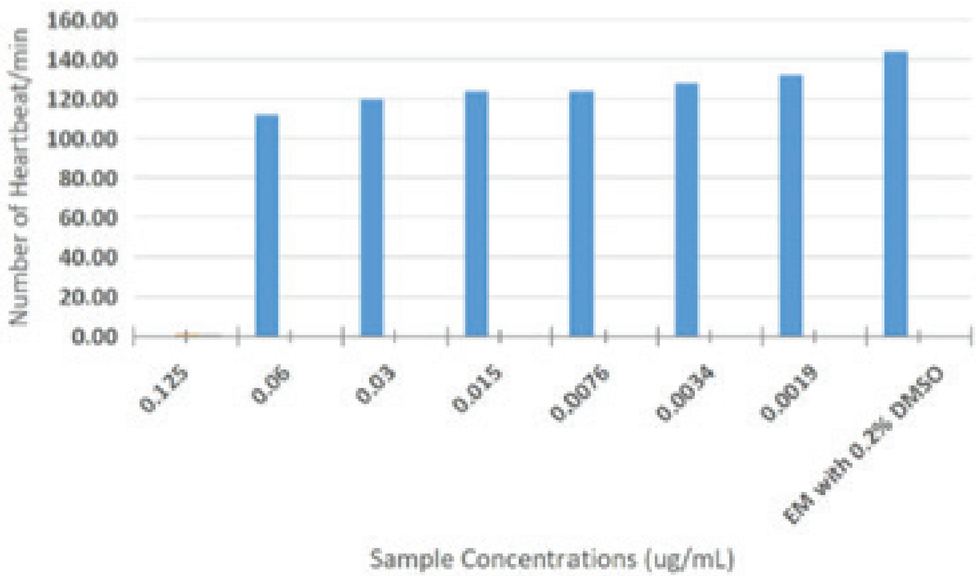


Figure 2.
Effect of varying OBDM sample concentrations on the heartrate of zebrafish larvae after 96-hour exposure.

Zebrafish embryo heartbeat stopped as OBDM concentrations increased as compared to embryos in the control group (Figure 2). Zebrafish embryos in the control group had the heartrate of 140–145 beats per minute (bpm). OBDM concentration of 0.06 mg/mL caused the heartbeat of zebrafish embryos to drop to 110 bpm. In a previous study, ethanol exposure during embryogenesis was found to obstruct cardiogenesis, and even cause defects in heart chamber and valve morphogenesis of juvenile zebra fish (Sarmah and Marrs, 2013). The severity of the defects varies depending on exposure duration, embryo's developmental stage and pollutant concentrations.

Please note that the cellular frameworks of zebrafish and mammalian hearts are comparable. This may indicate potential cardiogenic effects of exposure of marine mammals and humans to high OBDM concentrations that could be transferred across the marine food chain. Several important genes and regulatory networks involved in mammalian cardiogenesis have also been found in the regulatory networks essential for zebrafish cardiogenesis. Moreover, both the human fetal heartrate (130–170 bpm) and cardiovascular physiology more closely resemble that of the zebrafish than of the rodents (Sarmah and Marrs, 2016).

4. CONCLUSION

The findings of this research indicate that used OBDM is highly toxic due to its low LC50 value (5 ppm), owing to the higher concentration of heavy metals such as Ba, Pb and Zn in this sample in comparison to uncontaminated marine sediment. An increase in OBDM sample concentrations caused a reduction in zebrafish embryo survival rate, hatching rate and heartrate. These findings can be used to extrapolate the potential toxicity of OBDM to marine mammals, as well as humans, since zebrafish have a striking resemblance to mammalian cardiogenesis and human genetics. Strict regulations must be in place to regulate the proper disposal of used OBDMs to avoid their negative effects on the marine environment. Effective mitigation measures should be taken in case of accidental spillage of this hazardous material in the marine environment or whenever an unauthorized discharge is detected. Apart from this, countries involved in active oil and gas exploitation should focus on the development and use of low-toxicity, environmentally-friendly drilling mud additives.

ACKNOWLEDGEMENT

The authors would like to thank Mr. Che Mohd Hakiman Che Maail for his guidance in conducting the zebrafish embryotoxicity studies.

REFERENCES

Ahmad, F. et al., 2020. Effect of Pesticides and Metals on Zebrafish Embryo Development and Larval Locomotor Activity. bioRxiv Preprint.

Ahmed, N., Alam, M.S. & Salam, M.A., 2020. Experimental analysis of drilling fluid prepared by mixing iron (III) oxide nanoparticles with a KCl–Glycol–PHPA polymer-based mud used in drilling operation. Journal of Petroleum Exploration and Production Technology, 10(8), pp.3389–3397. Available at: http://dx.doi.org/10.1007/s13202-020-00933-1.

Alfa, A. K., 2019. Siderite as a Weighting Material in Drilling Mud. BAU Journal - Science and Technology, 1(1). Available at: https://digitalcommons.bau.edu.lb/stjournal/vol1/iss1/1.

Cordes, E.E. et al., 2016. Environmental Impacts of the Deep-Water Oil and Gas Industry: A Review to Guide Management Strategies. Frontiers in Environmental Science, 4. Available at: http://dx.doi.org/10.3389/fenvs.2016.00058.

Doric, B. & Dimovski, V., 2018. Managing petroleum sector performance – a sustainable administrative design. Economic Research-Ekonomska Istraživanja, 31(1), pp.119–138. Available at: http://dx.doi.org/10.1080/1331677x.2017.1421995.

Gamal, H. et al., 2019. Effect of pH on Rheological and Filtration Properties of Water-Based Drilling Fluid Based on Bentonite. Sustainability, 11(23), p.6714. Available at: http://dx.doi.org/10.3390/su11236714.

Gandhi, S.M. & Sarkar, B.C., 2016. Drilling. Essentials of Mineral Exploration and Evaluation, pp.199–234. Available at: http://dx.doi.org/10.1016/b978-0-12-805329-4.00015-6.

Hossain, M.E. & Islam, M. R., 2018. Problems Related to the Mud System. Drilling Engineering Problems and Solutions, pp.77–137. Available at: http://dx.doi.org/10.1002/9781118998632.ch3.

Jayasinghe, C.D. & Jayawardena, U.A., 2019. Toxicity Assessment of Herbal Medicine Using Zebrafish Embryos: A Systematic Review. Evidence-Based Complementary and Alternative Medicine, 2019, pp.1–17. Available at: http://dx.doi.org/10.1155/2019/7272808.

Kark, S. et al., 2015. Emerging conservation challenges and prospects in an era of offshore hydrocarbon exploration and exploitation. Conservation Biology, 29(6), pp.1573–1585. Available at: http://dx.doi.org/10.1111/cobi.12562.

Modarresi Chahardehi, A., Arsad, H. & Lim, V., 2020. Zebrafish as a Successful Animal Model for Screening Toxicity of Medicinal Plants. Plants, 9(10), p.1345. Available at: http://dx.doi.org/10.3390/plants9101345.

Neff, J.M., 2008. Estimation of Bioavailability of Metals from Drilling Mud Barite. Integrated Environmental Assessment and Management, 4(2), p.184. Available at: http://dx.doi.org/10.1897/ieam_2007-037.1.

Sarmah, S. & Marrs, J., 2016. Zebrafish as a Vertebrate Model System to Evaluate Effects of Environmental Toxicants on Cardiac Development and Function. International Journal of Molecular Sciences, 17(12), p.2123. Available at: http://dx.doi.org/10.3390/ijms17122123.

Sarmah, S. & Marrs, J.A., 2013. Complex cardiac defects after ethanol exposure during discrete cardiogenic events in zebrafish: Prevention with folic acid. Developmental Dynamics, 242(10), pp.1184–1201. Available at: http://dx.doi.org/10.1002/dvdy.24015.

Seyedmohammadi, J., 2017. The effects of drilling fluids and environment protection from pollutants using some models. Modeling Earth Systems and Environment, 3(1). Available at:
http://dx.doi.org/10.1007/s40808-017-0299-7.

Sharif MD, A. et al., 2017. Drilling Waste Management and Control the Effects. Journal of Advanced Chemical Engineering, 07(01). Available at:
http://dx.doi.org/10.4172/2090-4568.1000166.

Zhu, X. et al., 2008. Comparative toxicity of several metal oxide nanoparticle aqueous suspensions to Zebrafish (Danio rerio) early developmental stage. Journal of Environmental Science and Health, Part A, 43(3), pp.278–284. Available at:
http://dx.doi.org/10.1080/10934520701792779.

Feasibility Study of Monsoon Effect on Wave Power for Wave Energy Converter in Sabah, Malaysia

Nur Syafiqa Aifa Shahrom, M.N. Azzeri, Mohd Shukri Yusop, Mohd Norsyarizad Razali, Mohd Najib Bin Abdul Ghani Yolhamid, Ainul Rahman, Sarah Isnan, Afiqah Rosly, Mohd Arif Ahmad

This paper presents a research to determine the effects of the Northeast Monsoon (NEM) and the Southwest Monsoon (SWM) on wave power along the coastal area of Mandi Darah Island, Sabah. This study identified the daily data of wave height and wave period for 6 months from June to December 2018. The following period was chosen because it consisted of two monsoon seasons in Sabah. The data obtained from the Acoustic Doppler Current Profiler (ADCP) were thoroughly analyzed to estimate the wave height and the wave period to identify the wave power at Mandi Darah Island. The wave heights ranged from 0.01 m to 0.47 m while the wave periods ranged from 1.0 s to 8.6 s. The wave height range during the NEM was higher by 0.12 m than SWM, while the difference of wave period was significantly higher by 2.17 s during the NEM. The maximum wave power recorded at Mandi Darah Island was 1.57 kW/m throughout the period. During NEM, the wave power was significantly higher than during SWM, by 0.70 kW/m. These findings led to determining the wave energy type converter that suits the wave conditions at the Mandi Darah Island coastal area.

KEY WORDS

~ Wave energy converter
~ Wave power
~ Wave height
~ Wave period
~ Mandi Darah Island

Universiti Pertahanan Nasional Malaysia, Kuala Lumpur, Malaysia

e-mail: azzeri@upnm.edu.my

doi: 10.7225/toms.v10.n02.w05

Received on: 09.06.2021/ Revised on: 15.07.2021/ Accepted on: 21.07.2021/ Published online: 29.07.2021

1. INTRODUCTION

Since 2000 Malaysia has established the Eighth Malaysia Plan, which included renewable energy as a core element in the country's fuel policy, along with hydro, coal, gas and oil (Kardooni et al., 2018). Renewable energy has become important (Silva et al., 2015) and has a huge involvement to reduce the cost of fossils fuel and to save the environmental problems (Veigas et al., 2014). Ocean energy includes three essential components, i.e. wind, waves, and currents, which can create energy conversion. Wave energy is more predictable, has higher energetic density (Muzathik et al., 2010b; Neill & Hashemi, 2013) and is widely known as one of the most efficient alternative energy sources to replace renewable energy sources (Yaakob et al., 2016).

Seas and oceans are motion energy major sources, which include waves, tides, currents, thermal and salinity energies. Wave energy has been established as a renewable energy of wave energy converters (WECs) design since 1855 (Zanous et al., 2019). WECs have the advantage of operating under particular wave - climate conditions (wave height and wave-period) and their generation depends not only on the available resources, which are the coupling factor between the chamber and the air turbine, but also on the characteristics of the sea states (tidal level) (Veigas et al., 2014; López, I. & Iglesias, G., 2014). According to the study, in order to decide the optimum positions for a wave power plant, changes in WEC power spectrum under wave conditions should be considered in compliance with the available energy resource. The majority of wave energy potential calculations are limited to the estimation of wave energy potential in a given coastal region and the assessment of those areas with the largest amount of energy. The calculation is done by using wave power measurement.

The frequency of wave energy flow per unit of wave-crest length (wave power) can be calculated at any depth of water using the formula given (Foteinis et al., 2017; Vögler & Morrison, 2013). New calculation methodologies need to be built on both of these criteria in order to identify more accurate places and more wave-energy opportunities.

Many studies of wave power for energy conversion evaluation at various locations have been investigated over decades through established methodologies. Study of wave power potential of Malaysia (Mirzaei et al., 2014; Muzathik et al., 2010a; Samrat et al., 2014; Tan et al., 2017; Yaakob et al., 2006), Terengganu (Jaswar et al., 2014; Muzathik et al., 2010b) and Sabah (Ejria et al., 2010) can be found in the related literatures. There are different characters and energy densities depending on locations and weather conditions in different places. The design of nearshore wave energy converter generally consists of parameters of wave characteristics. The parameters of wave characteristics considered in WEC design were wave height and wave period. Knowledge about the behavior of the ocean waves is important in designing the suitable wave energy converter because the wave characteristics in deep water and shallow water are different (Tan et al., 2017).

Therefore, a significant effort is being made to explore the wave power potential of the coastal regions of Mandi Darah Island, Sabah in order to provide insight into the appropriate location for the selection and installation of WEC systems. The objective of this study is to determine the effects of NEM and SWM to the wave power along the coastal area of Mandi Darah Island. The wave data collected is going to be used for a proposal of WEC deployment to suit the wave regime in the coastal area of Mandi Darah Island.

2. GEOGRAPHICAL LOCATION

Mandi Darah Island is a small island located in Kudat Division (Monaliza & Samsur, 2011), which is the northern area of Borneo Island and bounded by latitude 6°55’44.52” N and longitude 117°20’2.37” E (Figure 1). As shown in Figure 2, synoptic charts from Malaysian Meteorology Department (MMD) utilizing National Centers for Environmental Prediction (NCEP) Reanalysis of Mandi Darah Island that depict Northeast Monsoon (NEM) and Southwest Monsoon (SWM). Mandi Darah Island location in synoptic maps also shown in Figure 2. Mandi Darah Island is subject to direct wind blow, particularly during the Northeast Monsoon (NEM), with occasional storms. This is because Mandi Darah Island is surrounded by Sulu Sea (Figure 3). The Sulu Sea is an enclosed sea, like the Mediterranean Sea, divided by a chain of islands from the surrounding waters: Borneo Island in the southwest, Palawan in the west, Busuanga and Mindoro in the north, Panay, Negros and Mindanao in the east, and the Sulu Archipelago in the southeast (Ejria et al., 2010).

The permanent residence on Mandi Darah Island is scarce, with about 35 houses constructed on the beach, where between 40 and 75 people abide. Mandi Darah Island was chosen as study area because due to the lack of infrastructure, wave energy is used to supply electricity to the villages as well as to the army camp situated on Mandi Darah Island.

Figure 1.
Location map of Mandi Darah Island in the northern part of Sabah.

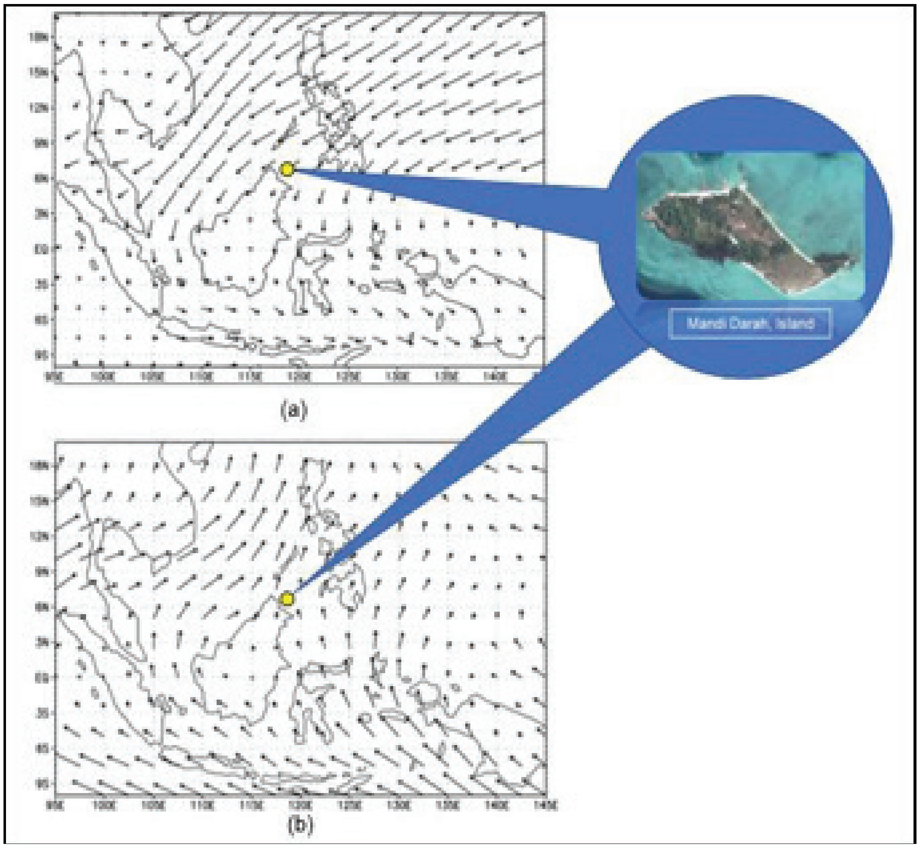


Figure 2.
Wind direction from the NCEP Reanalysis: (a) NEM and (b) SWM.

Figure 3.
Mandi Darah Island located in the Sulu Sea.

3. WAVE MEASUREMENT

This study was based on the six-hour data collected at wave measurements stations, covering the period from the Acoustic Doppler Current Profiler (ADCP). The ADCP is a hydroacoustic current meter similar to a sonar, which measures water velocity and direction over a range of depths, simultaneously measuring bathymetry. Based on Comprehensive Manual for ADCP (2018), an ADCP instrument transmits a short, constant-frequency sound pulse (“ping”) into the water, then listens for the echo and measures the change in the pitch or frequency of the echo. The frequency difference between transmitted and received pulses is proportional to water velocity.

The ADCP measures water velocity by emitting a sound pulse from microscopic suspended particles that float passively in the water and are supposed to travel at the same speed as water - the velocity of the particle recorded equals the velocity of the water surrounding the particle.

The instrument was deployed at 2 km to the south from the offshore island (Figure 4), at 13 m water depth. The instrument operated from 1 June, 2018 to 31 December, 2018. During this period, it completed the three monsoons season, i.e. Southwest Monsoon (SWM), Northeast Monsoon (NEM) and intermonsoon.

Wave data are required in order to investigate the wave energy harvesting in the study area. In this study, wave characteristics such as significant wave height (Hm0), and peak wave period (Tp) were recorded using the ADCP, as explained in the section above. After the quantitative analysis of the datasets, wave characteristics will be discussed in the result sections.

Figure 4.
The ADCP deployment 2 km offshore Mandi Darah Island.

3.1. Wave Theory

A wave is a dynamic disturbance in the propagation (change from equilibrium) of one or more quantities, as specified by the wave equation at times. A real wave is a water motion in the form of a moving shape distortion of the water surface with translational, rotational, and oscillatory motions. The water waves are transverse disturbances because the particle motion is apparently in one direction, which is up and down movement, and the direction of propagation of the disturbance is at the right angle to the direction of motion (Rameswar, 1978). An idealized approach of water wave is a sinusoidal curve that travels outwards.

The direction of wave can also be alternating; that is known as oscillatory motion, which is also called harmonic wave. Harmonic wave is an oscillating wave, and the term is applied to certain waves that are twice as high as their fundamental frequency (Mead, 1973). These waves will reflect off the obstacles, but they will not dissipate due to diffraction effects. It is generally applied to repeating signals, such as sinusoidal waves. The amplitude of harmonic waves is proportional to the square root of the wavelength; so, they have a smaller wavelength than other types of wave. This makes them capable of overcoming obstacles more efficiently than a sound or electromagnetic wave could overcome at that same frequency.

The wave power potential can be estimated both in deep water and shallow water. Deep water was classified as where the depth of the water is greater than or equal to half the wavelength (Marine Energy — Wave, Tidal and Other Water Current Converters, 2019). However, shallow water is defined by kinematic properties of waves as where the water depth is less than a twentieth of the wave length (Marine Energy — Wave, Tidal and Other Water Current Converters, 2019).

The characteristics of the wave are primarily based on the wind conditions and the shape of the seabed. The frequency of wave energy flowed per unit of wave-crest length (wave power) can be calculated at a given depth of water using the given formula (Foteinis et al., 2017; Vögler & Morrison, 2013):

$$P = \rho g \; \frac{H^2_{m0}}{16} \tag{1}$$

where ρ is the density of sea water, g is the acceleration of gravity, H^2_{m0} is the significant wave height and c_g is the group velocity (i.e., the velocity at which wave energy spreads), which can be calculated using:.

$$Cg = \sqrt{gd} \tag{2}$$

where in equation (2), d is the depth of the area. Cg in equation (2) will be included in equation (1).

The energy is divided between kinetic energy and wave potential. To calculate the wave power in a specified region, the ranges of wave period and the height at which the wave power is the maximum should be considered. These conditions are the basis for WEC design (Zanous et al., 2019). All wave energy converter performance data was given in terms of H_{m0} because it was easily measured (Muzathik et al., 2010a).

4. RESULTS AND DISCUSSION

The Mandi Darah Island coast of Sabah was selected to provide insight into the appropriate location for the selection and installation of WEC systems. The six-hour values of significant wave height (H_{mo}), peak wave period (T_p) and wave power (P) within the period from June to December 2018 were analyzed for this area. The mean and the maximum wave heights are shown in Figure 5. It shows that the maximum wave heights in the study area were lower from June to October and higher from November to December. The influence of the northeast and the southwest monsoons is the explanation for these phenomena. During the monsoon season, more energy can be supplied to the study area due to more storms and winds to the coast. The monthly average wave height obtained varied from 0.07 m to 0.13 m; thus, the recorded data show most of the wave heights occurring within 0.05 m to 0.10 m.

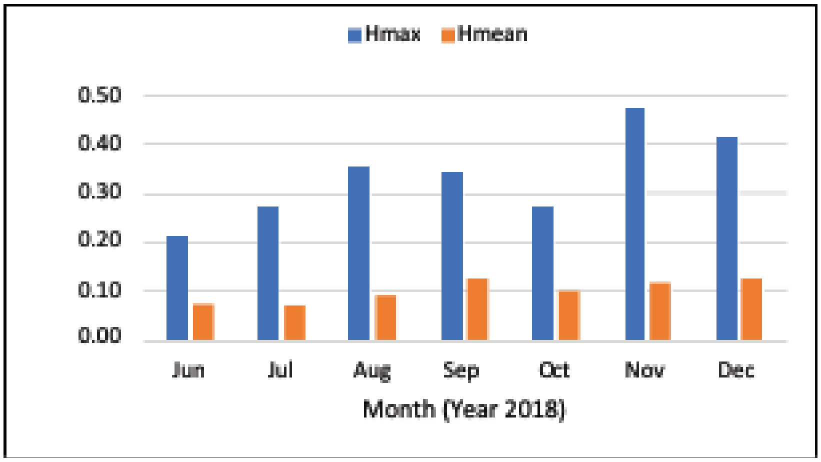


Figure 5.
The maximum wave height (H_{max}) and mean wave height (H_{mean}) recorded at Mandi Darah Island.

As shown in Figure 5, the maximum wave height recorded in Mandi Darah Island was 0.47 m. The data indicated that the wave height in the coastal area was relatively low compared to the wave height in the offshore area. The mean wave height was 0.10 m and the mean wave period was 1.97 s on Mandi Darah Island, Sabah, Malaysia.

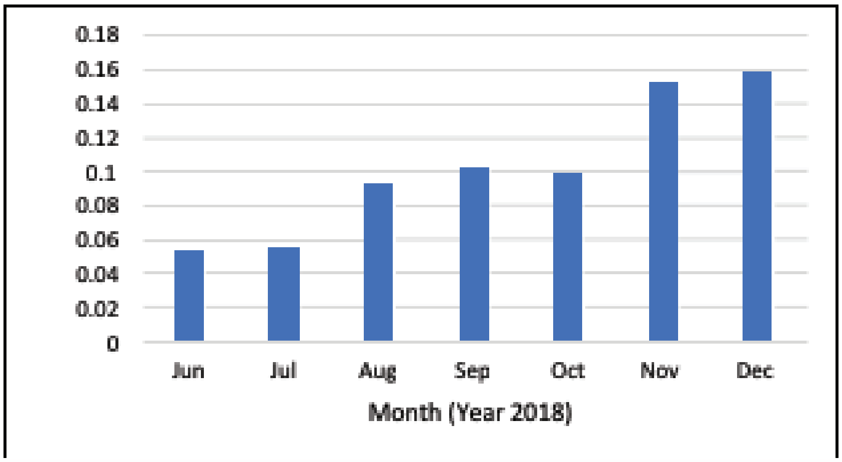


Figure 6.
Monthly average wave power (kW/m).

The study revealed that the annual average wave power was 0.11 kW/m. In the calculation of wave power on the Mandi Darah Island shore, for the average values of H_{m0} = 0.10 m and T_p = 1.97 s, one may consider it based on the available wave power. A bar graph has been plotted as in Figure 7 to better visualize the monthly variation of wave power potential. The monthly average wave power varied between 0.05 kW/m and 0.16 kW/m. It can also be noted that, in general, the average monthly wave power at the beginning of June and July was lower than at the end of the year.

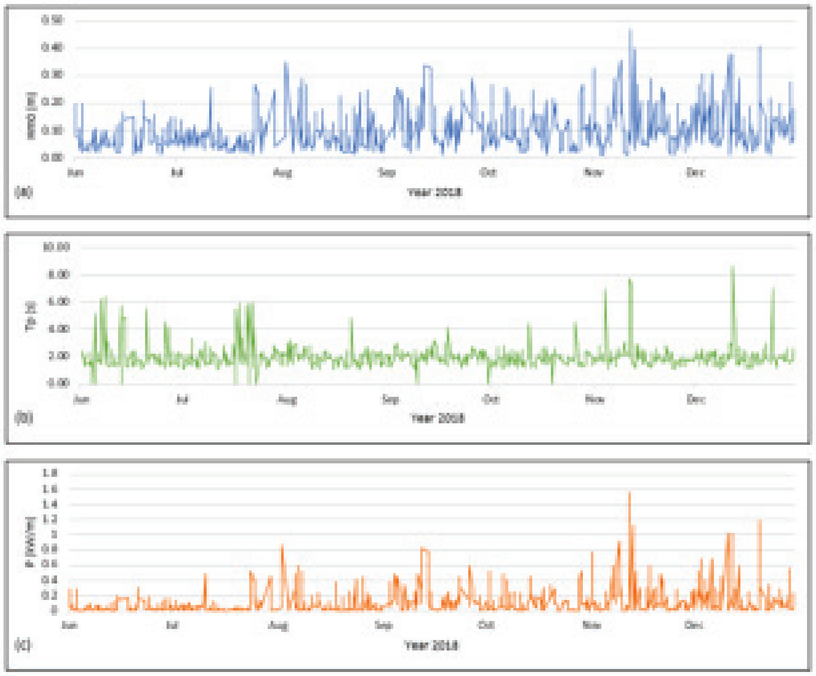


Figure 7.
Annual wave characteristics: (a) significant wave height (m), (b) peak period (s) and (c) wave power (kW/m).

The wave energy intensity differed seasonally, with the maximum energy density occurring during the northeast monsoon, with more storms and waves, while lower energy density occurred during the southwest monsoon. The annual wave characteristics of H_{m0}, T_p and wave power, which were calculated using Equation 1 are presented in Figure 8. It is clearly stated that Mandi Darah Island wave climates can be divided into three seasons: the first season covering the period from November to December; the second season covering the period from August to October; the third season covering the period from June to July. The third season presents the calm season in the study area which was from June to December 2018.

Figure 8 indicates that Mandi Darah Island had the most maximum values of H_{m0}, T_p and wave power during the NEM which was in November until December 2018. This is because wind from the NEM directly flowed through Mandi Darah Island from Sulu Sea. The wind speed during NEM was estimated achieve maximum value at 6.68 m/s. Wind data were obtained from MMD of NCEP Reanalysis.

The main directions of the wind during NEM were mostly coming from east. The wind speed for NEM accounts for more than 50% throughout the study period (Figure 9). However, during SWM in June to September period, Mandi Darah Island faced wind from the South China Sea and had low values of H_{m0}, T_p and wave power. This was related to the wind speed for SWM, which constitutes 25%. During SWM, the wind directions for the study period are from the West, followed by those from the Southwest (Figure 10).

The annual variation of wave characteristics is an essential parameter in WEC design. According to the wave conditions at Mandi Darah Island, the possibilities to utilize wave power to Mandi Darah Island shore was low because the wave height noted was lower than 0.5 m. It was lower than the requirement for the device to work (Najmuddin et al., 2021).

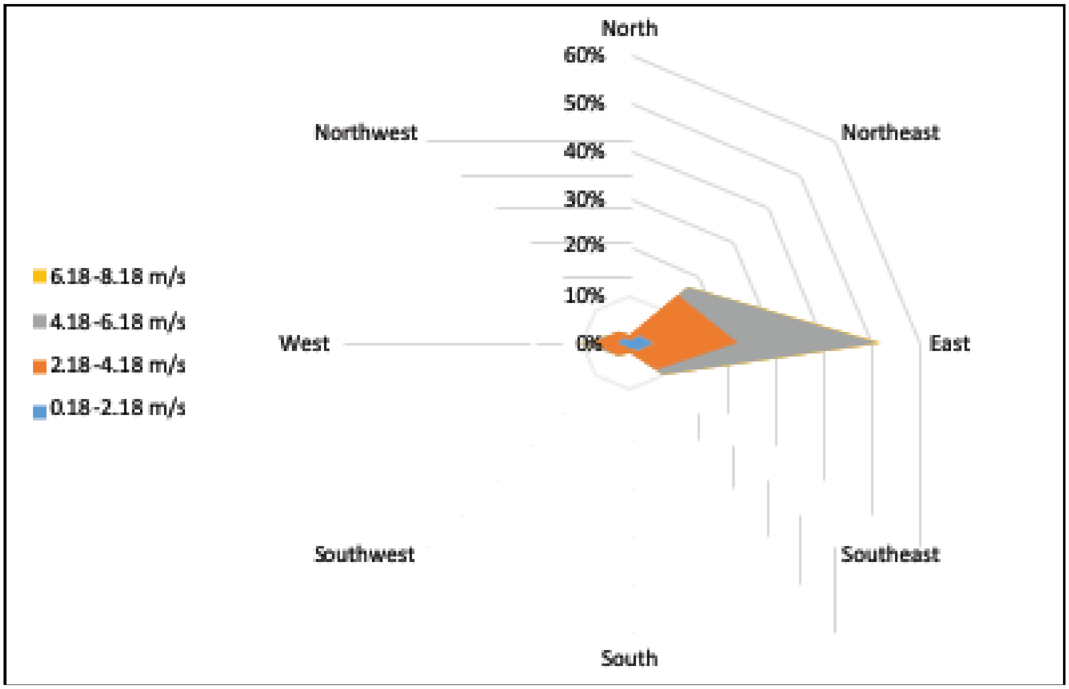


Figure 8.
Wind rose during NEM.

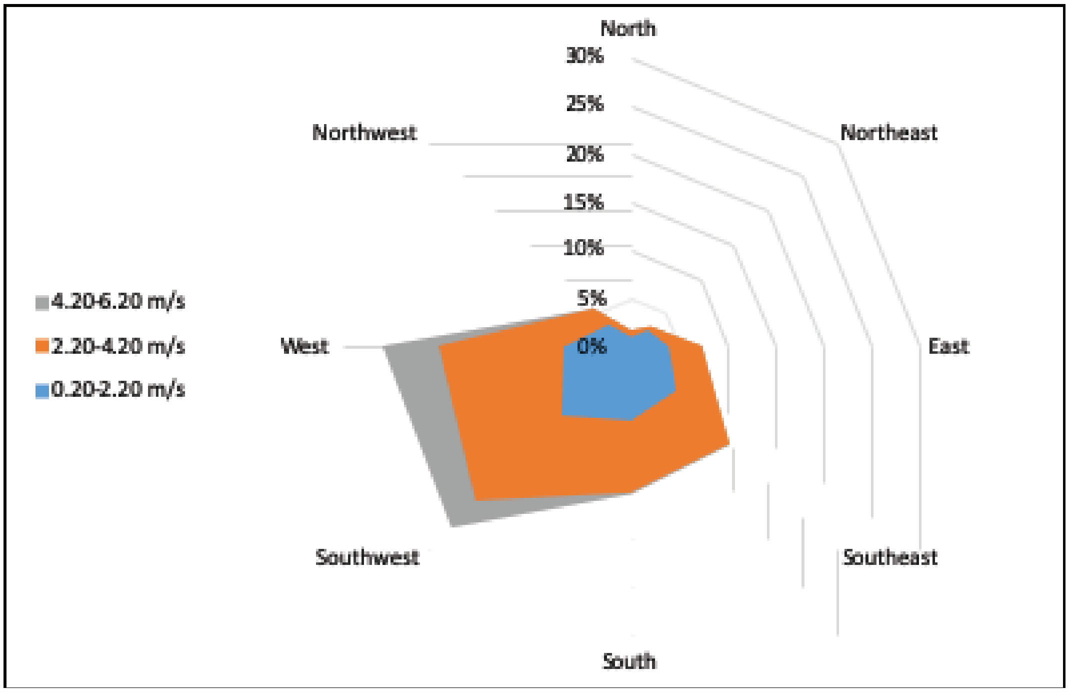


Figure 9.
Wind rose during SWM.

5. CONCLUSION

In conclusion, the study reviewed the wave characteristics of Mandi Darah Island. A wide range of parameters have to be tested and analyzed to determine the effects of the Northeast Monsoon (NEM) and the Southwest Monsoon (SWM) on the wave power along the coastal area of Mandi Darah Island. This study identified the monthly wave height and wave period data for 6 months, using the Acoustic Doppler Current Profiler (ADCP) equipment. All the data was thoroughly analyzed to estimate the highest probability wave height and wave period in the study area. The range of wave heights in the coastal waters surrounding Mandi Darah Island was found out to be 0.01 m to 0.47 m, and the wave periods ranging from 1.0 s to 8.60 s. It was found out that wave height and wave period during NEM was higher by 0.12 m and 2.17 s than that during the SWM. The maximum wave energy flow per unit of wave-crest length (wave power) at Mandi Darah Island was 1.57 kW/m throughout the period. During NEM, the wave power was significantly higher by 0.70 kW/m than the SWM. The wave power available was considered small and WEC cannot be fully utilized. Although the available energy was considered to be limited and cannot be completely exploited, special devices can be built in future using a relatively lower wave-height in Mandi Darah Island in order to convert the wave energy more effectively.

ACKNOWLEDGEMENT

We would like to thank Geohydrocean Services Sdn. Bhd. for providing with the ADCP wave measurements and for instruments deployment. The authors also wish to thank the Research and Innovation Centre, UPNM, for their financial support of this study through the Grant project (KeTTHA) Scientific Marine Research Group number UPNM/2018/AAIBE0KETTHA/TK/I/P2.

REFERENCES

Comprehensive Manual for ADCP., 2018. Available at: https://support.nortekgroup.com/hc/en-us/articles/360029839331-The-Comprehensive-Manual-ADCP.

Saleh, 2010. Wave Characteristics in Sabah Waters. American Journal of Environmental Sciences, 6(3), pp.219–223. Available at: http://dx.doi.org/10.3844/ajessp.2010.219.223.

Foteinis, S. et al., 2017. A comparative analysis of wave power in the nearshore by WAM estimates and in-situ (AWAC) measurements. The case study of Varkiza, Athens, Greece. Energy, 138, pp.500–508. Available at: http://dx.doi.org/10.1016/j.energy.2017.07.061.

Jaswar, J. et al., 2014. Estimation of Electrical-Wave Power in Merang Shore, Terengganu, Malaysia. Jurnal Teknologi, 66(2). Available at: http://dx.doi.org/10.11113/jt.v66.2476.

Kardooni, R. et al., 2018. Public opinion on renewable energy technologies and climate change in Peninsular Malaysia. Renewable Energy, 116, pp.659–668. Available at: http://dx.doi.org/10.1016/j.renene.2017.09.073.

López, I. & Iglesias, G., 2014. Efficiency of OWC wave energy converters: A virtual laboratory. Applied Ocean Research, 44, pp.63–70. Available at: http://dx.doi.org/10.1016/j.apor.2013.11.001.

Mirzaei, A., Tangang, F. & Juneng, L., 2014. Wave energy potential along the east coast of Peninsular Malaysia. Energy, 68, pp.722–734. Available at: http://dx.doi.org/10.1016/j.energy.2014.02.005.

Monaliza, M.D., & Samsur, M., 2011. Toxicity and toxin properties study of puffer fish collected from Sabah waters, Health and the Environment Journal, 2(1), pp. 14–17.

Muzathik, A.M., et al., 2010a. Wave energy potential of Peninsular Malaysia, ARPN Journal of Engineering & Applied Sciences, 5(7), pp. 11–23.

Muzathik, A.M., et al., 2010b. Ocean wave energy along Terengganu coast of Malaysia in The 2nd International Conference on Plant Equipment and Reliability (ICPER 2010) Proceedings, Kuala Lumpur, 15–17 June 2010, Universiti Teknologi Petronas, Malaysia.

Najmuddin, W.S.W.A. et al., 2020. Feasibility Study of Wave Energy Converter Using Compressed Air to Generate Electricity. Advances in Mechatronics, Manufacturing, and Mechanical Engineering, pp.147–153. Available at: http://dx.doi.org/10.1007/978-981-15-7309-5_15.

Neill, S.P. & Hashemi, M.R., 2013. Wave power variability over the northwest European shelf seas. Applied Energy, 106, pp.31–46. Available at: http://dx.doi.org/10.1016/j.apenergy.2013.01.026.

Rameswar, B., 1978. Dynamics of Marine Vehicles. John Wiley & Sons, Inc.

Samrat, N.H. et al., 2014. Prospect of wave energy in Malaysia. 2014 IEEE 8th International Power Engineering and Optimization Conference (PEOCO2014). Available at: http://dx.doi.org/10.1109/peoco.2014.6814412.

Silva, D. et al., 2015. High resolution local wave energy modelling in the Iberian Peninsula. Energy, 91, pp.1099–1112. Available at: http://dx.doi.org/10.1016/j.energy.2015.08.067.

Tan, W.C., Chan, K.W. & Ooi, H., 2017. Study of the potential of wave energy in Malaysia. Available at: http://dx.doi.org/10.1063/1.4993401.

Veigas, M., López, M. & Iglesias, G., 2014. Assessing the optimal location for a shoreline wave energy converter. Applied Energy, 132, pp.404–411. Available at: http://dx.doi.org/10.1016/j.apenergy.2014.07.067.

Vögler, A. & Morrison, J., 2013. Assessment of the grid capacity sharing potential for wave and wind energy conversion systems in the Outer Hebrides of Scotland in The European Wave and Tidal Energy Conference (EWTEC 2013), Aalborg, Denmark, 2–5 September 2013.

Yaakob, O. et al., 2016. Satellite-based wave data and wave energy resource assessment for South China Sea. Renewable Energy, 88, pp.359–371. Available at: http://dx.doi.org/10.1016/j.renene.2015.11.039.

Yaakob, O., Tengku Ab Rashid, T.M.A. & Mukti, M.A.A., 2006. Prospects for ocean energy in Malaysia in International Conference on Energy and Environment 2006 (ICEE 2006). Bangi, Malaysia, 28–30 August 2006, pp. 62–68.

Zanous, S.P. et al., 2019. Feasibility study of wave energy harvesting along the southern coast and islands of Iran. Renewable Energy, 135, pp.502–514. Available at: http://dx.doi.org/10.1016/j.renene.2018.12.027.

Optimum Welding Parameters for Friction Stir Welded AA6063 Pipe Butt Joint Using the Taguchi Method

Azman Ismail, Fatin Nur Zulkipli, Mokhtar Awang, Fauziah Ab Rahman, Puteri Zarina Megat Khalid, Bakhtiar Ariff Baharudin

Welding parameters for pipe joint friction stir welding (FSW) have been identified based on L-9 orthogonal arrays used in the Taguchi Method. Different welding parameters, such as rotation speed, travel speed and axial force, have been used to produce several quality friction stir welded AA6063 pipe butt joints. The reliability of products obtained in the FSW process can be improved through the identification of the optimum combination of welding parameters. Weld quality was evaluated based on its tensile strength and residual stress profiles. The S/N analysis and Analysis of Variance (ANOVA) have been used to determine significant welding parameters that affect weld quality. Maximum tensile strength with acceptable residual stress was obtained at the optimum welding parameters of 1300 rpm, 5 mm/s and axial force between 5 and 6 kN. The goal of this study was to optimize welding parameters for high tensile strength and low residual stress.

KEY WORDS

~ Optimum welding parameters
~ Tensile strength
~ Residual stress
~ Aluminum pipe
~ Butt joint

Universiti Kuala Lumpur Malaysian Institute of Marine Engineering Technology, Malaysia

e-mail: azman@unikl.edu.my

doi: 10.7225/toms.v10.n02.011

Received on: 28.06.2021/ Revised on: 25.09.2021/ Accepted on: 30.09.2021/ Published: 21.10.2021

1. INTRODUCTION

Friction stir welding (FSW) can be used to cater for various sectors, such as aerospace, shipbuilding, automobile, marine and petro-chemical industries (Kohak & Navthar, 2017). FSW is used in flat panel and pipe joining facilities. FSW is used to join two pieces together in a single run, soundly and without melting. During the FSW process, the material is plasticized by the stirring action of a high rotating tool and the joint is created through the plastic deformation of the material. This high rotating tool moves along the length of the weld, allowing the two pipes to be joined. The tool can rotate in two opposite directions, which are called the Advancing Side (AS), and the Retreading Side (RS). Tool rotation and weld directions are identical. This solid-state joining process is specifically used to weld the pieces that cannot be welded in the conventional way. There are many different types of FSW machines, including robots developed to cater to this purpose. However, FSW can still be performed by a normal CNC milling machine when welding small pieces. FSW joints have special characteristics, can have improved mechanical properties and be free from weld defects. The most significant process parameters that affect joint characteristics can be easily understood by studying the physical process in an experimental setting using the Taguchi method (Prasad & Namala, 2017). They may include very low distortion, no fume production, no filler metals, no special surface treatment and no shielding gas (Verma & Misra, 2017). During the FSW process, the stirred materials grow soft before reaching their melting point. Weld quality is dependent upon certain major welding parameters (Elanchezhian et al., 2014). Tool rotation speed, welding speed and axial force are critical, particularly when it comes to adjusting welding temperature to obtain better joining results. However, reverse conditions, such as low welding temperature, may create an insufficiently stirred interface, decrease tensile strength and increase residual stress. The low heat input in this welding technique helps avoid the degradation of the material and maintain high strength. The process can be carried out using a single pass method regardless of the thickness of the specimen involved (Senthil et al, 2020). The basic principle of the FSW process is shown in Figure 1 (Verma & Misra, 2017). The main objective of this research is to determine the parameters that have the greatest effect on experimental output and predict the optimum combination of welding parameters that would yield the best mechanical properties with the highest tensile strength and lowest residual stress of friction stir welded pipe butt joints. Taking the research a step further, the Taguchi method was applied that uses an orthogonal array to determine the effect of parameters on quality outputs in a minimal number of experimental trials and obtain reliable results. The use of Taguchi's dynamic experiment approach to develop a robust process design with multiple quality outputs was justifiable (Siva Rama Krishna, 2016).

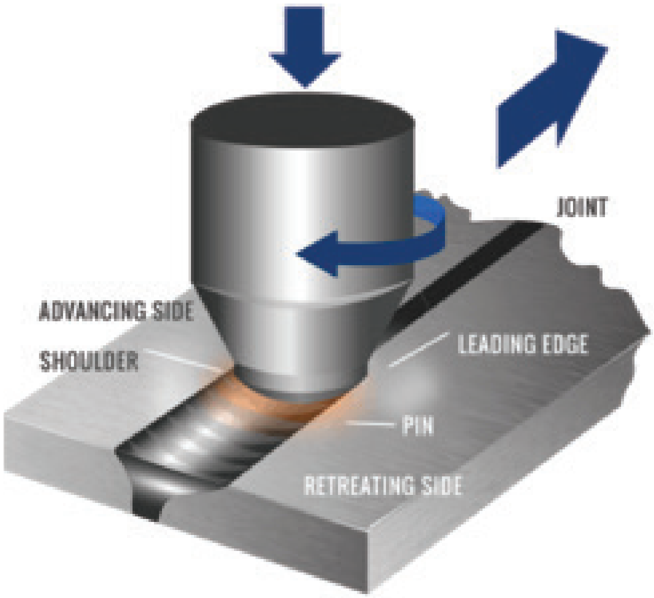


Figure 1.
The basic principle of the FSW process.

2. MATERIALS AND METHOD

The materials studied were AA6063 pipe structures. This aluminum pipe has the outside diameter of 89 mm, the length of 100 mm and wall thickness of 5 mm. The pipe joining setup for this experiment is shown in Figure 2. A configuration different than in the flat panel setup was used. Therefore, a customized jig was required. A cylindrically-shaped pin tool was used in the experimental setting, with the tool offset from the centerline by approx. 6 mm (Lammlein et al, 2011). The pipe was joined by FSW with various welding parameters as shown in Table 1. The welding parameters used in this study were tool rotation speed, travel speed, and axial force. Dwell time and plunge depth were set at 25 s and 4 mm, respectively, for all pipe specimens.

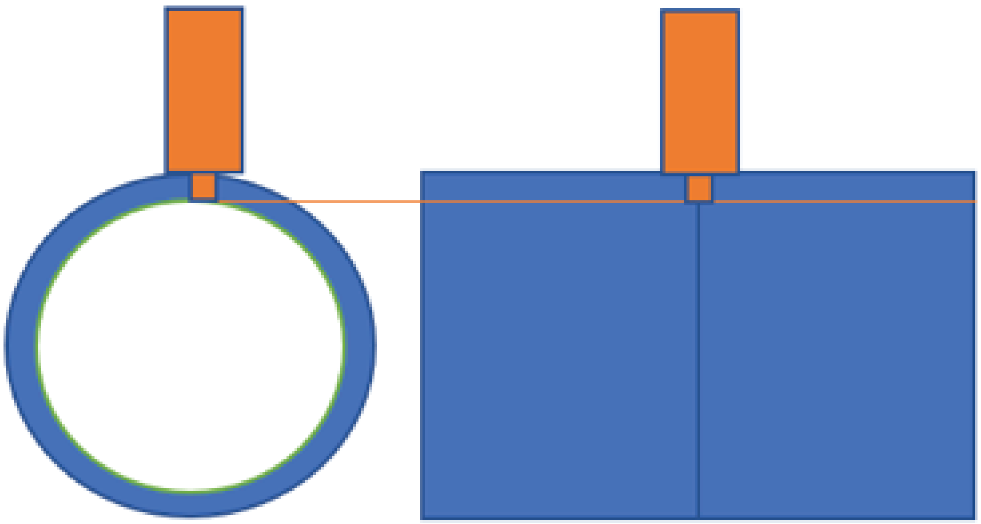


Figure 2.
Butt joint configuration for pipe joining.

Table 1.
Welding parameters.

Symbol	Parameter	Level 1	Level 2	Level 3
N	Tool rotation (RPM)	1000	1300	1600
S	Travel speed (mm/s)	3	4	5
F	Axial force (kN)	5	6	7

A cylindrical tool made from H13 high carbon steel, with the shoulder diameter of 25 mm, pin diameter of 5mm and pin length of 4 mm was used. The tool schematic is shown in Figure 3, and the arrangement of the equipment and pipe specimen in Figure 4.

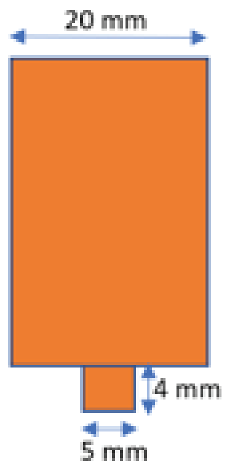


Figure 3.
FSW tool schematic.

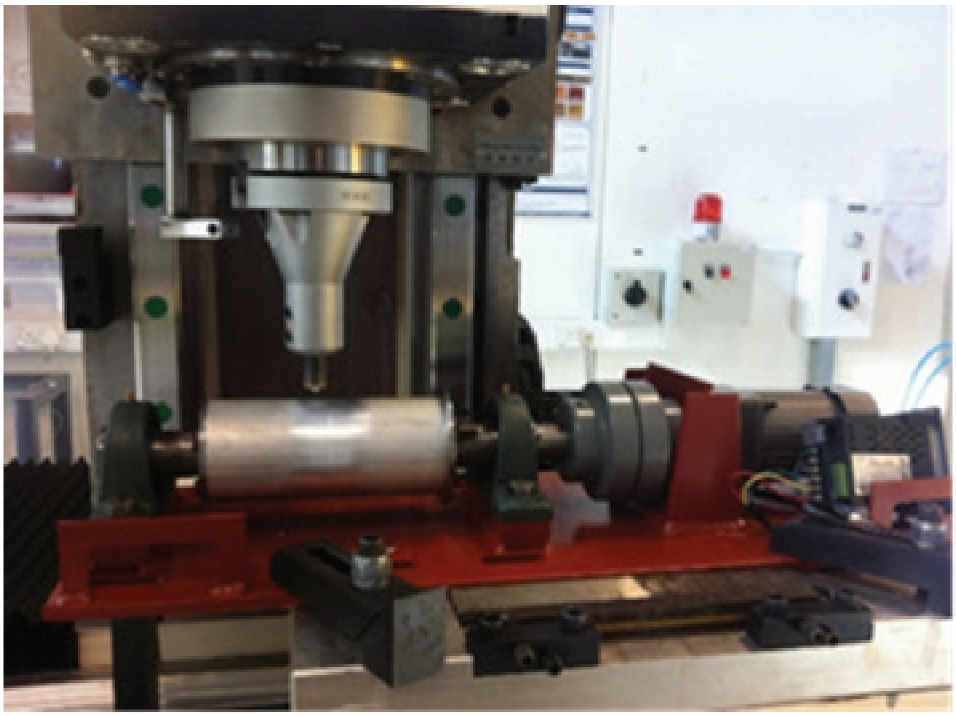


Figure 4.
Experimental setup.

Taguchi devised a new method for developing experiments based on well-defined guidelines to reduce the number of experiments and obtain reliable outputs based on a proven concept (Dhanesh et al, 2021). The method uses a special set of arrays called orthogonal arrays. These standard arrays help pinpoint the manner in which to conduct the minimum number of experiments capable of providing complete information on all factors that affect performance parameters. Therefore, Taguchi L9 orthogonal array was used to reduce the number of experiments and still obtain reliable results. Nine experimental runs were conducted using the Taguchi L9 orthogonal array, as shown in Table 2. All nine good friction stir welded pipe specimens have been successfully prepared, with the joining process output sample shown in Figure 5.

Table 2.
L-9 orthogonal array model.

Specimen No. (S. No.)	Rotational Speed, N (RPM)	Travel Speed, S (mm/s)	Axial Force, F (kN)
1	1000	3	5
2	1000	4	6
3	1000	5	7
4	1300	3	6
5	1300	4	7
6	1300	5	5
7	1600	3	7
8	1600	4	6
9	1600	5	5

Figure 5.
Friction stir welded pipe joint.

In this study, the analysis of variance (ANOVA) was used to determine the effect of significant parameters on the performance of friction stir welded AA6063 pipe specimen (Siva Rama Krishna R, 2016). Tensile strength and residual stress of the friction stir welded pipe specimen were response variables. Rotation speed, travel speed and axial force were selected as control variables. The experiments were based on the rank order obtained through the Taguchi method, and the results using the 50 kN Universal Testing Machine Amsler HA50 for tensile strength and PANalytical EMPYREAN Multi-function X-Ray Diffractometer (XRD) for residual stress. Experimental data were analysed in Minitab 19.

This analysis was evaluated for a 95% confidence level, with the significance level α equal to 0.05 (Pradeep et al, 2013). Experimental results were transformed into a Signal to Noise (S/N) ratio. The S/N ratio was defined as the ratio of the mean of the signal and the standard deviation of the noise. The S/N ratio indicates the degree of the predictable performance of a process in the presence of noise factors. The S/N ratio was calculated using "the bigger the better" method to determine the optimum tensile strength and "the smaller the better" method to determine the optimum residual stress. The control parameter with the strongest influence was identified using the difference between the maximum and minimum values of the mean of S/N ratios. The greater the difference between the mean of S/N ratios, the greater the influence of the control parameter.

3. RESULTS AND DISCUSSION

The tensile strength average for each pipe joint specimen and residual stress at the midpoint of each pipe joint specimen are shown in Table 3.

Table 3.
The experimental results.

S.No.	N (RPM)	S (mm/s)	F (kN)	Tensile (MPa)	Residual stress (MPa)
1	1000	3	5	158.66	-0.287
2	1000	4	6	162.14	-0.413
3	1000	5	7	166.47	-0.376
4	1300	3	6	158.14	-0.214
5	1300	4	7	163.65	-0.381
6	1300	5	5	170.52	-0.235

7	1600	3	7	160.91	-0.622
8	1600	4	6	162.87	-0.303
9	1600	5	5	161.69	-0.193

3.1. Tensile Strength

Tensile strength is the maximum strength that a material can withstand without breaking when exposed to external loads. The highest tensile strength is indicative of a material's good mechanical properties (Arora et al, 2019). Therefore, the bigger, the better method was used to calculate the S/N ratio and obtain optimum welding parameters for better tensile strength. The calculated values of tensile strength S/N ratios are shown in Table 4.

Analysis of Variance (ANOVA) is a statistical method used to discuss the relative importance of the overall control factor. It can also be used to identify the contribution of each parameter. The F-test proposed by Fisher was used as an auxiliary tool of inspection (Verma, 2019). Thus, the higher the F-test value, the more dominant the parameters (Singarapu et al., 2015). Table 5 shows the ANOVA table of pipe joint specimen tensile strength.

Table 4.
Tensile strength S/N ratio.

S.No.	N (RPM)	S (mm/s)	F (kN)	Tensile (MPa)	S/N ratio
1	1000	3	5	158.66	44.0096
2	1000	4	6	162.14	44.1976
3	1000	5	7	166.47	44.4265
4	1300	3	6	158.14	43.9806
5	1300	4	7	163.65	44.2782
6	1300	5	5	170.52	44.6356
7	1600	3	7	160.91	44.1314
8	1600	4	6	162.87	44.2369
9	1600	5	5	161.69	44.1739

Table 5.
ANOVA tensile strength table.

Factor	DoF (f)	Sum of Square (SS)	Mean of squares	F-value	P-value	Variance (V)	%
N	2	8.367	4.183	0.536346	0.650915	0.268173	7.10
S	2	73.38	36.691	4.703846	0.175322	2.351923	62.24
F	2	20.55	10.27	1.317308	0.431537	0.658654	17.43
Error	2	15.6	7.8				13.23
Total	8	117.897					100.00

Table 5 clearly shows that the combined effect of tool rotation speed and axial force is much lower than the effect of travel speed that was proven to be major - 62.24%. The detailed percentages of the effect of the S/N ratio of each parameter are indicated in Table 6. Similar travel speed, accounting for 62.75%, was identified as the main factor affecting tensile strength.

Optimum welding parameters can be identified using the response table shown in Table 7, while the main effect plot can be seen in Figure 6.

Table 6.
Effect of tensile strength S/N ratio in percentages.

Factor	DoF	Average S/N			Sum of squares	Mean square	%
		L1	L2	L3			
N	2	44.2112	44.2981	44.1807	0.02226	0.01113	6.74
S	2	44.0405	44.2376	44.4120	0.2072	0.10362	62.75
F	2	44.2940	44.1174	44.2787	0.05749	0.02874	17.41
Error	2				0.04324	0.02162	13.10
Total	8				0.33019		100.00

Table 7.
Tensile strength response table (Control factor: the bigger, the better).

Level	Rotational speed, N	Travel speed, S	Axial Force, F
1	44.21	44.04	44.29
2	44.30	44.24	44.12
3	44.18	44.41	44.28
Delta	0.12	0.37	0.18
Rank	3	1	2

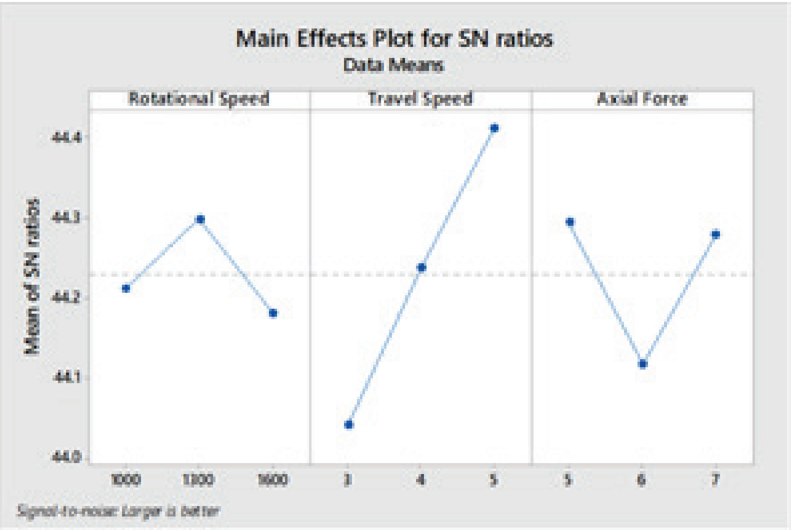


Figure 6.
Main effect plot for tensile strength S/N ratio.

Table 7 and Figure 6 show that the optimum welding conditions for high tensile strength are tool rotation speed of 1300 rpm, travel speed of 5 mm/s and axial force of 5 kN. These optimum parameters can be summarized as in Table 8.

Table 8.
Optimum parameters and levels (based on the highest response).

Factors	Level description	Level
Rotational speed, N	1300	2
Travel speed, S	5	3
Axial force, F	5	1

3.2. Residual Stress

Residual stress is the stress remaining in a body after all applied stresses have been removed (Xu et al, 2014). In combination with applied stress, it can cause failure at an unusually low level (Rajakumar et al., 2011). Therefore, residual stress must be kept as low as possible to prevent premature failure and maintain structural integrity. The smaller, the better method was used to calculate the residual stress S/N ratio. Then, the value of the residual stress S/N ratio was calculated and is indicated in Table 9. In this study, the ANOVA was used to identify the effect of each parameter and the results are shown in Table 10.

Table 9.
Residual stress S/N ratio (Mode*: C- compression mode).

S.No	Rotation speed, N (RPM)	Travel speed, S (mm/s)	Axial force, F (kN)	Residual stress (MPa)	Mode*	S/N ratio (dB)
1	1000	3	5	0.287	C	10.8301
2	1000	4	6	0.413	C	7.6848
3	1000	5	7	0.376	C	8.4907
4	1300	3	6	0.214	C	13.3817
5	1300	4	7	0.381	C	8.3709
6	1300	5	5	0.235	C	12.5731
7	1600	3	7	0.622	C	4.1264
8	1600	4	5	0.303	C	10.3688
9	1600	5	6	0.193	C	14.2733

Table 10.
ANOVA table for residual stress.

Factor	DoF (f)	Sum of square (SS)	Mean of squares	F-value	P-value	Variance (V)	%
N	2	0.01607	0.008037	0.468513	0.680967	0.008035	11.47
S	2	0.02088	0.01044	0.608746	0.62162	0.00522	14.91
F	2	0.06883	0.03442	2.0067	0.332591	0.0034415	49.14
Error	2	0.0343	0.01715				24.49
Total	8	0.14008					100.00

Table 10 shows that the combined effect of tool rotation speed and welding speed is much lower than the effect of axial force (Singarapu et al., 2015). Axial force has a major effect - 49.14%. The percentage of S/N ratio contribution for each parameter can be seen in Table 11, which also confirmed axial force as the main residual stress affecting factor with the share of 50.43%.

The optimum welding parameters can be identified using the response table shown in Table 12 and the main effect plot depicted in Figure 7.

Table 11.
Percentage of S/N ratio contribution of residual stress.

Factor	DoF	Average S/N			Sum of squares	Mean square	%
		L1	L2	L3			
N	2	9.0019	11.4419	9.5895	9.730	4.865	11.88
S	2	9.4461	8.8082	11.7790	14.68	7.338	17.92
F	2	11.2573	11.7799	6.9960	41.32	20.659	50.43
Error	2				16.203	8.1015	19.78
Total	8				81.933		100.00

Table 12.
Response table for residual stress (Control factor: small is better).

Level	Rotation speed, N	Travel speed, S	Axial Force, F
1	9.002	9.446	11.257
2	**11.442**	8.808	**11.780**
3	9.589	**11.779**	6.996
Delta	2.440	2.971	4.784
Rank	3	2	1

Table 12 and Figure 7 show that the optimum welding conditions for low residual stress are tool rotation speed of 1300 rpm, travel speed of 5 mm/s and axial force of 6 kN. These optimum parameters can be summarized as in Table 13.

Table 13.
Optimum parameters and levels (based on the highest response).

Factors	Level description	Level
Rotation speed, N	1300	2
Travel speed, S	5	3
Axial force, F	6	2

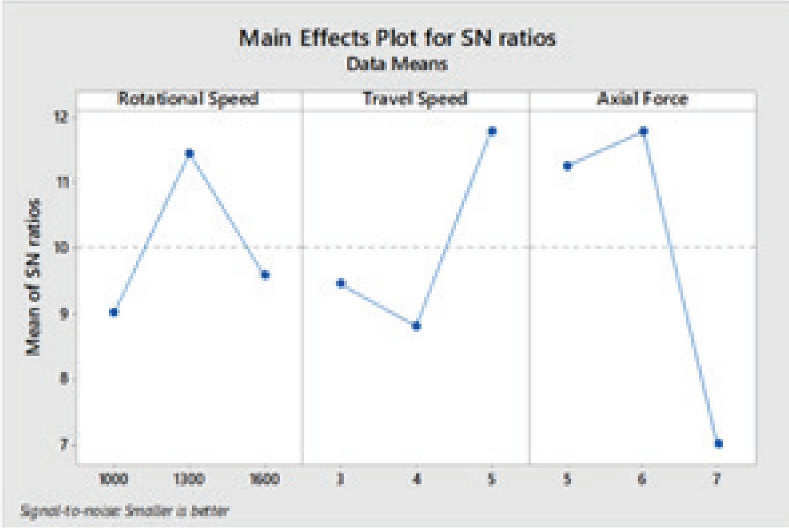
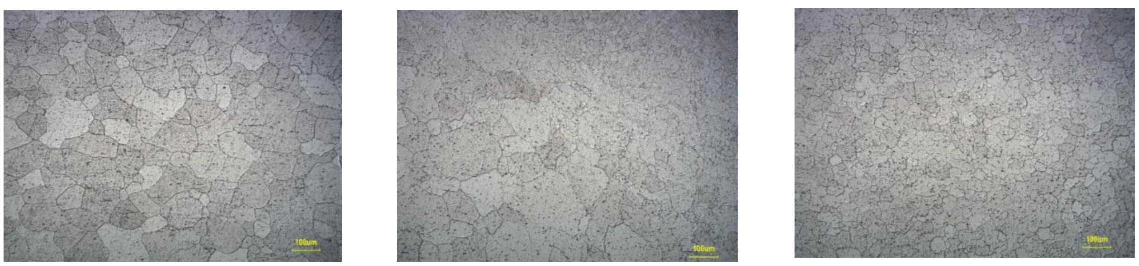


Figure 7.
Main effects plot for residual stress S/N ratio.

3.3. Microstructure Comparison

In spite of the different inputs used, such as tensile strength and residual stress, the calculations yielded quite similar welding parameters of the rotation speed of 1300 rpm, travel speed of 5 mm/s and axial force of 5-6 kN. The microstructure for this parameter is shown in Figure 8 (Ismail et al, 2020).

In Figure 8, microstructural images show uniform grain structure across the zones regardless of their size, with a finer grain structure in the WNZ. According to the Hall–Petch equation, the yield strength of the alloy increases with the decrease in grain size (Li, Bushby and Dunstan, 2016). Grain sizes were smaller than that of the base metal. That was the reason why the majority of the fractures occurred in the base metal region during the tensile test. Finer grain structure generated low residual stress in the friction stir welded zone (Ismail et al., 2021). Grain refinement can be attributed to the sufficient amount of friction heat generated under the selected welding parameters. These grain structures improved mechanical properties and residual stress characteristics confirmed by the findings.



a) b) c)

Figure 8.
Microstructural evolution under the stated welding parameters (a) Heat affected zone (HAZ), b) Thermo-mechanically affected zone (TMAZ), c) Weld nugget zone (WNZ).

4. CONCLUSION

The Taguchi method was successfully utilized to identify the optimum welding parameters for friction stir welded AA6063 pipe butt joints. Based on different tensile strength and residual stress inputs, the optimum welding parameters were found to be the rotation speed of 1300 rpm, travel speed of 5 mm/s and axial force of 5-6 kN. Factors with the greatest effect on tensile strength and residual stress are travel speed and axial force, respectively. These two parameters need to be closely monitored when friction stir welding pipe butt joints.

ACKNOWLEDGEMENT

The Short-Term Research Grant (STR20012) provided by the Universiti Kuala Lumpur was greatly appreciated.

REFERENCES

Dhanesh, G. M. and Gopi, S., 2021. Optimized Parameters Prediction for Single-Pass Friction Stir Welding on Dissimilar Aluminium Alloys T- Joint, International Journal on Emerging Technologies, 12(2), pp. 22-27.

Elanchezhian, C. et al., 2014. Parameter Optimization of Friction Stir Welding Of AA8011-6062 Using Mathematical Method. Procedia Engineering, 97, pp.775–782. Available at: http://dx.doi.org/10.1016/j.proeng.2014.12.308.

Arora, H., Singh, R. & Brar, G.S., 2019. Thermal and structural modelling of arc welding processes: A literature review. Measurement and Control, 52(7-8), pp.955–969. Available at: http://dx.doi.org/10.1177/0020294019857747.

Ismail, A. et al., 2019. The Effects of Welding Parameters on Macro and Micro-Structure of Friction Stir Welded Aluminium. IOP Conference Series: Materials Science and Engineering, 536(1), p.012014. Available at: http://dx.doi.org/10.1088/1757-899x/536/1/012014.

Ismail, A. et al., 2021. Residual stress analysis of friction stir welded AA6063 pipe butt joint by neutron diffraction technique of ENGIN-X. IOP Conference Series: Materials Science and Engineering, 1045(1), p.012007. Available at: http://dx.doi.org/10.1088/1757-899x/1045/1/012007.

Xu, J. et al., 2014. Residual Stress Analyses in a Pipe Welding Simulation: 3D Pipe Versus Axi-symmetric Models. Procedia Materials Science, 3, pp.511–516. Available at: http://dx.doi.org/10.1016/j.mspro.2014.06.085.

Lammlein, D.H. et al., 2011. The friction stir welding of small-diameter pipe: an experimental and numerical proof of concept for automation and manufacturing. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 226(3), pp.383–398. Available at: http://dx.doi.org/10.1177/0954405411402767.

Li, Y., Bushby, A.J. & Dunstan, D.J., 2016. The Hall–Petch effect as a manifestation of the general size effect. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 472(2190), p.20150890. Available at: http://dx.doi.org/10.1098/rspa.2015.0890.

Pradeep, A. & Muthukumaran, S., 2018. An analysis to optimize the process parameters of friction stir welded low alloy steel plates. International Journal of Engineering, Science and Technology, 5(3), pp.25–35. Available at: http://dx.doi.org/10.4314/ijest.v5i3.3.

Prasad, M.V.R.D. & kumar Namala, K., 2018. Process Parameters Optimization in Friction Stir Welding by ANOVA. Materials Today: Proceedings, 5(2), pp.4824–4831. Available at: http://dx.doi.org/10.1016/j.matpr.2017.12.057.

Praveen, G. K., & Navthar, R. R., 2017. Optimization of Process parameters of Friction Stir Welding for Similar HE-30 Aluminium Alloy. International Research Journal of Engineering and Technology (IRJET), 4(7), pp.1040–1048. Available at: https://irjet.net/archives/V4/i7/IRJET-V4I7238.pdf.

Rajakumar, S., Muralidharan, C. & Balasubramanian, V., 2011. Statistical analysis to predict grain size and hardness of the weld nugget of friction-stir-welded AA6061-T6 aluminium alloy joints. The International Journal of Advanced Manufacturing Technology, 57(1-4), pp.151–165. Available at: http://dx.doi.org/10.1007/s00170-011-3279-5.

Singarapu, U., Adepu, K. & Arumalle, S.R., 2015. Influence of tool material and rotational speed on mechanical properties of friction stir welded AZ31B magnesium alloy. Journal of Magnesium and Alloys, 3(4), pp.335–344. Available at: http://dx.doi.org/10.1016/j.jma.2015.10.001.

Siva Rama Krishna, P. K. T., 2016. Optimization of Process Parameters of Friction Stirs Welding of Aluminum Alloys (6061) Using Taguchi Method. International Journal of Science and Research (IJSR), 5(3), pp.1988–1994. Available at: http://dx.doi.org/10.21275/v5i3.nov162391.

Senthil, S.M. et al., 2020. A multi-objective optimization of the friction stir welding process using RSM-based-desirability function approach for joining aluminum alloy 6063-T6 pipes. Structural and Multidisciplinary Optimization, 62(3), pp.1117–1133. Available at: http://dx.doi.org/10.1007/s00158-020-02542-2.

Verma, S., Misra, J.P. & Gupta, M., 2019. Study of Temperature Distribution and Parametric Optimization during FSW of AA6082 Using Statistical Approaches. SAE International Journal of Materials and Manufacturing, 12(1), pp.73–82. Available at: http://dx.doi.org/10.4271/05-12-01-0005.

Verma, S. & Misra, J.P., 2015. A Critical Review of Friction Stir Welding Process. DAAAM International Scientific Book, pp.249–266. Available at: http://dx.doi.org/10.2507/daaam.scibook.2015.22.

Investigation of Numerical Hydrodynamic Performance of Deformable Hydrofoil (Applied on Blade Propeller)

Noh Zainal Abidin[a], Cédric Leblond[b], Mohd Najib Abdul Ghani Yolhamid[a], Mohamad Abu Ubaidah Amir Abu Zarim[a], Farizha Ibrahim[a], Ameer Suhel[a]

The hydrofoil is a hydro-lifting surface that significantly contributes to marine transportation such as a boat, ship, and submarine for its movement and maneuverability. The existing hydrofoils are in fixed-shaped National Advisory Committee for Aeronautics (NACA) profiles, depending merely on the variation of Angle of Attack (AOA) such as rudder, hydroplane, and propeller blade. This research is concerned with the deformable hydrofoil that aims at modifying its NACA profile rather than its AOA. However, there is still a lack of knowledge about designing an appropriate deformable hydrofoil. Therefore, a numerical investigation of hydrodynamic characteristics for selected hydrofoils was conducted. After undergoing the 2D numerical analysis (potential flow method) at specific conditions, several NACA profiles were chosen based on the performance of NACA profiles. NACA 0017 was selected as the initial shape for this research before it deformed to the optimized NACA profiles, NACA 6417, 8417, and 9517. The 3D CFD simulations using the finite volume method to obtain hydrodynamic characteristics at 0 deg AOA with a constant flow rate. The mesh sensitivity and convergence study are carried out to get consistent, validated, and reliable results. The final CFD modeled for propeller VP 1304 for open water test numerically. The results found that the performance of symmetry hydrofoil NACA 0017 at maximum AOA is not the highest compared to the other deformed NACA profiles at 0 deg AOA. The numerical open water test showed that the error obtained on K.T., K.Q., and efficiency is less than 8% compared to the experimental results. It shows that the results were in good agreement, and the numerical CFD setting can be used for different deformed profiles in the future.

KEY WORDS
~ CFD
~ NACA
~ Numerical analysis
~ Hydrodynamic
~ Potential flow
~ Finite volume

a. Universiti Pertahanan Nasional Malaysia, Kuala Lumpur, Malaysia
e-mail: noh@upnm.edu.my
b. Naval Group/Ecole Centrale de Nantes, France
e-mail: cedric.leblond@naval-group.com

doi: 10.7225/toms.v10.n02.012

Received on: 28.06.2021/ Revised on: 16.08.2021/ Accepted on: 14.09.2021/ Published: 21.10.2021

1. INTRODUCTION

Hydrodynamic effects are the fluid interaction with the moving bodies, which is the backbone of designing the hydrofoil for marine vehicles such as ships (L.Birk, 2019). Commonly, the vessel has a rudder, propeller, and fin stabilizer that apply the advantages of hydrodynamic effects on itself. The airfoil design and analysis were carried out to increase lift characteristics and decrease drag characteristics as much as possible. In general, when the fluid strikes the airfoil, it results in two components of forces: one in the perpendicular direction and the other in the horizontal direction.

The vertical force represents the lifting force, while the horizontal force represents a drag force. Lift is caused by a pressure difference between the upper and lower surfaces. It is different from drag caused by pressure distribution at the leading and trailing edge (pressure drag), and viscous resistance occurred at the wall surface of the airfoil (viscous or friction drag) (Sun, Mao and Fan, 2020). Concerning this hydrodynamic potential, the deformable hydrofoil design should have the features to change the original foil's shape into the different NACA profiles. The concept can also be beneficial for other applications: dive bars of submarines and propeller blades. For instance, the ability to deform a propeller blade to maintain optimal propulsive performance for different speeds is technically fascinating.

Thus, the best possible design is formulated based on the application required. It is essential to have an accurate and trustworthy estimation of the hydrofoil performance at the design stage. Here, the CFD analysis is used to estimate the fundamental hydrodynamic characteristic, including drag, lifting, pressure distribution, vortices, and velocity profile. The disadvantages are the modeling errors occurring due to the simplified flow physics. Thus, the CFD results need to be compared with the experimental results for validation (Seo et al., 2013).

1.1. What is Hydrofoil?

The development of marine knowledge in ship design and construction, one of the valuable inventions in the shipping industry, is the hydrofoil. Generally, a hydrofoil is a lifting surface like a foil but operated in the water (submerged) to create lift when mounted at the hull of a boat or ship. In the shipping industry, hydrofoils are mainly used for rudder, fin stabilizer, and propeller (Mahmud, 2015), while for the propeller, the blade itself uses the concept of hydrofoil to create lift, and the resultant force will generate thrust when rotating the blade (IV, 2012).

1.2. Deformable Hydrofoil

The deformable hydrofoil is defined as the airfoil with a specific shape NACA that can modify the shape to change to the other NACA profile to enhance the hydrodynamic features for its use. Some studies are made by installing the mechanical actuator on the structure inside of hydrofoil to change and control the relative thickness, camber, and position. Figure 1 represents an example view of the deformable shape from one shape of NACA to another shape.

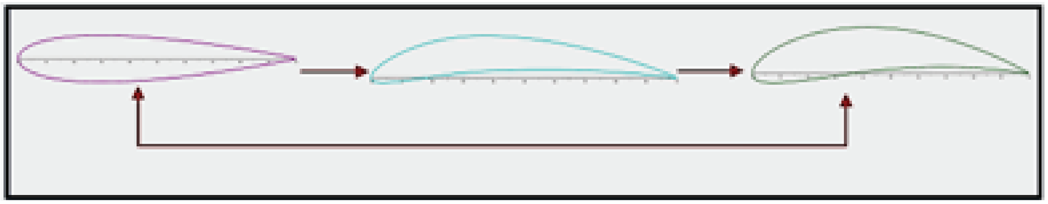


Figure 1.
The flow of foil deformation.

Previous researchers conducted various experiments and numerical analyses to determine the hydrodynamic performance on 2D and 3D hydrofoils at various physics conditions. According to the invention made by Lucio Flavio, Campanile explains that the shape and construction of the deformable airfoil towards the enhancement of the existing fixed hydrofoil. The operating mechanism depended on the stiffening struts inside the airfoil is not rigid, whereas it can permit deformation on the ribs that lead to the deformable outer skin. By changes the angles of inclination between the struts able to control the camber shape of the airfoil (Campanile and Hanselka, 2000).

One of the studies conducted in 2011 towards the ability of the fish to manipulate its hydrodynamic forces. The hydrodynamic forces being controlled through the active modulation of the fin's kinematics and mechanical properties. The fin's fish is illustrated as a deformable foil shape that can deform to the other NACA shape to manipulate the hydrodynamic forces for its benefit. This phenomenon is clearly explained precisely in the experiment made by (Tangorra et al., 2011). As a result, the forces' magnitudes depend on the fin's stiffness and the direction of forces. Therefore, the variation in magnitude of the thrust, lift, and others components occur. Future research needs to be carried out in the natural biology environment to obtain an accurate hydrodynamic force in actual conditions.

In 2016, a study was carried out by T.L Grigorie regarding the design, numerical simulation, and experimental testing on the control system for self-adapting morphing model in order to improve the laminar flow over the wing upper surface lead to the reduction of drag (Grigorie, Botez and Popov, 2016). Eventually, the morphing motion is successfully obtained and can be controlled for beneficial aerodynamic characteristics. Nevertheless, this study is still in progress to achieve the aim of this project: promoting large laminar regions on the wing surface, which reduces the drag.

Rediniotis et al. (2002) developed a shape-memory-alloy actuated bio-mimetic hydrofoil in order to achieve a submerged hydrofoil with high controllability. This hydrofoil shape can be deformed to different NACA shapes mimicking aquatic animals swimming to increase its performance. The numerical procedure based on the potential flow approach applied to analyze the hydrodynamic performance of the 3D NACA 4412 under the free surface was developed by Xie and Vassalos, 2007; Ghassemi, Iranmanesh, and Ardeshir, 2010; Ghassemi and Kohansal, 2013. They determined pressure distribution, lift, drag, and wave generated profiles to analyze various conditions of the 3D hydrofoil near the free surface. The hydrofoil's hydrodynamic performance was numerically studied using the Finite Volume Approach (Djavareshkian and Esmaeili, 2013).

Nowruzi, Ghassemi, and Ghiasi (2017) study the hydrodynamic performance in 2D and 3D of NACA0012, and NACA0015 hydrofoils were performed. Based on the cited works, a lack of study related to the comprehensive investigation on the hydrodynamic performance of submerged 2D and 3D hydrofoils under different geometrical and physics conditions is detectable. Besides that, CFD analysis of flow over 2D and 3D hydrofoils under different environmental and geometrical conditions has a reasonable computational cost. The CFD data for predicting hydrofoil performance with high accuracy and low computational cost. Therefore, the 2D and 3D analyses will be carried out in this research on the initial hydrofoil NACA 0017 and expected deformed shape NACA 6417, 8417, and 9517 to obtain the hydrodynamic performance and characteristic.

1.3. Application in this Project (Deformable Hydrofoil)

The hydrofoil is designed and modeled by the Fabrication and Material Department (FMD), Naval Group. The concept applied to the deformation is quite similar to Grigorie, Botez, and Popov (2016) study. However, in this project, the deformation ability was applied on the upper and lower part of hydrofoil and application of the flexible skin surface on both parts. The mechanical parts that control the deformation are the volume of compressed air injected inside the foil's vicinity and the material composite's ability for skin and middle support plate to control deformation to the specific NACA profile required.

Figure 2 shows the first model of the hydrofoil NACA 0017 constructed in the laboratory by FMD. In (a) shows the inner part (red) as the pressurized line that links to compressor air supply and inner cavities of foil. It also acts as a rigid bone to control the required deformation. In (b) is shown the black composite material with an elastic capability, which holds both the upper and lower parts of foil. Figure (c) shows the flexible skin that can deform when compressed air is injected into both cavities. In (d), the whole model has two pressure lines: injection and suction line for compressed air being attached together by flexible support plate made by the composite material to allow deformation on two parts. The line will be connected to the regulator valve and air compressor. The regulator valve functioned to control the air pressure injected. The automatic pressure cut off to limit pressure inside less than the tensile strength of the material used the hydrofoil to avoid fracture and leakage.

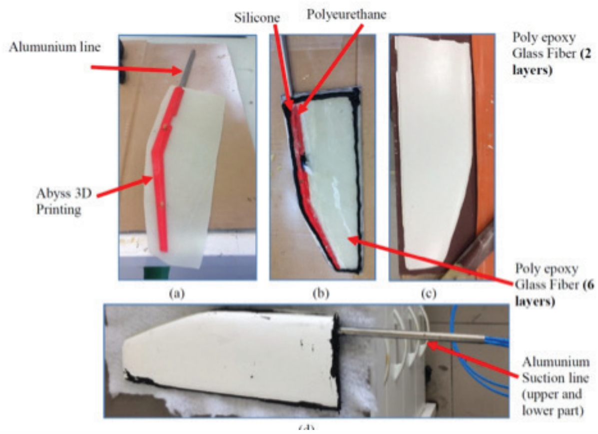


Figure 2.
Inner and outer parts of the 3D hydrofoil.

The basic theory of the associated deformation is by referring the Hooke's law as stated in equation form below:

$$F = k \Delta L \quad (1)$$

Two rules of deformation applied on hydrofoil:

- The hydrofoil should return to its original shape when the force is removed.
- The size of the deformation is proportional to the force.

Rychlewski (1984) shows the linear region that obeys Hooke's law. The slope of the region is *1/k*. The elastic region is the region for material that can return to its initial shape when the force is removed. However, when the force continues injected into the material eventually will lead to fracture. It can observe the permanent deformation region has a greater slope compare to other regions. It means that the slight changing of the force in this region will lead significant increase of *L* before its fracture. In our case, we need to consider three specific deformations:

tension and compression, shear stress, and changes in volume. The others deformations explain in the form of the equation below.

$$\Delta L = \frac{1}{Y} \frac{F}{A} L_0 \tag{2}$$

Equation (2) is the relationship between the deformation and the applied force. Y is Young's Modulus which depends on the material of the foil. A is the cross-sectional area, and L_0 is the original length. When the material has a considerable Y value, significant tensile stiffness will have minor deformation when it exerts tension and compression. The ratio of force to the area is defined as stress measured in N/m^2. The ratio of the change in length to original length is defined as strain (dimensionless). The relationship of strain with stress is presented in equation (4). The expression for shear deformation is showing in equation (5).

$$\sigma = \frac{F}{A} \tag{3}$$

$$\varepsilon = \frac{\sigma}{Y} \tag{4}$$

$$\Delta x = \frac{1}{S} \frac{F}{A} L_0 \tag{5}$$

Where S is shear modulus, F is the force applied perpendicular to L_0 and parallel surface. In our case, the foil volume will change when the compression and expansion are exerted inside the inner structure. The relationship of the change in volume to other physics quantities is stated as:

$$\Delta V = \frac{1}{B} \frac{F}{A} V_0 \tag{6}$$

Where B is the bulk modulus, V_0 is the original volume, while the F is the force per unit area applied uniformly on the surface. The deformation process and whole theory involved in the 3D point of view will detail by FMD. Eventually, the hydrofoil needs to undergo fatigue testing to plan the structure's lifetime to be less than the failure point on the S - N Curve. The fatigue test on the structure or flexible skin can be referred to Richard and Sander (2016). The parameters of substances used for inner and outer structure showed in Figure 2 are mentioned in Table 1.

Table 1.
The material for the structure of hydrofoil (given from FMD).

Material	Layer	Skin	Young Modulus (GPa)	Thickness (mm)
Glass fiber reinforced plastic (polyepoxy matrix)	2	outer	3.1	0.71
Glass fiber reinforced plastic (polyepoxy matrix)	6	Inner	9.2	1.61

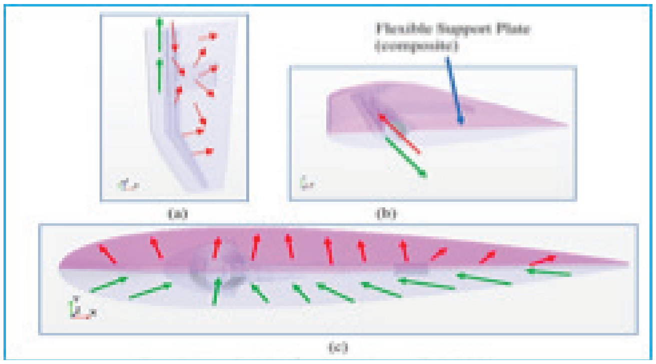


Figure 3.
The operating mechanism of hydrofoil deformation.

Figure 3 shows the operating mechanism of a hydrofoil on the deformation process. A green arrow shows the inlet pressure injected inside the upper side, while the red shows the air pressure is removed from the lower side of foil cause deformation. Then, the upper side expands, and the lower side contracts and leads to curvature forming at a specific NACA profile. The flexible support plate at the middle between two parts of the foil is the significant structure that controls the limit of curvature as well as the volume pressure injected in cavities. Nevertheless, this project is still ongoing research, so that the study will continue carried out until the main objective achieves.

1.4. Application on this Project (Deformable Hydrofoil)

Nowadays, many marine propellers existed in the market, such as fixed propellers, ducted propellers, podded propellers, contra-rotating, Controllable Pitch Propeller (CPP), and others. However, all of them used rigid blades in which not be able to deform. In 1997, Robert Kuklinski initiated an invention on a deformable propeller blade (Kuklinski, 1999). The study was made in order to optimize the operation of the propeller in various AOA. It used heat elements in order to do the deformation on the flexible skin of the blade. The operating mechanism is in the figure below.

In this research, the propeller chosen is the type of CPP, Model Propeller VP1304 in which carried out the open water tests, cavitation test, and LDV measurements as defined in the ITTC Open Water procedure (Van et al., 2011). The model had tested in the towing tank of Potsdam Model Basin in steady flow (Barkmann et al., 2011). Furthermore, this model is prepared for research purposes to validate our numerical simulation setting by comparing the numerical results to the experiment. Eventually, the validated CFD numerical setting will be used to other simulation test that imposed deformation on the blade as required in future. The model of VP1304 showing in figure 4 used in experiment Potsdam Model Basin.

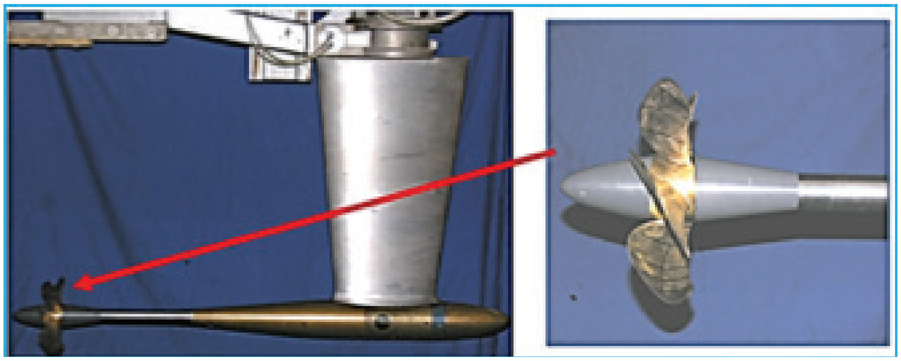


Figure 4.
Dynamometer H39 with VP1304 (Barkmann et al., 2011).

1.5. Theory

Firstly, the research is conducted on 2D numerical simulations such as XFOIL/Qblade that used potential flow theory and panel code to study the hydrodynamic characteristic of the 2D airfoil. Eventually, the application of viscous solver STAR-CCM+ to perform CFD simulation for 3D analysis for our hydrofoil to achieve our objectives.

1.5.1. Airfoil Theory

Before going further, the foil definition is fundamental to identifying the parameter that can be modified to enhance the performance. Both propeller blade cross-section and airfoil are similar in terms of physics and functionality. The figure above has four essential parameters: chord, c, relative thickness, *e/c* (10-30%), relative camber, *f/c* (~2%), and AOA angle between flow and the chord line. By e/c laws, we can obtain the structural resistance and adjust the performances based on the pressure gradient. Camber laws act to modify the load distribution on the blade. While chord laws allow to unload blade tip and lead to decreases on the tip vortex. The aspect ratio of the blade is used to adjust the ratio between the loads and reduce the mechanical surface. The number of blades on CPP is used to balance the loads during rotation (Martelli et al., 2014). There are two significant parameters when it comes to interaction between body and fluid as:

- Stresses- wall shear stresses, τ, due to viscous effects
- Normal stresses due to pressure

The detailed distribution of τ and pressure is difficult to obtain; hence, integrated or resultant effects of these distribution are needed to produce Lift, L and Drag, D as shown in Figure 1.1. D is the force on the foil downstream, while the L is the force normal to upstream velocity. The equation below explains that the relationship between D and L corresponds to shear stress and pressure.

$$D = e_x . \int \sigma_{(n)} \, dA = \int (-p+\tau_{rr}) \, (-\cos\theta) + \tau_{r\theta} \sin\theta \, dA \qquad (7)$$

$$L = \int (-p+\tau_{rr}) \, (\sin\theta) + \tau_{r\theta} \cos\theta \, dA \qquad (8)$$

Where τ and p are in N/m^2, therefore, the widely alternative way to define the dimensionless lift and drag coefficients to approximate values through simplified analysis, numerical technique, and appropriate experiment (Sun, Mao and Fan, 2020):

$$C_L = \frac{L}{\frac{1}{2}\rho S V^2} \tag{9}$$

$$C_D = \frac{D}{\frac{1}{2}\rho S V^2} \tag{10}$$

$$Performance = \frac{L}{D} \tag{11}$$

$$C_f = \frac{\tau}{\frac{1}{2}\rho V^2} \tag{12}$$

$$C_p = \frac{p - p_0}{\frac{1}{2}\rho V_\infty^2} \tag{13}$$

Where;

S = the projected area by c and span, s (m^2)

V= Velocity of the fluid (m/s)

ρ = density of the fluid (kg/m^3)

C_f= Frictional coefficient

p_0 = Reference pressure

C_f and C_p are the essential parameters that identify the location and the flow detachment and regime along the chord. It shows the boundary layer detachment happened earlier on the low Re number than the turbulent boundary layer. It means that the laminar boundary layer has less energy than the turbulent boundary layer, and flow separation occurs quickly.

1.5.2. Airfoil Theory

In our research, the NACA profile chosen is NACA 0017 as the initial shape profile. The four digits mean as follows:

- 00 = there is no camber and symmetric
- 17 = profile have a maximum thickness of 17% relative to the chord

The half-thickness equation of NACA 00xx is given by:

$$y_t = \frac{t}{0.2} c \left[0.2969 \sqrt{\frac{x}{c}} - 0.1260 \left(\frac{x}{c}\right) - 0.3516 \left(\frac{x}{c}\right)^2 + 0.2843 \left(\frac{x}{c}\right)^3 - 0.1015 \left(\frac{x}{c}\right)^4 \right] \tag{14}$$

Where:

c is the chord

x is the position along with the c and 0

y is the half-thickness for a given x

t is the max thickness relative to the chord

The non-symmetric NACA profile used for the expected deformable profile as presented in Section 3 is four digits. The same type of Equation 14 but with a cambered line:

$$y_c = \begin{cases} m \frac{x}{p^2} \left[2p - \frac{x}{c}\right] & 0 \le x \le pc \\ m \frac{c-x}{1-p^2} \left[1 + \frac{x}{c} - 2p\right] & pc \le x \le c \end{cases} \tag{15}$$

- *m* is the maximum camber relative to chord (first digit)
- *p* is the position of the max camber for leading-edge
- Mainly for four digits non-symmetry, the maximum thickness is located at 30% of the chord from the leading edge.

1.5.3. Propeller Definition Diagram

The CPP chosen will undergo the CFD simulation in the open water test domain to obtain the significance parameter corresponding to propeller performance and efficiency. This study confronts the forces and moments acting on the propeller when operating in a constant fluid stream at the same RPM. The forces and moments produced by the propeller will be expressed in non-dimensional terms are as follows:

$$\textit{Advance Coefficient:} \quad J = \frac{V_a}{nD} \tag{16}$$

$$\textit{Thrust Coefficient:} \quad K_T = \frac{T}{\rho n^2 D^4} \tag{17}$$

Torque Coefficient: $K_Q = \dfrac{Q}{\rho n^2 D^5}$ (18)

Propeller efficiency: $\eta_0 = \dfrac{T.V_a}{2\pi nQ}$ (19)

Propulsive efficiency: $\eta_0 = \dfrac{R_t.V_s}{2\pi nQ}$ (20)

All the parameters of the non-dimensional term in Equation 16 – 20 will be obtained by using CFD simulation. The results obtained will be compared to the experimental results to check the validity and use in the subsequent research.

1.5.4. 2D Panel Method (XFOIL)

The 2D numerical simulation conducted using QBlade (2013) developed by David Marten integrates with XFOIL (1986) written by Mark Drela to compute the flow around subsonic isolated airfoils. This integration, which is also being improved, allows the fast design of custom airfoils and computation of their lift and drag polar (Marten and Wendler, 2013). Our attention is on the XFOIL code because it is the central part for 2D numerical analysis on the airfoil selected. XFOIL code applied the 2D panel method, and an integral boundary layer formulation is combined to analyze potential flow around the airfoils.

XFOIL code applied the 2D potential code to predict stationary flow and performance over an airfoil. It used the panel method with the distribution of source and vortex along the discretized chord. Equation closed with Kutta condition (Drela, 1989). The potential method is coupled with a boundary later code to get the viscous boundary layer. It allows analyzing the boundary layer regime accurately. Streamline function, as illustrates above, is a superposition of a vortex, a source, and a uniform flow. The equation form is as follows;

$$\psi(x,y) = u_\infty y - v_\infty x + \frac{1}{2}\pi \int \gamma(s) \ln r(s;x,y)\, ds + \int \sigma(s)\, \theta(s;x,y)\, ds \quad (21)$$

1.5.5. CFD Modelling

The main objective of this research is to model the CFD simulation on the hydrofoil. This section will explain some background of the CFD method used. Most natural fluid flow applications involve turbulent flow that provides the unsteady, three-dimensional, and presents significant spatial and temporal variations. These will lead to the formation of large eddies, transferring their energy to somewhat smaller eddies. This energy will cascade in which the energy is transferred to successively smaller and smaller eddies. In the end, the kinetic energy of turbulence is converted into heat. Kromolgorov's theorem in the figure below explains the energy transferred from larger to smaller eddies until energy dissipation. The turbulence model is the most crucial parameter in CFD simulation (Ducoin et al., 2009).

1.5.5.1. RANSE

The RANSE principle is based on the Reynolds decomposition. It means that all the quantities on Navier-Stokes (N.S.) equation will be written as a summation of a mean and fluctuating quantity. The decomposition made on velocity and pressure is written below.

$$V = \bar{V} + \tilde{v} \quad (22)$$

$$P = \bar{P} + \tilde{p} \quad (23)$$

Where $\bar{V}$ and $\bar{P}$ are mean quantity while $\tilde{v}$ and $\tilde{p}$ are the fluctuating quantity. The initial mass and momentum conservation equations of N.S. are as below:

$$\frac{\partial V_k}{\partial x_k} \quad (24)$$

$$\frac{\partial V_i}{\partial t} + \frac{\partial V_i}{\partial x_k} V_k = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\mu}{\rho}\left(\frac{\partial^2 V_i}{\partial x_k \partial x_k}\right) + f_i \quad (25)$$

Then, average the NS Equation 26 and 27 in which the Reynold decomposition used to produce the RANSE as below:

$$\frac{\partial \overline{V_k}}{\partial x_k} \quad (26)$$

$$\frac{\partial V_i}{\partial t} + \frac{\partial V_i}{\partial x_k} V_k = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} - \frac{\partial V_i V_k}{\partial x_k} + \frac{\mu}{\rho}\left(\frac{\partial^2 V_i}{\partial x_k \partial x_k}\right) + f_i \quad (27)$$

In Equation 27, after applying the Reynold decomposition method in Equation 25, a new term appears called as Reynold stress tensor at the right-hand side as:

$$R_{ij} = -\rho\,(\overline{\widetilde{V}_i \widetilde{V}_k}) \quad (28)$$

Due to the minimal fluctuations in Equation 28, the turbulence modeling techniques based on the Boussinesq hypothesis were applied. This hypothesis is to link the Reynold stresses and velocity gradients through eddy viscosity.

$$R_{ij} = \mu_t\left(\frac{\partial \overline{V_i}}{\partial x_j} + \frac{\partial \overline{V_j}}{\partial x_i}\right) - \frac{2}{3}\rho k \delta_{ij} \quad (29)$$

μ_t is eddy viscosity while k is turbulent kinetic energy to be determined using various models (Rumsey et al., 2018). Some of them are:

- 0 equation model: Mixing length, Cebeci-Smitch, Baldwin-Lomax, etc.
- 1 equation model: Spalart-Allmaras, Wolfstein, k-model, etc.
- Two equations model: *k-ε, k-ω, k-τ, k-L*, etc.

2. METHODOLOGY

In this study, the number of different 2D NACA profiles will be conducted in XFOIL code numerically. Then, some NACA profiles will be selected according to the highest hydrodynamic performance characteristics at the turbulence flow condition. The selected 2D NACA profiles will be designed for 3D NACA hydrofoil before undergoing the Finite Volume Analysis in CFD. The hydrodynamic performance on each 3D NACA hydrofoil will be collected and analyzed at this research's end. As for the podded propeller chosen, the CFD analysis will be conducted to obtain the hydrodynamic coefficients and be compared to the experiment results for validation. All of the numerical CFD setups will be used for the subsequent research for optimization.

2.1. The Scope of the Work

The detailed explanations of the work involved are as follows:

- List all the possibilities foil shapes from NACA profiles 0012 to 0017 that are possible to deform.
- Conducted the 2D numerical analysis) on several NACA profiles at Re= 35 x 10^6 to obtain the dimensionless hydrodynamic coefficient.
- Choose the best NACA profiles with the highest performance at 0 deg AOA to design the 3D hydrofoil using CATIA software to evaluate the design. The selection process used a genetic Method shown using Pareto Front Diagram.
- Construct the design using CATIA with the full-scale model to fabricate and will be computed numerically using Viscous Solver STAR-CCM+ and test experimentally in the future.
- Ensure the meshing rule will obey the viscous and sub-viscous layer. The value of y+ should be less than two at the viscous layer around the foil surface.
- Identify the physics model and turbulence model used in the simulation.
- Do the 3D simulation using STAR-CCM+ on the selected hydrofoil.
- The simulation is conducted at the same speed, Vs= 6 m/s at 0 deg AOA at the steady-state.
- Observe all the hydrodynamic characteristics produced during simulation, such as lift and drag forces, wall shear stress, and Pressure distribution along hydrofoil.
- Observe the vortices and detachment produced, which lead to the loss of performance. All the results will be compared to the experimental result in the future by FMD.
- Study the advantages of the deformable hydrofoil on the results obtained being applied to the propeller blade in terms of thrust, maintaining the optimal propulsive performance for different speeds, flexibility, and efficiency in the future.

2.2. Selection of Several Possible Shapes of NACA to Deform (2D Analysis)

In this study, to analyze the different NACA profiles quickly, the QBlade that used XFOIL code was utilized. XFOIL is a program used to simulate and study subsonic isolated airfoils that take the 2D airfoil properties, Reynolds number, and Mach number and calculate global and local performances. XFOIL uses the potential flow theory, the boundary layer code, as explained in a viscous flow. In this way, the streamlines induced by the viscous flow can be modified. Here, the 2D foil analysis with Re= 35x 10^6 (turbulent) conducted on several NACA 6412 to 9517 is given by FMD.

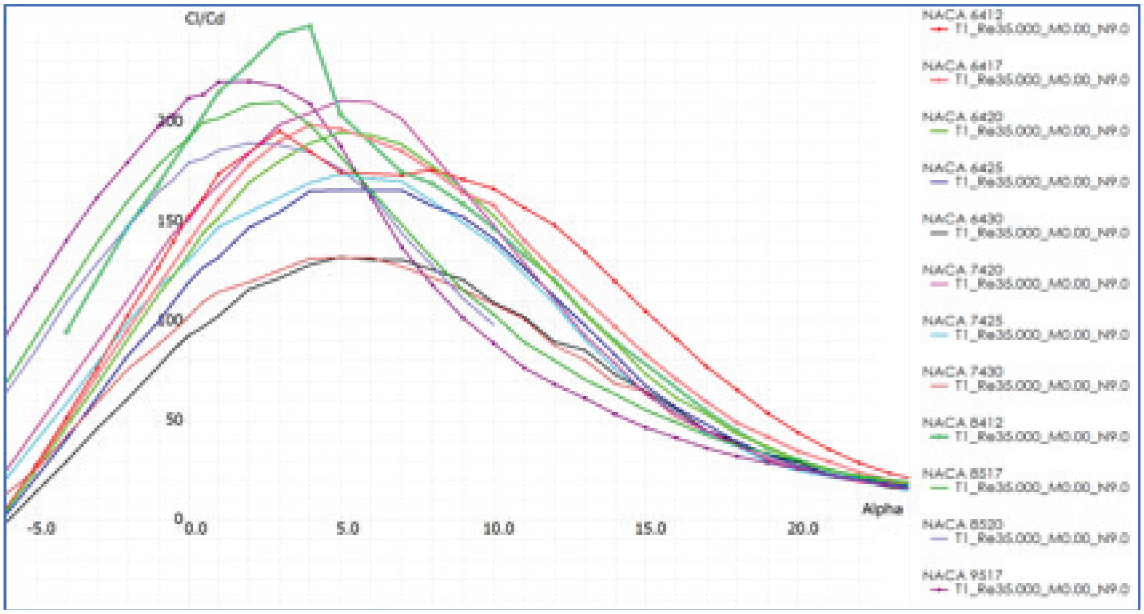


Figure 5.
Performance, C_l/C_d on Each Foil.

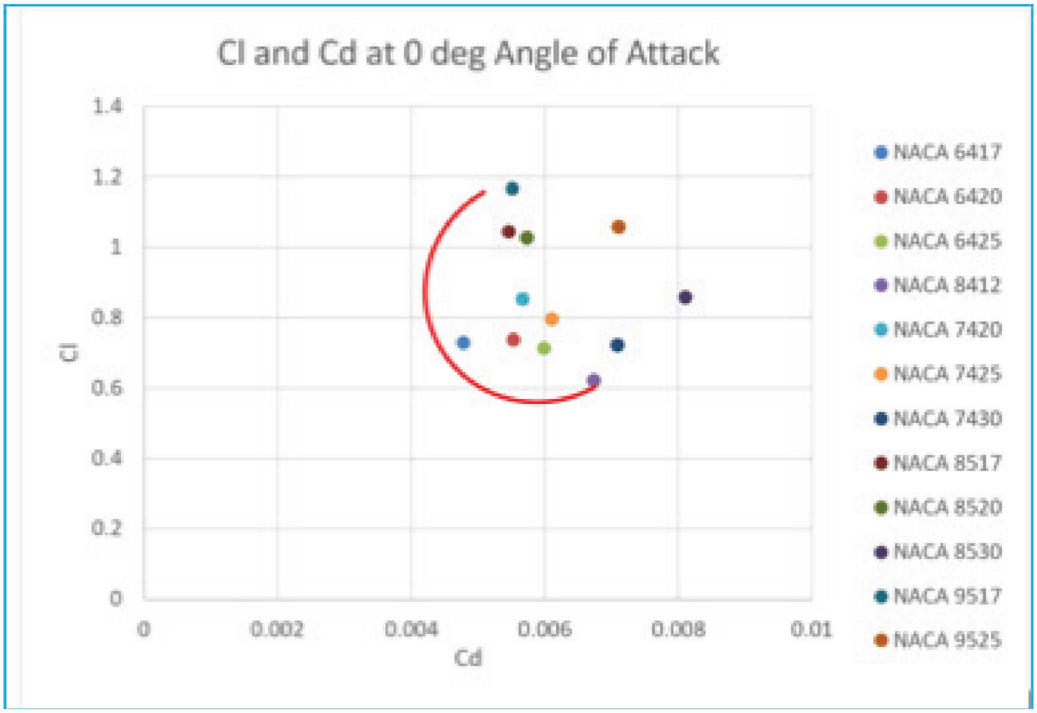


Figure 6.
The Pareto Front Diagram on Two Objectives Function, High C_l and Less C_d.

Figure 5 shows the best performance at 0 deg Angle of Attack (AOA) as required in the objective of this project. The results will compile and combine using the Stochastic Method to identify the best range of deformable NACA. According to Figure 5, the performance was obtained at the 0 deg AOA on different Non-Symmetry NACA profiles. The objectives function at 0 deg AOA at the constant Re= 35 x 10^6 are stated as follows:

- High Lift, C_l
- Less Drag, C_d

Figure 6 illustrates the best NACA that achieved and satisfied both functions (Red curve), which are NACA 6417, NACA 8412, and NACA 9517. The 2D numerical results on the selected NACA profile as illustrated in Figure 2.3. Figure 7 shows that the NACA 9517 produces the highest performance at 0 deg AOA compare to other NACA profiles. It means that the lifting coefficient produce is higher and has less drag compared to other profiles. The degree performance of profile is NACA 0017 > 6417 > 8412 > 9517.

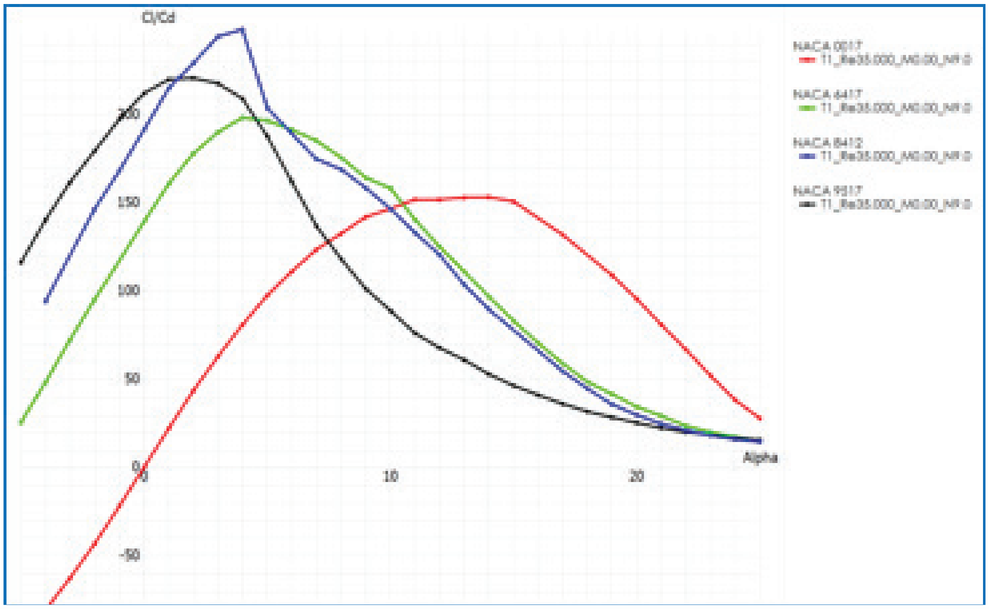


Figure 7.
Performance, Drag, and Lifting Coefficient on Selected Foil.

2.3. Design of Hydrofoil

The FMD gives the parameter and dimension of the hydrofoil for CFD analysis. The CAD design showed in Figure 9. The primary dimension of 3D hydrofoil is presented in Figure 8.

- Height, *h* = 290 mm
- Chord (top), *CT* = 94mm
- Chord (Lower) *CL* = 34mm
- Thickness = according to NACA profile respect to chord.

Figure 8.
Basic Hydrofoil Dimension.

Figure 9.
CAD Design for NACA 0017 and Expected Deformed Shape NACA 8412, 6417 and 9517.

2.4. Numerical Setting

According to Siemen (2017) and Muralikrishna et al.(2017), as explained previously, it is necessary to use the same physics configuration upon all hydrofoils. Some of the physics model settings are as follows:

- Steady-state simulation
- The fluid in the domain is a liquid with constant density at T=23 deg C.
- Turbulence model: Realizable k-ε two-layer All y+ is better than the Standard K-Epsilon model for many applications and can generally be relied upon to give at least as accurate answers. It enables to be used with fine meshes that resolve the viscous sub-layer.
- Segregated flow method: Apply for incompressible flow (constant density) to compute pressure and velocity. It helps accelerates the convergence process.

The physics values to compute Reynold Number (Re) in order to identify the flow regime are mentioned in Table 2.

Table 2.
Physics Value for CFD Simulation.

V (m/s)	μ (Pa.s)	ρ (kg/m3)	CT (m)
6	0.9348 x 10-3	997.561	0.096

$$Re = \frac{\rho \times V \times d}{\mu} = \frac{997.561 \times 6 \times 0.094}{0.9348 \times 10^{-3}}$$

$$= 601{,}866.07 \text{ (turbulence flow)}$$

The distribution of *Re* from CT to CL, y/h = 0.31, 0.55, 0.92 and 0.98 as presented in figure 9. Figure 9 represents the distribution of Re along the hydrofoil from C.T. to CL. It shows the lowest *Re* is 2.8 x 10^5 and the highest is 6 x 10^5. All of them are in the turbulent flow due to Re > 1 x 10^5, as stated in (Ducoin et al., 2009) study. Therefore, the numerical setting is included for the turbulent eddy viscosity model, such as the Realizable k-ε model for solving the flow problem.

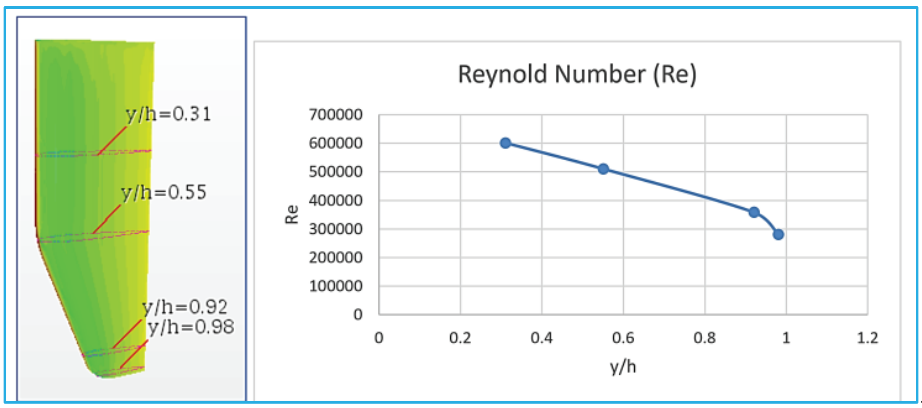


Figure 10.
Re Distribution along Hydrofoil CT to CL (y/h).

2.5. Domain

The domain of the simulation is the spatial region in which the simulation takes place. The shape of the domain is a rectangular box. The domain can be seen in Figure 11. The boundary condition is shown in Table 3.

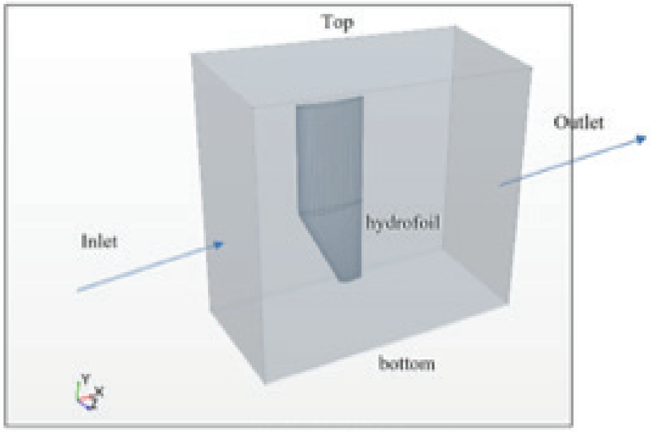


Figure 11.
The domain of The Hydrofoil From Inlet To Outlet.

Table 3.
Boundaries and Boundary Conditions of the CFD Setup.

Name of Boundary	Boundary Condition
Inlet	Velocity Inlet, prescribed with V
Outlet	Pressure Outlet
Hydrofoil	Wall (No slip)
Top	Wall (Slip)
Bottom	Wall (Slip)
Side	Wall (Slip)

2.6. Spatial Discretization

The volume mesh consists of hexahedrons in a structured grid. The mesh is generated using the trimmer-mesh function in STAR-CCM+. Boundary layer mesh called prism layer is used on the hydrofoil surface to make a reasonable estimation of the shear stresses and lifting. According to Table 4 and Figure 12, the refinement zone of the hydrofoil from inlet to outlet. It shows the 3-refinement zone used to refine the mesh in the essential regions. The purpose of the refinement zone is to capture the flow profile on the region and get the value of Y+ less than 5, which leads to the increment of accuracy and trusts results.

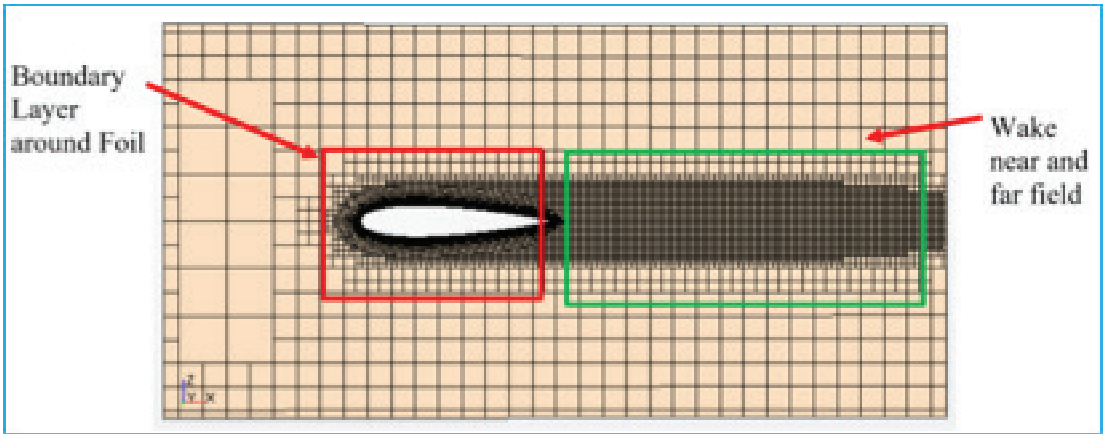


Figure 12.
The Refinement Zone of The Hydrofoil from Inlet to Outlet.

Table 4.
Refinements Zones of the CFD Setup.

Name of Refinement Zone	Refinement Direction
Hydrofoil	All Boundary layers around
Wake (near to far-field)	Longitudinal and transverse

2.7. Meshing Sensitivity

Before compiling the computational on 3D analysis, the mesh sensitivity was conducted to obtain the optimum cells for our mesh to provide the acceptance results without wasting too many cells and reducing computing time. For the first mesh rule analysis, we analyze the hydrofoil NACA 0017 at AOA 0 deg, take the lower dense to higher dense cells, and compare the lifting forces generated. The range number of cells on mashing should be from 100,000 to 4,000,000 cells. The lifting force generated should be 0 N due to the hydrofoil's symmetry. By doing that, the most meshing that gives 0 N will be the fine mesh and be a setting to other hydrofoil CFD simulations. Figure 13 illustrates the ratio of the fluid domain concerning hydrofoil in the ratio 1.4. Hence, we decided to set the base size of the whole cell as 0.002m as a constant and construct the refine mesh near to hydrofoil wall. Seven tests of mesh sensitivity were carried out, as mentioned in Table 5. As explained previously, the refined mesh will be emphasized at the viscous sub-layer to get the y+ < 5. After we conducted seven mesh sensitivity tests above, it can be summarized in Table 5.

Table 5 shows that when the no of the cell increases near the wall, it will reduce the y+ value. It shows that the highest value of y+ is around 1 to 15 (test 1) rather than 0 – 0.86 (test 5 to 7). Figure 13 indicates that the y+ value keeps decreasing until a certain number of cells that produce lifting force value becomes constant. Here shows that the no of cell that gives the reliable result is 1.2 million and above, which produce lifting force near 0 N.

In conclusion, the sufficient No. of cells for this simulation is around 1.2 million to 2 million (test 4 - 6). Thus, the numerical CFD setting for the next simulation will be similar to Test 5, which is 1.7 million cells producing persistent and efficient results.

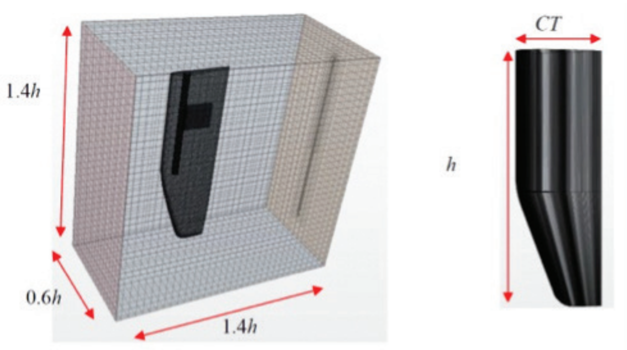


Figure 13.
The Dimension of the Domain and Hydrofoil NACA 0017.

Table 5.
The Summary of No of Cells Generated in Mesh Sensitivity.

Test	No. Cells	Y+	Lifting Force, Fz (N)
1	535,222	1 - 15	1.9161
2	657,479	1 - 9	1.9125
3	974,468	1 - 2.5	0.0473
4	1,220,018	0 - 1.16	0.0264
5	1,774,770	0 - 0.92	0.00128
6	2,127,170	0 - 0.9	0.001272
7	4,027,678	0 – 0.86	0.001271

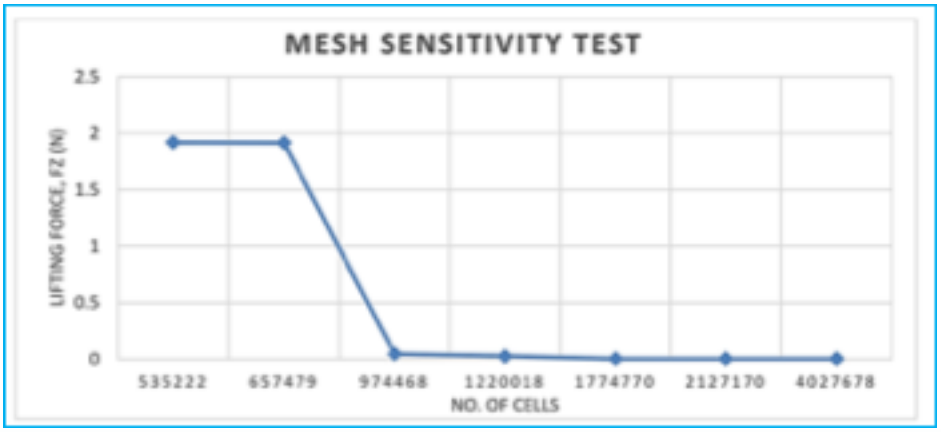


Figure 14.
Mesh Sensitivity Test Results Against the Number (No.) of Cells.

2.8. Convergence Study

The convergence study is necessary to perform (Larsson, Stern and Visonneau, 2013). It shows that the residual of continuity, conservation momentum, and turbulent kinetic energy change become too small until converged. At convergence state, all conservation equations are computing in all cells that fulfilled the criteria below:

- The solution was obtained to produce a constant value even though the iteration number increased.
- The balance of the mass, momentum, energy, and scalar obtained
- The value of residual should be less than 1 x 10^{-4}

The residual value is the vital parameter to check in order to ensure the calculation is converged. Residual is used to measure the imbalance or error in conservation equations. The residual is commonly required to be in the order of 1 x 10^{-3} and 1 x 10^{-4} for convergence state reach. The convergence state obtained can be shown in the residual chart below (Test 5).

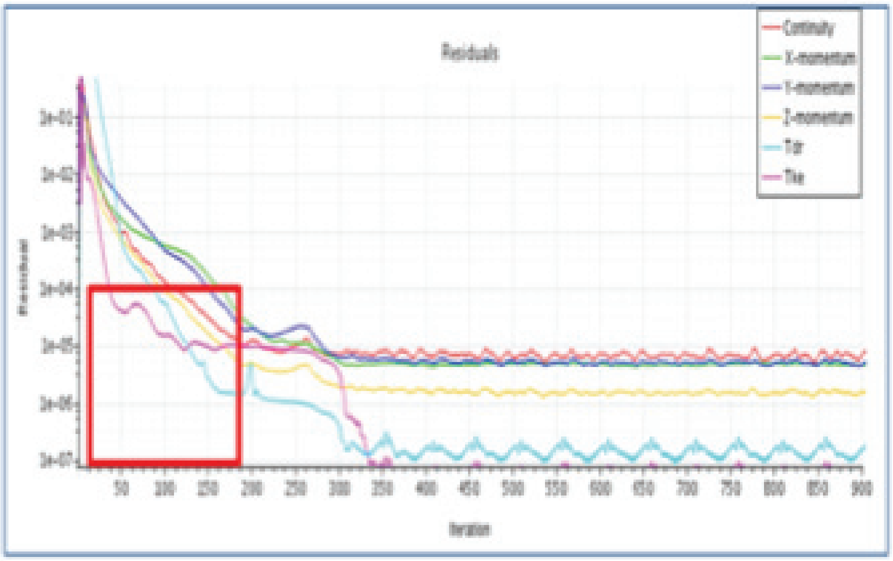


Figure 15.
The Residual Value for Convergence Study.

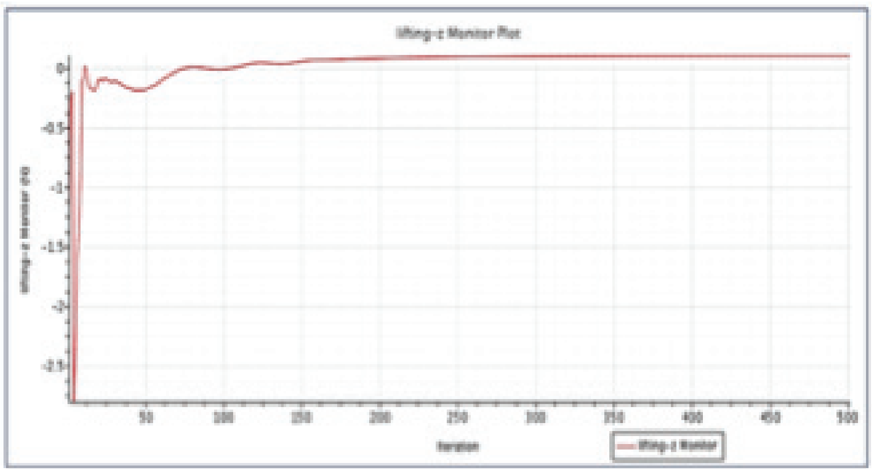


Figure 16.
The Lifting Forces Result Shown Converged.

From Figure 15, it can be observed that the computation has converged at iteration around 180 in which less than 1×10^{-4} (red box) then the residual reduced little bit and keep on constant until the end of iterations which mean balance state achieved. *Tdr* is a turbulent dissipation rate in the graph legend, while *Tke* is turbulent kinetic energy used to determine the turbulent eddy viscosity. Besides that, the convergence state can also be checked according to the local or global variable of interest. In this case, we can check on the lifting or drag force results to identify the equilibrium state reach, as shown in Figure 16. It shows above that the value of lifting force keeps constant when reaching iteration 180 and above. It means that the solution has converged and balance states reach even though the iteration is increasing.

3. RESULT AND DISCUSSION

After identifying all the parameters involved in the meshing rule, boundaries condition, and physics characteristic, the hydrofoil geometry will be imported to the STAR-CCM+ for simulation. The parts and regions will be created in order to adapt all the settings required. Eventually, the simulation will be executed, and the results obtained as follows. The summary of these tasks and objectives to simulate the CFD are as follows:

- Hydrofoil NACA 0017 at the highest performance of AOA: The highest AOA will be estimated from 2D analysis using QBlade/XFOIL on NACA 0017, which contributes the highest performance at specific Re applied in experiment and CFD simulation. Then, the study will simulate the 3D analysis by STAR-CCM+. These results will be compared to the performance obtained by the other deformable hydrofoil.
- Deformable Hydrofoil of NACA 6417, 8412, and 9517: The results obtained will be compared to NACA 0017 at AOA (highest performance – 2D analysis).
- Open Water Test on Propeller VP 1304 (Barkmann, Heinke and Lübke, 2011): The propeller of VP 1304 has been agreed to be used for future research on deformable blade propellers based on the data by the previous experiment. It is significant to compare the CFD results with experimental to ensure the results of CFD solver is applicable for doing subsequent CFD analysis on different deformable blade profile by the same CFD setting.

3.1. Objective 1

The 2D numerical hydrodynamic performances of NACA 0017 at different AOA are summarized in Table 6.

Table 6.
The NACA 0017 Performance on Each AOA.

AOA (deg)	L(N)	D(N)	L/D
2	111.393	11.3873	9.78
8	223.593	19.73	11.33
9	291.91	28.49	10.25
12	321.539	32.77	9.81
14	359.516	40.23	8.94
16	362.36	49.78	7.28

As represented above, it proved that Re chosen produces the same assumption on the AOA that achieves the highest performance, which is 8 deg between 2D and 3D solutions. Then, the result of AOA 8 deg will be compared to other deformable profiles at AOA 0 deg to observe the deformable profile able to have the performance more than the original profile (NACA 0017) at the highest AOA 8 deg. Before going further on simulation to another deformable hydrofoil, we can observe the differences in the velocity vector at the plane (*y/h*= 0.31).

According to Figure 17, it can be observed that the velocity profiles along the hydrofoil are different according to AOA. The highest AOA will generate the highest velocity flow lead to generating higher lift more than others. However, it will have a significant risk that the flow detaches earlier. The AOA 16 deg occurs flow separation earlier in which before the trailing edge. Most of them will experience detachment at the end of the trailing edge. Flow detachment is the source of performance reduction due to the increment of drag. It shows that the suction part contains the highest velocity profile and reduces it to the pressure part. The blue contour shows the detachment in which the velocity near wall is 0, led to increasing adverse pressure. Eventually, it will create vortices. It can be seen that AOA 16 deg and 14 deg contribute the highest flow detachment compare to others. AOA 8 deg does not show much detachment caused has the higher performance. The video flow simulation had also recorded to study the behavior of flow and vortices on the profile

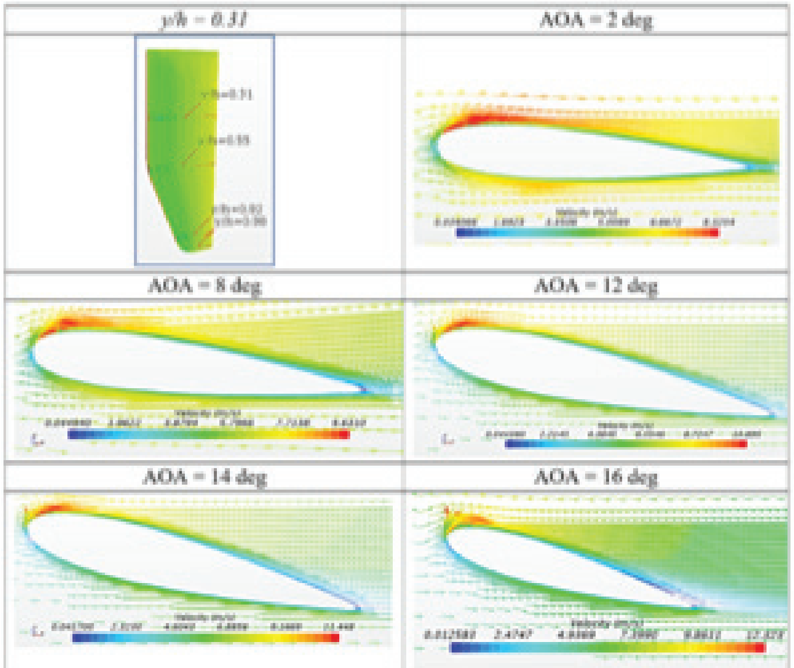


Figure 17.
Velocity Profile on different AOA in Vector Scene.

3.2. Objective 2

The CFD simulation was carried out using STAR CCM+ on hydrofoil NACA 6417, 8412, and 9517 at 0 deg AOA to obtain the hydrodynamic characteristics. The simulation is modeled according to the setup decided in Section 2. The velocity profiles and shear stress generated are illustrated in Figures 18, 19, and 20. It can be observed that the velocity profile along the hydrofoil

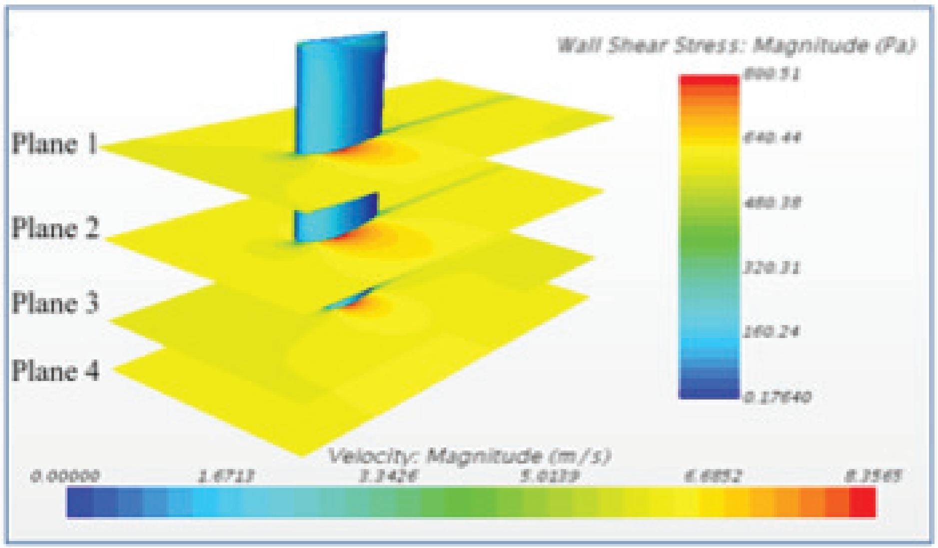


Figure 18.
Velocity Profile and Shear Stress on Deformable Hydrofoil NACA 6417 (No cells: 1,780,037).

is different with the thickness and chord at each plane. The upper hydrofoil has the more significant chord and thickness compared to Plane 4. The upper part contains the highest velocity profile and reduces when it comes to the lower part. The blue contour showed the flow detachment in which the velocity near the wall is almost 0 m/s, leading to increasing adverse pressure at the suction side at the trailing edge. It can observe that the blue contour develops at the trailing edge of foil called as Trailing Edge Vortex (TEV).

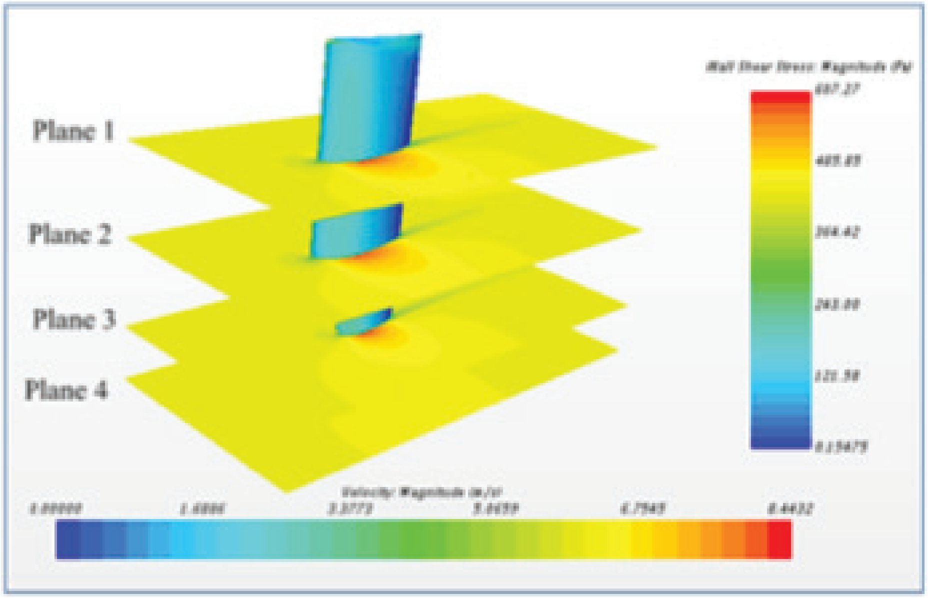


Figure 19.
Velocity Profile and Shear Stress on Deformable Hydrofoil NACA 8412 (No cells: 1,888,789).

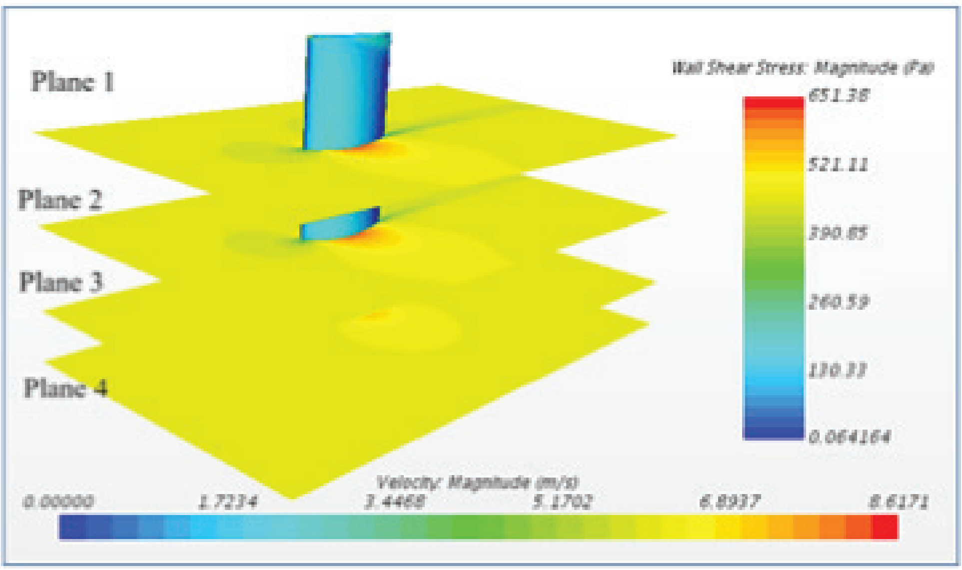


Figure 20.
Velocity Profile and Shear Stress on Deformable Hydrofoil NACA 9517 (No cells: 1,805,494).

3.3. Objective 3

The propeller's primary properties are shown in table 8. At the end of the simulation, the CFD results will be compared to experimental results to check their validity and used as the setting for the following research. This simulation will perform in the range of *J* (from 0.6 to 1.4). In this study, we will find the thrust coefficient, K_T, the torque coefficient, K_Q, and the open water efficiency, η_o, and eventually will be compared to the experiment. The operating conditions for the simulation are listed in Table 7.

Table 7.
Main data of Model Propeller VP 1304 (Barkmann, Heinke and Lübke, 2011).

			VP1304
Diameter	D	[m]	0.250
Pitch ratio r/R = 0.7	P 0.7 / D	[-]	1.635
Area ratio	$A_E A_0$	[-]	0.77896
Chord length r/R = 0.7	$c_{0.7}$	[m]	0.10417
Skew	Θ	[°]	18.837
Hub ratio	d_h/D	[-]	0.300
Number of blades	Z	[-]	5
Sense of rotation		[-]	right
Type		[-]	controllable pitch propeller

Table 8.
The Operating Condition for Simulation.

Density of Water (at 17.5 oC)	998.67 kg/m3
Dynamic Viscosity of Water	0.001068 Pa s
Propeller Diameter	0.25m
Number of revolutions	15 rps
Velocity Inlet (m/s)	2.25 m/s, 3 m/s, 3.75 m/s 4.5 m/s and 5.25 m/

3.3.1. Propeller Design and Numerical setting

The same propeller is modeled using CATIA and obeyed all the geometry provided by Barkmann et al.(2011) before exporting the CAD file to STARCCM+. The propeller design is as Figures 21 and 22. Some of the numerical CFD settings for physics and mesh rule used is similar to hydrofoils, section 2.4 and refers to Siemens (2017) with the additional physics conditions in Table 8.

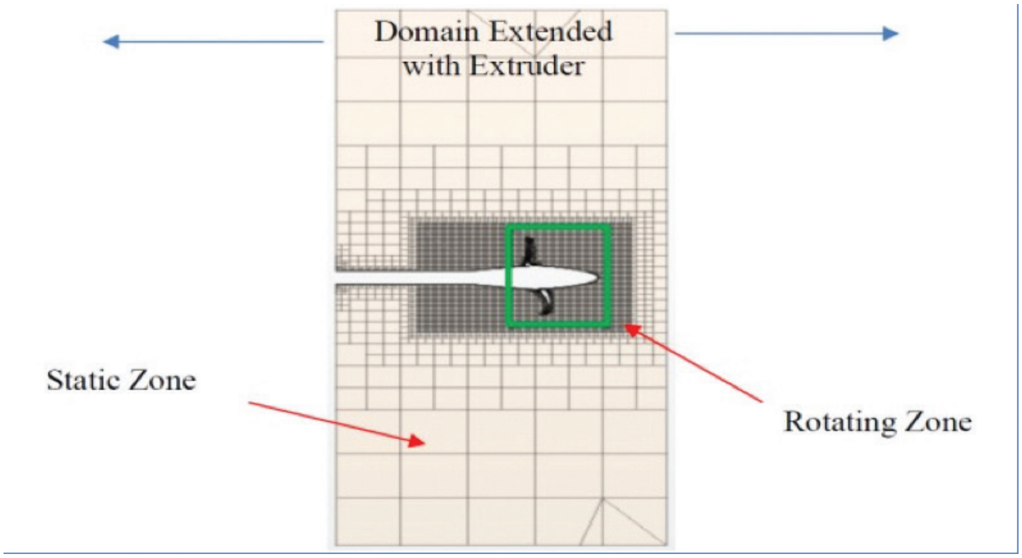


Figure 21.
The Refinement Zone for Propeller.

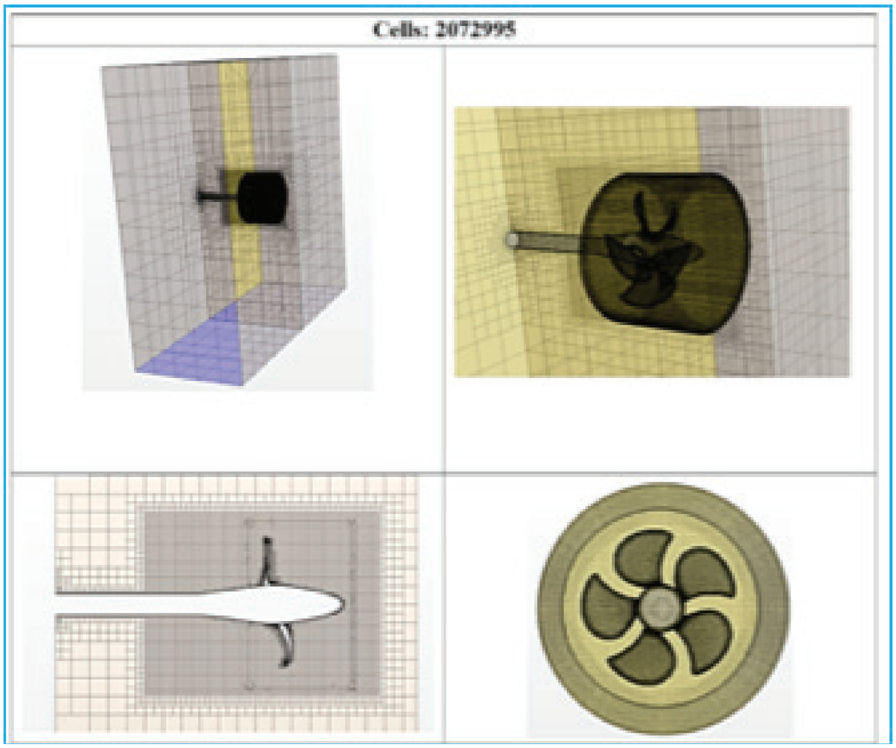


Figure 22.
Generated Volume Mesh for Propeller (Top, Side, Front).

3.3.2. Mesh Rule

The mesh setting for this simulation is different compared to the setting used for hydrofoil. In this case, the propeller's rotation will be modeled using Moving Reference Frame (MRF). It has two regions which are for the rotating region and static region. The zones involved are as follows:

For this simulation, the value of y+ is outside the buffer layer 5 to 30. Here we aim the wall y+ value greater than 30. The small y+ less than 5 is not applicable to use it due to involved the MRF. Otherwise, the number of cells increased and increased the computation time. Considering the refinement zone involved, the number of cells used is not much and is applicable to simulation. Therefore, the All Y+ Wall Treatment Approach was chosen to have better configurations that emulate the low y+ wall treatment for fine meshes and the high y+ wall treatment for coarse mesh. Due to the y+ value is more than 30, then the high y+ wall treatment option will automatically be activated in which the treatment does not resolve the viscous sub-layer. Therefore, it used the wall shear stress, turbulent production, and turbulent dissipation are derived from equilibrium turbulent boundary layer theory.

3.3.3. Scalar Scene

Figure 23 represents the boundary condition setup for the whole fluid domain. It shows the velocity of fluid flow from right to the upstream region then impacted the propeller rotating blade against the thrust generating by propeller eventually go to the downstream region. The simulation conducted on 5 velocities inlet which are 2.25 m/s, 3 m/s, 3.75 m/s 4.5 m/s and 5.25 m/s at the constant RPM, n = 15 rev/s. Figure 24 illustrates the flow streamline from hub till blade propeller and produces swirling effect induced. Besides that, it shows the highest pressure impacted at the leading edge of the blade tip. Figures 25 and 26 represented the results of Thrust and Torque produced. It shows that when the J increases, the propeller produces less torque and thrust. It shows that the inflow speed becomes greater than the propeller's rotation and against the thrust generated.

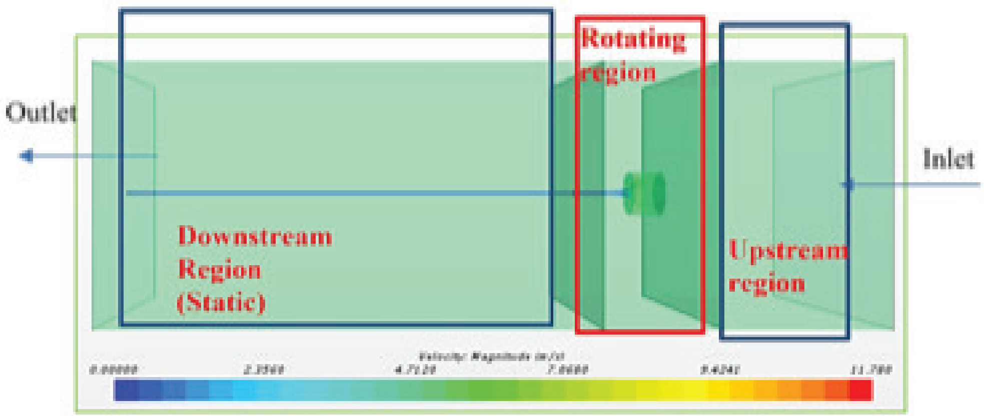


Figure 23.
Fluid Domain and Boundary Condition of Open Water Test Simulation.

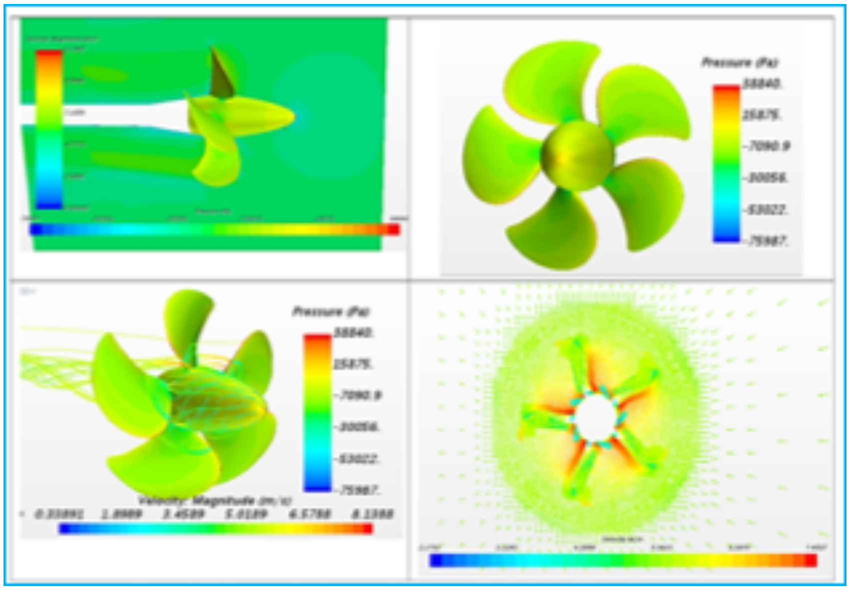


Figure 24.
Pressure Distribution and Velocity Profile (Scalar and Vector Scene) at J= 0.6.

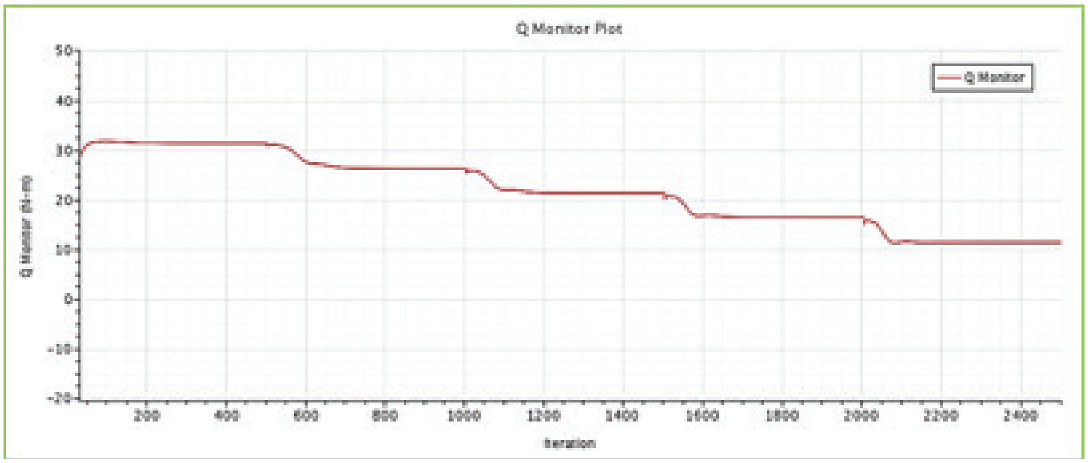


Figure 25.
The Torque Coefficient.

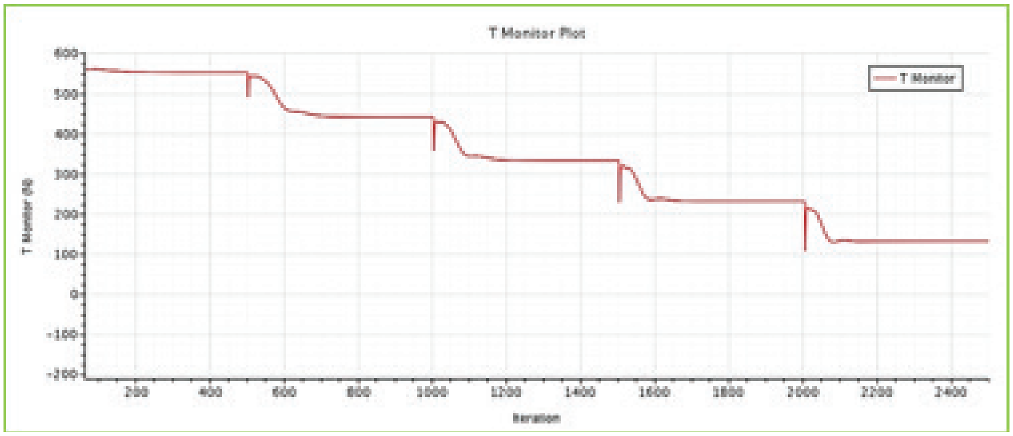


Figure 26.
The Thrust Coefficient.

4. CONCLUSION

After undergoing all the procedures required, all hydrodynamic characteristics on hydrofoils and propeller has successfully obtained. The results of a hydrofoil on 3D simulation can be summarized in Table 9.

Figure 27 represents that the highest lifting force generated is hydrofoil 9517, while the lowest is hydrofoil 6417. It can be observed that the relative camber and thickness play a significant role in producing the highest lift of hydrofoil.

Table 9.
CFD Hydrodynamic Results on All Hydrofoils.

Hydrofoil	AOA (deg)	Cl	L (N)	Cd	D (N)	Cl/Cd
H0017	0	0.000016	0.00	0.02	9.48	0.00
H0017-8	8	0.52	223.59	0.05	19.73	11.33
H8412	0	0.59	252.03	0.04	18.32	13.76
H6417	0	0.41	176.07	0.03	14.57	12.08
H9517	0	0.61	261.55	0.06	24.08	10.86

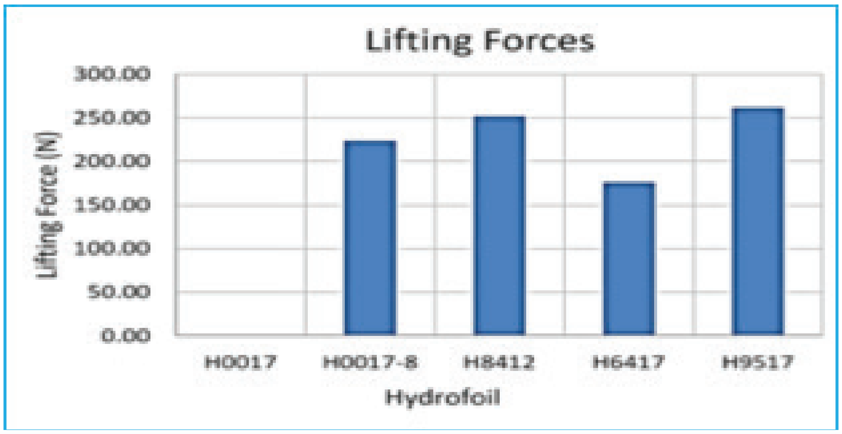


Figure 27.
Lifting Forces of Each Hydrofoil.

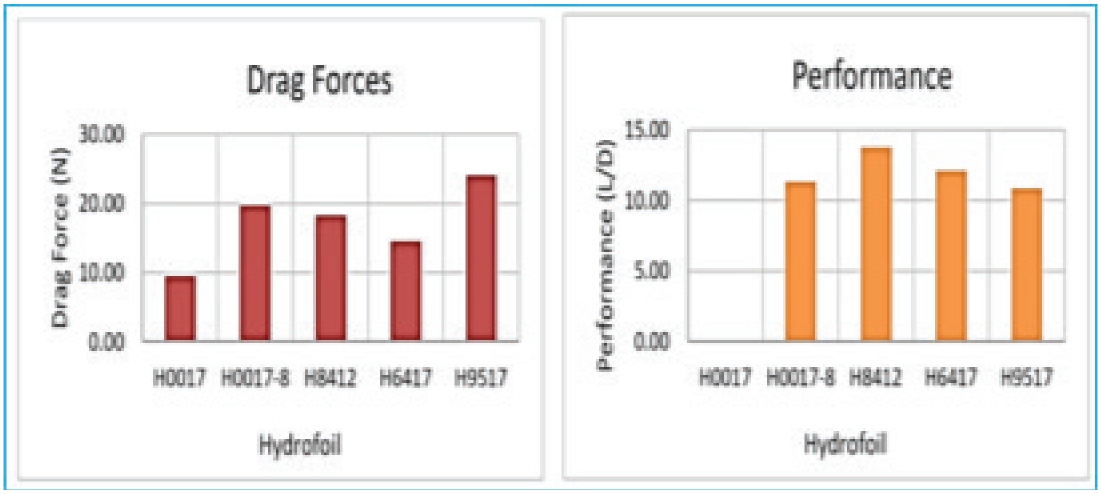


Figure 28.
Drag Forces and Performance Generated on Each Hydrofoil.

Nevertheless, as represented in Figure 27, the hydrofoil 9517 also produces the highest drag, followed by 8412, 0017 at AOA 8 deg and 6417. It shows that the greater relative camber can generate a significant lift but also increase the drag. Furthermore, the highest performance is hydrofoil 8412, followed by 6417, 0017 AOA 8 deg, and 9517. It proved that deformable hydrofoil on the hypothesis that the hydrofoil can achieve good performance without changing the AOA or remaining at 0 deg. It shows that the deformable profiles 8412 and 6417 produce higher lift at 0 deg AOA than the initial profile 0017 at the highest performance AOA 8 deg. Remain AOA at 0 deg believe to produce more efficient and reliable performance due to the flow separation and detachment is hard to experience.

Even though all of these results are obtained according to the CFD simulation procedure, it is still necessary to validate with experimental results that will be performed in the future. The CFD results will be submitted to FMD for comparison with experimental results.

For Objective 3, the aim is to initiate the research by selecting the initial shape of the blade propeller before it deforms for CFD 3D simulation. The comparison with the experimental results to validate the results and the numerical setting applied to solve in the future. The comparison results of the open water test CPP can be summarized in Table 10.

Table 10.
The comparison of Experiment and CFD results.

	Experiment Results			CFD Results		
	KT	10KQ	Efficiency	10KQ	KT	Efficiency
0.6	0.6288	1.3964	0.43	1.427394	0.629388	0.420893
0.8	0.51	1.178	0.5512	1.19468	0.502377	0.535196
1	0.3994	0.9749	0.652	0.970287	0.379381	0.622044
1.2	0.2949	0.776	0.7258	0.74958	0.263095	0.670072
1.4	0.1878	0.5588	0.7487	0.516642	0.149334	0.643786

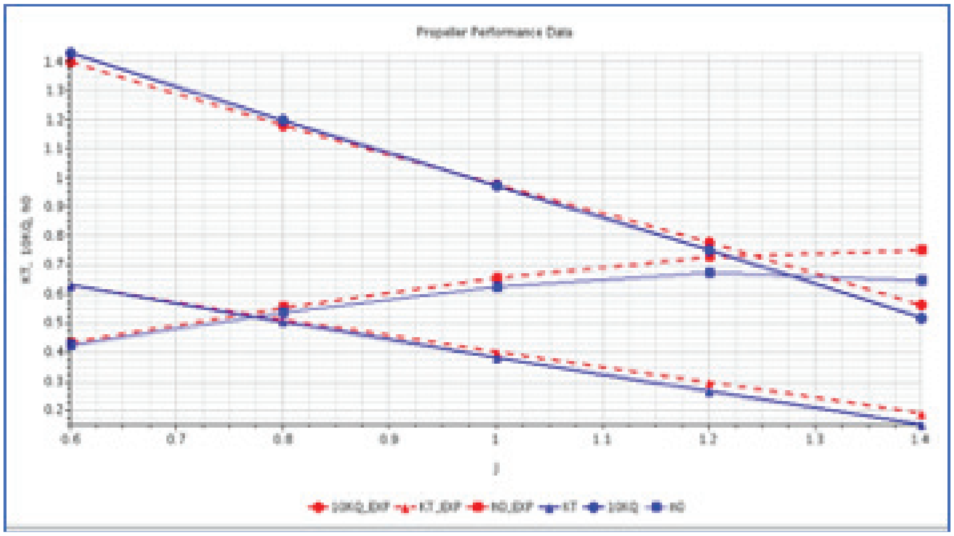


Figure 29.
Comparison Experiment CFD Results.

According to Table 10 and Figure 29, it can be observed that the results obtained are almost similar to the experiment data. The error percentage for both cases is mentioned in Table 11. Table 12 represents the error obtained concerning experiment data. The highest error is 8%; however, it's considered as a small error, and the CFD is decided as agreeable, trusted, and validated. These results and numerical CFD settings will be submitted to FMD for subsequent research on deformable blade propellers in different cases and scenarios.

In conclusion, all the objective 1,2 and 3 of this research achieved and further research need to be conducted for experimentally model testing.

ACKNOWLEDGEMENT

Highest appreciation for Dr. Antoine Ducoin for knowledge sharing and guidance, LHEAA, Ecole Central Nantes, Ms. Justine Taurine from Fabrication Material Department (FMD), Naval Group, and the National Defence University of Malaysia for sponsorship this research project.

REFERENCES

Barkmann, U., Heinke, H.-J. and Lübke, L., 2011. Potsdam Propeller Test Case (PPTC) Test Case Description in Second International Symposium on Marine Propulsors. Hamburg, pp. 1–6. Available at: https://www.marinepropulsors.com/smp/files/downloads/smp11_workshop/smp11_workshop/II-1_Barkmann.pdf.

Campanile, L. F. and Hanselka, H., 2000. Aerodynamic structure, for a landing flap, an airfoil, an elevator unit or a rudder unit, with a changeable cambering. Germany: United States Patent. Available at: https://www.freepatentsonline.com/6010098.html.

Djavareshkian, M.H. & Esmaeili, A., 2013. Neuro-fuzzy based approach for estimation of Hydrofoil performance. Ocean Engineering, 59, pp.1–8. Available at: http://dx.doi.org/10.1016/j.oceaneng.2012.10.015.

Drela, M., 1989. XFOIL: An Analysis and Design System for Low Reynolds Number Airfoils. Low Reynolds Number Aerodynamics, pp.1–12. Available at: http://dx.doi.org/10.1007/978-3-642-84010-4_1.

Ducoin, A. et al., 2009. Computational and experimental investigation of flow over a transient pitching hydrofoil. European Journal of Mechanics - B/Fluids, 28(6), pp.728–743. Available at: http://dx.doi.org/10.1016/j.euromechflu.2009.06.001.

Ghassemi, H. and Kohansal, A. R., 2013. Wave Generated by the NACA4412 Hydrofoil near Free Surface. Journal of Applied Fluid Mechanics, 6(01). Available at: http://dx.doi.org/10.36884/jafm.6.01.19474.

Ghassemi, H., Iranmanesh, M. and Ardeshir, A., 2010. Simulation of free surface wave pattern due to the moving bodies. Iranian Journal of Science & Technology, Transaction B: Engineering, 34, pp. 117–134. Available at: https://www.sid.ir/en/journal/ViewPaper.aspx?id=171824.

Grigorie, L., Botez, R.M. & Popov, A.V., 2016. Self-adaptive morphing wing model, smart actuated and controlled by using a multiloop controller based on a laminar flow real time optimizer. 24th AIAA/AHS Adaptive Structures Conference. Available at: http://dx.doi.org/10.2514/6.2016-1082.

IV, J. R. W., 2012. Propeller Design Optimization for Tunnel Bow Thrusters in the Bollard Pull Condition. Massachusetts Institute of Technology June. Available at: http://hdl.handle.net/1721.1/74896.

Kolakoti, A., 2013. CFD Analysis of Controllable Pitch Propeller Used in Marine Vehicle, Global Journal of Engineering, Design & Technology, 2(5), pp. 25–33. Available at: https://www.longdom.org/articles/cfd-analysis-of-controllable-pitch-propeller-used-in-marine-vehicle.pdf.

Kuklinski, R., 1999. Deformable Propeller Blade and Shroud' United States: United States Patent. Available at: https://patentimages.storage.googleapis.com/03/8f/8d/2f60463100eebe/US5934609.pdf.

Larsson, L., Stern, F. and Visonneau, M., 2013. CFD in Ship Hydrodynamics — Results of the Gothenburg 2010 Workshop in MARINE 2011, IV International Conference on Computational Methods in Marine Engineering, pp. 237–259. Available at: http://dx.doi.org/10.1007/978-94-007-6143-8.

Lothar Birk, 2019. Fundamentals of Ship Hydrodynamics: Fluid Mechanics, Ship Resistance and Propulsion John Wiley & Sons Ltd. Available at: www.wiley.com/go/birk/hydrodynamics.

Mahmud, M.S., 2015. The applicability of hydrofoils as a ship control device. Journal of Marine Science and Application, 14(3), pp.244–249. Available at: http://dx.doi.org/10.1007/s11804-015-1314-x.

Martelli, M. et al., 2013. Controllable pitch propeller actuating mechanism, modelling and simulation. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 228(1), pp.29–43. Available at: http://dx.doi.org/10.1177/1475090212468254.

Marten, D. and Wendler, J., 2013. QBlade Guidelines.

Muralikrishna, I.V. & Manickam, V., 2017. Principles and Design of Water Treatment. Environmental Management, pp.209–248. Available at: http://dx.doi.org/10.1016/b978-0-12-811989-1.00011-7.

Nowruzi, H., Ghassemi, H. & Ghiasi, M., 2017. Performance predicting of 2D and 3D submerged hydrofoils using CFD and ANNs. Journal of Marine Science and Technology, 22(4), pp.710–733. Available at: http://dx.doi.org/10.1007/s00773-017-0443-0.

Rediniotis, O.K. et al., 2002. Development of a Shape-Memory-Alloy Actuated Biomimetic Hydrofoil. Journal of Intelligent Material Systems and Structures, 13(1), pp.35–49. Available at: http://dx.doi.org/10.1177/1045389x02013001534.

Richard, H.A. & Sander, M., 2016. Fatigue Crack Growth. Solid Mechanics and Its Applications. Available at: http://dx.doi.org/10.1007/978-3-319-32534-7.

Rumsey, C., Smith, B., and Huang, G., (2019). Turbulence modeling resource. http://turbmodels.larc.nasa.gov. Last visited December 1, 2019.

Rychlewski, J., 1984. On Hooke's law, Journal of Applied Mathematics and Mechanics, 48(3), pp. 303–314. Available at: https://doi.org/10.1016/0021-8928(84)90137-0.

Seo, J.H. et al., 2010. Flexible CFD meshing strategy for prediction of ship resistance and propulsion performance. International Journal of Naval Architecture and Ocean Engineering, 2(3), pp.139–145. Available at: http://dx.doi.org/10.2478/ijnaoe-2013-0030.

Shih, T.-H. et al., 1995. A new k-ϵ eddy viscosity model for high reynolds number turbulent flows. Computers & Fluids, 24(3), pp.227–238. Available at: http://dx.doi.org/10.1016/0045-7930(94)00032-t.

Siemens, 2017. STAR-CCM+® Documentation Version 12.06. Availkable at: https://www.plm.automation. siemens.com/global/en/products/simcenter/STAR-CCM.html.

Sun, Z., Mao, Y. & Fan, M., 2021. Performance optimization and investigation of flow phenomena on tidal turbine blade airfoil considering cavitation and roughness. Applied Ocean Research, 106, p.102463. Available at: http://dx.doi.org/10.1016/j.apor.2020.102463.

Tangorra, J. et al., 2011. Use of Biorobotic Models of Highly Deformable Fins for Studying the Mechanics and Control of Fin Forces in Fishes. Integrative and Comparative Biology, 51(1), pp.176–189. Available at: http://dx.doi.org/10.1093/icb/icr036.

Van, S.-H. et al., 2011. The Propulsion Committee in Proceedings of 26th ITTC – Volume I, pp. 61–121. Available at: https://ittc.info/media/5518/04.pdf.

Xie, N. & Vassalos, D., 2007. Performance analysis of 3D hydrofoil under free surface. Ocean Engineering, 34(8-9), pp.1257–1264. Available at: http://dx.doi.org/10.1016/j.oceaneng.2006.05.008.

Xu, G.D. et al., 2020. The free surface effects on the hydrodynamics of two-dimensional hydrofoils in tandem. Engineering Analysis with Boundary Elements, 115, pp.133–141. Available at: http://dx.doi.org/10.1016/j.enganabound.2020.03.014.

Dynamic Mechanics of Rigid Helicopter Systems During Ditching

Mohamad Abu Ubaidah Amir Abu Zarim[a], Marja Azlima Omar[b]

Aircraft and helicopter often fly above open waters and thus have to observe regulations to ensure safe water landing under emergency conditions. This practice is also referred to as ditching - one of several types of slamming problems that are under review by the current regulations of the Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA). Ditching is related to the controlled landing on water, with distinctive features such as hydrodynamic slamming loads, complex hydromechanics at tremendous forward speeds, as well as the interaction of multiphase fluid dynamics (air, water, and vapor). This paper presents the knowledge on system mechanics during helicopter ditching. The discussion begins with the fundamental kinetics of the rigid body, and then delves into dynamic relations to describe the effect of forces on motions. In the end, the paper discusses several relevant theories to further contribute to the understanding of the problem of impact.

KEY WORDS
~ Helicopter ditching
~ Water entry
~ Mechanics of ditching

a. Universiti Pertahanan Nasional Malaysia, Malaysia
e-mail: amir.a@upnm.edu.my
b. Universiti Malaysia Sabah, Malaysia
e-mail: mazlima5@gmail.com

doi: 10.7225/toms.v10.n02.013

Received on: 20.05.2021/ Revised on: 28.07.2021/ Accepted on: 01.08.2021/ Published: 21.10.2021

1. INTRODUCTION

Aircraft and helicopters often fly above open waters and thus have to observe regulations that ensure safe water landing under emergency conditions, also referred to as ditching. This is particularly important for helicopters that are commonly used to support marine tasks, e.g. serve offshore platform. Ditching is related to controlled landing on water, and has some distinctive features, namely, hydrodynamic slamming loads, complex hydromechanics at tremendous forward speeds, and the interaction of multiphase fluid dynamics (air, water, and vapor).

The study of ditching dates back to Von Karman (Von Kármán, 1929) and Wagner (Wagner, 1932). Numerous studies have since considered a two-dimensional cross-section of a simple shape (wedge, cone, sphere, and cylinder) assuming that the structure is a rigid body. The water is generally modeled as an incompressible, irrotational, inviscid fluid. In early days, slamming during ship operation was the most explored design problem related to water impact.

Since slamming involves interaction between a structure and a free-surface fluid, research has expanded to other water entry problems such as water landing of solid rocket boosters and spacecraft, the ditching and water landing of aircraft, ballistic impacts on fuel tanks, and other applications (S. Abrate, 2013). This paper emphasized only principles relevant for further understanding of the current knowledge of helicopter ditching. Further in-depth review of hull slamming and water entry is provided in (Abrate, 2013).

2. BACKGROUND

2.1. Inertial Dynamics of Helicopters

2.1.1. Reference System

The mock-up moves with six degrees of freedom (DOF). Thus, its motion is defined using three coordinates for translations and three coordinates for rotations. The axis systems considered are explained below (see Figure 1):

- Earth-fixed frame (0-frame) (O, X_{ref}, Y_{ref}, Z_{ref}) is a right-handed orthogonal reference frame fixed to the earth and considered Galilean. Positive X_{ref} and Y_{ref} are orthogonal in the horizontal plane and Zref is positive towards up. Origin O is located on calm water surface.
- Body-fixed frame for motion equations (b-frame) This reference frame is fixed to the body where G is the Center of Gravity COG (G, x_b, y_b, z_b). Positive xb is pointed backwards from the nose, positive y_b points starboard and positive z_b points upwards. This frame is used to define the orientation of main particulars during free flight and impact. The translations in the study are monitored through the motions of G in the 0-frame.

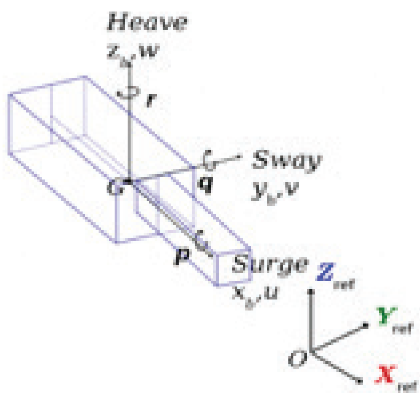


Figure 1.
Notation and sign convention description.

2.1.2. Vector Notation

The mathematical notation that allows the identification of position, velocity and acceleration points of interest for the mock-up had to be devised to express them in different frames, e.g. generic point of interest p in the mock-up (in this explanation, p and f are only used to describe the sample notation, and are unrelated to any notation in Figure 1).

- r_p^f denotes the position of p with respect to frame f:

$$r_p^f = x_p^f f_x + y_p^f f_y + z_p^f f_z \begin{bmatrix} x_p^f \\ y_p^f \\ z_p^f \end{bmatrix} = [x_p^f, y_p^f, z_p^f]^T \tag{1}$$

- v_p^f and v_p^f denote the velocity and acceleration of p with respect to frame f.
- Θ_{ob} is a vector of Euler angles that transport the 0-frame into the orientation of the b-frame.
- ω_{ob}^b denotes the relative angular velocity of the b-frame with respect to the 0-frame, decomposed in the b-frame.
-

2.1.3. Motion Coordinates and Reference Frames

The earth-fixed position of the mock-up is defined by the original coordinates of the b-frame, G relative to the 0-frame:

$$r_G^0 = \begin{bmatrix} x_G \\ y_G \\ z_G \end{bmatrix} \tag{2}$$

The mock-up attitude orientation is defined by the orientation of the b-frame relative to the 0-frame, which is presented by three intrinsic rotations that take the 0-frame into the b-frame defined roll Φ, pitch θ, and yaw Ψ. These rotations are called Tait-Bryan angles or Euler angles and are defined as:

$$\Theta_{ob} = \begin{bmatrix} \psi \\ \theta \\ \Phi \end{bmatrix} \tag{3}$$

Therefore, the position orientation vector is defined as:

$$\eta = \begin{bmatrix} R_G^0 \\ \Theta_{ob}^b \end{bmatrix} = [x_G, y_G, z_G, \psi, \theta, \Phi]^T \tag{4}$$

while the linear and angular velocity vector of the mock-up are conveniently expressed in the b-frame as:

$$v = \begin{bmatrix} v_G^b \\ \omega_{ob}^b \end{bmatrix} = [u, v, w, p, q, r]^T \tag{5}$$

where $v_G^b = [u, v, w]^T$ is the linear velocity of point G expressed in the b-frame, and $\omega_{ob}^b = [p, q, r]^T$ is the angular velocity of the b-frame with respect to the 0-frame expressed in the b-frame.

The velocity v^0 of any point of the solid in the galilean frame is expressed with $v^0 = v_G{}^b + \omega_{ob}{}^o \times r^b$.

2.1.4. Velocity transformations

Vector coordinates between different frames can be transformed by using appropriate matrices. According to (T. Perez, 2005), generic vector t can be depicted either in frame 0 or in frame b as:

$$t = \begin{bmatrix} x_t^0 \\ y_t^0 \\ z_t^0 \end{bmatrix}^0 = \begin{bmatrix} x_t^b \\ y_t^b \\ z_t^b \end{bmatrix}^b \tag{6}$$

This led to the transformation matrix with notation $R_b{}^0(\Theta_{ob})$ which can be expressed in the b-frame to the 0-frame as:

$$t^0 = R_b{}^0(\Theta_{ob}) . t^b \tag{7}$$

where rotation matrix $R_b{}^0(\Theta_{ob})$ is obtained by three consecutive rotations around the principal axes:

$$R_b{}^0(\Theta_{ob}) = R_{x,\Phi} R_{y,\theta} R_{z,\psi} \tag{8}$$

where (T. Perez, 2005):

$$R_{x,\Phi} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\Phi & -s\Phi \\ 0 & s\Phi & c\Phi \end{bmatrix},$$

$$R_{y,\theta} = \begin{bmatrix} c\theta & 0 & s\theta \\ 0 & 1 & 0 \\ -s\theta & 0 & c\Phi \end{bmatrix}, \tag{9}$$

$$R_{z,\psi} = \begin{bmatrix} c\psi & -s\psi & 0 \\ s\psi & c\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R_b{}^0(\Theta_{ob}) = \begin{bmatrix} c\psi c\theta & -s\psi c\theta + c\psi s\theta s\Phi & s\psi s\Phi + c\psi c\theta s\Phi \\ s\psi c\theta & c\psi c\Phi + s\Phi s\theta s\psi & -c\psi s\Phi + s\Phi c\Phi s\theta \\ -s\theta & c\theta s\Phi & c\theta c\Phi \end{bmatrix}$$

where c=cos , s=sin and t=tan. Thus:

$$R_b{}^0(\Theta_{ob}) = R_0{}^b(\Theta_{ob})^{-1} R_b{}^0(\Theta_{ob})^b \tag{10}$$

The transformation of velocities of the center of gravity is expressed in the b-frame (u,v,w), while the time derivative of the position in the 0-frame can be expressed as:

$$\begin{bmatrix} \dot{x}_G \\ \dot{y}_G \\ \dot{z}_G \end{bmatrix}^0 = R_b{}^0(\Theta_{ob}) = \begin{bmatrix} u \\ v \\ w \end{bmatrix} \tag{11}$$

Angular velocity vector $\omega_{ob}{}^b$ in the fixed-body frame, b-frame related to the time rate of change of Euler angles Θ_{ob} can be expressed as:

$$\dot{\Theta}_{ob} = T_\Theta(\Theta_{ob}) \cdot \omega_{0b}{}^b \quad or \quad \begin{bmatrix} \dot{\Phi} \\ \dot{\Theta} \\ \dot{\psi} \end{bmatrix} = (T_\Theta \Theta_{ob}) \begin{bmatrix} p \\ q \\ r \end{bmatrix} \tag{12}$$

where $T_\Theta(\Theta_{ob})$ is the transformation matrix and its inverse given by:

$$T_\Theta(\Theta_{ob}) = \begin{bmatrix} 1 & s\theta t\theta & c\Phi t\theta \\ 0 & c\Phi & -s\Phi \\ 0 & s\Phi/c\theta & c\Phi/c\theta \end{bmatrix}$$

$$T_\Theta(\Theta_{ob})^{-1} = \begin{bmatrix} 1 & s\theta t\theta & -s\theta \\ 0 & c\Phi & c\theta s\Phi \\ 0 & -s\theta & c\Phi/c\theta \end{bmatrix} \tag{13}$$

Transformation matrix $T_\Theta(\Theta_{ob})$ can be derived from (T. Fossen, 2002):

$$\omega_{0b}{}^b = \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} \dot{\Phi} \\ 0 \\ 0 \end{bmatrix} + R_{x,\Phi}{}^T \begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + R_{x,\Phi}{}^T R_{y,\theta}{}^T \begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix} = T_\Theta(\Theta_{ob})^{-1} \Theta_{ob} \tag{14}$$

2.2. Linear Momentum

General definition of momentum p of the solid R is given as:

$$p = \int_R v^0 \, dm \tag{15}$$

where v^0 is the velocity of elementary element dm in the Galilean reference frame. Momentum at the center of gravity can be established as:

$$p = \int_R v \, dm = \int_R \frac{dr^0}{dt} dm = \frac{d}{dt} \left(\int_R r^0 \, dm \right) = \frac{d}{dt} \left(m r_G^{\,0} \right) \tag{16}$$

where

$$\frac{d}{dt} \left(m r_G^{\,0} \right) = m v_G^{\,0} \tag{17}$$

Notice that the time derivative in Equation (16) was placed outside the integral whose region of integration R is time-dependent. This intervention is justified because the center of gravity of a rigid body behaves as a material point, as explained in (O'Reilly, 2019; Casey,1983).

2.3. Angular Momentum and Moment of Inertia

The angular momentum of a rigid body relative to its center of gravity and the fixed origin of the reference 0-frame, 0 are denoted respectively as h and h_0. By definition:

$$h = \int_R r^b \times v^0 \, dm, \; h_0 = \int_R r^0 \times v^0 \, dm \tag{18}$$

Expanding the angular momentum h:

$$\begin{aligned} h &= \int_R r^b \times (v_G^{\,0} + \omega_{0b}^{\,b} \times r^b) \, dm \\ &= \int_R r^b \times v_G^{\,0} \, dm + \int_R r^b \times (\omega_{0b}^{\,b} \times r^b) \, dm \\ &= \int_R r^b \times (\omega_{0b}^{\,b} \times r^b) dm \end{aligned} \tag{19}$$

Expanding the angular momentum h_0:

$$h_0 = \int_R r^0 \times v^0 \, dm = \int_R (r_G^{\,0} + r^b) \times v^0 \, dm = h + r_G^{\,0} \times p \tag{20}$$

Equation (19) can also be rewritten as:

$$\begin{aligned} h &= \int_R r^b \times (\omega_{0b}^{\,b} \times r^b) dm \\ &= \int_R ((r^b \cdot r^b)\, \omega_{0b}^{\,b} - (r^b \cdot \omega_{0b}^{\,b})\, r^b) \, dm \end{aligned} \tag{21}$$

Using

$$r_b = \begin{bmatrix} x_b \\ y_b \\ z_b \end{bmatrix}^{0b} \tag{22}$$

The expression can be developed into

$$h = \omega_{0b}^{\,b} \int_R (x_b^{\,2} + y_b^{\,2} + z_b^{\,2}) \, dm + \int_R r^b (x_b p + y_b q + z_b r) dm$$

$$= \int_R \begin{bmatrix} (y_b^{\,2} + z_b^{\,2}) & -x_b y_b & -x_b z_b \\ -x_b y_b & (x_b^{\,2} + z_b^{\,2}) & -y_b z_b \\ -x_b z_b & -y_b z_b & (x_b^{\,2} + y_b^{\,2}) \end{bmatrix} \omega_{0b}^{\,b} \tag{23}$$

where the matrix of inertia with respect to the center of gravity $I_g^{\,b}$ appears:

$$h = I_g^{\,b} \, \omega_{0b}^{\,b} \tag{24}$$

2.4. Newton/ Euler Second Law

Mock-up motions in 3 degrees of freedom (DOF) were therefore computed by applying the standard Euler's law to the b-frame with the G (G, x_b, y_b, z_b) coinciding with the COG. The inertia matrix remains constant when a reference frame is fixed to the body. However, the frame of reference now rotates with angular velocity $\omega_{0b}{}^{b}$, resulting in:

$$\frac{dP}{dt} = m\left(\frac{dv_G{}^b}{dt} + \omega_{0b}{}^b \times v_G{}^b\right) = F_b \tag{25}$$

$$\frac{dh}{dt} = I_g{}^b\left(\frac{d\omega_{0b}{}^b}{dt} + \omega_{0b}{}^b \times I_g{}^b v_G{}^b\right) = M_b \tag{26}$$

Where m is mass, while $F_b = (F_x, F_y, F_z)$ and $M_b = (M_x, M_y, M_z)$ are the vectors of force and moment acting on the mock-up. The vector of force, moment and translational velocity in the body-fixed reference b-frame can be transformed into their counterparts in the earth-fixed reference frame, 0-frame, as follows:

$$F_0 = R_b{}^0(\Theta_{0b})\, F_b \tag{27}$$

$$M_0 = R_b{}^0(\Theta_{0b})\, M_b \tag{28}$$

$$v_0 = R_b{}^0(\Theta_{0b})\, v_G{}^b \tag{29}$$

2.5. Energy Conservation

The definition of the kinetic energy for the solid (mock-up) is given by:

$$E_{ks} = \frac{1}{2}\int_R v^2\, dm \tag{30}$$

when preceding definitions are applied, we get:

$$E_{ks} = \frac{1}{2}\, mv_G{}^b . v_G{}^b + \frac{1}{2}\, \omega_{0b}{}^b . I_G{}^b \omega_{0b}{}^b \tag{31}$$

2.6. Fluid Force on the Body

The force exerted on the body by the fluid is given by the integral of the local stress T over the surface:

$$E_{fluid} = \iint_S T\, dS \tag{32}$$

This can also be expressed by using the Cauchy stress tensor:

$$E_{fluid} = \iint_S \bar{\bar{\sigma}}\, ndS \tag{32}$$

The Cauchy stress tensor can be decomposed in $\bar{\bar{\sigma}} = -p\,\bar{\bar{I}} + \bar{\bar{\tau}}$, with p being the local pressure, $\bar{\bar{\tau}}$ the viscous stress tensor and n is a normal pointing outward of the body.

3. SIMPLIFIED SOLUTIONS FOR WATER ENTRY OF RIGID BODIES

Von Karman (Von Kármán, 1929) and Wagner (Mizoguchi and Tanizawa, 1996; Wagner, 1932) developed two simplified theories on the impact of rigid bodies on the free surface of a fluid. Both theories are widely used and have provided useful insight into impact dynamics. Their description of the issue of 2-dimensional water entry in calm waters is illustrated below.

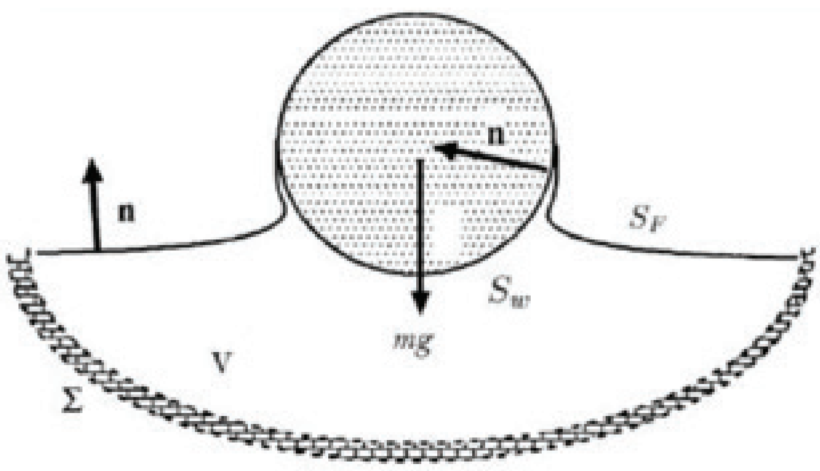


Figure 2.
Vertical impact.

This section examines body movement inside a fluid domain having volume V, limited by surface $S = S_w S_F \Sigma$, where S_w is wetted body surface, S_F is fluid surface, and Σ is a patch in the water. The problem is illustrated in Figure 2.

3.1. Von Karman's Approach

When the Newton/Euler 2nd law Equation (25) is applied to this problem, the external forces F_b are the sum of the forces exerted by fluid F_{fluid} and the weight mg. To evaluate F_{fluid} using Equation (33) we need to know the stress across the body surface. Von Karman decomposed F_{fluid} as the sum of the hydrodynamic impact force F_I, buoyancy force F_B, steady-state drag force F_D, and capillary force F_C. The motion equation can be written using Newton's second law as (S. Abrate, 2013):

$$mv = mg - F_I - F_B - F_C - F_D \quad (34)$$

v is velocity penetration relative to undisturbed water surface, where an overdot stands for the time derivative. During penetration, virtual mass M (added mass) of the fluid is considered to move with the body, so that the force applied by the fluid on the wetted surface of the body is equal and opposite to the force applied by the body on the fluid. The motion of the added mass is governed by:

$$F = \frac{d}{dt} Mv = Mv + \frac{dM}{d\zeta} v^2 \quad (35)$$

If Equation (35) is substituted with Equation (34) the following expression is obtained:

$$\frac{d}{dt} [(m + M) v] = mg - F_B - F_c - F_D \quad (36)$$

With respect to the water entry problem, since the impact is rapid, water surface elevation, the effect of surface tension and the effect of viscosity and gravity on hydrodynamics of the fluid can be assumed to be very small and hence negligible. The motion in Equation (36) is then deduced as follows:

$$\frac{d}{dt} (m + M) v = 0 \quad (37)$$

Given that t = 0 is initial at impact, added mass M = 0, $\dot{\zeta}(0)=v_0$, where v_0 is initial impact velocity. Integration with respect to time expresses the conservation of linear momentum throughout the water entry:

$$mv_0 = (m+M)v \quad or \quad v = \frac{mv_0}{m+M} \tag{38}$$

The development of Von Karman's approach is shown in the next subsection, in term of added mass. However, the impact load and added mass are likely to be underestimated, particularly for a small deadrise angle since this model neglects water surface elevation, as stated in (Mizoguchi and Tanizawa, 1996).

3.1.1. In terms of added mass

Impact transfers energy from the solid body to the fluid. When the integration from Newton's law is applied, the impulse-momentum principle can be determined as:

$$\int_{t_1}^{t_2} \frac{d}{dt}(Mv)dt = \int_{t_1}^{t_2} F\, dt_i\, (Mv)_2 - (Mv)_1 = \int_{t_1}^{t_2} F\, dt \tag{39}$$

where M is added mass. The added mass is obtained from kinetic energy E_{kf} of the fluid in motion (volume V), as follows:

$$M = \frac{2E_{kf}}{v^2} = \frac{\rho_{kf}}{v^2} \iiint_V (\nabla \Phi)^2\, dV \tag{40}$$

When the last expression is transformed using Green's theorem and surface S around volume V, the following expression is obtained:

$$M = \frac{-\rho}{v^2} \int_S \Phi \frac{\partial \Phi}{\partial n}\, dS \tag{41}$$

Given the complexity of each initial condition, defining the energy balance during impact is useful. The changes of kinetic energy exerted on the structure are as follows:

$$\Delta E_{ks} = \frac{1}{2} m\,(v_0^{\,2} - v^{\,2}) = \frac{1}{2} mv_0^{\,2} \frac{m(2m+M)}{(m+M^2)} \tag{42}$$

while the changes of kinetic energy exerted on the fluid can be expressed as:

$$\Delta E_{kf} = \frac{1}{2} Mv^{\,2} = \frac{1}{2} mv_0^{\,2} \frac{mM}{(m+M)^2} \tag{43}$$

At t=0, added mass M=0 and v_0 is velocity at impact.

$$\frac{\Delta E_{kf}}{\Delta E_{ks}} = \frac{m}{2m+M} \tag{44}$$

3.2. Wagner's Approach

Disregarding gravity and friction on the body surface, Wagner derived a more rational water impact theory that includes the hydrodynamic effect of small deadrise angles as discussed in (Abrate, 2013; Mizoguchi and Tanizawa, 1996). The hydrodynamic force is obtained from the pressure acting on the wetted surface S_w of the body as follows:

$$F_{fluid} = -\int_{S_w} p\, ndS \tag{44}$$

where p is pressure and n is an outside normal of the body of the surface element dS. Fluid flow is governed by Navier-Stokes equations on the conservation of momentum and the continuity equations; both have an important connection with the fluid velocity field v.

During impact, flow can be considered irrotational and incompressible. First condition is that ($\nabla \times v = 0$) and velocity can be written in terms of potential function Φ:

$$v = \nabla \Phi \tag{45}$$

With Incompressibility, the continuity equation becomes $\nabla.v=0$. Hence Equation (45) can be rewritten as a Laplace's equation:

$$\nabla.v = \nabla.(\nabla \Phi) = \nabla^2 \Phi = 0 \tag{46}$$

When Equation (45) is substituted with Navier-Stokes equations on the conservation of momentum, and the effects of viscosity and gravity are disregarded, Bernoulli's equation is obtained:

$$\frac{P}{\rho} = \frac{\partial \Phi}{\partial t} - \frac{1}{2}(\nabla \Phi . \nabla \Phi) \tag{47}$$

which establishes a connection between pressure p and velocity potential Φ. However, identifying a potential function that meets both Laplace's and boundary conditions (should consist of wetted surface S_w and free surface S_F, both of which are unknown) is problematic. The velocity of the body v_b and the fluid are the same in the normal direction on the wetted surface, thus:

$$v.n = v_b.n \tag{48}$$

On the wetted surface, the velocity of the fluid in the normal direction can be expressed as $\frac{\partial \Phi}{\partial n} = v \cdot n$. Given that the pressure on the free surface = 0:

$$\frac{\partial \Phi}{\partial n} + \frac{1}{2}(\nabla \Phi . \nabla \Phi) = 0 \tag{49}$$

Hence the force on the body in Equation (44) can be obtained using Bernoulli's equation:

$$F_{fluid} = -\rho \int_{S_W} \left(\frac{\partial \Phi}{\partial n} + \frac{1}{2}(\nabla \Phi . \nabla \Phi)\right) ndS \tag{50}$$

Wagner gave us a water impact theory that takes the hydrodynamic effect into account (S. Abrate, 2013; S. Mizoguchi and K. Tanizawa, 1996). Wagner's model is shown in Figure 3, where c is the half width of the wet area, β is the deadrise angle, and v_p the velocity of the point of impact. In this model, also known as Wagner's expansion model, distance c increases with the depth of penetration.

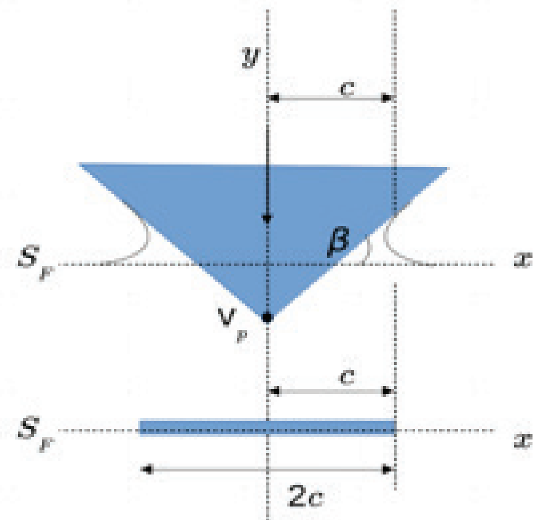


Figure 3.
Wedge entering the water (top) and Wagner's expansion model (bottom).

In two dimensions, the body is replaced with a flat plate having the length 2c. The velocity vector is given as:

$$v = \nabla \Phi = \frac{\partial \Phi}{\partial x} i + \frac{\partial \Phi}{\partial y} j \tag{51}$$

While Wagner's potential is expressed as:

$$\Phi = -v_p \sqrt{(c^2 - z^2)} \quad where \quad z = x + iy \tag{52}$$

The horizontal component of velocity along the plate given in (|x|<c,y=0) is

$$\frac{\partial \Phi}{\partial x}(x, 0) = v_p \frac{x}{\sqrt{(c^2 - z^2)}} \tag{53}$$

while the vertical component of velocity is zero along the bottom surface of the plate. Notice that the velocity of the fluid v is zero in the center (x=y=0) and becomes infinite along the edge (x=c,y=0). Hence, when Bernoulli's equation is applied in Equation (47), pressure along the bottom plate is obtained as follows:

$$\frac{p(x)}{\rho} = \frac{\partial \Phi}{\partial x}\left(v_p\sqrt{c^2-x^2}\right) - \frac{1}{2}\left(v_p\frac{x}{\sqrt{(c^2-x^2)}}\right)^2 \quad (54)$$

Since the length of the bottom plate and velocity vary with time,

$$\frac{p(x)}{\rho} = \sqrt{c^2-x^2}\frac{dv_p}{dt} + v_p\frac{c}{\sqrt{(c^2-x^2)}}\frac{dc}{dt} - \frac{1}{2}\frac{v_p^2x^2}{\sqrt{(c^2-x^2)}} \quad (55)$$

Examine the equation on the right-hand side; given that $x \to c$, the first term tends to be zero, while the others become infinite. At the maximum penetration, when $v_p = v$:

$$c(t) = \left(\frac{\pi}{2}\right)\left(\frac{v(t)}{\tan\beta}\right) \text{ hence } \frac{dc}{dt} = \frac{\pi v_p \cot\beta}{dt} \quad (56)$$

If substituted and simplified, the following expression is obtained:

$$p(x) = \frac{1}{2}\rho v_p^2\left[\frac{\pi\cot\beta}{\sqrt{1-x^2/c^2}} - \frac{x^2/c^2}{1-x^2/c^2} + \frac{2v_p}{v_p^2}\sqrt{c^2-x^2}\right] \quad (57)$$

where c is the half width of the wet area, β is the deadrise angle, and v_p the velocity of the expanding flat plate in the uniform flow. Numerous studies have been conducted based on this theory, but only a few explored the issue in 3-dimensions, particularly in ship application, which is theoretically understood. Therefore, there is a need for 3-dimensional ditching theories and numerical methods.

4. CONCLUSION

This paper has presented fundamental equations required to calculate force during helicopter ditching events. Fixed and mobile reference systems for the issue of ditching have been introduced, together with mechanics equations useful for experiment analysis. Some information on water impact theories available have been given, while Von Karman's and Wagner's theories have been succinctly described. It was shown that impact load can be evaluated using the concept of added mass in either momentum or energy analysis without any contradiction. After impact, the body's mechanical energy is transferred to the fluid.

ACKNOWLEDGEMENT

Authors would like to thank Universiti Pertahanan Nasional Malaysia for grant UPNM/2021/GPJP/STG/1.

REFERENCES

Abrate, S., 2011. Hull Slamming. Applied Mechanics Reviews, 64(6). Available at: http://dx.doi.org/10.1115/1.4023571.

Casey, J., 1983. A Treatment of Rigid Body Dynamics. Journal of Applied Mechanics, 50(4a), pp.905–907. Available at: http://dx.doi.org/10.1115/1.3167171.

Fossen, T., 2002. Marine control systems: guidance, navigation and control of ships, rigs and underwater vehicles. Norwegian University of Science and Technology Trondheim, Norway.

Mizoguchi, S., and Tanizawa, K., 1996. Impact wave loads due to slamming. A Review Ship Technology Research, 43.

O'Reilly, O.M., 2019. Engineering Dynamics, 3rd Edition. Springer.

Payne, P.R., 1993. The spray sheets produced during vertical wedge impact and steady planing. Ocean Engineering, 20(3), pp.247–261. Available at: http://dx.doi.org/10.1016/0029-8018(93)90023-b.

Perez, T., 2005. Ship Motion Control: Course Keeping and Roll Stabilization Using Rudder and Fins. series Advances in Industrial Control. Springer.

Von Kármán, T., 1929. The impact on seaplane floats during landing. National Advisory Committee on Aeronautics, Washington, DC.

Wagner, H., 1932. Über Stoß- und Gleitvorgänge an der Oberfläche von Flüssigkeiten. ZAMM - Zeitschrift für Angewandte Mathematik und Mechanik, 12(4), pp.193–215. Available at: http://dx.doi.org/10.1002/zamm.19320120402.

Content Analysis of International Standards for Human Factors in Ship Design and Operation

Farizha Ibrahim, Mohd Norsyarizad Razali, Noh Zainal Abidin

Human-related factors account for more than 80% of accidents at sea, based on studies. According to Global Claims Review 2017 released by Allianz Global Corporate & Specialty, an estimated 75-96% of shipping accidents have a high probability of involving human error (AGCS, 2017). Designs that do not meet human factors' needs play a significant role in contributing to human error. Documents in terms of design standards and guidelines, rules, and laws are analyzed. As a result, several documents related to human factors have been identified. These documents are based on whether to implement it, even if some are prescriptive, and others are mandatory, being published at different enforcement levels. In ensuring the consistent implementation of human factors, regulators and authorities need to take stricter measures in all the processes involved in designing and building such ships.

KEY WORDS

~ Human Factor, Ship Design
~ American Bureau of Shipping (ABS)
~ Lloyd's Register (LR)
~ Det Noske Veritas (DNV)
~ International Organisation for Standardization (ISO)
~ International Maritime Organization (IMO)
~ American Society for Testing and Materials (ASTM)

National Defence University of Malaysia, Faculty of Science and Defence Technology, Kuala Lumpur, Malaysia

e-mail: farizha@upnm.edu.my

doi: 10.7225/toms.v10.n02.014

Received on: 28.06.2021/ Revised on: 17.10.2021/ Accepted on: 18.10.2021/ Published: 21.10.2021

1. INTRODUCTION

This journal describes how ship design covers aspects of human factors. Generally, 75-96% of shipping accidents have a high probability of human error (AGCS, 2017; McAfferty & Baker, 2006). This study aims to enhance appreciation of the cause of maritime accidents in terms of the role of human factors.

Results from poor management, maintenance of faults, incorrect installation, imperfect design, and the system's weaknesses are factors that tend to make the user a victim (Muschara, 2017). Therefore, user-centred design is vital in integrating non-engineering design disciplines into marine engineering during building of ships (Ahola, Murto & Mallam, 2018).

Human factor elements are on the bottom of interest in Corporate social responsibility (CSR) for the top 15 shipping companies, which control 80% global container shipping market, even though it is an exciting issue (Tang & Gekara, 2020). Imposing disciplinary action on any accidents at work, giving speeches and encouragement to work more safely, adding manuals or written procedures, or providing additional training will not overcome human errors caused by weaknesses in workplace design (Dekker, 2017; Ross, 2017). To find out the design is human friendly and good, three methods can be used:

Accepting the design, the rules and regulations set by such an organization must comply with ship design. Ross also identified the rules and standards appropriate to ship design, such as hull shape, structure, engine, machine interface with human and general arrangement (Papanikolaou et al., 2019).

Relevant human factors literature was studied, and the ship design model was discovered using reference analysis. In addition, relevant codes, regulations, laws, and guidelines were

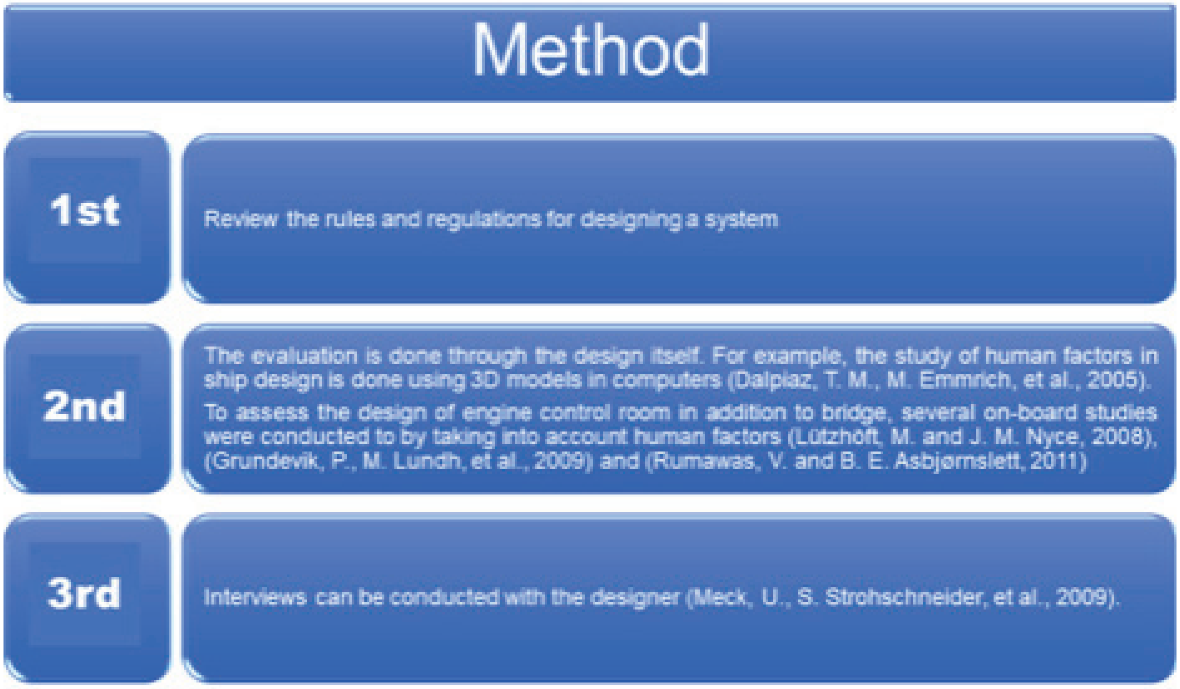


Figure 1.
Method to Measure Human Factors on Board Ships.

reviewed. The aim is to examine how human factors guidelines are provided and what things to discuss. The findings can be helpful for those engaged in ship construction and attentive in incorporating human-factors-related concepts in their design.

2. BACKGROUND AND RELATED WORKS

In this literature review, the human factor principle in ship design are established. It begins with the definition of the human factor from the investigated shipping community. Then, the ship planning stage is addressed. Finally, in the construction of ships, the application of the human element must be taken into consideration.

The word 'human element' for human factors is used and described by the International Maritime Organization (IMO, 2004) as "All aspects of human activities carried out by lawmakers, ship crews, shipyards, recognized organizations, regulatory bodies, land management, and other related parties involved in the human factor."

Human Factors and Ergonomics Society (HFES) defines human factor as "Applications related to what we understand about humans, the work they do, the environment in which they work, the characteristics and limitations of the equipment design they use and their capabilities are emphasized in the Human factor" (2020).

The human factor is also defined by The International Ergonomics Association (IEA, 2020) as "Emphasis on understanding the relationship between humans and other systems through scientific discipline that applies methods to design, data, principles, and theories, with the purpose of overall the system performance itself and optimize human wellbeing."

2.1. Ship Design Process

Ship designing is a lengthy and interrelated process, separated into several phases or stages. The design process involves developing needs, performing analysis, developing sketches and plans, building electronic models, and developing written specifications.

Figure 2.
Three major ships design process.

Current developments influence the method of dividing and naming the three major ship development processes (Trincas et al., 2018). It has later distinguished the two stages of ship design depicted in Figure 3 (Andrews, 2018):

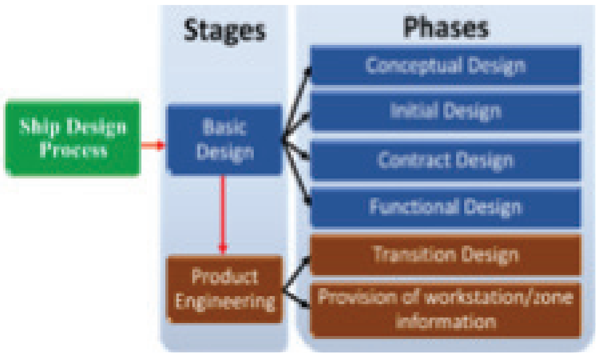


Figure 3.
Two stages of ship design.

The ship design process is divided into four phases in the book "Ship Design and Construction Textbook", as shown in Figure 4 (Papanikolaou, 2019).

The first step in this process is the mission statement, such as the area it will operate in and the type of ship to be built based on its operational nature. The longer this process, the more detailed the problems identified, e.g. HVAC diagram as well as an equipment list, installation diagram, electrical equipment, accommodation arrangement, pipe, machinery room, and machinery control room design, bridge design, ship layout, the type of machine to be installed, the type of hull to be used and the dimensions of the ship.

Any of the subjects discussed above are typical marine-based concerns, and not all issues are relevant to human factors, but may still affect their work efficiency, effectiveness, and safety.

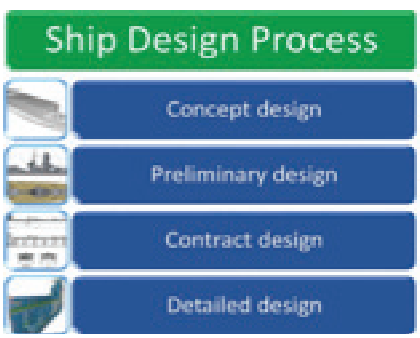


Figure 4.
Four-phase ship design process.

2.2. Human Factors in Ship Design

From acquisition until disposal, people are interested in a ship's life cycle. This process involves founders, architects-designers, registration boards, regulatory agencies, shipbuilders, manufacturers, managers/ operators of ships, sailors/unions, and insurers (Tang & Gekara, 2020). They all have distinct yet critical impacts on protection, productivity, and effectiveness. In addition, all regulatory authorities play a significant function and can have an extensive safety effect.

The maritime administration's role, serving as the national controller of the ship's flag, is to ensure conformity with the regulations (Χαζίζα, 2019). The classification authority shall set criteria and technical rules. However, they still must guarantee that the building and specifications are up to par. The designation authority has been traditional to conduct regulator roles as the flag state. Much of this information is stipulated in the specifications and recommendations that prioritize human factors to reduce design costs.

According to Rawson and Tupper, the human aspect in architecture is protected by a team with vast knowledge and experience, such as psychologists, physiologists, mechanics, and physicists who make up the squad. This human-factors team will inform engineers about how to build structures or facilities. As a result, individuals can execute activities more reliably, increase machine quality, improve human output, and have an eventual degree of environmental parameters (Trincas et al., 2018).

In a ship design and construction book published by the SNAME (Society of Naval Architects and Marine Engineers), human factor is considered as a descriptive concept encompassing all facets of the system's biomedical and psychological considerations that occur to humans. Human factors are often listed, including life support and human engineering, worker's selection, facilities for training and preparation, job equipment, as well as achievement assessment and appraisal. Human factor engineering is separately specified in ship construction. Human factor engineering incorporates strategies to assess the role of humans in dynamic environments, simulation, and modelling of human resources reduction, crew workloads, assessment of workloads for operator/maintenance, decision-making tools to minimize human error and injuries, to increase human efficiency and protection and advanced human-machine interfaces, as well as approaches and data for ship design (Charlton & O'Brien, 2019).

Lloyd's Register (LR) identifies human variables as relevant to the activities they undertake and the context in which they operate (Lloyd's register, 2008). The word human factor signifies, as used for the construction, the function of a ship and its structures, taking human ability, expertise, weaknesses, needs into account and human usage as part of the system. The human factor describes the work environment's analysis and design for the value of protection, performance, productivity, health, and comfort. Shipyards, equipment control rooms, galleys, and elements relevant to work processes and procedures provide work conditions. For any ship to run safely and efficiently, it must be built to serve the persons on board without risking their wellbeing, protection, and efficiency.

In ship design, nine human factors describe motion, vision, sound, climate, safety and health, human-machine interface (Charlton and O'Brien, 2019). Concerning human factors, LR consistently identifies many different concept qualities. This concept involves the following (Lloyd's register, 2008):

Habitability - is the availability of sufficient and convenient living space, including furniture and laundry services, galleys, and room for leisure. In terms of scale, form, gender, and different environmental pressures, such as noise, heat, and vibration, this provision must consider multiple marine differences.

Maintenance - arranging the production of maintenance activities to be fast, secure, and practical, enabling systems and equipment to reach a defined standard of achievement. It involves entry concerns, removing paths, instruments, skills, disposal, and lifetime help.

Workability - customers, activities, facilities (including some software), material, processes, and the physical and social setting.

Controllability - planning the layout of ship control centres, machinery control spaces, freight control rooms, considering the integration of personnel and facilities, devices and interfaces, such as contact equipment, monitors, screens, computer stations, video monitoring units, and alarms.

Manoeuvrability - has suitable manoeuvrability for the ship's position and operating ability, including the propulsion systems, steering arrangements, including the output of shaft arrangements.

Survivability - is the fire protection facilities, damage management, and life-saving provision.

3. METHODOLOGY

Systematic literature review methods such as reference analysis are needed to determine how human factors are accepted in ship design, such as regulations, rules, specifications, and recommendations.

3.1. Content Analysis

Content analysis is a study tool to draw inferences that can be copied and checked in the sense of its usage from available models or data (Cohen et al., 2017). Neuendorf, Leedy & Omron characterize content analysis as a comprehensive, systematic, thorough evaluation and explanation of relevant literature to find trends, meanings, prejudices, and themes (Kyngäs, 2020). In a quantitative study, the content analysis may be implemented deductively, resulting in groups' frequency of previously chosen values or values relevant to particular variables (Heidi, 2008). In order to respond to the problems in this report, this approach is considered essential. Thus, the study of material can be seen as an observation of organized and quantitative literature to see how human factors are considered in constructing ship designs and systems.

To date, there is no systematic taxonomy available in the maritime domain about human factors. LR gives the three structures the best rational and detailed framework, thus used as the fundamental framework (Lloyd's register, 2009). Measurements for coding purposes are defined and named as eight construction characteristics, as depicted in Figure 4.

Several components and facets are defined under each dimension. It realized that the system does not always follow the concept of mutually exclusive and complete code sheet development; overlap exists, and certain elements are contradictory in classifying components or aspects. Table 1, which generates the original code sheet along with the method of coding, is presented.

A code sheet was developed based on the formation of the human factor principle of ship construction. Its formation is very fluid and multi-dimensional, as depicted in Table 1.

LR Construction Characteristics
Habitability (HAB)
Maintainability (MAIN)
Workability (WORK)
Controllability (CONT)
Manoeuvrability (MANV)
Survival (SURV)
Occupational Health and Safety (OHS)
System Safety (SS)

Figure 5.
The LR eight construction characteristics.

3.2. Sample and Limitation

To illustrate the coverage of human factors in ship construction, several papers can be discussed. First, a textbook and a ship construction guidebook, as seen above in section II. A (Human Factors in Ship Design) is a credible source. Next, a significant knowledge source would be published newspapers, meeting articles, studies, bulletins, and magazines. Furthermore, the recommended protocols, criteria, laws, instructions, and procedures issued by the classification agencies are the last listed, but most important. Since they are liable for classifying ships, the classification agencies' publications may authentically portray the industry's reality.

This study focuses on construction using an international standard system. Research population identified as records, rules, regulations, or guidance provided by the related classification agencies and foreign agencies regulating certain aspects of ship design may influence human efficiency, health, or safety on board. In the study, three prominent classification organizations as samples: Det Norske Veritas (DNV), Lloyd's Register (LR), and the American Bureau of Shipping (ABS) and China Classification Society (CCS). In addition, the following organizations also have been sampled, which is ASTM, IMO, and ISO.

According to the level of research facility, only two data discovery stages were conducted. First, a detailed survey brings the list of publications in each source in the first instance. At this point, the document's title is determined. Next, a thorough reference review is conducted on each chosen document by applying a predefined code sheet covering keywords relevant to human factors.

3.3. Society for Classification

The three primary classification societies, DNV, LR, and ABS, constitute a large part of the ship classification sector and are significantly involved in the human factors considered in maritime architecture. This analysis also will include CCS due to its importance in shipping classification and acceptance by 55 major global shipping countries.

Figure 6.
Classification Societies.

Table 1.
Code sheet.

Dimension	Component	Aspect / object
Habitability (HAB)	Accommodation	Galleys, Mess Recreational Space Cabin
	Crew Variant	Size Shape Gender
	Environment Pressure	Surrounding Condition Indoor Climate Comfort, Noise, Sound Heat, Temperature Air Speed, Ventilation Air quality, smell Ship Motion Vibration Lighting
Maintainability (MAIN)	Maintenance Task	Layouts, Entrance, Exit Equipments Specialist Disposal Lifelong Support

Workability (WORK)	Users Assignment Equipment and Software Material & procedure Physical and Social Environment	Accessibility Arrangement Space
Controllability (CONT)	Control Center	Bridge Engine Control Room Combat Information Center
	System-Crew Integration Man-machine Interface	Communication Equipment Swicth and Control Display, video display unit Alarm Autamation Computer Station
Manoeuvrability (MANV)	Propulsion System Steering System Thrust	
Survivability (SURV)	Fire Fighting Damage Control Life Saving Equipments	
Occupational Health and Safety (OHS)	Impact on Work Working Environment Accomodation Condition	
System safety (SS)	Risk Assessment	

A few recommendations are presented by ABS covering problems relevant to human factors and include supplementary notes such as HAB and COMF. DNV gives extra COMF notation. In addition to the laws and regulations, LR includes CEPAC notation and allows much effort.

The four global major classification bodies are the Det Norske Veritas (DNV), Lloyd's Register (LR), American Bureau of Shipping (ABS), and China Classification Society (CCS). They display a particular interest in the human factors in naval architecture. The ABS guides resolving human factor challenges and includes supplementary notations such as Comfort (COMF) and Habitability (HAB). The DNV gives extra COMF notation. In addition to regulations and guidelines, The LR includes the Crew and Embarked Personnel Accommodation Comfort (CEPAC) notation.

3.3.1. Det Norske Veritas (2020)

DNV defines the regulations and guidelines from Ship Classification Laws, High-Speed Classification Rules, Regulatory Definition, Service Requirements, Offshore Operation Criteria, Offshore Standards, and Practices Suggested. The publications released by the DNV in Table 2 can accommodate human factors in commercial and naval vessel construction.

Not all the publications referred to in Table 2 were built on the foundation of the facets of human factors. For example, the Definition of Vibration in Part 6, Chapter 15 was rendered by considering that vibration can influence the operation of some vital equipment and machinery and cause harm to any significant arrangements. SILENT Class Notation in Chapter 24 implements the correct operation of the machinery utilized by the ship.

DNV defines the regulations and guidelines from Ship Classification Laws, High-Speed Classification Rules and Navy Ships, Regulatory Interpretation, Service Requirements, Offshore Operation Specifications, Offshore Standards, and Practices Suggested.

The publications released by the DNV in Table 3 are known to accommodate human factors in commercial and naval vessel construction.

Table 2.
The DNV Human factors related to rules for classification of ships and vessels.

Rules for Ship Classification		
Part 3	Hull and equipment – Main Class	
	Ch 3	Ship Hull and Safety Equipment
Part 4	System and Machinery – Main Class	
	Ch 9	Control and Monitoring System
	Ch 10	Fire Fighting
	Ch 14	Steering Gear
Part 5	Special Type and Class– Additional Class	
	Ch 12	Comfort Class
Part 6	Special Equipment and System Class – Additional Class	
	Ch 2	Redundancy Propulsion System
	Ch 3	Machinery Room Without Periodic Supervision
	Ch 4	Additional Fire Protection System
	Ch 8	Nautical Safety
	Ch 9	Computer Systems for Longitudinal Stability and Strength
	Ch 15	Vibration Class
	Ch 24	Notation Class SILENT

Table 3.
The remaining DNV documents taking human factors into account in the design stage.

Recommended Action	
A203	New Technology Qualifications
C205	Environmental Conditions and Environment
D102	Analysis of Failure and Impact Methods of Overlapping Systems
D201	Dependence on Integrated Software Systems

3.3.2. Lloyd's Register (2020)

The regulations and laws are divided into two classifications by the LR: energy and maritime. There are 130 documents in the maritime division, and 25 documents in the resources category. Table 4 provides the documents from the LR applicable to ship construction, focusing on human factors.

Table 4.
The LR documents related to human factors.

Rules and Regulations for Ship Classification		
Part 3	Ships Structure (General)	
	Ch 3	Ships Control System
Part 5	Main and auxiliary machinery	
	Ch 18	Integrated Propulsion System
	Ch 19	Steering Gear Control
	Ch 21	Requirements for System Condition Monitoring
	Ch 22	Redundancy Propulsion and Steering Control
	Ch 23	Safely Return to the Port
Part 6	Control, Electricity, Cooling and Fire	
	Ch 1	Engineering Control System
	Ch 2	Electrical Engineering
	Ch 4	Fire Protection, Detection and Control Requirements
Part 7	Other Ship Systems and Types	
	Ch 9	Integrated Navigation and Bridge Systems
	Ch 11	Arrangements and Equipment for Environmental Protection
	Ch 12	Integrated Fire Protection System (IFP)
	Ch 13	Comfort of Passenger and Crew Accommodation
	Ch 15	Requirements for Engineering Machines and Systems for Unconventional Design
Guide Notes		
	Vibration and Noise Guide Notes on Ships	

3.3.3. The American Bureau of Shipping (2020)

According to the ABS, 138 maritime business regulations and rules cover ships, offshore installations, floating structures, underwater vessels, machinery, parts, and products. Therefore, a total of seventeen articles in this study can be classified as targeted papers (see Table 5).

3.3.4. China Classification Society (CCS) (2021)

The CCS offers specific guidelines for vehicles, offshore facilities, vessels, and associated manufacturing goods and develops certification, classification and professional advisory support in an unbiased, objective, and truthful way. There are 22 papers from the CCS applicable to ship construction standards, focusing on the human factor (see Table 6).

Table 5.
The ABS human factors in ship design rules and regulations.

Pub#	Title
86	Application of Ergonomics to Marine Systems
94	Bridge Design and Navigational Equipment/Systems
97	Risk Assessment Applications for the Marine and Offshore Oil and Gas Industries
102	Crew Habitability on Ships
103	Passenger Comfort on Ships
116	Review and Approval of Novel Concepts
117	Risk Evaluations for the Classification of Marine Related Facilities
119	Ergonomic Design of Navigation Bridges
112	Alternative Design and Arrangements for Fire Safety
141	Fire-Fighting Systems
145	Vessel Manoeuvrability
147	Ship Vibration
151	Vessels Operating in Low Temperature Environments
154	Means of Access to Tanks and Holds for Inspection
163	Crew Habitability on Workboats
170	Rapid Response Damage Assessment
185	Integrated Software Quality Management (ISQM)

Table 6.
The CCS documents on the human factor.

Rules and Notations for Ship Classification			
Part 2	Chapter 2	Section 18	Helicopter Facilities
Part 3	Chapter 8		Z-propulsion
	Chapter 8		Thruster
	Chapter 8		Controllable Pitch Propeller
	Chapter 8		Waterjet Unit
Part 4	Chapter 2	Section 15	Electrical Propulsion System
Part 5	Chapter 2		Automation of Machinery Space
	Chapter 3		Machinery Centralized Control
	Chapter 4		Bridge Remote Control
Part 7	Chapter 2	Section 2	Life Saving Appliance
	Chapter 2	Section 3	Communication Equipment
	Chapter 2	Section 4	Navigation Equipment
	Chapter 2	Section 5	Signalling Equipment

	Chapter 3		Crew Accommodation Equipment
	Chapter 3		Comfort (Noise)
	Chapter 3		Comfort (Vibration)
	Chapter 4	Section 3	Clean Naval Ship
	Chapter 7		Manoeuvrability of naval ships at sea
Part 8	Chapter 4		Open man Bridge Operation
	Chapter 8	Section 3	Refrigeration System
	Chapter 11		Dynamic Positioning System

3.4. International and Industry Standards

Three other related bodies in legislation and standardization were assessed in addition to the classification body, as presented in Figure 7.

Figure 7.
International and Industry Standards.

3.4.1. The American Society for Testing and Materials (ASTM, 2020)

The organization by the ASTM was created referring to international principles with the consensus volunteers. In 1978, the ASTM founded a committee named F25 to create Ships and Maritime Technology Standards. Two unique norms suit the purpose of this study:

F1166-07	Maritime Structures, Machinery, and Services Standard Practices for Human Engineering Architecture
F1337-10	Best Procedures for Ships and Structures, Machinery, and Services Specifications for the Human Engineering Program

Figure 8.
The ASTM unique norm covers human factor.

3.4.2. International Maritime Organization (IMO, 2020)

The IMO is responsible for ensuring that legislation is continuously modified to ensure that as many countries as possible ratify those regulations and fully adopt all treaties and agreements by the countries that adopt them. Human factors in ship activities link to a vast number of the IMO publications. In numerous formats, the IMO documents issues: agreements, circulars, guidelines, conventions, guides, manuals, model classes, practices, suggestions, laws, rules, and resolutions. Conventions and codes promulgated by the IMO are depicted in Figures 8 and 9.

The STCW covers the acoustic impedance on board, and applies to code and resolution as to code and convention. These codes and conventions suggest that in the IMO publication specific issues are discussed more than once.

Conventions	
STCW	International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers
SOLAS	International Convention for the Safety of Life at Sea
Load Lines 1966	International Convention on Load Lines
COLREGS	International Regulations for Preventing Collisions at Sea

Figure 9.
The essential Conventions referring to human factor.

Codes
• **STCW Code** - International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers
• **Noise Levels** - International Convention for the Safety of Life at Sea
• **LSA Code** - International Convention on Load Lines
• **FSS Code** - International Regulations for Preventing Collisions at Sea
• Code on Alerts and Indicators, 2009

Figure 10.
The human-factors-related IMO Codes.

Examples of other IMO publications related to human factors in ship construction include:

Table 7.
The IMO publications concerning human factors in the construction of ships.

IMO Circulars, MSC Circulars	
587	Life Saving Appliances
601	Fire Protection in Machinery Spaces
616	Evaluation of Free-Fall Lifeboat Launch Performance
645	Guidelines for Vessels with Dynamic Positioning Systems
834	Guidelines for Engine-Room Layout, Design and Arrangement
846	Guidelines on Human Element Considerations for the Design and Management of Emergency Escape Arrangements on Passenger Ships
849	Guidelines for the performance, location, use and care of emergency escape breathing devices (EEBD's)
982	Guidelines on Ergonomic Criteria for Bridge Equipment and Layout
1002	Guidelines on Alternative Design and Arrangements for Fire Safety
Assembly Resolutions (RES)	
A.342(IX)	Recommendation on Performance Standards for Automatic Pilots
A.468(XII)	Code on Noise Levels on Board Ships
A.601(15)	Provision and Display of Manoeuvring Information on Board Ships
A.708(17)	Navigation Bridge Visibility and Functions
A.817(19)	Performance Standards for Electronic Chart Display and Information Systems (ECDIS)
A.861(20)	Performance Standards for Shipborne Voyage Data Recorders (VDRs)
A.947(23)	Human Element Vision, Principles and Goals for the Organization
A.1021 (26)	Code on Alerts and Indicators
Maritime Safety Committee (MSC) Resolution	
128(75)	Performance Standards for a Bridge Navigational Watch Alarm System (BNWAS)
137(76)	Standards for Ship Manoeuvrability
190(79)	Performance Standards for the Presentation of Navigation-Related Information on Shipborne Navigational Displays

3.4.3. The International Organization for Standardization (ISO, 2020)

The ISO creates universal principles and publishes them. The Technical Committee (TC)/Sub Committee (SC) in the International Classification for Standards (ICS), which is accountable for supplying those standards, may be used to access the ISO norm. For example, the ICS number 47 encompasses shipbuilding and marine structures standards, while TC 8 encompasses shipbuilding and marine technologies standards. In TC 159, ergonomics rules are described differently.

Documents under TC 159 exclusively include human factors represented in Figure 11.

Table 8.
Human factors related to the ISO documents.

ISO	Document Tittle
2412:1982	Shipbuilding - Colours of indicator lights
8468:2007	Ships and marine technology - Ship's bridge layout and associated equipment - Requirements and guidelines
27991:2008	Ships and marine technology - Marine evacuation systems -- Means of communication
24409-1:2010	Ships and marine technology - Design, location and use of shipboard safety signs, safety-related signs, safety notices and safety markings - Part 1: Design principles
20283-4	Mechanical vibration - Measurement of vibration on ships - Part 4: Measurement and evaluation of vibration of the ship propulsion machinery
20283-2:2008	Mechanical vibration - Measurement of vibration on ships - Part 2: Measurement of structural vibration
17894:2005	Ships and marine technology - Computer applications - General principles for the development and use of programmable electronic systems in marine applications
17631:2002	Ships and marine technology - Shipboard plans for fire protection, life-saving appliances and means of escape
6954:2000	Mechanical vibration - Guidelines for the measurement, reporting and evaluation of vibration with regard to habitability on passenger and merchant ships
5489:2008	Ships and marine technology - Embarkation ladders
5488:1979	Shipbuilding - Accommodation ladders
3797:1976	Shipbuilding - Vertical steel ladders
2923:1996	Acoustics - Measurement of noise on board vessels
2631-1:1997	Mechanical vibration and shock - Evaluation of human exposure to wholebody vibration - Part 1: General requirements

ISO/TR 16982:2002	Human device interaction ergonomics - Techniques of usability that promote human-centered architecture
ISO 11064-3:1999	Control centre ergonomic architecture - Section 3: Configuration of the control space
ISO 9241-210:2010	Human system interface ergonomics; Part 210: Dynamic machine human-centered architecture
(VDTs)	Section 1: General introduction
ISO 9241-1:1997	Ergonomic specifications for visual interface terminals for office jobs
ISO 26800:2011	Ergonomics General strategy, values and definitions
ISO 6385:2004	In the construction of job processes, ergonomic concepts

Figure 11.
The ISO documents under TC159 that exclusively include human factors.

ICS 47.040 and 47.020, TC8/SC 8, TC 8/SC 6, and TC 8/SC 1 represent the scope of this study. Table 8 illustrates the descriptions of ISO documentation relevant to human elements in ship design.

4. ANALYSIS AND RESULTS

With multiple processing units, two phases of data analysis were conducted, followed by all related document reviews from the seven institutions. The paper's title as the unit of study was the measurements of human factors (Table 1) as the basis for coding. Secondly, it chooses and then analyses in depth some of the most significant and most applicable articles, in which a part of human factors in terms of the elements and facets are presented as a coding sheet.

4.1. Publication Analysis

Some documents are relatively thin, just two pages, and some of them reach hundreds of pages. A full text is described by specific names, while others reflect chapters from a collected document, as represented in Table 9.

117 paper titles already focus on the human element. Detailed findings are provided in the Appendix to Table A1, while the description is presented in Table 9. Table 9 indicates that usable records span all aspects of human variables: regulation,

rule, legislation, and instructions. Clearly, "System Safety" is the most frequently stated in the paper since security has always been a big concern, whereas "Maintainability" is the most unchecked.

Table 9.
Overview of paper outcomes in ship construction, covering human factors.

Publication Body	No of Document	Human Factor / Ergonomic	Habitability	Maintainability	Workability	Controllability	Maneuverability	Survivability	Occupational Health and Safety	System Safety
ABS	17	2	6	1	7	4	1	3	3	9
DNV	18	0	1	1	6	7	3	3	0	11
LR	16	0	2	1	2	6	3	6	1	7
CCS	22	3	2	2	7	10	7	1	3	7
IMO	29	2	2	1	6	8	3	11	4	14
ISO (TC8)	13	0	7	0	3	2	0	4	0	2
ASTM	2	2	1	1	2	1	0	1	1	2
Total	117	9	21	7	33	38	17	29	12	52

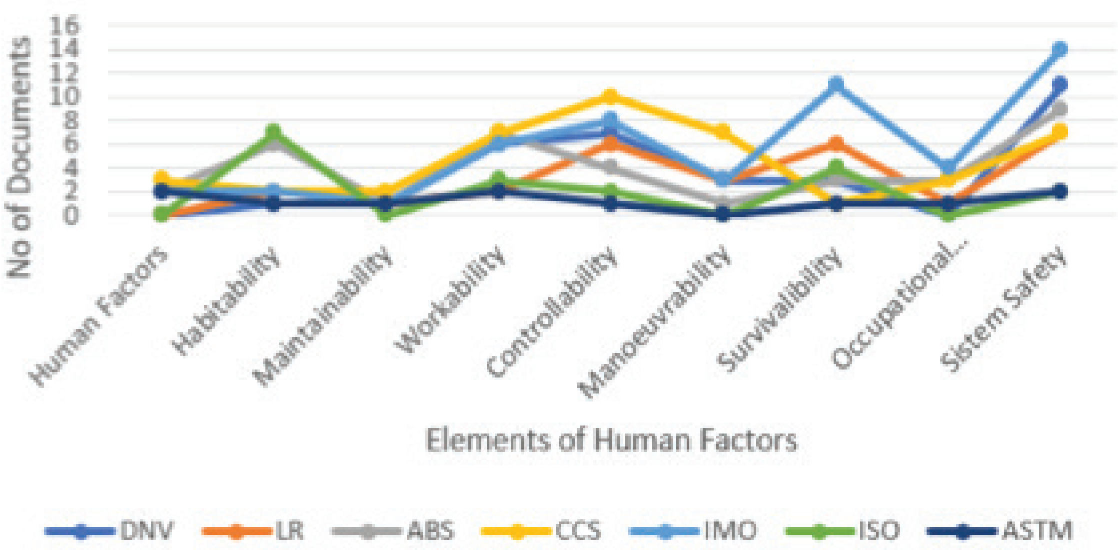


Figure 12.
Documents in ship construction, covering human factors.

These results support Andersson's and Lützhöft's (IMO, 2004) critiques of engine control rooms' lousy nature. Meanwhile, "Survivability," "Controllability," and "Workability" include a large number of papers. "Habitability" is reasonably covered; however, as the emphasis of this review is on the "OHS" portion, not too many records cover "design".

4.2. Study On Material

As described, a comprehensive evaluation conduct, utilize the materials and facets of each human factors field. More elements and aspects are uncovered as the coding process continues and eventually integrated into the system, becoming a very lengthy list. As the system is created, the coding phase performs repeatedly. In the Appendix to Table A2, the final results can be seen. Any records addressing very particular subjects, such as life-saving and steering devices, fire protection software, and risk control, are not included. In ship design, the nature of human influences occupies all of these aspects. The "Workability" and "System safety" are below "Habitability."

The most widely addressed subjects of "Controllability" are sensors, control centres, workstations, buttons, and switches. These documents have clarified the fundamental problems of human factors on board. However, more complex issues emerge as simple problems are addressed. Noise, for example, is known as an onboard concern. A total of 15 records have the overall parameters of the noise level on board in this study. Among all 15 articles, the overwhelming majority does not discuss concrete concerns. The only paper describing "tonal sound" and "impulsive noise" is the ISO 2923, but it does not explain how to cope with them. The CCS also covers noise in the comfort notation in Part 7, Chapter 3, Section 7, noting the enclosure regulated at the stated sound level.

Vibration is another simple HF problem that is adequately discussed. According to this report, it has been bound by 14 records. Generally, vibration cannot be treated as an intimidating issue any more. The CCS covers vibration in the comfort notation in Part 7, Chapter 3, Section 7, noting the enclosure regulated at the stated vibration level. However, it tends to be challenging, created from certain primary forms of "vibration" (Trincas et al., 2018): ship slamming and rotation. From the aspect of human factors, one paper addresses ship motion: ISO 2631-1. This paper is the first text that separates sensations between two systems: low frequencies (for motion sickness: <0.5 Hz) and high frequencies (for wellbeing, relaxation, and perception: >0.5 Hz). The Motion Sickness Dosage Value (MSDV) accepted onboard by the ISO 2631 is applied by ABS 103 and 147. The ABS 86 deals with slamming, from all the documents surveyed in this report. A common trend often appears in "alarms" protected by 14 survey records. Thus, the underlying dilemma of alarms is resolved. However, more complex alarms have been uncovered like an irrelevant number of alarms that irritate operators. Fortunately, the IMO A.1021(26) pointed out the following problems indicate how to include specific info and decrease alarms.

5. DISCUSSION

While different manuals have adequately discussed the problems of human factors, they are not mandatory. The standard bodies' laws and regulations are voluntary or optional, while the remainder are recommendations. The actual enforcement of human factors values relies mainly on the shipowner's devotion. Shipyards certainly play an essential function. The freight owner or the buyers and the personnel might have some feedback to make things work. However, the classification societies and the regulators should go further. Without exception, such intrinsic human conditions as noise, sound, motion, and indoor environment should be obligatory. Prospective naval architects and shipbuilders need to add some of these subjects, such as ship-human related requirements.

Three publications addressing the issue of human factors are considered to be comprehensive: the ASTM F1166, DNV Nautical Protection, and ABS 86, which have become the preferred manuals for coping with human factors in the construction of ships regardless of the flag, anywhere the ships are recorded and listed. Several problems were found in the coding sheet production stage, but have not been enclosed in any text, such as the disparities in ethnicity, disabilities, and religious differences of seafarers.

The analysis does not provide any reliability index because of inadequate resources. The reliability over time is, however, verified. Compared to the results reported earlier, this research shows that human factor involvement in ship design is increasingly evolving, represented by a growing number of published papers. Relatively stable is the trend of all the facets of human factors considered, such as disturbance, vibration, and alarms.

Concerning the least addressed problems on board, such as ship motion, i.e. slamming, smell, gender issues, and high-pitch erratic noise, they are described in (Trincas et al., 2018), choosing the feature of human factors to recognize in design process through a more intelligent approach. A fast comparison with the HF reference reveals that some of the records analysed in this sample do not cover human reliability, decision-making, and social considerations.

6. CONCLUSIONS

Using a reference analysis approach, a literature review of other documentation has been performed. The research was conducted to discuss whether human aspects are ignored in the design and construction of ships. At least 117 publications describe it as essential to resolving human factors in the construction of ships, and the numbers continue to rise exponentially. It can be inferred from the analysis that human factors are not ignored in ship design specifications. 30 articles discuss it in depth. Human factors turn out to be an extensive aspect comprising several ship materials and dimensions, but their degree of coverage differs throughout the dimensions. The two dimensions often covered are protection and survivability, indicated by the overall number of papers published on the subjects. The broadest coverage is that of habitability and controllability. A more assertive intervention proposes to promote the values of human factors incorporated into ship design. The research on human factor implementation on board can be conducted using the available documents that set up the standards internationally. Performing research by questioning shipbuilders, shipyards, marine mechanics and naval architects is recommended.

REFERENCES

Ahola, M., Murto, P., & Mallam, S., 2018. When people are the mission of a ship—design and user research in the marine industry. Marine Design 13, pp.285-290.

Allianz Global Corporate and Specialty (AGCS), 2017. Global Claims Review: Liability In Focus.

American Bureau of Shipping, 2020. Rules and Guides Downloads. Available at: http://www.eagle.org/eagleExternalPortalWEB/appmanager/absEagle/absEagleDesktop?_nfpb=true&_pageLabel=abs_eagle_portal_marine_rules_guides_download_page.

Andrews, D., 2018. The Sophistication of Early Stage Design for Complex Vessels. International Journal of Maritime Engineering, Vol 160(SE 18). Available at: http://dx.doi.org/10.3940/rina.ijme.2018.se.472.

ASTM, 2020. ASTM Overview. Available at: http://www.astm.org/ABOUT/overview.html.27.

CCS, 2021. CCS Overview. Available at: https://www.ccs.org.cn/ccswzen/.

Charlton, S.G. & O'Brien, T.G. eds., 2019. Handbook of Human Factors Testing and Evaluation. Available at: http://dx.doi.org/10.1201/9781003000815.

Cohen, L., Manion, L. & Morrison, K., 2017. Coding and content analysis. Research Methods in Education, pp.668–685. Available at: http://dx.doi.org/10.4324/9781315456539-34.

Dekker, S., 2017. The Field Guide to Human Error Investigations. Available at: http://dx.doi.org/10.4324/9781315202778.

DNV, 2020. DNV Rules and Standards. Available at: http://exchange.dnv.com/publishing/ServiceDocs.asp.

Heidi, J., 2008. Content Analysis. Thousand Oaks, USA, SAGE Publications.

HFES, 2020. Definition of Human Factors and Ergonomics. Available at: http://www.hfes.org/Web/EducationalResources/HFEdefinitionsmain.html, accessed on: October 2020.

IMO, 2004. Human Element Vision, Principles and Goals for the Organization. A 23/Res. 947. IMO. A.947(23).

IMO, 2020. Introduction to IMO. Available at: http://www.imo.org/About/Pages/Default.aspx.

International Ergonomics Association, 2020. What is Ergonomics. Available at: http://www.iea.cc/01_what/What%20is%20Ergonomics.html.

ISO, 2020. About ISO. Available at: http://www.iso.org/iso/about.htm.

Kyngäs, H., 2019. Inductive Content Analysis. The Application of Content Analysis in Nursing Science Research, pp.13–21. Available at: http://dx.doi.org/10.1007/978-3-030-30199-6_2.

Lloyd's Register, 2008. The Human Element: An Introduction. London, Lloyd's Register.

Lloyd's Register, 2009. The Human Element Best Practice for Ship Operators. London, Lloyd's Register.

Lloyd's Register, 2020. Rules and Regulations, Leading expertise for a safer world. Available at: http://www.lr.org/sectors/marine/Compliance/RulesandRegulations.aspx.

McCafferty, D.B. et al., 2006. Trending the Causes of Marine Incidents. Learning from Marine Incidents 3. Available at: http://dx.doi.org/10.3940/rina.mi.2006.

Muschara, T., 2017. Risk-Based Thinking. Available at: http://dx.doi.org/10.4324/9780203731734.

Papanikolaou, A. ed., 2019. A Holistic Approach to Ship Design. Available at: http://dx.doi.org/10.1007/978-3-030-02810-7.

Papanikolaou, A. et al., 2019. A holistic approach to ship design: Tools and applications. In SNAME Maritime Convention.

Ross, J.M., 2017. Human Factors for Naval Marine Vehicle Design and Operation. Available at: http://dx.doi.org/10.1201/9781315253022.

Tang, L. & Gekara, V., 2018. The Importance of Customer Expectations: An Analysis of CSR in Container Shipping. Journal of Business Ethics, 165(3), pp.383–393. Available at: http://dx.doi.org/10.1007/s10551-018-4062-4.

Trincas, G. et al., 2018. Handling the path from concept to preliminary ship design. In Marine Design 13, pp.181-191.

Χαζίζα, Α., 2019. The role of flag states administration in the shipping industry. Master's thesis, Πανεπιστήμιο Πειραιώς.

APPENDIX
Document Content Analysis

No	Source	ID**	HF	HAB	MAN	WORK	CONF	MANV	SUR	OHS	SS
1	DNV	Pt 3 Ch 3	0	0	0	0	0	1	0	0	0
2	DNV	Pt 4 Ch 9	0	0	0	1	1	0	0	0	1
3	DNV	Pt 4 Ch 10	0	0	0	0	0	0	1	0	1
4	DNV	Pt 4 Ch 14	0	0	0	0	1	0	0	0	0
5	DNV	Pt 5 Ch 12	0	1	0	0	0	0	0	0	0
6	DNV	Pt 6 Ch 2	0	0	0	0	0	0	0	0	1
7	DNV	Pt 6 Ch 3	0	0	1	0	0	0	0	0	1
8	DNV	Pt 6 Ch 4	0	0	0	0	0	0	1	0	1
9	DNV	Pt 6 Ch 6	0	0	0	0	1	0	0	0	0
10	DNV	Pt 6 Ch 7	0	0	0	0	1	0	0	0	0
11	DNV	Pt 6 Ch 8	0	0	0	1	1	1	0	0	1
12	DNV	Pt 6 Ch 9	0	0	0	0	0	0	0	0	1
13	DNV	Pt 6 Ch 20	0	0	0	1	1	1	1	0	1
14	DNV	Pt 6 Ch 26	0	0	0	1	1	0	0	0	0
15	DNV	A203	0	0	0	1	0	0	0	0	1
16	DNV	C205	0	0	0	0	0	0	0	0	0
17	DNV	D102	0	0	0	0	0	0	0	0	1
18	DNV	D201	0	0	0	1	0	0	0	0	1
	DNV		**0**	**1**	**1**	**6**	**7**	**3**	**3**	**0**	**11**
19	LR	Pt 3 Ch13	0	0	0	0	0	0	0	0	0
20	LR	Pt 5 CH 18	0	0	0	0	1	1	0	0	0
21	LR	Pt 5 CH 19	0	0	0	0	0	0	0	0	0
22	LR	Pt 5 CH 21	0	0	1	0	0	0	0	0	0
23	LR	Pt 5 CH 22	0	0	0	0	1	1	1	0	1
24	LR	Pt 5 CH 23	0	0	0	0	0	0	1	0	1
25	LR	Pt 6 Ch 1	0	0	0	0	1	0	1	0	1
26	LR	Pt 6 Ch 2	0	0	0	0	1	1	1	0	1
27	LR	Pt 6 Ch 4	0	0	0	0	0	0	1	0	1
28	LR	Pt 6 Ch 1	0	0	0	0	0	0	0	0	0
29	LR	Pt 7 Ch 4	0	0	0	1	1	0	0	0	0
30	LR	Pt 7 Ch 9	0	0	0	1	1	0	0	0	0
31	LR	Pt 7 Ch 12	0	0	0	0	0	0	1	1	1
32	LR	Pt 7 Ch 13	0	1	0	0	0	0	0	0	0
33	LR	Pt 7 Ch 15	0	0	0	0	0	0	0	0	1
34	LR	GN	0	1	0	0	0	0	0	0	0
	LR		**0**	**2**	**1**	**2**	**6**	**3**	**6**	**1**	**7**
35	ABS	86	1	1	1	1	1	0	0	1	1
36	ABS	94	0	0	0	1	1	0	0	0	0
37	ABS	97	0	0	0	0	0	0	0	0	1
38	ABS	102	0	1	0	0	0	0	0	0	0
39	ABS	103	0	1	0	0	0	0	0	0	0
40	ABS	116	0	0	0	0	0	0	0	0	1
41	ABS	117	0	0	0	0	0	0	0	0	1
42	ABS	119	1	0	0	1	1	0	0	0	0
43	ABS	122	0	0	0	0	0	0	1	0	1
44	ABS	141	0	0	0	0	0	0	1	0	0
45	ABS	145	0	0	0	0	0	1	0	0	0
46	ABS	147	0	1	0	1	0	0	0	0	0
47	ABS	151	0	1	0	1	0	0	0	1	1
48	ABS	154	0	0	0	1	0	0	0	1	1
49	ABS	163	0	1	0	0	0	0	0	0	0
50	ABS	170	0	0	0	0	0	0	1	0	1
51	ABS	185	0	0	0	1	1	0	0	0	1
	ABS		**2**	**6**	**1**	**7**	**4**	**1**	**3**	**3**	**9**

No	Source	ID**	HF	HAB	MAN	WORK	CONF	MANV	SUR	OHS	SS
52	CCS	Pt 2 Ch 2	0	0	0	1	0	0	0	0	1
53	CCS	Pt 3 Ch 8	0	0	0	0	1	1	0	0	0
54	CCS	Pt 3 Ch 8	0	0	0	0	1	0	0	0	0
55	CCS	Pt 3 Ch 8	0	0	0	0	1	1	0	0	0
56	CCS	Pt 3 Ch 8	0	0	1	0	0	0	0	0	0
57	CCS	Pt 4 Ch 2	0	1	1	1	1	1	0	0	1
58	CCS	Pt 5 Ch 2	0	0	0	1	1	0	0	0	1
59	CCS	Pt 5 Ch 3	1	0	0	1	1	0	0	0	1
60	CCS	Pt 5 Ch 4	1	0	0	1	1	1	0	0	1
61	CCS	Pt 7 Ch 2	0	0	0	1	0	0	1	1	0
62	CCS	Pt 7 Ch 2	0	0	0	0	0	0	0	0	0
63	CCS	Pt 7 Ch 2	0	0	0	0	1	1	0	0	0
64	CCS	Pt 7 Ch 2	0	0	0	0	1	0	0	0	0
65	CCS	Pt 7 Ch 2	0	0	0	0	0	0	0	0	0
66	CCS	Pt 7 Ch 3	1	1	0	0	0	0	0	1	0
67	CCS	Pt 7 Ch 3	0	0	0	0	0	0	0	0	0
68	CCS	Pt 7 Ch 3	0	0	0	0	0	0	0	0	0
69	CCS	Pt 7 Ch 4	0	0	0	0	0	0	0	1	0
70	CCS	Pt 7 Ch 7	0	0	0	0	0	1	0	0	0
71	CCS	Pt 8 Ch 4	0	0	0	1	0	1	0	0	0
72	CCS	Pt 8 Ch 8	0	0	0	0	0	0	0	0	1
73	CCS	Pt 8 Ch 11	0	1	0	0	1	0	0	0	1
	CCS		**3**	**2**	**2**	**7**	**10**	**7**	**1**	**3**	**7**
74	IMO	COLREGS	0	0	0	0	1	0	0	0	1
75	IMO	LL	0	0	0	0	0	0	0	0	1
76	IMO	SOLAS	0	0	0	0	0	0	0	0	1
77	IMO	STCW	0	0	0	1	0	0	0	0	0
78	IMO	ALI	0	0	0	0	0	0	1	0	1
79	IMO	CAI	0	0	0	0	0	0	1	0	1
80	IMO	FSS	0	0	0	0	0	0	1	0	1
81	IMO	LSA	0	0	0	0	0	0	1	0	1
82	IMO	NOISE	0	1	0	0	0	0	0	0	0
83	IMO	A 342 (IX)	0	0	0	0	1	0	0	0	1
84	IMO	A 468 (XII)	0	1	0	0	0	0	0	0	0
85	IMO	A 601 (15)	0	0	0	0	0	1	0	0	0
86	IMO	A 708 (17)	0	0	0	0	1		0	0	0
87	IMO	A 817 (19)	0	0	0	1	1	1	0	0	0
88	IMO	A 830 (19)	0	0	0	0	0	0	0	0	0
89	IMO	A 861 (20)	0	0	0	0	0	0	0	0	1
90	IMO	A 947 (23)	1	0	0	0	0	0	0	0	0
91	IMO	Res 128 (75)	0	0	0	0	0	0	1	1	1
92	IMO	Res 137 (76)	0	0	0	0	0	1	0	0	0
93	IMO	Res 190 (79)	0	0	0	1	1	0	0	0	0
94	IMO	Circ 587	0	0	0	0	0	0	0	0	0
95	IMO	Circ 601	0	0	0	0	0	0	1	0	1
96	IMO	Circ 616	0	0	0	0	0	0	1	0	1
97	IMO	Circ 645	0	0	0	1	1	0	0	0	0
98	IMO	Circ 834	0	0	1	1	1	0	1	1	1
99	IMO	Circ 846	0	0	0	0	0	0	1	0	0
100	IMO	Circ 849	0	0	0	0	0	0	1	1	0
101	IMO	Circ 982	1	0	0	1	1	0	0	0	0
102	IMO	Circ 1002	0	0	0	0	0	0	1	0	1

	IMO		2	2	1	6	8	3	11	3	14
101	ISO	2631-1:1997	0	1	0	0	0	0	0	0	0
102	ISO	2923:1996	0	1	0	0	0	0	0	0	0
103	ISO	3797:1976	0	0	0	1	0	0	0	0	0
104	ISO	5488:1979	0	1	0	0	0	0	0	0	0
105	ISO	5489:2008	0	1	0	0	0	0	1	0	0
106	ISO	6954:2000	0	1	0	0	0	0	0	0	0
107	ISO	17631:2002	0	0	0	0	0	0	1	0	1
108	ISO	20283-2:2008	0	1	0	0	0	0	0	0	0
109	ISO	20283-4	0	1	0	1	1	0	0	0	0
110	ISO	24409-1:2010	0	0	0	0	0	0	1	0	1
111	ISO	27991:2008	0	0	0	0	0	0	1	0	0
112	ISO	8468:2007	0	0	0	1	0	0	0	0	0
113	ISO	2412:1982	0	0	0	0	1	0	0	0	0
	ISO		**0**	**7**	**0**	**3**	**2**	**0**	**4**	**0**	**2**
114	ASTM	F1166-07	1	1	1	1	1	0	1	1	1
115	ASTM	F1337-10	1	0	0	1	0	0	0	0	1
	ASTM		2	1	1	2	1	0	1	1	2

Sustainable Development of Port Cities from the Perspective of Transition Management

Alen Jugović[a], Miljen Sirotić[a], Ivan Peronja[b]

The strong and close relationship between the port and the city, which is often a consequence of historical circumstances, has become disrupted due to the negative impact of the port on the urban environment. The disruption of this relationship is forcing port city authorities worldwide to find effective methods to renew the port – city relationship. As an additional element to this complex relationship, the concept of sustainability is taken into consideration. Therefore, the relationship between the port and the city needs to be studied in compliance with economic, social and environmental criteria. This paper studies port and urban systems interdependently, as well as their integration into a sustainable whole. The dynamics of change in the port – city interface zone require careful planning and assessment before intervention and development. Accordingly, transition management is presented as a mechanism for renewing, coupling, and monitoring the relationship between the port and the city concerning their complex and dynamic nature. The paper's key findings are based on the contribution of relevant economic, social, and environmental criteria through which the possibility of developing a systematic framework for a coordinated transition to a cooperative relationship between the port and the city from the perspective of sustainability is realized.

KEY WORDS
~ Port city
~ Sustainable development
~ Transition management

a. University of Rijeka, Faculty of Maritime Studies, Croatia
e-mail: ajugovic@pfri.hr
b. University of Split, Faculty of Maritime Studies, Croatia
e-mail: iperonja@pfst.hr

doi: 10.7225/toms.v10.n02.w01

Received on: 13.04.2021 / Revised on: 03.05.2021 / Accepted on: 08.06.2021 / Published online: 14.06.2021

1. INTRODUCTION

Ports and cities are historically strongly connected and are developing in close relations. The relationship between ports and cities is strengthened in such a way that increased port activity leads to increased urban activity and vice versa (Hall and Jacobs, 2012). However, in recent decades the link between ports and cities has weakened. This weakening is a consequence of the growth and development of the port and its transshipment facilities with the aim of adapting to the constantly growing, changing and dynamic market conditions. Due to continuous market competition, a negative change of social priorities regarding the use of urban space along the coast of port cities is manifested through the weakening of interest in increasing the quality of urban life. This has caused the ports to be socio-economic drivers for a wider area (hinterland), while at the same time they are the cause of socio-economic deterioration in the neighboring areas (city and region). This duality implies that ports can have negative, but also positive external consequences that affect the well-being of the cities to which they are connected, i.e. where negative external consequences can be linked to the expansion of port territories, and positive external consequences can arise, for example, from converting obsolete ports' facilities into recreational and additional urban facilities (Saz–Salazar et al., 2015).

Ports and cities have also become places of separation of economic, environmental, and social factors. Economic and ecological separations are the result of the negative impact that the port has on the environment due to high levels of energy consumption, air pollution, water pollution and consumption of natural resources. Socio-technical segregations are the result of efforts aiming at achieving economic growth and development while preserving certain cultural sites, landscape, i.e. the city (Girard, 2013).

In addition, the relationship between the port and the city is characterized by a dynamic, multi-level and interconnected landscape, which has been created by a constant interaction of maritime (port) activities and associated activities of the city through trade and movement of people through migration and diaspora (Ravetz, 2013). Due to the fact that this relationship has been violated, new approaches and tools are required in order to plan and manage these separations through complementarity and the so-called "win-win" perspective, i.e. synergistic perspective (Ravetz, 2013). The authors consider it necessary to develop criteria for designing a systemic framework through which the port-city relationship could become collaborative rather than competitive. This systemic framework should be based on economic, social, and environmental criteria. The port and the city should be considered as one holistic entity and they should interact through synergy, involving all participants (port, city and intermediary) with the aim of achieving sustainability, long-term prosperity and security. This can be done through transitional management as this is perhaps the only adequate form of management for a dynamic environment such as a port city.

2. ANALYSIS OF CHANGING DYNAMICS OF PORT - CITY RELATIONS

The strong and close connection and mutual intertwining of the joint development of the port and the city has been a recurring topic throughout history, starting with the emergence of the earliest organized societies (civilizations). The port city or city port is a crucial element in the global maritime transport and trading system and the main drive of economic life of the majority of coastal countries. Ports are considered to be the center of local, regional, and often national and international activities (Hoyle, 2001). At the same time, port cities are key socio-economic-geographical cores because they are the leading agglomerations in terms of economic strength and influence. This statement is confirmed by the data shown in Chart 1, which shows that 14 of 20 economically strongest cities in the world are port cities (based on nominal GDP, GDP per capita, and GDP growth rate).

If factors such as the economic strength of a city, physical capital, financial maturity, and institutional effectiveness are taken

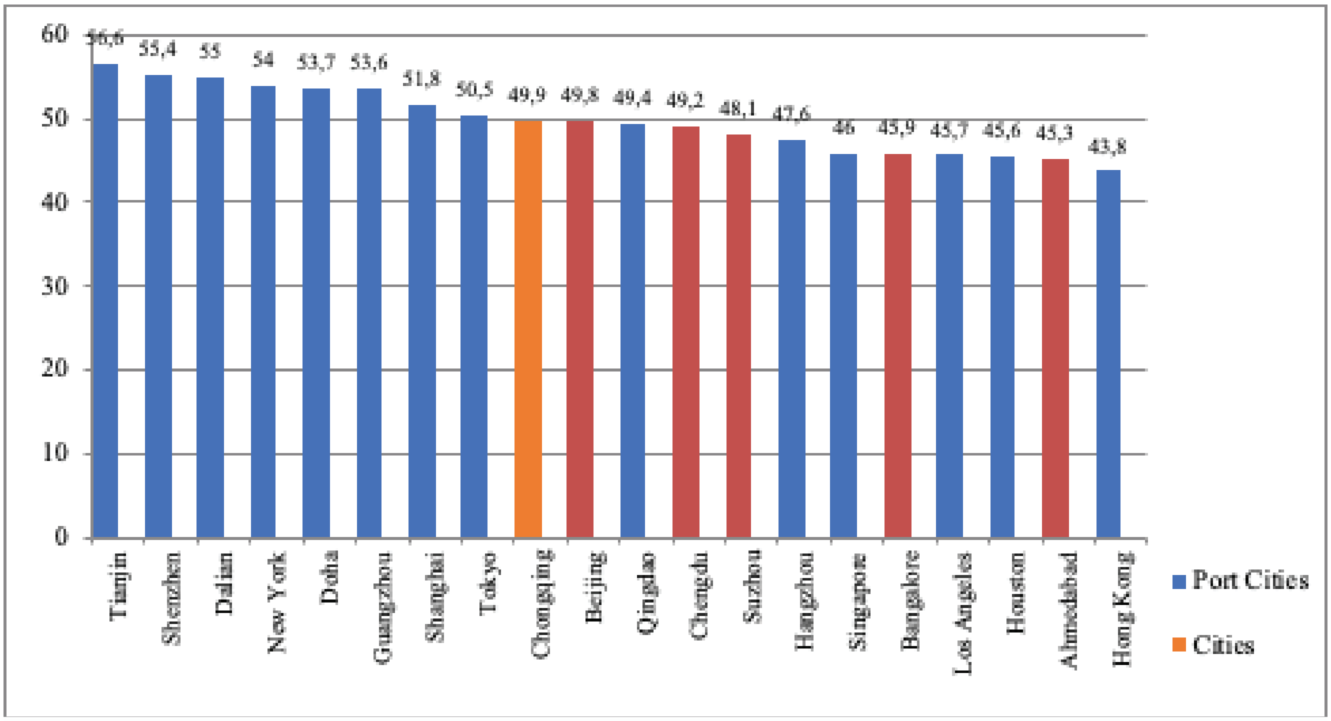


Figure 1.
Top 20 economically strongest cities in the world – Source: The Economist Intelligence Unit (2012).

into account, port cities are the dominant core of competition; port cities account for 38 of the 50 most competitive cities in the world (Girard, 2013). Their dominant share can also be seen in the ranking of human capital indicators, among which the most prominent indicators are: population growth, share of working-age population, intensity and maturity of entrepreneurship, quality of education, and quality of health system. Taking all these criteria into account, it can be seen that 14 out of top 20 cities in the world are port cities (Girard, 2013). However, as the world started becoming more interconnected (globalization), ports within port cities gradually became exclusively specialized for maritime transport purposes, resulting in a functional breakdown of relations between ports and cities to which they originally belonged (Li, 2019).

Containerization is considered to be the main cause responsible for this administrative and spatial diffusion between ports and cities. It has spurred a rapid advancement of shipping technology, a growing demand for large areas of land required by modern port terminals in order to have as much cargo flow as possible so as to achieve the necessary agility to meet financial thresholds, and the need for a better access to inland transport networks so as to be able to achieve a better connection between the port and the hinterland (Pigna, 2014). The constant advancement of shipping technology manifested by increased dimensions of ships with the aim of achieving economies of scale has resulted in a more intense demand for greater pier depth and some additional land near the pier. The majority of city ports have reached or will reach their maximum threshold in terms of space constraints because cities are also constantly expanding and occupying limited space. Therefore, the conclusion is that the lack of cooperation between city and port is manifested in their mutual element of demand – land (as shown in Figure 1).

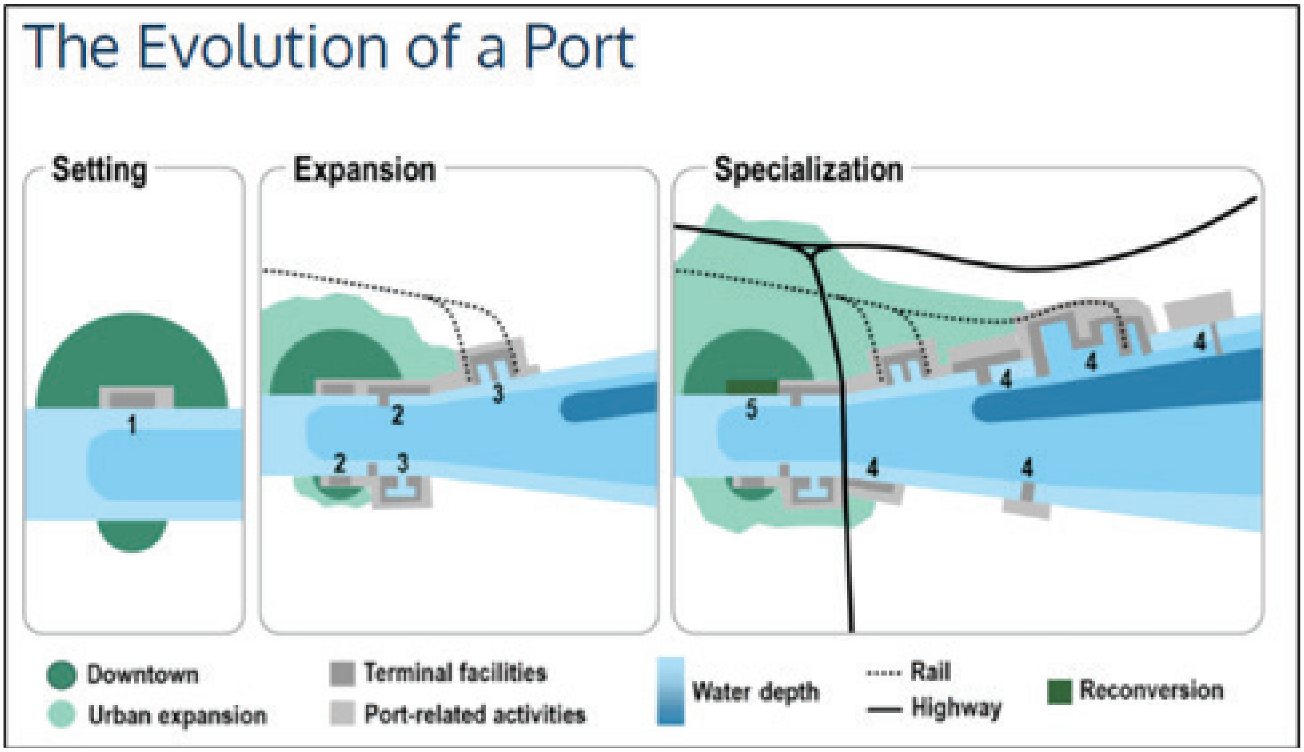
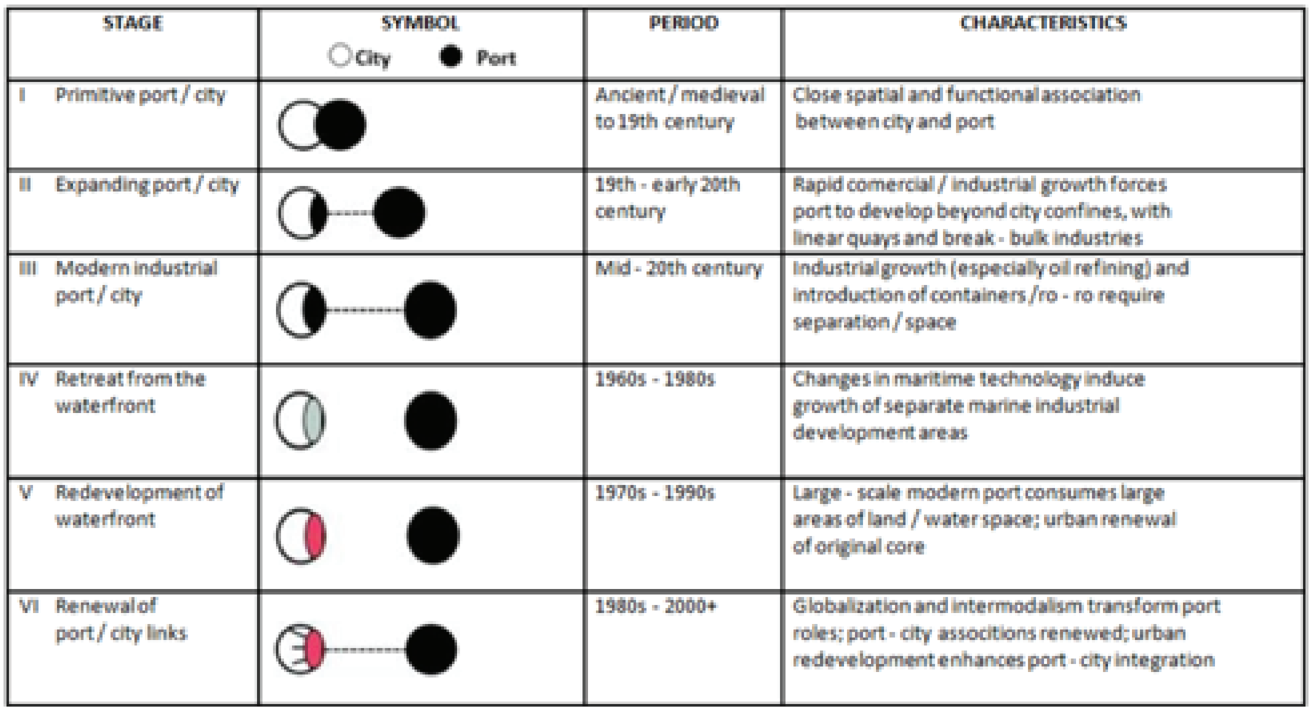


Figure 2.
Overview of urban and port expansion in relation to limited free area – land – Source: Port Economics, Management, and Policy: A Comprehensive Analysis of the Port Industry.

The lack of land has encouraged ports to develop spatially as far as possible from the city center towards the sea. Such an example is the case of the Port of Rotterdam, which originated upstream, but began to expand downstream in its various developmental stages over time, with each additional expansion of the port (Merk, 2018). However, gradual expansion (relocation) of the port is possible only if there is enough free land next to the current port for further development of the port territory; this being a natural development process for ports that have sprung up in cities founded at river mouths. This is crucial only for ports that develop along a river mouth. Contrary to the above mentioned, many ports are located in bays and are completely surrounded by the city. In this case, the only area where the development and upgrade of the new port territory can take place is in the sea, creating an "off-shore" terminal by building embankments. It should be noted that the relocation of the port in terms of upgrading the port territory, regardless of its spatial and geographical layout, also has a negative impact on the relationship between the port and the city. This is manifested by the fact that the relocation of port operations downstream or "off-shore" leaves behind large parts of abandoned, empty and neglected heavy industrial urban land (Pigna, 2014).

This neglect of heavy industrial urban areas is also a consequence of the relocation of port transshipment machinery to port terminals, where the intensity of cargo flow is more evident. Moreover, the continuous increase in the quality of port transshipment machinery through automation, digitization, and cybernetics has resulted in a reduction in the total number of workers in ports and will continue to affect the number and structure of workers in port terminals and facilities. Consequently, ports have ceased to be the main centers of direct employment for local urban population and have become highly developed logistics hubs within transport networks, where the direct number of employed citizens no longer has the same impact on the city (sense of community) as it once did. The manifestation of this phenomenon can be explained through the economic perspective of reducing the importance of ports in the city labor market due to increased port automation and operational rationalization, and the fact that cities have become less dependent on ports for their own local economic growth (Jacobs et al., 2010).

Taking into consideration the above mentioned, it can be concluded that the relationship between ports and cities is constantly transformed over time and that this transformation is a geographical transformation of the relationship. In academic literature this relationship is also referred to as "port - city interface" and the most relevant evolutionary model of this relationship is developed by Hoyle (1989). Hoyle's model is based on six different stages of port - city interactions, as shown in Figure 3.



STAGE	SYMBOL ○ City ● Port	PERIOD	CHARACTERISTICS
I Primitive port / city		Ancient / medieval to 19th century	Close spatial and functional association between city and port
II Expanding port / city		19th - early 20th century	Rapid comercial / industrial growth forces port to develop beyond city confines, with linear quays and break - bulk industries
III Modern industrial port / city		Mid - 20th century	Industrial growth (especially oil refining) and introduction of containers /ro - ro require separation / space
IV Retreat from the waterfront		1960s - 1980s	Changes in maritime technology induce growth of separate marine industrial development areas
V Redevelopment of waterfront		1970s - 1990s	Large - scale modern port consumes large areas of land / water space; urban renewal of original core
VI Renewal of port / city links		1980s - 2000+	Globalization and intermodalism transform port roles; port - city associtions renewed; urban redevelopment enhances port - city integration

Figure 3.
Development stages of spatial evolution of the "port-city interface" relationship – Source: Hoyle (1989).

3. COMPLEXITY OF PORT CITY EVOLUTION THROUGH SUSTAINABLE DEVELOPMENT

Restoring the relationship between the port and the city can be considered almost an imperative because port cities, according to their own essential characteristics, have a close relationship with the natural environment. This is reflected in the fact that private shipping companies and port authorities together oppose the laws of natural (shifting of water lines, sea level rise, threat of flooding, dredging the bottom due to deposition of sediments, climate change, etc.), which can have a significant impact on smooth functioning of maritime transport operations. Taking into account their dependence on the natural environment and their impact on the maritime industry (which is a major economic drive in most cities and countries), port cities are constantly exploring long-term economic development, creation of city wealth and resource management for the benefit of city authorities, with the aim of creating city sustainability and resilience (Hein, 2014).

Ports and cities are two different spatial economies and are always in a dynamic state of interaction and interdependence. Sustainable development is reflected in sustainable port cities through port – city interaction because the port benefits the city through its role in facilitating trade, employment, economic development, and environmental sustainability while relying on the city for the workforce and managerial talent (Zheng et al.). Finding and developing unified guidelines for the realization of a sustainable port city concept is challenging due to the fact that connecting port cities through various commodity flows creates specific spatial elements within their urban environments, including financing, technology, lifestyle, everyday life concept and building materials. The individuality of port cities is manifested in the fact that there is no specific shape, pattern, or dynamics that characterizes port cities, but still port cities show common features, which allows the study of their different characteristics through similar systematic frameworks (Hein, 2013).

Despite their individuality, port cities can be classified by influence within transport networks based on the criteria of city size (land area and population) and port activity (intensity of commodity flows manipulated within the port territory). Using these criteria, a matrix of the relationship between the port and the city is created (in terms of the degree of correlation between the port and the city) (Ducruet, 2007; Ducruet and Jeong, 2005). The matrix consists of a total of nine classification groups in terms of port - city relations. Within the matrix, the degree of correlation between the port and the city is studied in more detail through the centrality parameter, which is an urban functional parameter, and also through the intermediate parameter, which is a port functional parameter (Ducruet and Lee, 2006). The matrix contains two diametrically opposed diagonals. The first diagonal shows the optimal balanced development of the port - city relationship from the coastal city to the port metropolis, while the second diagonal shows the extremely unbalanced development within which there are two extremes, where the first is a metropolis with an insignificantly small port and the second is a world port with an insignificantly small city. In the center of the matrix, at the intersection of the diagonals, there is the port city, which can be considered an adequate balance between the port and the city. The matrix also contains the relations of the port and the city of milder balance, starting with "Out port", which depends on neighboring cities to be economically viable, and followed by "Urban port", which limits (by subordinating) its port activities to the needs of the city; "Maritime city", which by chance (without a directed intent) has efficient port and maritime activities; and "Gateway", which is characterized by the city's strong subordination to the port hinterland. The matrix of the relationship between the port and the city with the above mentioned nine classification groups regarding port - city relationships is illustrated in Figure 4.

As a concept, the port – city interface is more than six decades old; it was conceived during the 1960s to better understand the relationship between the port and the city through contemporary transformations of the urban waterfront interface. The complexity of the relationship between the port and the city seeks to be presented, analyzed, and explained in a simplified way by creating diagrams and models that depict and interpret the evolutionary trends of ports in relation to cities. Shortcomings in the analysis of the complex relationship between the port and the city are manifested in the presentation of changes in the spatial and functional relationship between the port and the city without considering the key causes of this change: economic, social, and environmental. The port city interface is a dynamic spatial concept characterized by constant change through the continuous intertwining of economic, social, and environmental factors. Due to local and global pressures today, these factors are becoming more common and current, and their amalgamation is sustainability. Therefore, it can be concluded that there is a gap in the study of the dynamic relationship between the port and city interface from the aspect of sustainability and that the "Port - City Interface" is perceived as a sensitive zone due to competition and conflict of port and city interests.

Based on the above mentioned, it is evident that research on only one element of the port - city relationship has been conducted – the geographical element. This is due to the fact

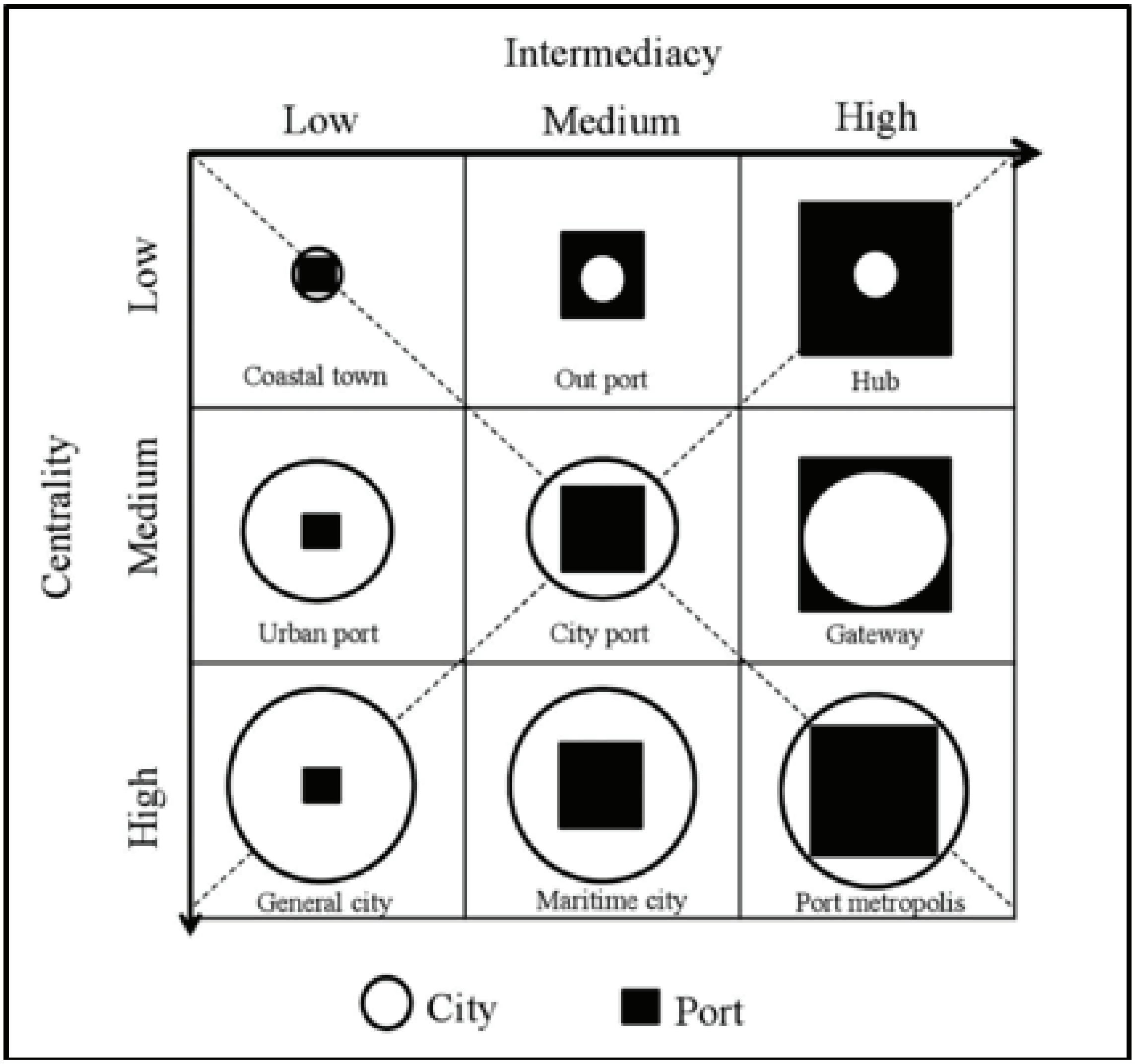


Figure 4.
Matrix of the relationship between the port and the city – Source: Ducruet and Jeong (2005).

that this element is an area of transition between the use of land by the port and the use of land by the city. The study and definition of the complex relationship between the port and the city interface exclusively from the perspective of compatible use of the available land is not based on the concept of sustainable development. This results in the fact that the complex relationship between the port and the city interface is not perceived as an interactive socio-economic- ecological system (Van der Berghe et al., 2018). Within the port and city interface, however, there are specialized business activities that are related to the port, shipping, and the city through various types of transactions (e.g. finance, risk management, consulting, etc.) (Zhao et al., 2017). These specialized business activities within the port-city interface go beyond the administrative boundaries of trade liberalization and take place irrespective of the quality of rational land use and even affect its use. In this context, the port-city interface can be considered an agglomeration of a number of port, maritime and city activities and should be perceived as a complex multidimensional dynamic entity consisting of many socio-economic-ecological layers, rather than one-dimensional through spatial analysis of the compatibility of available land for the expansion of port and urban territory (Hesse, 2017; Merk, 2014).

In this regard, it is important that the port and the city adapt to economic, social, and environmental issues and cooperate in a way that creates an integrated port city in the wider region, and this cooperation needs to be vital for solving problems of the past with the aim of achieving success in the future (Carpenter and Lozano, 2020). This is reflected in the fact that awareness is slowly being created about the long-term nature of port investments because focusing only on economic benefits can create accompanying environmental and social problems and, thus, ultimately compromise the tangible economic return on port investment. Therefore, the authors propose to accept the port - city interface as a dynamic and interactive socio-economic system with many participants that needs strategic coupling to enable participants to connect with territorial dynamics at local and regional level of the port city with network dynamics at national, international, and global level (Yeung, 2015).

4. ROLE OF TRANSITION MANAGEMENT IN PORT CITY SUSTAINABLE DEVELOPMENT

The gradual introduction of the concept of sustainability in the complex and dynamic relationship between the port and the city requires consistent consideration and the development of a planned framework for a sustainable port city development. Transitional management represents an adequate approach through which a systematic framework for planning and analyzing the current and predicting the future outcome of the development of a sustainable relationship between the port and the city could be designed. The construction of guidelines for the implementation of transitional management in port cities requires an understanding of the sustainability concept in relation to the port city. The latest definition of a sustainable port city is based on the original definition of sustainability contained in the Brundtland Report compiled in 1987 by the World Commission on Environment and Development: "The development of the port and the city should meet the current and future needs of different parties (stemming from the use of the port through market - business relations) without compromising the ability of future generations to meet their own needs." (WCED, 1987; Lam and Yap, 2019). On the basis of this definition, it can be concluded that the study of the concept of sustainability in relation to the port city refers to the original elements of sustainable development that include relevant economic, social, and environmental factors.

Guiding port cities towards change in terms of the desired direction of sustainability has thus become a key challenge that needs to be accepted and institutionalized at the local, regional, and national levels. In order to properly address today's complex socio-economic-environmental problems for transition to sustainable society, it is necessary to adopt a new approach to policy and governance which is more adequate for mitigating and addressing the growing negative complexities and diversities (Loorbach, 2002). A theoretical and methodological framework that offers operational guidelines on how to establish a systemic process for strategic coupling of participants in the port-city system, taking into account interventions aimed at changes

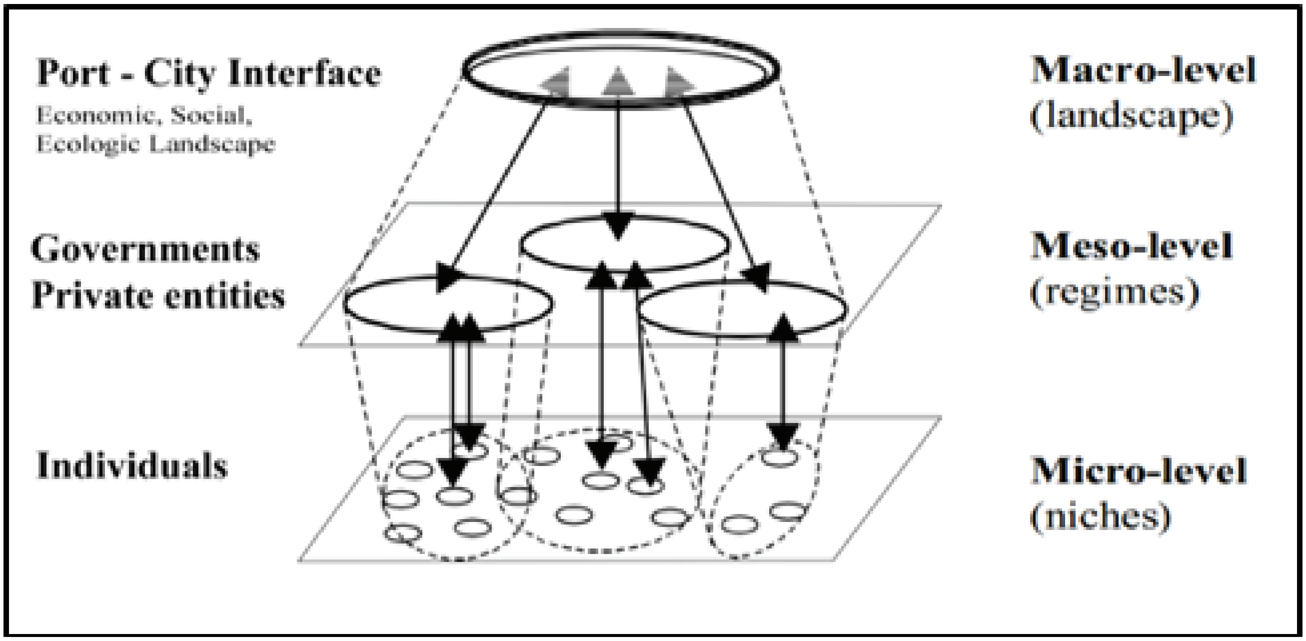


Figure 5.
Multilevel interaction of domains in transition within the port - city interface – Source: Adapted according to Geels and Schot (2007).

in complex adaptable social (sub-)systems, is called transition management (Nevens et al., 2013).

Transition management as a form of management is based on socio-technical transformations and strategic development for socio-technical transformative changes directed towards the realization of the concept of sustainability (Jaeger, 2009). The main goal of transition management is to focus on persistent structural and cultural constraints that underlie change towards more sustainable lifestyles. This is accomplished by emphasizing the need for long-term fundamental changes in existing socio-technical systems. At the same time, through transition management, guidelines are developed and provided for understanding on how socio-technical systems such as governance, cultural systems, infrastructure, and social practices co-evolve through mutual intertwining, resulting in radical changes (Kemp et al., 2007). A precondition for the realization of the transition is to have several events in different domains (economic, social, and environmental) at different levels (micro, meso, and macro) connected and mutually reinforced. An example of multilevel domain interaction in transition within a port - city interface is shown in Figure 5.

Analysis of Figure 3 indicates that transition management is a tool through which the interplay of macro (landscape), meso (regimes) and micro (niche) levels is defined. This multilevel concept serves to provide insight into changes within a dynamic socio-economic-ecological unit such as a port city, as follows:

- Macro-level: for a port city, generic indicators such as economy, demography, political climate, and culture are taken into account because they are inert, difficult to change, but very important and influential indicators
- Meso-level: for a port city, private and public institutions and infrastructure operating within the port and city interface are taken into account, as well as their values, common opinions, customs, unwritten rules and practices. Together they form a regime that in most cases aims at protecting its own existence through maintaining the status quo, rather than changing through innovation and optimization.
- Micro-level: for a port city, individual initiatives and innovations of an individual or a group (groups) of individuals are taken into account, which analyze i.e. critically evaluate the existing regime.

These levels intertwine, and through their intertwining the transition is manifested as follows:

The meso-level (private and public institutions) is characterized by resistance to change due to the fact that they (unconsciously) respect and practice social norms, belief systems and business models that they try to perpetuate. Private and public institutions operate according to strictly defined development guidelines with an aim to better adapt to the situational circumstances on the free market. However, the resistance of the meso-level is gradually beginning to dissipate as their adaptation to market conditions is made through the emergence of socio-economic and technical innovations. Therefore, there is a manifestation of contradictions within the meso-level regime because innovations force private and public institutions to change their own strictly defined development guidelines. After a certain period of time, the mentioned contradictions, due to their size, cannot be resolved on their own and they are poured over to other levels: to the macro-level through the change of worldview and perception of the observed phenomenon, and to the micro-level through the intensification of innovation by individuals, as they begin to experiment with alternative possible solutions to difficulties and challenges within the existing levels. Thus, the transition has the following characteristics (Loorbach, 2002):

1. It is oriented towards a large-scale technological, economic, ecological, socio-cultural, and institutional development that mutually influence and strengthen each other,
2. It is a long-term, evolutionary process involving at least one generation (25 years),
3. There are interactions between different levels (macro–landscape, meso–regimes, micro–niches)

The study of dynamic interactions between the port and the city through transition management can be considered adequate as it proposes the development of a systemic framework aiming at sustainable development of port cities. Table 2 provides an overview of economic, environmental, and social criteria that can serve as relevant indicators for designing a systemic framework through which the concept of sustainability for the port and urban system will be accomplished in a cooperative way.

The selected relevant criteria for designing a systematic framework for the implementation of transition management, with the aim of achieving a sustainable port - city relationship are based on the fact that the port city serves as a link between the local and global economies; it is the interaction of the city and the port system and it gives importance to its complex and dynamic nature (Pitelis and Teece, 2010). Using these criteria, the city and port authorities can coordinate the transition of sustainable port – city cooperation in the following ways (Fusco Girard, 2010; Megahed, 2014; Gurpinar and Balcioglu, 2018):

1. Considering sustainability, creativity, and resilience, ports could become development opportunities for port cities.
2. Protection of the architectural cultural heritage of ports has the possibility of a positive impact on the sustainable social development of port cities.
3. Protection of the coastal ecosystem and historical heritage would have a positive impact on improving the quality of life of the local population and could promote the physical and psychological perception and health of the urban population.
4. Green operational efficiency of the port from the port waterfront and the port hinterland would promote the economic and ecological development of port cities.

Table 1.
Relevant criteria regarding the design of a systematic framework for the implementation of transitional management with the aim of achieving a sustainable relationship between the port and the city – Source: Adapted according to PESTLE Analysis; UNCTAD (2016); Coles and Caserio (2001); Rueda (2012); ESPO Environmental Report 2019; Xiao and Siu Lee Lam (2016); Schiozzi et al. (2018).

General criteria	Generic criteria	Specific criteria	
		Port	City
Economic	gross domestic product interest rates exchange rates recessions / depressions taxes supply and demand ratio productivity added values	port revenues port costs port flow depreciation costs port operations taxes (corporate and land lease)	GDP per capita quantity of commercial activities (corporate, public) purchasing power of the citizen productivity of the city itself (labor, capital flow)
Social	quality of life health and well-being education, life skills and lifelong learning sense of community and local identity sense of security social inclusion recreation and sports	safety at work labor employment multiplier diversity of business positions sense of maritime heritage and culture spatial impact of port on community	unemployment rate political stability quality of transport, morphology of the city commercial social programs (social inclusion) transparent and efficient governance
Ecological	waste level energy consumption water quality water usage air quality soil quality noise carbon footprint evaluation of marine ecosystems assessment of terrestrial habitats	environmental protection (air, water, and soil) from pollutants from ships, port transshipment machinery and activities from port hinterland stricter conditions regarding waste production (ship-recycling facilities)	environmental quality (air, water, and soil) from urban activities (transport) and neighboring port activities disposal of (hazardous) waste (recycling, reuse, circularity) protection of marine ecosystems (coastal hydrology)

5. Port plans for environmental protection could guide the ecological sustainability of port cities.

The study of the development of the port-city relationship terms of sustainability from the aspect of transition management is also proposed since over several decades there has been a sharp increase in the number and scope of cooperation agreements involving ports and various participants in the vertical and horizontal value chains of ports with which they cooperate. Furthermore, after the Great Recession of 2008, special attention has been paid by the management and scientific communities to the creation, deepening, and expansion of collaborative approaches to governance (which included ports and cities). This resulted in the emergence of the concept of coopetition, which is a combination of the words cooperation and competition within the port system, the city system, and internationally distributed value chains.

Transition management provides a new, sophisticated management approach with the goal of achieving an effective port - city relationship. A new balance between the port and the city could be achieved through renewed co-orchestration and joint organization of different parties within the port and city landscape, port authorities, cargo handling companies, industrial companies, freight forwarders, distributors, shipping alliances, hinterland service providers and land terminals (Haezendonck and Verbeke, 2018). The main feature of this management model is based on the fact that port activities are becoming increasingly associated with a wider range of participants, and their operations are based on geographically dispersed economic participants, which are a prerequisite for long-term sustainability, growth and economic performance of ports and cities in terms of creating and capturing value (Haezendonck and Verbeke, 2018).

In this regard, it is important to achieve a new effective system of sustainable values through transition management, which will be characterized by positive economic growth with greater spill-over effects at all its levels (macro, meso, and micro). It is also necessary to focus on joint creation of opportunities and values through localized clusters and international systems. Port cities have an advantage in terms of these guidelines since they are strong economic entities supported by a long tradition of maritime activities, where different cultures and different environments meet on the border between the land and the sea (Xiao and Sie Lee Lam, 2016). Global, transport, logistics, industrial and financial hubs are extremely important as geographic entities and, therefore, play a key role in the formation of economic, social, and environmental values as people, commodities, ideas, and meanings pass through them.

5. CONCLUSION

Ports are considered important logistics and transport hubs with a key role in global maritime trade and movement of people. They are a place of modal exchange between maritime and land transport and have been centers of trade, investment, and innovation since the advent of civilization. Due to the already mentioned advantages that ports provide to their community, many settlements in their vicinity have developed into economically and politically influential urban agglomerations – cities. However, the cooperative relationship between the port and the city weakened in the early 1960s when the maritime transport system was radically transformed due to the implementation of containerization. This resulted in the change of both the port and the city as separate entities and at the same time it changed their relationship. Since the emergence of containerization, this newly created change in terms of separation of common interests between the port and the city is attempted to be explained using the concept of the port-city interface. By studying the concept of the port-city interface, it is concluded that the relationship between the port and the city, despite the fact that they are separated, becomes increasingly intertwined and complex as new changes affecting both the port and the city are constantly emerging.

The relations between the port and the city are thus variable, both spatially and over time, and the idea of the interdependence of port activities and urban phenomena has been re-emerging throughout the history and around the world. Today's port cities face economic, social, and environmental challenges, and their amalgamation is called sustainability. In order to achieve sustainability, ports and cities should operate in a collaborative way so that both can benefit from the mutual development (progress). The results of the research in this paper are visible in defining the guidelines for rebuilding the relationship between ports and cities through suggestion of the relevant criteria and in terms of designing a systematic framework for transitional management in a holistic way to improve the concept of sustainability between the port and the city. This framework is based on the criteria that respect the concept of sustainability by including: a) economic criteria to identify which factors affect prosperity, b) social criteria to identify which factors affect social inclusion; and c) ecological criteria to identify which factors affect the well-being of the natural environment. Using the presented theoretical concept of transition management could facilitate and improve the study of the dynamic relationship between the port and the city from all levels of the port - city interface, both today and in the future.

However, in further consideration of providing a solution for the reconciliation of the port - city relationship, a more detailed analysis of the mentioned relevant criteria is needed. In their further research, the authors are preparing to conduct an analysis of the correlation of relevant criteria through professional interviews and to test the results using the AHP method or MCDM method in order to obtain more accurate and reliable results.

CONFLICT OF INTEREST: The author(s) declares no conflict of interest.

REFERENCES

Carpenter, A. and Lozano, R., 2020. European Port Cities in Transition – Moving Towards More Sustainable Sea Transport Hubs. Springer Nature Switzerland AG, Cham, Switzerland.

Coles, R., and Caserio, M., 2001. Development of Urban Green Spaces to Improve the Quality of Life in Cities and Urban Regions. School of Architecture & Landscape, Faculty of the Built Environment, UCE, UK, Birmingham.

Ducruet, C. & Lee, S.-W., 2006. Frontline soldiers of globalisation: Port–city evolution and regional competition. GeoJournal, 67(2), pp.107–122. Available at: http://dx.doi.org/10.1007/s10708-006-9037-9.

Ducruet, C. and Jeong, O. J., 2005. European Port - City Interface and Its Asian Application. Gyeonggi - do: Korea Research Institute for Human Settlements.

Ducruet, C., 2007. A metageography of port - city relationships, In Wang, J., Olivier, D., Notteboom, T. & Slack B., Ports, Cities, and Global Supply Chains, England; Ashgate Publishing Limited, Chapter 11, pp. 157 - 172.

ESPO Environmental Report, 2019. Eco Ports in Sights 2019. European Sea ports Organisation, Brussels, Belgium.

Fusco Girard, L., 2013. Toward a Smart Sustainable Development of Port Cities/ Areas: The Role of the "Historic Urban Landscape" Approach. Sustainability, 5(10), pp.4329–4348. Available at:
http://dx.doi.org/10.3390/su5104329.

Geels, F.W. & Schot, J., 2007. Typology of sociotechnical transition pathways. Research Policy, 36(3), pp.399–417. Available at:
http://dx.doi.org/10.1016/j.respol.2007.01.003.

Haezendonck, E. & Verbeke, A., 2018. Introduction: Co-orchestrating Sustainable Port Ecosystems. Sustainable Port Clusters and Economic Development, pp.1–8. Available at:
http://dx.doi.org/10.1007/978-3-319-96658-8_1.

Hall, P.V. & Jacobs, W., 2012. Why are maritime ports (still) urban, and why should policy-makers care? Maritime Policy & Management, 39(2), pp.189–206. Available at: http://dx.doi.org/10.1080/03088839.2011.650721.

Hein, C., 2013. Port Cityscapes: Town and Harbour Development in the Global Context.

Hein, C., 2014. Port cities and urban wealth: between global networks and local transformations. International Journal of Global Environmental Issues, 13(2/3/4), p.339. Available at:
http://dx.doi.org/10.1504/ijgenvi.2014.064510.

Hesse, M., 2017. Approaching the Relational Nature of the Port-City Interface in Europe: Ties and Tensions Between Seaports and the Urban. Tijdschrift voor economische en sociale geografie, 109(2), pp.210–223. Available at:
http://dx.doi.org/10.1111/tesg.12282.

Hoyle, B., 2001. Fields of Tension: Development Dynamics at the Port-City Interface. Jewish Culture and History, 4(2), pp.12–30. Available at:
http://dx.doi.org/10.1080/1462169x.2001.10512227.

Hoyle, B.S., 1989. The port—City interface: Trends, problems and examples. Geoforum, 20(4), pp.429–435. Available at:
http://dx.doi.org/10.1016/0016-7185(89)90026-2.

Jacobs, W. et al., 2010. Integrating world cities into production networks: the case of port cities. Global Networks, 10(1), pp.92–113. Available at:
http://dx.doi.org/10.1111/j.1471-0374.2010.00276.x.

Jäger, J., 2009. The governance of science for sustainability W. N. Adger & A. Jordan, eds. Governing Sustainability, pp.142–158. Available at:
http://dx.doi.org/10.1017/cbo9780511807756.009.

Kemp, R., Loorbach, D. & Rotmans, J., 2007. Transition management as a model for managing processes of co-evolution towards sustainable development. International Journal of Sustainable Development & World Ecology, 14(1), pp.78–91. Available at:
http://dx.doi.org/10.1080/13504500709469709.

Lam, J. & Yap, W., 2019. A Stakeholder Perspective of Port City Sustainable Development. Sustainability, 11(2), p.447. Available at:
http://dx.doi.org/10.3390/su11020447.

Li, Z., 2018. Conflicts and Reconciliation at the Port-City Interface in Contemporary European Cities. Engineering Management Research, 8(1), p.1. Available at:
http://dx.doi.org/10.5539/emr.v8n1p1.

Loorbach, D., 2002. Transition Management: Governance for Sustainability, DRIFT Dutch Research Institute for Transitions, pp. 1 - 15.

Merk, O., 2014. The Port - city Interface: What is It, and How to Improve It?, Paper given at the 2014 Conference of AIVP in Durban, South Africa, Unpublished Manuscript.

Merk, O., 2018. Containership size and port relocation, Discussion Paper. International Transport Forum, Paris.

Nevens, F. et al., 2013. Urban Transition Labs: co-creating transformative action for sustainable cities. Journal of Cleaner Production, 50, pp.111–122. Available at: http://dx.doi.org/10.1016/j.jclepro.2012.12.001.

PESTLE Analysis: Economic Factors Affecting Business. Available at: https://pestleanalysis.com/economic-factors-affecting-business/.

Pigna, F.J., 2014. The City - Port Relationship: its evolution, changing dynamics and challenges for port authorities. Sefacil Foundation.

Pitelis, C.N. & Teece, D.J., 2010. Cross-border market co-creation, dynamic capabilities and the entrepreneurial theory of the multinational enterprise. Industrial and Corporate Change, 19(4), pp.1247–1270. Available at:
http://dx.doi.org/10.1093/icc/dtq030.

Port Economics, Management and Policy: A comprehensive analysis of the port industry. Available at: https://porteconomicsmanagement.org/.

Ravetz, J., 2013. New Futures for Older Ports: Synergistic Development in a Global Urban System. Sustainability, 5(12), pp.5100–5118. Available at:
http://dx.doi.org/10.3390/su5125100.

Rueda, S., 2012. Ecological Urbanism Certification - Urbanism Certification with Sustainability Criteria. Barcelona Urban Ecology Agency, Barcelona.

Saz-Salazar, S. del, García-Menéndez, L. & Merk, O., 2015. Port–City Relationship and the Environment: Literature Survey and Methodological Approach for Project Appraisal in Presence of Environmental Externalities. Journal of Urban Planning and Development, 141(3), p.04014029. Available at:
http://dx.doi.org/10.1061/(asce)up.1943-5444.0000230.

Schiozzi, D., Jugović, A. & Smojver, Ž., 2018. Comparative Analysis of the Related Interests of Relevant Stakeholders in the Development of Seaports in Relation to the Spatial Concept of the City. Pomorstvo, 32(1), pp.36–41. Available at:
http://dx.doi.org/10.31217/p.32.1.17.

The Economist Intelligence Unit, 2012. Hot Spots Benchmarking global city competitiveness, The Economist Intelligence Unit Limited 2012, pp.1 - 39.

UNCTAD., 2016. Port Performance - Linking Performance Indicators to Strategic Objectives. United Nations, Switzerland, Geneva.

Van den Berghe, K., Jacobs, W. & Boelens, L., 2018. The relational geometry of the port-city interface: Case studies of Amsterdam, the Netherlands, and Ghent, Belgium. Journal of Transport Geography, 70, pp.55–63. Available at:
http://dx.doi.org/10.1016/j.jtrangeo.2018.05.013.

WCED, 1987. Our Common Future (First), Oxford, Oxford University Press.

Xiao, Z. and Siu Lee Lam, J., 2016. A Systems Framework for Sustainable Development of Port City: Case Study of Singapore's Policies. Research in Transportation Business and Management, 22, pp.255 – 262. Available at:
https://doi.org/10.1016/j.rtbm.2016.10.003.

Yeung, H. W. C., 2015. Regional Development in the Global Economy: A Dynamic Perspective of Strategic Coupling in Global Production Networks, Regional Science Policy & Practice 7, pp. 1 - 23.

Zhao, Q. et al., 2017. Building a bridge between port and city: Improving the urban competitiveness of port cities. Journal of Transport Geography, 59, pp.120–133. Available at:
http://dx.doi.org/10.1016/j.jtrangeo.2017.01.014.

Information on Resource Utilisation for Operational Planning in Port Hinterland Transport

Per Wide, Violeta Roso

To meet increased freight flows through maritime ports, a high level of resource utilisation in hinterland transport is of crucial importance. However, various perspectives on resource utilisation create issues with use of information for operational decisions in port hinterland. The purpose of this paper is to explore the use of information related to resource utilisation for operational planning in port hinterland freight transport to facilitate its improvement. The study is case-based, and the data is collected through semi-structured interviews, visual observations, and company documents. The findings are analysed with a framework built from literature emphasising different resource utilisation perspectives and the use of information in road freight transport chain decisions. The findings show that the use of information on resource utilisation in operational freight transport decisions in the port hinterland transport system is limited and lacks a complete system overview. Instead of the information on measured parameters, different types of estimates of efficiency parameters (including resource utilisation) are commonly used for operational planning decisions. The information about the measured indicators has to be combined with other information to obtain an efficient level of resource utilisation; otherwise, it could generate incorrect assumptions regarding utilisation. The paper contributes to the topic of operational freight transport planning by describing the use of information on resource utilisation.

KEY WORDS
- ~ Port hinterland transport
- ~ Resource utilisation
- ~ Road freight transport
- ~ Logistics service provider
- ~ Decision making
- ~ Operational planning

Chalmers University of Technology, Department of Technology Management and Economics, Gothenburg, Sweden

e-mail: violeta.roso@chalmers.se

doi: 10.7225/toms.v10.n02.w02

Received on: 23.09.2020 / Revised on: 04.06.2021 / Accepted on: 19.07.2021 / Published online: 28.07.2021

1. INTRODUCTION

With increasing maritime freight transport, the development in ports and hinterland operations has to be matched. According to Parola et al. (2017), the second most important factor driving port competitiveness after port service costs is port hinterland connectivity. However, despite its importance, hinterland connectivity, i.e. hinterland operations or capacity of inland modes, is usually one of the main barriers in functional intermodal transport chains, resulting in congestion and other sustainability issues (Behdani et al., 2020; Black et al., 2018). High resource utilisation leads to lower transport costs and at the same time reduces environmental impact (Santén, 2016). Furthermore, the energy efficiency of transport increases as resource utilisation increases, creating further incentives for the actors in the system to improve the load factor (Santén et al., 2018). However, actors in the hinterland transport chain are struggling to obtain high resource utilisation (e.g. Behdani et al. (2020); Elbert and Walter (2014). A port's hinterland is not statically determined, but it varies dynamically due to developments in technology, economy, and society; related operational decisions are constantly challenged by these dynamic changes (SteadieSeifi et al., 2014), which generate changes in the planned resource utilisation. Hinterland freight transport by road carries with it issues related to resource utilisation in transport route and consolidation decisions, illustrated by a high level of empty running (McKinnon and Ge, 2006) and waiting times at terminals (Jacobsson et al., 2017; Phan and Kim, 2015). Uneven workload at terminals (Murty et al., 2005) contributes to existing problems of low resource utilisation for intermodal terminal operators. Furthermore, Sternberg (2008) demonstrated waste in activities of truck drivers which indicated a potential for better resource utilisation in this area.

Technological advancements such as information communication technologies (ICTs) could provide new opportunities for increasing resource utilisation via efficient freight transport operations (Stefansson, 2006; Elbert and Walter, 2014). These advancements provide improved possibilities in dealing with the dynamic and stochastic nature of operative freight transport (Steadie Seifi et al., 2014) through information exchange and support for decision making during unexpected events (Meyer et al., 2014). So far, information in the hinterland literature has mainly covered planning (e.g. Elbert and Walter, 2014) or synchronisation between actors (e.g., Jacobsson et al., 2018), but research on information as a tool for reporting on resource utilisation (used resources) in order to make it more efficient has been scarce. New technologies could improve information for measuring resource utilisation and for sharing that information with decision makers. Different perspectives on resource utilisation regarding coverage and measurements (Samuelsson and Tilanus, 1997) make it difficult to provide sufficient information to decision makers (Meyer et al., 2014). Therefore, the purpose of this paper is to explore the use of information related to resource utilisation for operational planning in port hinterland freight transport in order to facilitate its improvement. Behdani et al. (2020), in their critical review on port hinterland transport, emphasised the need for research related to capacity optimisation efforts, which are closely related to resource utilisation, in order to lower the environmental footprint of the hinterland transport system.

2. FRAME OF REFERENCE

Van Klink and Van den Berg (1998) define a port's hinterland as 'the interior region served by the port' or 'places that can be served by the port more cheaply than from other ports'. For many ports, the weakest link in their transport chain is access to/from their hinterland, where congested roads cause delays (Roso et al., 2019). That, combined with low resource utilisation of transport modes and other resources, contributes to an increase in transport costs, all together influencing the dynamics of the hinterland.

2.1. Freight Planning Decisions

Freight transport research has broadly covered decisions taken in the freight transport planning processes (see, e.g. Steadie Seifi et al., 2014, and Guastaroba et al., 2016, for general freight transport planning, and Gumuskaya et al., 2020, for hinterland transport focus). Transport planning decisions can take place on three levels: strategic, tactical, and operational, with each level executing planning at different time horizons, long term, medium term, and short term respectively (Crainic and Laporte, 1997). Additionally, Stank and Goldsby (2000) argued for a decision scope ranging from macro to micro, representing decisions taken considering the whole network and those involving one node or link. Planning on the operational level is highly influenced by conditions set during strategic and tactical planning, e.g. network design (Woxenius, 2007; Guastaroba et al., 2016) or collaboration strategies (Barratt, 2004).

Crainic and Laporte (1997) classify transport planning processes for transport providers (called 'carriers') at the operative level into scheduling of services, empty vehicle distribution or repositioning, crew scheduling, and allocation of resources. Service schedules at the tactical level are expressed in detail, including time of departure and arrival from origin to destination and, if applicable, time and length of terminal stops. Less-than-load (LTL) road freight applies time intervals in contrast to shipping lines, which use fixed times for departure. Imbalances in demand, both in amount and time, generate shortages or surpluses of resources such as trailers, containers, and trucks in one node or area (Lumsden, 2006). To deal with these imbalances, planning of empty vehicle distribution and repositioning is needed. Crew scheduling includes, among other things, scheduling for terminal operators and truck drivers to vehicles. For terminal operators, uneven arrival of trucks can generate spread-out workloads that make it difficult to stick to schedules (Murty et al., 2005). Similarly, allocation of resources includes allocating limited resources to tasks to fulfil demand (Crainic and Laporte, 1997). Operational decisions for the terminal operator mainly deal with scheduling incoming and outgoing flows and carriers, assigning carriers to gates (or tracks in rail transport), and temporary storage at nodes (Van Belle et al., 2012; Boysen et al., 2012).

Involvement of many different actors in an intermodal transport chain creates complexity in the sense that it is difficult to track the goods and control the chain. Complexity also increases with the various roles the actors play, e.g. the transport operator can be a road haulier and/or a rail operator, depending on the transport mode in the transport chain. The transport buyer can be either a consignee or a consignor, and the transport service provider role can be taken by the transport coordinator or by the transport operator (Woxenius, 2012). This complicates the understanding of information on resource utilisation as one actor can deal with many decisions in a transport chain or only a part of them. Decisions on what to transport as well as the amount and time boundaries are controlled by the transport buyer, and this actor can also dictate how the transport is done, e.g. without consolidation. Time restrictions from the transport buyer could constrain the possibility of consolidation (Stank and Goldsby, 2000). Transport operators dealing with only one link in the transport chain are not responsible for decisions affecting resource utilisation such as what shipments to consolidate and which route to take. However, they might take other decisions affecting resource utilisation, such as what operations to offer in order to keep the vehicle and driver running as much as possible. The logistics service provider deals with demands from the transport buyer and coordinates transport from origin to destination (Wolf and Seuring, 2010). Decisions can be static or dynamic depending on the information available at the time. Static decision problems are solved via one decision (Schönberger, 2011). Dynamic decision problems involve a sequence of decisions needed to achieve the goal; decisions are constrained by earlier and later decisions, and changes in the problems are presented by the environment or by action from a decision maker (Edwards, 1962). Available information for these decisions can be in the form of real-time information (Meyer et al., 2014), such as continuously updated information, or historical data, which could be based on experience (Knemeyer et al., 2009).

2.2. Resource Utilisation

Resource utilisation is defined as the ratio of used to available resources, which is seen as part of efficiency according to Caplice and Sheffi (1994). It has also been treated as a part of performance measurement (Shaw, 2009). Performance is similar to efficiency, defined as the ratio between inputs and outputs for a given process. Performance in logistics is usually divided into utilisation, usage of input, productivity, ratio of actual output and input, effectiveness, and quality of output (Caplice and Sheffi, 1994). In this paper, the focus is on utilisation. A resource can be defined by ownership as something a company owns or has access to, including temporary access (Mills et al., 2002) or as a 'factor that has the potential to contribute economic benefit' (Galbreath, 2005: 890). A common classification of resources differentiates between tangible, physical, and financial assets such as buildings and vehicles, and intangible resources such as experience, skills, and intellectual property (Galbreath, 2005). Andersen and Suat Kheam (1998) point out that tangible resources are easily understood as financial or physical resources, but there are differing views on what should be considered as intangible resources.

Resource utilisation is often used in hinterland transport literature to measure efficiency improvements at various port and hinterland setups (Li et al., 2018; Elbert and Walter, 2014). Mainly, the utilisation revolves around the port, e.g. truck waiting or crane utilisation (Li et al., 2018). However, discussions about different perspectives on resource utilisation for transport operations are mainly found in general freight transport literature. Therefore, the following sections include perspectives on resource utilisation for freight transport, focusing on road transport to correspond to the case study described below in this paper.

Resource utilisation is coupled with resources: poor decisions by terminal operators will not only lead to lower resource utilisation at the port terminal, but also to longer waiting times and lower resource utilisation for vehicle and truck drivers. This generates a need to consider resource utilisation from a larger perspective than merely the actor. The system view is of further importance as freight transport often revolves around complex setups of actors and activities (Sternberg et al., 2013), generating trade-offs in objectives for some processes. For example, the owner of a resource such as a trailer for road transport usually aims for a high load factor (capacity utilisation of the vehicle), resulting in the trailer waiting at a terminal until fully loaded (or as much as possible) so that it is still profitable. However, the freight owner might hinder this by demanding shorter lead times (faster transport of goods to the destination). Furthermore, information for resource utilisation can be represented in different ways, adding to the complexity of using the information for planning decisions. Load factor and capacity utilisation are frequently used in freight transport to assess the resource utilisation of a transport mode. This can be done by considering limitations of weight, space/volume, and deck area (McKinnon, 2000). The level of utilisation of one transport mode might change over time, e.g. due to unbalanced flow when a trailer is fully loaded in one direction, but empty on back-haul. Therefore, in the example above, empty running and fuel consumption (McKinnon and Ge, 2004) need to be considered in order to holistically evaluate utilisation of resources. A vehicle travelling completely loaded from on node to another, but coming back empty might be fully utilised from an economical viewpoint if both directions are included in the price, but only half are physically utilised (Lumsden, 2006). In this regard, empty running, according to (McKinnon and Ge, 2004), is an indicator covering capacity and distance.

Samuelsson and Tilanus (1997) provide a comprehensive approach to transport efficiency in which they divide efficiency into factors of time, distance, speed, and capacity, along with the subgroups of each factor. This would not only apply to vehicles, which the authors use as the resource, but also e.g. trailers and terminal operators. Following Samuelsson and Tilanus (1997) approach, this paper takes two perspectives on resource utilisation, one related to the transport route (including time, distance, and speed) and the other related to the unit load (including capacity). These different perspectives on resource utilisation in the literature are summarised in Table 1.

Table 1.
Summary of different perspectives on resource utilisation in the literature.

Route-related resource utilisation	Unit load-related resource utilisation
Amount of time active (vehicle) (McKinnon and Ge, 2004; Samuelsson and Tilanus, 1997)	Physical capacity (Lumsden, 2006)
Efficiency waste by not doing value-added work (Sternberg, 2008)	Load factor - volume, weight, etc. (McKinnon and Ge, 2004; Samuelsson and Tilanus, 1997)
Directness (Woxenius, 2012)	Economical capacity (payed load factor, payload) (Lumsden, 2006)
Extra distance (Sanchez Rodrigues, 2014)	
Deviation from schedule (McKinnon and Ge, 2004; Samuelsson and Tilanus, 1997)	
Fuel consumption, eco driving (McKinnon and Ge, 2004; Díaz-Ramirez et al., 2017)	

McKinnon and Ge (2004) introduced vehicle time utilisation and classified activities into running on road, loading or unloading, waiting for departure, waiting for loading or unloading, maintenance or repair, and driver pause and idle. The perspective of distance includes efficiency problems due to not taking the shortest route, not having a return load, not executing stops in optimal sequence, detours due to round trips, and deviations between planned and actual trip. Woxenius (2012) introduced directness as an indicator for dealing with detours due to disruptions. Similarly, extra distance is introduced due to disruptions in transport operations that change distances (Sanchez Rodrigues, 2014). McKinnon and Ge (2004) emphasise deviations from schedule as this can affect utilisation planning on multiple collection or delivery rounds. The factor of speed includes inefficiency when not driving at maximum speed due to congestion and differences in speed limits. Speed variations can be included as part of eco-driving (Díaz-Ramirez et al., 2017), which is associated with fuel consumption (McKinnon and Ge, 2004). Distance and speed include input and output relations (productivity), but they are important factors in considering how well a resource is being utilised. The capacity and capacity utilisation of a trailer (loading unit) can be measured in various ways from different perspectives such as by volume, weight, floor space occupancy, and height (Santén, 2017). The reasoning behind measuring capacity (load factor) in terms of vehicle level or load unit level has likewise been stressed by McKinnon and Ge (2004) and Santén (2017) respectively.

3. METHODOLOGY

To capture the system view, the logistics service provider (LSP) perspective is chosen for this paper due to its coordinating role in freight transport (Ramstedt and Woxenius, 2006). This actor makes dynamic operational decisions which should generate a need for information on resource utilisation. Connections should be provided to other actors proposing a better understanding of resource utilisation from a system view. This research uses a single case study method to explore how information regarding resource utilisation is used in the studied context (Yin, 2014; Eisenhardt, 1989). The case is based on an LSP offering sea transport solutions mainly between Sweden and the UK, in which the regional part of scheduling and consolidation decisions for road hinterland freight transport is the focus of the study. The transport company was chosen as it represents an LSP in a hinterland transport chain in which the LSP's influence on operational decisions is high (Ramstedt and Woxenius, 2006). The chosen company is involved in operational decisions directly linked to the utilisation of both its own resources and those of other actors. The primary data for the study was collected through six semi-structured interviews and through observations during three on-site visits focusing on transport planning and transport operations. Furthermore, the company documents were studied in order to fill in gaps as well as for confirmation of some interview findings. At the company's request, details such as company name and names of the interviewees are not revealed here.

The six semi-structured interviews were around 30–60 minutes long. Four interviews were performed with three freight planners/coordinators, one at each planning group. One of the three planners was interviewed twice as he had knowledge and work experience in two of the planning groups. Additionally, one interview with a planning group manager was done, and one was done with a general manager focusing on follow-up (control) of resource utilisation. The semi-structured interviews with the planners were based on different topics in order to cover the purpose of the paper. First, to understand the decisions taken, broader topics were included such as the type of planning executed, how the planning decisions were carried out, and what type of information was used. Thereafter, the focus of the interviews was on the role resource utilisation has in planning and on what kind of information regarding resource utilisation is available, received, and used. This division is made in order to get a better overview of the decisions taken and the information regarding resource utilisation. The interview with the general manger focused on information regarding operational activities at a higher level that were presented to the planners, but not in connection to operational decision making. Only the interview with the general manager was audio recorded as the interviews with the planners took place in an open landscape office, making it difficult to obtain a proper audio recording. All interviews were done face-to-face except for the interview with the planning group manager conducted via telephone. Extensive notes were taken during all interviews. The sample size for interviewees was not fixed beforehand; rather, an evaluation was made of when enough data was collected and saturation was reached (Flick, 2014).

The on-site observations at the freight planning department were conducted on three occasions, giving insight into how the planning was actually performed. Documents for internal reporting were examined to obtain data on information reported to management and quality work.

Research quality was ensured through triangulation of different methods of data collection. Extensive notes from each interview were compiled and shared for confirmation to each responder to avoid incorrect interpretations. All operative freight planning groups at the case company were covered to provide richness of collected data.

4. FINDINGS AND ANALYSIS

In this section, the case company and its operational decisions are briefly described, followed by the interview findings, which are analysed and discussed in relation to the frame of reference.

4.1. Case Description

The case company delivers import shipments and collects export shipments on trailers via the transport mode road. Trailers arriving at the port are scheduled for distribution by either direct delivery to the customer or other regions, or by consolidation via the regional cross-dock terminal. The collection of shipments is done in the same region in Sweden as planned exports. The plans for these two activities are compiled and modified with the objective of creating a route schedule that combines both deliveries and collections as backhaul to mitigate empty running. The case company acts as a logistics service provider, transport coordinator, and terminal operator, owning 800 trailers and operating cross-dock terminals. Trucks and truck drivers are outsourced to different hauliers.

The operational transport decisions taken at the company are classified into three different planning groups, as illustrated in Table 2. As a consequence of the choice for consolidation of shipments, decisions on what shipments to consolidate are made. Next, route planning is performed in which flows of freight leaving Sweden through the port are combined with import flows to obtain appropriate round trips. Finally, decisions on combining the proposed distribution and collection routes are taken. Additionally, in this decision group, adaptations to the proposed route are made in the case of unforeseen changes in transport activities.

Table 2.
Illustrating the operational planning groups with main decisions at the case company.

Planning groups	Main decisions
Distribution	Direct delivery or consolidation with other shipments
Shipment consolidation for distribution	
Collection	Shipment consolidation for collection
Combining distribution and collection routes into one round trip and assigning resources (contacting haulier)	Combining distribution and collection route to one drivers' route - contacting haulier to assign route

The decisions are in line with the operational scheduling of services discussed by Crainic and Laporte (1997), being made in real time (Brehmer, 1992). The allocation of resources such as terminal operator and truck driver is performed by other actors, and the control of these decisions is done by the company studied. The control can be in the form of making phone calls to ensure that the haulier has booked the drivers. The planning decisions regarding empty trailer distribution or repositioning are included in the different planning groups. The interviews revealed the main focus on costs and customer satisfaction in transport decisions. Furthermore, dangerous goods, loading security, etc. overrule or limit the possibility of achieving high resource utilisation. The operational decisions are built on rules of thumb and experience from conceptual usage of information coming mainly from complaints. For modifications in operations that influenced resource utilisation, the planners were mainly informed via email and phone.

4.2. Information on Resource Utilisation

Three main resources influencing planning decisions were identified: trailer (T), truck and truck driver (TD, discussed as one resource), and terminal and terminal operator (TO, discussed as one resource). Considering the resources of a truck and the belonging truck driver as one resource follows the interpretation from the planners who provided the empirical data. The planners plan the truck and the truck driver jointly (as one resource) as the services for these two resources are outsourced to hauliers. The main findings of the case study are summarised in Table 3, and they demonstrate what types of resource information were available and what kinds of resource utilisation the information focused on.

Overall, the received information regarding resource utilisation was scarce for the studied operational decisions. Nevertheless, three types of use for available information were found. First, the information collected and followed up on by management at the case company was input for strategic decisions and not with the aim of providing instant indications of resource utilisation for operational decisions. This could be explained by the fact that the main purpose of this type of information was for documentation, such as ISO, and not to support operational decisions. Examples of this information type are load factor (on outgoing trailers from terminal based on payload from bookings), service level, CO_2 emissions, eco-driving, and truck Euro class. Second, information available for operational planning decisions was found to be based either on forms of real-time information or on information from experience. Regarding real-time information, only information on load factor was identified as available to planners for direct evaluation of resource utilisation. The company's IT system supported the collection of that type of information. These three types of use of available information correspond well with the previous literature findings regarding use of information for real-time decisions (Meyer et al., 2014), experience-based decisions (Knemeyer et al., 2009), and input to strategic decisions (SteadieSeifi et al., 2014).

Table 3.
Representation of information available for different types of resources and their utilisation.

Type of resource utilisation	Information available for		
	Real-time operational planning decisions	Experience-based planning decisions	Input to strategic decisions
Unit load resource utilisation	T PL*	TO	TD
	TO	T PL*	
Route-related resource utilisation	TD	TD	
		TO	

** PL stands for payload.*

4.2.1. Information on Resource Utilisation Related to Unit Load

Information regarding unit load is mainly related to the trailer as the resource. The trailer capacity was important for all planning groups, corresponding to the fact that the company owns the trailers and wants high-capacity utilisation of their resources. Information for the expected trailer payload is given directly in the planning process. The observational data in this information is illustrated in Table 4., where each row is a shipment, and the total payload (PL) is summed up. The figure indicates information about resource utilisation directly when a decision of shipment consolidation is made. Importantly, the information does not represent capacity utilisation; for this calculation, the load as capacity for the trailer is needed. Information relevant to planning decisions is provided, but it requires manual combination with other information to obtain capacity utilisation. This leads to a risk of assuming incorrect capacity utilisation if incorrect trailer capacity is assumed.

Table 4.
Observational data from planning system of the payload for shipments consolidated in one trailer is shown in last column (Fkg), giving direct feedback of filled payload. TBId stands for transport booking ID, and Fkg is the payload. Customers and receivers are hidden due to confidentiality.

TBId	Shipper		Reciever		FKg
11917822	SE	AVESTA	GB	CRADLEY	18400
11637822	SE	LUDVIKA	GB	HEREFORD	800
11651822	SE	LUDVIKA	GB	HEREFORD	600
11960823	SE	KIL	GB	SITTINGBOURNE	130
11803822	SE	KRISTINEHAMN	GB	BIRMINGHAM	800
12758822	SE	GOTEBORG	GB	COLCHESTER	135
11351822	SE	TORSAS	GB	NEWTON AYCLIFFE	262
12780822	SE	BORAS	GB	BRADFORD	3200

The payload in Table 4. is calculated by adding planned shipments based on either weight, volume or load meter (based on length) of the shipment (taken from transport booking), depending on which one is the most limiting and generates the highest price. Importantly, this is the chargeable weight payload based on the transport bookings and not the actual load. The payload and the booking parameters may differ from the actual load at pick-up. Interestingly, there seems to be no clear objective, desired level for the payload. This can partly be explained as the received information has to be combined with trailer capacity, and even then, it only represents one part of capacity (not actual capacity used), making the whole resource utilisation (or efficiency) problematic. Using this information as a base for resource utilisation in consolidation decisions considers only one aspect of capacity utilisation (payload).

An actual filled load is more difficult to obtain than payload as it demands information for resource utilisation after pick-up has occurred. For example, if a planned shipment includes four pallets, but at pick-up three or even five are loaded, the information about the new load factor needs to be obtained. To measure the actual load may require extra work or technical implementation. Monthly reports on average payload are presented to planners, but they are mainly used to ensure that planners are aware of the importance of payload factor in order to make decisions on strategic and tactical levels as well as to convince others that the planning is going well. This kind of information makes connections to specific operational decisions difficult. The information reported monthly or quarterly usually focuses on important aspects at a higher strategic level, e.g. achieving a high economic payload on the sea portion of the transport chain and not focusing on each route performed. Additionally, the capacity of the terminal may be considered if the planner, through experience, knows that during some hours or days the terminal is usually busy; they can plan without driving via terminal to avoid high demand. This reasoning in planning can affect the utilisation of the trailers in a negative way as they perform transport directly without using consolidation to increase capacity utilisation. As the terminal is operated by the case company, more emphasis on a system view, including the terminal needs, can be expected. Specific information about workload at the terminal regarding capacity and time was not identified, but using complaints from the terminal as information brought experience into the equation regarding terminal workload. In this way, experience was used rather than the information on actual workload for a specific day.

4.2.2. Information on Resource Utilisation Related to the Route

The resource of truck and truck driver was considered when making route decisions. Some planners mentioned that they want to keep a good relationship with their hauliers and so generate routes that allow them to get good utilisation of the truck (and driver) for one working day. Complaints were received via phone from hauliers about bad or inappropriate features on routes. This worked as information, not in the form of any measured indicator, but conceptually to understand truck drivers' problems with routes. These problems were e.g. insufficient driver resting schedules and the need to return to origin by the end of the day. The planning group with the main responsibility for haulier and truck driver contact emphasised this point to a higher degree than the other groups as they probably receive most of the feedback from hauliers. Regarding information on the distance, the trailer resource was the focus. Knowledge about the distance between stops combined with estimated times for loading and unloading (at customer, pick-up at supplier or terminal) directly provides estimated times for planning. No measured indicator as information for this was evident. This also illustrates previous reasoning regarding the lack of a desired level of utilisation. Varied experiences lead to different buffers being built into the planning so as to cope with unexpected events. Distance was also mentioned in regard to empty running in connection to the trailer resource, but without any information about distance or empty running. Empty running was estimated via distance and payload from the planners to obtain an overview. Furthermore, as mentioned above, time utilisation by terminal and terminal operators was included in the planning decisions with the intention of spreading out the terminal workload. No specific measured indicator was found for this, only complaints from the terminal that provided experience.

The impact of decisions on the environment was not mentioned by the interviewees. However, other main objectives provide good side effects for the environment, such as lower fuel consumption. Environmental indicators of emissions and fuel usage (from haulier) were collected on tactical levels, but not used directly in operational decisions.

4.2.3. System View on Usage of Indicators for Resource Utilisation

The information for the studied operational decisions is limited in covering all perspectives of resource utilisation, as can be seen in Table 3. The system view of utilisation is limited in representing the complete picture of resource utilisation in hinterland transport. The case company focuses on unit load capacity in terms of payload instead of on broader utilisation coverage of actual capacity (based on actual weight) used. The studied case, therefore, lacks a broad coverage of capacity, pointed out to be important for sufficient indication of capacity (McKinnon and Ge, 2004; Lumsden, 2006).

By using limited information about resource utilisation, the case company may obtain an incorrect impression of their resource utilisation, such as how well they are utilising their trailers. Additionally, the environmental concerns related to resource utilisation (e.g., (McKinnon and Ge, 2004; Díaz-Ramirez et al., 2017) had no linked information at the operative planning level. Rather, to satisfy customer needs, customer service had priority in planning, in contrast to the perception in the literature of plans being made to achieve environmentally positive (McKinnon and Ge, 2004) or shortest route (Woxenius, 2012) targets.

The planners take resources from other actors into account, which should suggest resource utilisation models that cover perspectives of many actors' resources as being more practically suitable. However, information about utilisation of these resources is mainly based on experience within the case company and lacks the integration of other actors in the planning process. The complex setups of transport planning examined by Sternberg et al. (2013) make the consideration of other actors difficult. Information exchange between actors could provide possibilities to compile more detailed information, adding a new dimension to the current data. To avoid suboptimal solutions, information with broader system views of actors and utilisation are needed. Furthermore, ICT could support information about resource utilisation. This is important for planners to connect resource utilisation to a specific decision. Most decisions are based on experience of 'what works', and little information about resource utilisation is given in connection to the decisions. As indicated by Meyer et al. (2014), this points towards the importance of closing information gaps in operational planning in order to improve operational transport decisions.

In line with Meyer et al. (2014), the issue of providing updated information during unexpected events in operations is salient. Lack of information about resource utilisation during operative planning additionally limits the ability to effectively deal with dynamic operative decisions as indicated by Steadie Seifi et al. (2014). If re-plan adjustments are made to the original plan due to unexpected events during transport operations, resource utilisation is influenced and needs to be updated. The lack of updated, direct information on resource utilisation for planners impedes the ability of planners to understand the re-plan decision's impact on resource utilisation. The focus may not be on providing only a feasible plan after the unexpected event (Meyer et al., 2014; Li et al., 2018), but a feasible plan without too much negative impact on resource utilisation. Since the planners lack this information, it is difficult to know how much the new plan will impact resource utilisation, either positively or negatively.

5. CONCLUSION

Operational decisions by a logistics service provider were examined from the perspective of using information on resource utilisation. The purpose of this paper was to explore the use of information related to resource utilisation for operational planning in hinterland freight transport in order to facilitate its improvement. A case study was designed around a hinterland LSP to capture information regarding resource utilisation for hinterland transport decisions. Findings from the case study show that consideration of information on resource utilisation in transport decisions is limited at the case company. Estimations based on experience of efficiency parameters, including resource utilisation, are used instead of measured parameters as information for operational decisions.

The study suggests that information with a broader system view is not used in operational decisions. The information used does not give a full picture of resource utilisation, only payload for capacity, which limits the possibility of covering resource utilisation appropriately in decisions. Furthermore, actual resource utilisation is not known exactly, but is estimated from available data that represent a combination of different types of information, potentially generating the risk of incorrect assumptions regarding resource utilisation. These insights about information around resource utilisation provide theoretical contribution to hinterland transport literature by broadening the view of information to resource utilisation instead of considering information for planning purpose or synchronisation between actors. While practical contribution is in increased understanding on information around resource utilisation, transport and logistics managers can use the different viewpoints of resource utilisation to understand how their current use of information in the operational planning provides support to their planners.

Advancements in ICT could provide possibilities for better measuring utilisation with more precise information. The results point towards lack of measurements, which limits the information on resource utilisation. This implies that further research is needed on how to use ICT to measure and share utilisation and information. The results further imply that the LSP should consider how ICT can be used to enable direct information sharing for resource utilisation when something unexpected occurs. Finally, information for resource utilisation that includes a broader system view could contribute to information sharing in freight transport literature, where information is not only playing a role in changing and directly improving activities for some actor(s), but contributes to the resource utilisation when unexpected events occur.

The limitation on the generalisability of a single case study can be addressed by future research investigating a similar approach with other actors or transport setups. Furthermore, the findings in this paper rely on qualitative data, which can be used for setup of future quantitative studies. Future research could start with the lack of information around re-planning identified in this study, e.g. information about when to re-plan, and how the re-plan will impact the planned resource utilisation.

ACKNOWLEDGMENT

This research was funded in part by the EU Interreg Öresund-Kattegat-Skagerrak Value2Sea project.

REFERENCES

Andersen, O. & Suat Kheam, L., 1998. Resource-based theory and international growth strategies: an exploratory study. International Business Review, 7(2), pp.163–184. Available at:
http://dx.doi.org/10.1016/s0969-5931(98)00004-3.

Barratt, M., 2004. Understanding the meaning of collaboration in the supply chain. Supply Chain Management: An International Journal, 9(1), pp.30–42. Available at: http://dx.doi.org/10.1108/13598540410517566.

Behdani, B. et al., 2020. Port-hinterland transport and logistics: emerging trends and frontier research. Maritime Economics & Logistics, 22(1), pp.1–25. Available at: http://dx.doi.org/10.1057/s41278-019-00137-3.

Black, J. et al., 2018. Issues in Dry Port Location and Implementation in Metropolitan Areas: The Case of Sydney, Australia. Transactions on Maritime Science, 7(1), pp.41–50. Available at:
http://dx.doi.org/10.7225/toms.v07.n01.004.

Boysen, N. et al., 2012. Shunting yard operations: Theoretical aspects and applications. European Journal of Operational Research, 220(1), pp.1–14. Available at:
http://dx.doi.org/10.1016/j.ejor.2012.01.043.

Brehmer, B., 1992. Dynamic decision making: Human control of complex systems. Acta Psychologica, 81(3), pp.211–241. Available at:
http://dx.doi.org/10.1016/0001-6918(92)90019-a.

Caplice, C. & Sheffi, Y., 1994. A Review and Evaluation of Logistics Metrics. The International Journal of Logistics Management, 5(2), pp.11–28. Available at:
http://dx.doi.org/10.1108/09574099410805171.

Caplice, C. & Sheffi, Y., 1994. A Review and Evaluation of Logistics Metrics. The International Journal of Logistics Management, 5(2), pp.11–28. Available at:
http://dx.doi.org/10.1108/09574099410805171.

Díaz-Ramirez, J. et al., 2017. Eco-driving key factors that influence fuel consumption in heavy-truck fleets: A Colombian case. Transportation Research Part D: Transport and Environment, 56, pp.258–270. Available at:
http://dx.doi.org/10.1016/j.trd.2017.08.012.

Edwards, W., 1962. Dynamic Decision Theory and Probabilistic Information Processings. Human Factors: The Journal of the Human Factors and Ergonomics Society, 4(2), pp.59–74. Available at:
http://dx.doi.org/10.1177/001872086200400201.

Eisenhardt, K.M., 1989. Building Theories from Case Study Research. The Academy of Management Review, 14(4), p.532. Available at:
http://dx.doi.org/10.2307/258557.

Elbert, R. & Walter, F., 2014. Information flow along the maritime transport chain - a simulation based approach to determine impacts of estimated time of arrival messages on the capacity utilization. Proceedings of the Winter Simulation Conference 2014. Available at:
http://dx.doi.org/10.1109/wsc.2014.7020028.

Flick, U., 2014. An introduction to qualitative research, Sage publiations.

Galbreath, J., 2005. Which resources matter the most to firm success? An exploratory study of resource-based theory. Technovation, 25(9), pp.979–987. Available at: http://dx.doi.org/10.1016/j.technovation.2004.02.008.

Guastaroba, G., Speranza, M.G. & Vigo, D., 2016. Intermediate Facilities in Freight Transportation Planning: A Survey. Transportation Science, 50(3), pp.763–789. Available at:
http://dx.doi.org/10.1287/trsc.2015.0631.

Gumuskaya, V. et al., 2020. A framework for modelling and analysing coordination challenges in hinterland transport systems. Maritime Economics & Logistics, 22(1), pp.124–145. Available at:
http://dx.doi.org/10.1057/s41278-019-00139-1.

Jacobsson, S., Arnäs, P.O. & Stefansson, G., 2017. Access management in intermodal freight transportation: An explorative study of information attributes, actors,

resources and activities. Research in Transportation Business & Management, 23, pp.106–124. Available at:
http://dx.doi.org/10.1016/j.rtbm.2017.02.012.

Jacobsson, S., Arnäs, P.O. & Stefansson, G., 2018. Differentiation of access management services at seaport terminals: Facilitating potential improvements for road hauliers. Journal of Transport Geography, 70, pp.256–264. Available at:
http://dx.doi.org/10.1016/j.jtrangeo.2018.06.009.

Knemeyer, A.M., Zinn, W. & Eroglu, C., 2008. Proactive planning for catastrophic events in supply chains. Journal of Operations Management, 27(2), pp.141–153. Available at:
http://dx.doi.org/10.1016/j.jom.2008.06.002.

Li, N. et al., 2018. Disruption management for truck appointment system at a container terminal: A green initiative. Transportation Research Part D: Transport and Environment, 61, pp.261–273. Available at:
http://dx.doi.org/10.1016/j.trd.2015.12.014.

Lumsden, K., 2006. Logistikens grunder: Teknisk logistik, Studentlitteratur, ISBN: 9789144124827.

Mckinnon, A., 2000. Sustainable distribution: Opportunities to improve vehicle loading. Industry and Environment, Vol. 23 No. 4, pp. 26-27.

McKinnon, A.C. & Ge, Y., 2004. Use of a synchronised vehicle audit to determine opportunities for improving transport efficiency in a supply chain. International Journal of Logistics Research and Applications, 7(3), pp.219–238. Available at:
http://dx.doi.org/10.1080/13675560412331298473.

McKinnon, A.C. & Ge, Y., 2006. The potential for reducing empty running by trucks: a retrospective analysis. International Journal of Physical Distribution & Logistics Management, 36(5), pp.391–410. Available at:
http://dx.doi.org/10.1108/09600030610676268.

G. Meyer, G. et al., 2014. Intelligent products for enhancing the utilization of tracking technology in transportation. International Journal of Operations & Production Management, 34(4), pp.422–446. Available at:
http://dx.doi.org/10.1108/ijopm-11-2012-0530.

Mills, J. et al., 2002. Strategy and Performance. Available at:
http://dx.doi.org/10.1017/cbo9780511754692.

Murty, K.G. et al., 2005. A decision support system for operations in a container terminal. Decision Support Systems, 39(3), pp.309–332. Available at:
http://dx.doi.org/10.1016/j.dss.2003.11.002.

Parola, F. et al., 2016. The drivers of port competitiveness: a critical review. Transport Reviews, 37(1), pp.116–138. Available at:
http://dx.doi.org/10.1080/01441647.2016.1231232.

Phan, M.-H. & Kim, K.H., 2015. Negotiating truck arrival times among trucking companies and a container terminal. Transportation Research Part E: Logistics and Transportation Review, 75, pp.132–144. Available at:
http://dx.doi.org/10.1016/j.tre.2015.01.004.

Ramstedt, L., Woxenius, J., 2006. Modelling approaches to operational decision-making in freight transport chains. Proceedings from the NOFOMA 2006 conference, 8-9 June, Oslo.

Roso, V., Russell, D. & Rhoades, D., 2019. Diffusion of Innovation Assessment of Adoption of the Dry Port Concept. Transactions on Maritime Science, 8(1), pp.26–36. Available at:
http://dx.doi.org/10.7225/toms.v08.n01.003.

Samuelsson, A. & Tilanus, B., 1997. A framework efficiency model for goods transportation, with an application to regional less-than-truckload distribution. Transport Logistics, 1(2), pp.139–151. Available at:
http://dx.doi.org/10.1163/156857097300151660.

Sanchez Rodrigues, V. et al., 2014. Developing “Extra Distance” as a measure for the evaluation of road freight transport performance. International Journal of Productivity and Performance Management, 63(7), pp.822–840. Available at:
http://dx.doi.org/10.1108/ijppm-05-2013-0091.

Santén, V., 2016. Towards environmentally sustainable freight transport - shippers’ logistics actions to improve load factor performance, Doctoral Thesis, Chalmers University of Technology.

Santén, V., 2017. Towards more efficient logistics: increasing load factor in a shipper’s road transport. The International Journal of Logistics Management, 28(2), pp.228–250. Available at:
http://dx.doi.org/10.1108/ijlm-04-2015-0071.

Santén, V., et al., 2018. Energieffektivisering genom ökad fyllnadsgrad i sjötransporter.

Schönberger, J., 2011. Model-based control of logistics processes in volatile environments, Springer-Verlag New York Inc., ISBN: 9781441996817.

Shaw, E.H., 2009. A general theory of systems performance criteria. International Journal of General Systems, 38(8), pp.851–869. Available at:
http://dx.doi.org/10.1080/03081070903270543.

Stank, T.P. & Goldsby, T.J., 2000. A framework for transportation decision making in an integrated supply chain. Supply Chain Management: An International Journal, 5(2), pp.71–78. Available at:
http://dx.doi.org/10.1108/13598540010319984.

SteadieSeifi, M. et al., 2014. Multimodal freight transportation planning: A literature review. European Journal of Operational Research, 233(1), pp.1–15. Available at:
http://dx.doi.org/10.1016/j.ejor.2013.06.055.

Stefansson, G., 2006. Collaborative logistics management and the role of third-party service providers B. Gammelgaard, ed. International Journal of Physical Distribution & Logistics Management, 36(2), pp.76–92. Available at:
http://dx.doi.org/10.1108/09600030610656413.

Sternberg, H., 2008. Transportation visibility and information sharing: A case study of actors' requirements. World Review of Intermodal Transportation Research, 2(1), pp. 54-71. Available at:
https://doi.org/10.1504/writr.2008.021485.

Sternberg, H., Germann, T. & Klaas-Wissing, T., 2013. Who controls the fleet? Initial insights into road freight transport planning and control from an industrial network perspective. International Journal of Logistics Research and Applications, 16(6), pp.493–505. Available at:
http://dx.doi.org/10.1080/13675567.2013.856391.

Sternberg, H., Prockl, G. & Holmström, J., 2014. The efficiency potential of ICT in haulier operations. Computers in Industry, 65(8), pp.1161–1168. Available at:
http://dx.doi.org/10.1016/j.compind.2014.07.002.

Van Belle, J., Valckenaers, P. & Cattrysse, D., 2012. Cross-docking: State of the art. Omega, 40(6), pp.827–846. Available at:
http://dx.doi.org/10.1016/j.omega.2012.01.005.

Van Belle, J., Valckenaers, P. & Cattrysse, D., 2012. Cross-docking: State of the art. Omega, 40(6), pp.827–846. Available at:
http://dx.doi.org/10.1016/j.omega.2012.01.005.

Wolf, C. & Seuring, S., 2010. Environmental impacts as buying criteria for third party logistical services Á. Halldórsson, ed. International Journal of Physical Distribution & Logistics Management, 40(1/2), pp.84–102. Available at: http://dx.doi.org/10.1108/09600031011020377.

Woxenius, J., 2007. Generic Framework for Transport Network Designs: Applications and Treatment in Intermodal Freight Transport Literature. Transport Reviews, 27(6), pp.733–749. Available at: http://dx.doi.org/10.1080/01441640701358796.

Woxenius, J., 2012. Directness as a key performance indicator for freight transport chains. Research in Transportation Economics, 36(1), pp.63–72. Available at: http://dx.doi.org/10.1016/j.retrec.2012.03.007.

Yin, R.K., 2014. Case Study Research Design and Methods (5th ed.), Sage publications.

Volatility of Ship Demolition Index Prices

Bangar Raju Totakura[a], Vrinda Sharma[a], Vishal Kashav[a], Subir Ranjan Das[b]

Aim: The main objective of this paper is to explore the volatility of ship demolition indices. Ship demolition indices are becoming increasingly important owing to the growing number of norms and rules imposed by the International Maritime Organization. Financial crunch and stricter emission norms are forcing vessel owners to consider ship demolition options. This study examines the volatility of ship demolition rates of the Baltic Demolition Index and the causal relationship between the Chinese and Indian subcontinent indices.

Methods: EGARCH models have been used to explore the volatility and asymmetric effects in the time series. The relationship between the two indices was established using the Granger causality test.

Results and conclusion: The final analysis confirmed that ship demolition indices are both volatile and asymmetric. This study is unique and useful to ship owners, vessel operators, and banks as it helps them understand the risks involved.

KEY WORDS

~ Causality
~ Volatility
~ EGARCH
~ Baltic demolition index

a. University of Petroleum and Energy Studies, Dehradun, India
e-mail: bangarraju@gmail.com
b. Sharda University, Greater Noida, India
e-mail: subir.das@sharda.ac.in

doi: 10.7225/toms.v10.n02.w04

Received on: 07.06.2020 / Revised on: 27.02.2021 / Accepted on: 26.07.2021/Published online: 09.08.2021

1. INTRODUCTION

Shipbreaking is the disassembling of old ships to recover steel scrap and different materials. The ship-breaking industry is a reusing industry that recovers steel from ships or, in other words, 90% of the vessels. Other materials, comprising the remaining 10%, are machines and gear, furniture and fittings, asbestos, wood boards, oil, synthetic substances, electrical fittings, and so on. Ship-breaking practices, originally reserved for high-income nations, have gradually also been adopted by low-income nations with their raising awareness of environmental concerns and the consequent introduction of more stringent controls. In the course of that process, the ship-breaking industry has transformed from a capital-serious sector to a work-escalated industry. The ship demolition or shipbreaking industry is important due to its major effect on ship supply and demand, as it affects freight rates on both freight shipping and shipbuilding markets. The need to understand the said demolition markets is of critical importance. Although the shipbreaking industry has the potential for financial development, it also brings the additional risks of different national regulations. Until the 1970s, ship breaking practices have largely been concentrated in the newly created nations. Nations like India, Bangladesh, China and Pakistan have less stringent labor standards or less effective enforcement of labor regulations. The data from (UNCTAD, 2019) illustrate ship demolition trends over the last 4 years.

Figure 1 shows continuous ship demolition growth at the global level until 2016. However, 2017 saw a decline in the tonnage of demolished ships. The volumes have remained promising for the industry.

Figure 2 shows that China accounts for approximately 15% of demolitions, while the subcontinent, consisting of India, Pakistan, and Bangladesh, accounts for approximately

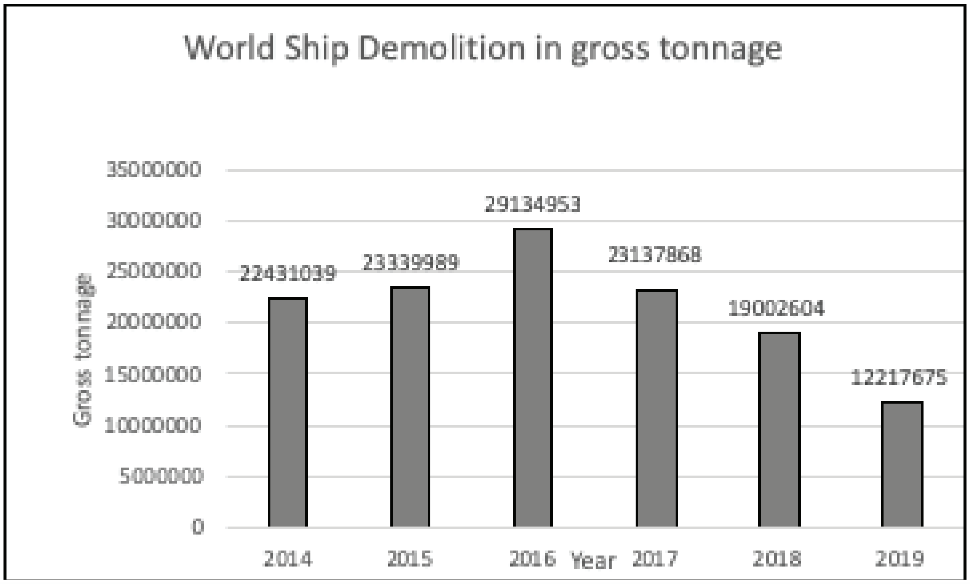


Figure 1.
World ship demolition in gross tonnage.

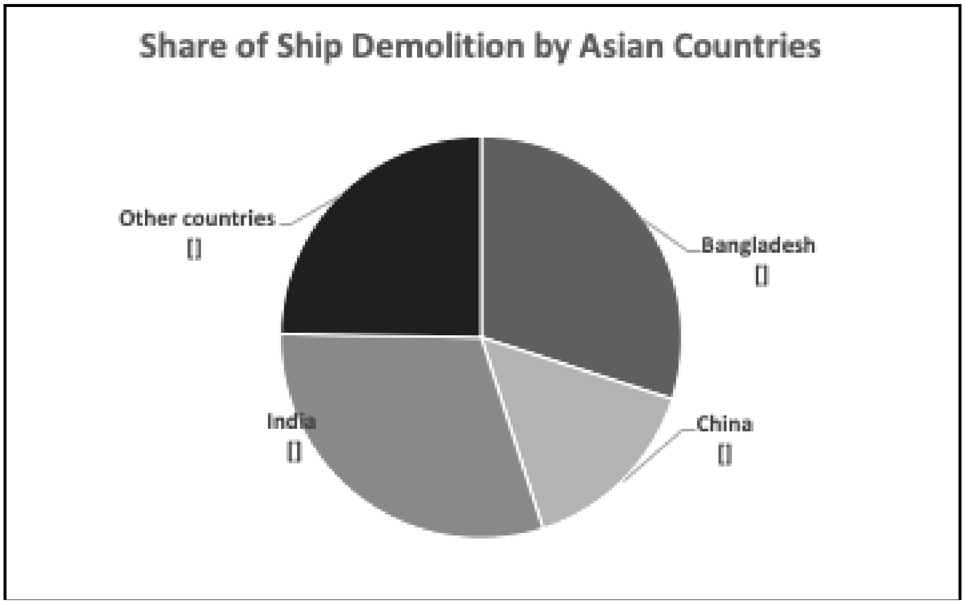


Figure 2.
Ship demolition by Asian countries.

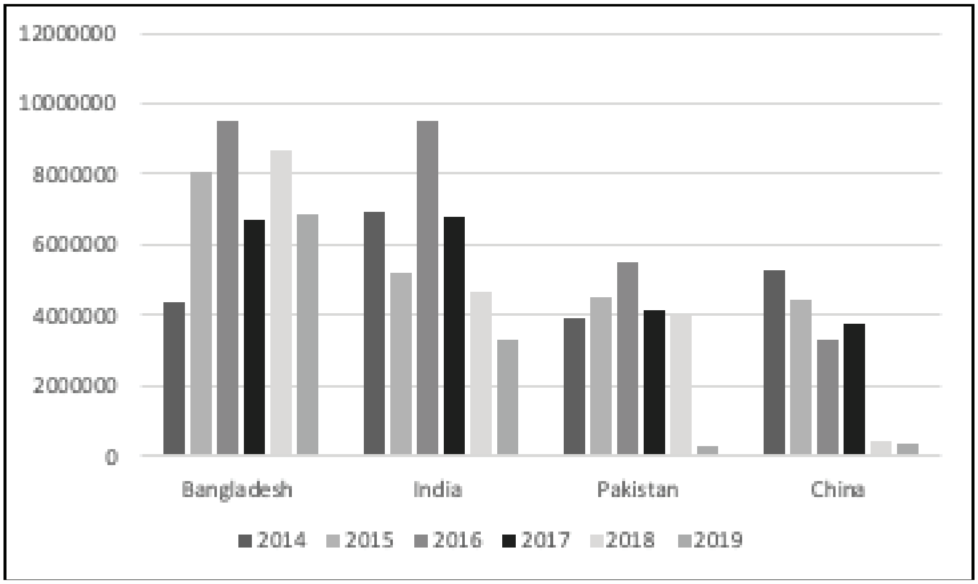


Figure 3.
Increase in the gross tonnage of demolished ships in top four countries.

60%. Figure 3 illustrates growing demolition volumes in India, Pakistan, and Bangladesh. India and Bangladesh are shown to have experienced satisfactory growth except in 2017.

Having gained an understanding of the market share of various countries in ship demolition over the last four years, we chose China and the subcontinent as two major markets to be targeted by our study. We are yet to understand the relationship between the two markets, even though volumes are quite promising.

According to (UNCTAD, 2017) four countries - India, Bangladesh, Pakistan, and China - account for 94.9 per cent of known ship scrapping. Turkey managed to keep the market niche of gas carrier, ferry and passenger ship scrapping. All other countries combined account for only 1.6 per cent of the world's total. The report shows that the gross tonnage of demolished ships in 2017 decreased by one quarter compared to 2016, which is an indicator of improved market optimism. Though bulk carrier and container ship scrapping slowed down in response to improved market conditions, tanker recycling increased. The study is quite distinctive as there is little understanding of the relationship between the two demolition indices. The majority of ship scrapping continued to take place in India, followed by Bangladesh and Pakistan. This paper attempts to understand the volatility, leverage effects and causality relationships between the two Baltic Demolition indices.

2. LITERATURE OVERVIEW

Little has been written about the ship demolition market, a fundamental component in the shipping supply/demand ratio. Only a limited number of studies examined the economic and econometric models in the ship demolition and recycling domain. Research papers and reports referred to in this section are presented in chronological order. The working report by (Stuer-Lauridsen, Kristensen, & Skaarup Cowi, 2003) discusses various driving instruments of the shipbreaking process and gives an account of the environmental consistency of select offices of OECD nations which might be utilized to scrap ships secured by Danish controls.

All shipbreaking takes place in Asia, especially in Pakistan, India, Bangladesh and China. Ship owners find scrap ship rates offered by shipbreakers from those countries (exceeding OECD rates by up to two times) attractive. Consequently, only a limited number of shipyards in OECD countries still provide shipbreaking services. The reasonable limits of Canada, France, Germany, the UK, and other OECD nations have not been researched due to the absence of shipbreaking records. Similarly, the USA was excluded, although experts in charge of obsolete navy vessels have authorized four US organizations for dispatch rejection. The Mexican shipbreaking industry has downscaled in the last decade. In (Ea Krogstrup, 2006), the authors discus political and environmental issues relevant to various ship scrapping stakeholders. The thesis examines whether ships are considered products or waste at the time of scrapping, which depends on the policies of various countries and the International Maritime Organization. The initial market analysis of ship demolition has been discussed in (Buxton, 1991). The author has brought forward various elements of the purchase and sale of ships. Economic obsolescence, affected by freight market levels, seems to be a significant factor in ship scrapping. The cost of ship demolition and the realizable value of materials have an effect on the choice of the country of demolition. The paper analyses the trend based on data from the 1960s, when the shipbreaking market was shifting from Taiwan and western Europe to the Indian subcontinent. In (Kaiser, 2008) Mark Kaiser discusses ship and rig scrapping in the American Gulf of Mexico. The paper also reviews factors that have an impact on disposal and shipbreaking costs.

An early attempt at econometric modelling in the ship demolition market was made in (Knapp, Kumar, & Remijn, 2008). The aim of econometric analysis was to understand the dynamics of the ship demolition market. The results indicate the positive effect on ship scrap prices and negative effect on ship earnings. Of all countries, Bangladesh was found to be the most sensitive to ship scrap prices, followed by India, Pakistan and Turkey. Other variables like ship age, ownership, flag of registration and profile were also analyzed. The system dynamic approach was used in (Kusumaningdyah, Eunike, & Yuniarti, 2013) to gain an understanding of the economic benefits and environmental losses attributable to the shipbreaking industry. The impact of shipbreaking activity on the environment, health and safety in Bangladesh was studied in (Hossain, Fakhruddin, Chowdhury, & Gan, 2016). Effective management practices and adequate planning are required to mitigate environmental impacts, and improve the health and safety of workers. In addition, the issues and challenges relating to fatal accidents during ship demolition in Bangladesh were discussed in (Rabbi & Rahman, 2017).

The effect of foreign exchange rates on ship demolition was studied in (Karlis, Polemis, & Georgakis, 2016). The results indicate a strong correlation between foreign exchange rates and ship scrap prices. Karlis also explained how money flows are affected by currency fluctuations in (Karlis & Polemis, 2016). Ship demolition market forecasting and modelling was conducted in (Nikos D. Kagkarakis, Andreas G. Marikas, 2016). The correlation between international steel scrap prices and ship demolition was established using the Vector Autoregressive model (VAR). The model was applied to south Asian countries which depend on steel scrap importation and are experiencing growing ship demolition activity. The impact of various factors like less efficient ships, financial crisis, etc. on ship demolition in different market conditions has been analyzed using the survival distribution function in (Yin & Fan, 2018).

The above overview clearly shows that only a limited number of studies have tried to explain the volatility of ship demolition indices and that econometric analysis in this area is scarce. Therefore, there is a need to explore the volatility of ship demolition indices.

3. RESEARCH METHODOLOGY

The time series are initially tested for unit root by using the Augmented Dickey-Fuller test (David A. Dickey and Wayna A. Fuller, 1981). The volatility of both indices was determined using the EGARCH model (Nelson, 1991). The EGARCH (1,1) model is given below.

$$log\,(\sigma_t^2) = \alpha_0 + [\,1 - \beta_1\,]^{-1}\,[\,1 + \alpha_1\,]\,\gamma z t_{-1} \qquad (1)$$

Where σ_t^2 is conditional and $z(t)$ residual volatility.

α_0 = constant in the variance equation, α_1 = ARCH parameter, β_1 = GARCH parameter and

γ =asymmetry parameter.

As an extension of the study, we also explored whether there was any spillover between the two markets. We used the Granger Causality test (C. W. J. Granger, 1969). However, as the test established the presence of spillovers, an extensive study on spillovers should be conducted separately.

4. DATA

Two time series (Baltic Exchange limited, 2019) have been analyzed in this paper:

Weekly Baltic China index rates for bulk carriers of per long ton displacement between 7000 dwt and 12000 dwt lightweight from 07/01/2008 to 17/09/2018 - 552 observations.

Weekly Baltic Subcontinent index rates for bulk carriers of per long ton displacement between 7000 dwt and 12000 dwt lightweight from 07/01/2008 to 17/9/2018 - 552 observations.

5. ANALYSIS

We estimated the volatility of ship demolition index rates in China and the Indian subcontinent (India, Pakistan, and Bangladesh). The data have a weekly frequency, and span the period from the first week of January 2007 to the third week of September 2018 (552 observations). We used logarithmic differences for our analytical purposes. First, we estimated the summary statistics for both series. The results are given in Table 1. The results indicate that both series are negatively skewed and exhibit fat-tails. This finding is corroborated by JB statistics that confirm the non-normal distributional nature of both series.

Table 1.
Summary statistics.

Parameters	China	P-values	Subcontinent	P-values
minimum	-0.09396		-0.14709	
mean	-0.00036		-7.79E-05	
maximum	0.095947		0.048919	
Standard deviation	0.013188		0.013506	
Skewness	-0.781	0.000	-4.3865	0.000
Excess Kurtosis	15.5	0.000	40.812	0.000
JB statistics	5566.9	0.000	39933	0.000

6. EGARCH ANALYSIS

We have used conditional volatility models from the GARCH family. The GARCH model was introduced by Engle and Bollerslev (Engle & Bollerslev, 1986). GARCH family models assume that volatility has a specific functional form are therefore called conditional volatility models. GARCH models are classified based on the functional form of volatility and require that the data used in the model be stationary.

Consequently, we applied the Augmented Dicky Fuller (ADF) (David A. Dickey and Wayna A. Fuller, 1981) test on the log differenced series. The results are given in Table 2.

Table 2.
Unit root test results.

Series	Statistic	P- values
China	-12.882	0.000
Indian subcontinent	-11.324	0.000

In the ADF test, the null hypothesis is that there is a unit root present in the data, i.e. the series is non-stationary. The unit root test results clearly show that the null of unit root is rejected for both series, implying that both series are stationary. Therefore, it is safe to proceed with volatility modeling. Before attempting conditional volatility modeling, we need to establish whether the dataset exhibits autocorrelation and volatility clustering. We thus estimated the Ljung-Box Q statistic (BOX, 1978) for autocorrelation for the standardized squared residuals and the ARCH-LM test (Engle, 1982) for volatility clustering. The results are presented in Table 3. The results of the Ljung-Box test suggest that the null hypothesis that there is no autocorrelation is rejected for both series. Similarly, the null hypothesis that there is no volatility clustering is rejected for both India and the subcontinent in the ARCH LM test results.

The pre-estimation diagnostic test results indicated the presence of conditional volatility in the data. We then proceeded with GARCH model estimation. We used Exponential GARCH, a.k.a EGARCH (Nelson, 1991) model to estimate the conditional volatility present in the dataset. EGARCH was selected because (a) it is not limited by the positivity constraints of GARCH models, (b) EGARCH can distinguish the impact of negative news and

Table 3.
Pre-estimation diagnostics.

Tests	China	P-values	Subcontinent	P-values
LB(Q^2) [5]	13.745	0.000	67.088	0.000
ARCH LM [5]	97.1952	0.000	275.789	0.000

positive news on volatility, and thus captures the asymmetric nature of volatility, whereas the standard GARCH model is incapable of capturing asymmetry. Due to the data's abnormal nature, we estimated the AR(1)-EGARCH (1,1) model under three distributions - normal, student-t and skewed student-t for both series. We chose the best model after comparing AIC values. The AR(1)-EGARCH(1,1) using the student-t distribution was found to minimize AIC values for both China and the subcontinent. Hence, this model was selected for further analysis. The results are shown in Table 4.

Table 4.
Estimated model parameters.

Parameters	China	P-values	Subcontinent	P-values
μ	-0.0004	0.152	0.00094	0.077
AR(1)	0.50174	0.00	0.56458	0.000
α_0	-0.32415	0.097	-1.13796	0.028
α_1	-0.08590	0.428	-0.01669	0.805
β_1	0.96023	0.000	0.878053	0.000
γ_1	0.96746	0.000	0.464784	0.001
shape	2.1	0.000	2.710021	0.000
MAE	0.0010	0.0010	0.0033	0.0033

First, we analyzed EGARCH model output for China. The ARCH parameter α_1 was found to be statistically insignificant, whereas GARCH parameter β_1 was found to be statistically significant and high (>0.9). This implies persistent volatility of the ship demolition rate in China. Past conditional variances impact volatility, and it takes time for shocks to die out. The asymmetry parameter γ is statistically significant, implying the asymmetric influence of positive and negative news on the volatility of the ship demolition rate. The shape parameter is also significant, thereby confirming the abnormal nature of the data. Next, the EGARCH model output for the subcontinent was analyzed. Here too, the ARCH parameter α_1 was found to be statistically insignificant. The value of the GARCH parameter β_1 was 0.878. The persistent nature of volatility of the ship demolition rate for the Indian subcontinent was confirmed. Once again, γ was found to be significant, implying the asymmetric impact of positive and negative news on the volatility of the ship demolition rate in the Indian subcontinent. Both models exhibit reasonable forecasting ability, as indicated by the Mean Absolute Error (MAE) values, estimated on a 5-period in-sample forecast.

After the estimation, the next logical step was to see whether the estimated models captured data volatility in an adequate manner. We thus conducted the same tests (Ljung-Box Q test and ARCH LM test) on EGARCH residuals. If the model successfully captures the volatility present in the data, the residuals should be free from autocorrelation and volatility clustering. The post estimation diagnostic test results are shown in Table 5.

Table 5.
Post-estimation diagnostic test results.

Tests	China	P-values	Subcontinent	P-values
LB(Q^2) [5]	0.442	0.966	0.421	0.969
ARCH LM [5]	0.598	0.854	0.122	0.982

The results show that both residuals are free from autocorrelation and volatility clustering. The models successfully captured the volatility dynamics of ship demolition rates in both China and the Indian subcontinent. To conclude, the ship demolition index rates for China and the Indian subcontinent are volatile. Further, the volatility is found to be asymmetric in nature.

7. GRANGER CAUSALITY TEST RESULTS

We examined whether there is any causal relationship between ship demolition rates in China and the Indian subcontinent by using the Granger causality test (C. W. J. Granger, 1969). Granger causality can be interpreted as a test of predictive ability. Consider two series, X and Y. The X series granger causes Y if Y can be better predicted by using the values of X along with the lagged values of Y.

While interpreting the results, it must be noted that the Granger causality test is a test of predictive ability rather than a test of actual causality. The Granger causality requires both series analyzed to be stationary. As they have previously been tested for stationarity by unit root testing, this criterion is met. The results of the Granger causality test for ship demolition rates in China and the Indian subcontinent are given in Table 6. The Granger test's optimal lag length was determined using the AIC (Akaike Information Criteria) values and was found to be 3.

Table 6.
Granger Causality test results.

Hypothesis	Statistic	P-values
China(NGC)Subcontinent	5.0658	0.001
Subcontinent(NGC)China	7.464	0.000
Note: NGC stands for "Not Granger Causes."		

Bidirectional causality between China and India was examined. The null hypothesis is that X does not granger cause Y and vice versa. Granger causality test results indicate that the null of no Granger causality should be rejected in both cases. Therefore, we have evidence of existence of a bidirectional causal relationship, i.e. evidence that ship demolition rates of China and the Indian subcontinent influence each other.

8. CONCLUSIONS

The ship demolition segment is hugely important in the maritime domain and responsible for active fleet supply stabilization. The decision to scrap a ship depends on a number of elements, such as ship age and obsoleteness, amendments to maritime and environmental regulations, as well as circumstances in the maritime domain. Under the worst conditions, even ships as young as ten years are sent to the scrapyard to ensure continued balance on the market and the survival of ship owners in bad times. The decision is dependent upon ship demolition prices. The analysis performed in this study propounds essential knowledge of the ship demolition segment, which is different from what was done in earlier studies. In this research, time series were first tested for unit root by using the Augmented Dickey-Fuller test, followed by the establishment of the volatility of both indices with the EGARCH model. The foremost aim of this study was to estimate the volatility of ship demolition index rates for China and the Indian subcontinent (India, Pakistan, and Bangladesh) to allow ship owners to pick the appropriate time and price of ship demolition. A thorough overview of literature has shown that a study of this type was long awaited. In the developing economies the increasing need for a comfortable life is counterbalanced by growing unemployment. For developing countries with a vast population and growing demand the ships demolition business is of great interest since materials ranging from steel, engines and toilets can be put into use. Also, the costs of labor are meagre compared to those in the developed economies. Moreover, ship demolition activities are a major source of environmental pollution as large quantities of carcinogens and toxic materials are emitted which are not only dangerous for workers but also increase the acidity of soil and coastal waters. For all these reasons, developed countries have banned ship demolition activities. Based on years of observation of trends in all countries we came to the conclusion that the five leading countries in the ship demolition business are India, Bangladesh, Pakistan, China and Turkey. Given that these countries are dominating the ship demolition market, we decided to take a closer look at the relationship between the markets of China and the subcontinent to help vessel owners choose the most favourable ship demolition region. The analysis of the first objective has shown that ship demolition indices are volatile and asymmetric by nature. Vessel owners should thus make timely decisions should they decide to demolish their ships in either of these regions. The Granger Causality Test helped us find evidence of bidirectional causality between the two ship demolition indices, implying that the ship demolition rates of China and the subcontinent influence each other. This implies that whenever vessel owners are thinking about ship demolition, they have to consider both these markets before making their final decision, as one affects the other. Owing to the recession of 2008-09 and its impact in the following years, some ship owners worldwide opted to demolish younger, but unemployed fleet for cash. China and the sub-continent are the leading ship demolition markets and hence volatile. Therefore, if vessel owners are deciding which market to choose for demolition, they must consider both due to their bi-directional mutual influences. They can never make this decision focusing on a single index series; both must be taken into account if they want their decision to be sound. This analysis is a brief insight into demolition considerations that individual ship owners should keep in mind and is intended to help shipping companies, primarily smaller entities, to make profitable scrapping decisions. This study will also contribute to the ship owners' understanding of the volatility and correlation between ship demolition rates at the global level, helping them reap the benefits of more favorable demolition rates.

REFERENCES

Baltic Exchange limited, 2019. Market Information. Retrieved September 30, 2019, from Daily independent shipping market information website: https://www.balticexchange.com/en/data-services/market-information0.html.

Buxton, I.L., 1991. The market for ship demolition. Maritime Policy & Management, 18(2), pp.105–112. Available at: http://dx.doi.org/10.1080/03088839100000034.

Dickey, D.A. & Fuller, W.A., 1981. Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root. Econometrica, 49(4), p.1057. Available at: http://dx.doi.org/10.2307/1912517.

Ea Krogstrup, K. K. N. A., 2006. Ship Scrapping – a Floating Scenario. University of Roskilde, Denmark.

Engle, R.F. & Bollerslev, T., 1986. Modelling the persistence of conditional variances. Econometric Reviews, 5(1), pp.1–50. Available at: http://dx.doi.org/10.1080/07474938608800095.

Engle, R.F., 1982. Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation. Econometrica, 50(4), p.987. Available at: http://dx.doi.org/10.2307/1912773.

Granger, C.W.J., 1969. Investigating Causal Relations by Econometric Models and Cross-spectral Methods. Econometrica, 37(3), p.424. Available at: http://dx.doi.org/10.2307/1912791.

Hossain, M.S. et al., 2016. Impact of ship-Breaking activities on the coastal environment of Bangladesh and a management system for its sustainability. Environmental Science & Policy, 60, pp.84–94. Available at: http://dx.doi.org/10.1016/j.envsci.2016.03.005.

Kagkarakis, N.D., Merikas, A.G. & Merika, A., 2016. Modelling and forecasting the demolition market in shipping. Maritime Policy & Management, 43(8), pp.1021–1035. Available at: http://dx.doi.org/10.1080/03088839.2016.1185181.

Kaiser, M.J., 2008. A Review of Ship Breaking and Rig Scrapping in the Gulf of Mexico. Ocean Development & International Law, 39(2), pp.178–199. Available at: http://dx.doi.org/10.1080/00908320802013701.

Karlis, T. & Polemis, D., 2016. Ship demolition activity. Pomorstvo, 30(2), pp.128–132. Available at: http://dx.doi.org/10.31217/p.30.2.5.

Karlis, T., Polemis, D., & Georgakis, A., 2016. Ship demolition activity. An evaluation of the effect of currency exchange rates on ship scrap values. Journal of Economics and Business, 66(3), pp. 53–70.

Knapp, S., Kumar, S.N. & Remijn, A.B., 2008. Econometric analysis of the ship demolition market. Marine Policy, 32(6), pp.1023–1036. Available at: http://dx.doi.org/10.1016/j.marpol.2008.02.004.

Kusumaningdyah, W., Eunike, A. & Yuniarti, R., 2013. Modeling Tradeoff in Ship Breaking Industry Considering Sustainability Aspects: A System Dynamics Approach. Procedia Environmental Sciences, 17, pp.785–794. Available at: http://dx.doi.org/10.1016/j.proenv.2013.02.096.

Ljung, G.M. & Box, G.E.P., 1978. On a measure of lack of fit in time series models. Biometrika, 65(2), pp.297–303. Available at: http://dx.doi.org/10.1093/biomet/65.2.297.

Nelson, D.B., 1991. Conditional Heteroskedasticity in Asset Returns: A New Approach. Econometrica, 59(2), p.347. Available at: http://dx.doi.org/10.2307/2938260.

Rabbi, H.R. & Rahman, A., 2017. Ship Breaking and Recycling Industry of Bangladesh; Issues and Challenges. Procedia Engineering, 194, pp.254–259. Available at: http://dx.doi.org/10.1016/j.proeng.2017.08.143.

Stuer-Lauridsen, F., Kristensen, N., & Skaarup Cowi, J. A., 2003. Shipbreaking in OECD. Retrieved from http://www.shipbreakingplatform.org/shipbrea_wp2011/wp-content/uploads/2013/03/Shipbreaking-in-OECD-Cowi-2003.pdf.

UNCTAD, 2017. Review of Maritime Transport 2017. Review of Maritime Transport. Available at: http://dx.doi.org/10.18356/a9b345e7-en.

UNCTAD, 2019. Ship scrapping by country of demolition, annual report, 2014-2017.

Yin, J. & Fan, L., 2018. Survival analysis of the world ship demolition market. Transport Policy, 63, pp.141–156. Available at: http://dx.doi.org/10.1016/j.tranpol.2017.12.019.

Maritime Stock Prices and Information Flows: A Cointegration Study

Joshua Shackman, Paul Lambert, Phoenix Benitiez, Nathan Griffin, David Henderson

In this study, the issue of how global maritime stock prices influence the stock prices of large transportation companies in the U.S. and other large markets is examined. Maritime stocks are chosen because they are central in global trade and thus may be good indicators of future global stock market and economic trends. Maritime companies are often owned by families or governments and are traded in stock markets with lower standards of accountability, hence information flows from maritime stocks may be slower than flows from other stocks. Cointegration and vector error-correction analysis is used to analyze the short-term and long-term relationships between maritime stocks, rail stocks, and trucking stocks. Evidence is found of a gradual diffusion of information from maritime stock prices to large rail or trucking stocks. This suggests that price changes in maritime stocks may help predict changes in prices in non-maritime transportation stocks.

KEY WORDS
~ Maritime stocks
~ Stock price prediction
~ Cointegration
~ Corporate governance

California State University, Maritime Academy, Vallejo, US
e-mail: jshackman@csum.edu

doi: 10.7225/toms.v10.n02.018

Received on: 28.05.2020 / Revised on: 16.10.2021/ Accepted on: 18.10.2021/ Published: 21.10.2021

1. INTRODUCTION

Few industries are more central to international trade than the maritime sector, as over 90% of international trade is done through ocean shipping (International Maritime Organization, 2020). The maritime industry is also unique in that despite its large size, leadership in this sector often comes from smaller countries such as Greece, Singapore, Norway, and South Korea, with shipping of the U.S. and U.K. playing a surprisingly modest role. In addition, ownership of even the largest companies tends to be concentrated in the hands of a single family. But despite the central importance of the maritime industry and its unique global ownership structure, very little research has been done on maritime stocks.

Giannakopoulou, et al. (2016) point out that despite the large size of the maritime sector, family ownership is common in many countries that have large shipping industries. For example, despite Denmark's AP Moller-Maersk being the world's largest container shipping company, it still has over 50% of its voting shares controlled by a holding company owned solely by the founding family. The Mediterranean Shipping Company and CMA CGM Group are the second and third largest shipping companies in the world respectively, but both are majority-owned and operated by the founding families. None of the top twenty shipping companies are traded on U.S. stock exchanges, perhaps because foreign stock exchanges can be more conducive to family-controlled companies.

Even those shipping companies listed on American stock exchanges are often controlled by the founding family. Syriopoulos and Tsatsaronis (2011) find that Greek shipping firms listed in U.S. stock markets follow a model of corporate governance similar to maritime companies listed on non-U.S. stock exchanges. 80% of these Greek shipping firms were found to have a CEO from the founding family, and on average the board of directors controlled 28% of the shares.

The fact that many of the leading maritime shipping companies are family-owned and headquartered in dispersed countries has several implications as to how their stock prices may behave. First of all, family ownership and control may lead to information being closely held and not widely released to the public. This may slow information available to stock traders and slow information flows, leading to a lack of market efficiency. Also, maritime stocks are traded in different stock exchanges around the world rather than on the major U.S. stock exchanges, which may also slow information flows. Valuable information about future trends in the global transportation industry may be embedded within maritime stock prices, and this information could be useful to predict future stock prices in other transportation companies, such as truck and rail companies. Since these flows may be slow rather than instant, changes in maritime stock prices may predict future changes in rail or trucking stocks, but with a slow rather than instant adjustment period. This slow adjustment period and lack of market efficiency might mean that transportation stock prices can be predicted using maritime stock prices, allowing investors to profit from this lack of efficiency.

This study will examine whether a change in maritime stock prices can be used to predict rail or truck stock prices, as well as how far in the future they can be predicted. Due to the nature of stock market data, the chosen methods for this study are designed to distinguish between correlation and causality between maritime and other transportation stocks. In a standard linear regression, one can test the hypothesis that an independent variable X has a causal impact on dependent variable Y. This is done through the method of ordinary least squares the slope of X. A significant slope for X is evidence of a causal impact of X on Y. However, if you reverse the equation and make X the independent variable and Y the dependent variable, you will also get a significant slope for Y. Hence this method alone does not help distinguish if X causes Y. It might also be the case that Y causes X, or there might be bidirectional causality.

As an alternative to simple linear regression, this study uses the method of Granger causality (Granger, 1969). This concept of causality presumes that the future value of X cannot predict the past values of Y. However, Granger Causality also proposes that if past values of X predict future values of Y, then it is evidence of a causal relationship or information flow between X and Y. Instead of simple correlation between X and Y, Granger uses a time series approach. In this approach it examines how past changes in X lead to future changes in Y. Separate regressions can be done with current values of Y as the dependent variable and past values of X as the independent variable and vice versa. In this study, we examine if past changes in maritime stock prices impact future changes in rail or truck prices and vice versa using Granger Causality.

In addition to testing for Granger causality, this study examines a possible long-term equilibrium relationship between maritime, truck, and rail stocks using the concept of cointegration (Engle and Granger, 1987). Cointegration is used instead of correlation since testing for correlation between stock prices is known to be prone to spurious and unreliable results due to the random walk-type movements. Cointegration is a concept whereby stocks may appear to move randomly and independently from each other, but do not stray too far from each other and have prices that exist in equilibrium with each other.

In summary, this study examines a possible information flow of maritime stock prices to stocks of other transportation sectors. Given the corporate governance and transparency issues in the maritime industry, these information flows may be slow. To test for information flows of one or two months, Granger causality is used to see if a change in one stock price in one month leads to a change in another stock's price in the following month. For slower information flows, cointegration is used to test a long-term equilibrium relationship between stocks in different transportation sectors. While the focus of this study is the impact of maritime stock prices on stock prices in rail and trucking, the methods used also allow for testing of the opposite causal direction to see if rail and truck stock prices can predict maritime stock prices.

2. LITERATURE REVIEW

The unique financial risks of the maritime shipping industry have been the focus of some recent research. Yazir and Sahin (2017) find that derivatives in the maritime shipping industry can be effectively modelled through linear regression analysis, an approach that outperforms the standard Black and Scholes approaches of prior studies. Similarly, Kyriakou et al., (2017) find that a mean-reverting exponential model performs better than standard lognormal models when analyzing Baltic derivatives. The interest in financial risks of the maritime industry has extended to stock prices, where systematic risk has generally been found to be low in an extensive review of the shipping finance literature (Alexandridis et al., 2018). For example, Mohanty et al., (2021) and Drobetz et al., (2010) find that shipping stocks have overall low systematic risk as measured by beta (correlation with the market). While low betas indicate low market risk, shipping sector risk can be driven by other factors unique to the shipping industry, such as freight rate volatility (Drobetz et al., 2016; Drobetz et al., 2010) or maritime freight rates (Mohanty et al., 2021).

The finding of low systematic risk for maritime shipping stocks is just one unique aspect of these stocks. Other evidence of the unique nature of shipping stocks was found by Grelck et al., (2009) who found that adding shipping stocks has diversification benefits and can lead to a higher Sharpe ratio. Another unique aspect of maritime stocks is a significant opening day underpricing and longer-term underperformance of initial public offerings (Merikas et al., 2009; Merikas et al., 2010). Evidence of market inefficiency for maritime shipping stocks includes Syriopoulos and Bakos (2019), who find evidence of investor herding behavior in this sector and Abdullah et al., (2020), who find that container shipping stock behaviour is inconsistent with the efficient market hypothesis. An overall theme of the literature on shipping stocks is that they move somewhat independently on the rest of the market, and do not exhibit features of efficiently priced stocks.

Interest in the maritime industry's impact on the stock market has focused heavily on the Baltic Dry Index (BDI), which is a measure of freight rates in the global dry bulk shipping sector. Erdogan et al., (2013) find bidirectional causality between the BDI and the Dow Jones Industrial Average. Bakshi (2011) found that the BDI not only predicts global stock prices but also commodity prices and economic activity. They find informational spillovers to be time-varying and dependent on market conditions. Alizadeh and Muradoglu (2014) find that the BDI can be used to predict U.S. stock prices, which they attribute to gradual information diffusion. More recently Manoharan and Visalakshmi (2019) find that the BDI can significantly predict stock price movements in China, and Giannarakis et al., (2017) find that the BDI is positively associated with the Dow Jones Sustainability Index. Lin et al., (2019) find significant volatility spillovers between the BDI and dry bulk stock prices and Choi et al., (2019) find that the BDI has significant volatility spillovers with some sectors of the Korean stock market.

Just as the BDI can be a vital indicator of the global economy or global stock markets, it may be the case that maritime stocks transmit vital information useful for stock market investors around the world. Just as Alizadeh and Muradoglu (2014) and Xiao (2012) find a gradual diffusion of information from the BDI, other studies have demonstrated the gradual diffusion of information from stock market returns. Rapach et al., (2013) find evidence of gradual information diffusion by demonstrating that U.S. stock market returns can predict future returns in other stock markets around the world. They attribute their result in part to the possibility of stock market traders focusing on the U.S. exchanges before giving attention to other global markets. Similarly, Lin (2015) finds that stock returns in many Asian markets can be predicted by Singapore stock market returns. Other evidence of the international gradual diffusion hypothesis has been found in a sample of firms in twenty-two emerging market countries (Finke and Weigert, 2017), and by examining information flows between the foreign exchange market and stock market returns (Hasselgren et al., 2020)

Another factor that may slow down flows of information from maritime stock prices is corporate governance. Chan and Hameed (2006) argue that family ownership or poor corporate governance may slow down information flows from stocks. Lagoarde-Segot and Lucey (2008) find that poor corporate governance is associated with market inefficiency in the emerging markets, which should also lead to slower information flows. Other literature suggests that firms with concentrated ownership have lower agency costs and thus a better information environment, and information from these stocks can be used to predict stock prices of firms with more dispersed ownership (Farooq and Aktaruzzaman, 2019). Given the high degree of ownership concentration in maritime stocks, this research suggests that information from maritime stocks may be able to predict the prices of non-maritime stocks.

Just as maritime stock prices reflect information that can predict global macroeconomic trends, business trends for a maritime company are also likely to spill over into other transportation stocks. For example, Beuthe et al., (2001, 2014) find that rail, truck, and coastal shipping are substitutes for each other using Belgian cross-cost elasticity data. On the other hand, since trucking is often used for pre and post-haul for commodities shipped on rail or sea, then trucking also represents a complement to maritime and rail shipping (Rich et al., 2011). For example, Mitchell (2000), using cross-price elasticity data from Australia, finds that rail and coastal shipping are strong substitutes, while road and coastal shipping are mild complements. Recent research on rail and road transportation has shown that the degree of substitutability varies greatly from country to country, with low degrees of substitutability in Pakistan (Khan and Khan, 2020), but a high degree of substitutability between these modes in the U.S. (McCullough and Hadash, 2019). The degree to which one mode of transportation serves as a complement or substitute for the other one likely depends on the specific route and commodity shipped. However, it is also clear that the financial fortunes of companies in one mode of transportation will affect the fortunes of companies in other modes of transportations. Hence if maritime stock prices contain information about the financial condition of the maritime industry, maritime stock prices should have predictive power for stock prices of other companies in the transportation industry.

3. DATA

Monthly stock price data was collected on the ten largest publicly traded marine transportation companies in the world based on the twenty-foot equivalent unit capacity of their fleet. All but two of these companies are from Asia, including three from Taiwan and three from Japan. The only non-Asian companies in the top ten are AP Moeller-Maersk, which is headquartered in Denmark, and Hapag-Lloyd, which is headquartered in Germany.

Table 1.
Companies and Indices Used in Study.

Company or Index	Country	Sector	Abbreviation	Source
A.P. Moller-Maersk Group	Denmark	Maritime Freight	MAERSK	Yahoo Finance
Baltic Dry Index	U.K.	Freight Rate Index	BDI	Baltic Exchange
Canadian National Railway	Canada	Rail Freight	CNI	Yahoo Finance
China Ocean Shipping Company	China	Maritime Freight	COSCO	Yahoo Finance
DSV A/S	Denmark	Trucking	DSV	Yahoo Finance
Evergreen Marine Corporation	Taiwan	Maritime Freight	EVERGREEN	Yahoo Finance
Hapag-Lloyd AG	Germany	Maritime Freight	HLAG	Yahoo Finance
Hyundai Merchant Marine	South Korea	Maritime Freight	HYUNDAI	Yahoo Finance
J.B. Hunt Transport Services, Inc	U.S.	Trucking	JBHT	Yahoo Finance
Kawasaki Kisen Kaisha, Ltd.	Japan	Maritime Freight	K-LINE	Yahoo Finance
Mitsui O.S.K. Lines	Japan	Maritime Freight	MITSUI	Yahoo Finance
Nippon Yusen Kabushiki Kaisha	Japan	Maritime Freight	NYKA	Yahoo Finance
Union Pacific Railroad	U.S.	Rail Freight	UNP	Yahoo Finance
Wan Hai Lines Ltd.	Taiwan	Maritime Freight	WANHAI	Yahoo Finance
Yang Ming Marine Transport	Taiwan	Maritime Freight	YANGMING	Yahoo Finance

To test the impact of these maritime stock prices on other transportation stocks, monthly stock price data was collected from the largest publicly traded trucking and rail companies. These include Union Pacific (UNP), which is a U.S.-based rail company, and JB Hunt (JBHT), which is the largest trucking company in North America. Data was also collected on the National Railway (CNI) and DSV A/S (DSV), the latter being a Danish company and the fourth largest trucking company in the world. Finally, monthly data on the BDI was collected. Table 1 lists the companies included in the study, along with their country of origin.

Data was collected monthly on each stock starting from 1/1/1993 with 1/1/2018 being the last month in which data was collected. Data for non-maritime companies generally went back farther than maritime companies, most of which have gone public more recently. Table 2 lists the time periods for each company covered in this study, along with their average annual growth during this period. Notably, non-maritime companies generally performed the strongest during this period, with growth rates ranging from 13.9 percent to 16 percent for the rail and truck companies. Among maritime companies only Hapag-Lloyd had a strong growth at 26.8 percent, but this is only for a short period since they did not go public until 11/1/2015. The remaining maritime companies had a growth ranging from -11.2 percent for Hyundai to 4.1 percent for Wan Hai. Also notable is that some of the family-controlled maritime companies, such as Hyundai and Maersk, have very high stock prices. This indicates a lack of stock splits. Since most companies split their stock shares when their price gets too high in order to be friendly to new investors, it seems these insider-controlled companies are not so interested in seeking new outside investors.

Table 2.
Descriptive Statistics.

Name	Start Date	End Date	High Price	Low Price	Annual Growth Rate
BDI	07/01/1999	1/1/2018	11440	317	0.7%
CNI	11/01/1996	1/1/2018	82.8	2.9	16.0%
COSCO	06/01/2005	01/01/2018	34.1	2.6	1.5%
DSV	01/01/2000	1/1/2018	494	1.7	20.8%
EVERGREEN	01/01/2002	01/01/2018	26.7	5.2	1.3%
HLAG	11/01/2015	1/1/2018	37.6	15.9	26.8%
HYUNDAI	01/01/2002	1/1/2018	288576	4665	-11.2%
JBHT	01/01/1993	1/1/2018	120.8	2.9	16.2%
K-LINE	01/01/2002	01/01/2018	16870	980	3.0%
MAERSKA	01/01/2001	1/1/2018	14840	3300	1.9%
MITSUI	01/01/2002	1/1/2018	18840	1750	3.7%
NYKA	12/01/2009	1/1/2018	33.6	13.5	0.7%
UNP	01/01/1993	1/1/2018	134.1	7.6	13.9%
WANHAI	01/01/2002	1/1/2018	38.6	5	4.1%
YANGMING	01/01/2002	1/1/2018	66	10.1	-4.4%

4. METHODOLOGY

For purposes of this study, standard linear regression is not suitable. The challenge of this study is to see if maritime stock prices can predict future movements in other stocks rather than to simply find a correlation between stocks. An established method to see if past values of one variable can predict future values of another variable is Granger causality (Granger, 1969). Granger causality operates under the assumption that the future does not cause the past, but if past values of a time series variable X are associated with future values of a variable Y, then it is evidence of causality. Under cross-sectional regression, a significant correlation between two variables may be evidence of an association, but inferences about which variable is causing which is difficult to infer. Granger causality involves time series data and involves examining how past values of one variable predict future values of one or more other variables.

Under this method, past changes in maritime stock prices will be used to predict future values of other transportation stocks. For example, suppose ΔX_{t-1} is last month's change in Stock X's price and ΔY_t is this month's change in a Stock Y's price. If Granger causality holds, changes in last month's Stock X price should show a positive relationship with this month's change in Stock Y's price. On the other hand, this method could equally be done to test the opposite hypothesis, according to which changes in last month's Stock Y price can predict this month's Stock X price. The simplest form of Granger causality with just two variables and a one-month lag would be:

$$\Delta Y_t = \alpha_0 + \alpha_1 \Delta Y_{t-1} + \alpha_2 \Delta X_{t-1} + \mu_t \quad (1)$$

$$\Delta X_t = \beta_0 + \alpha_1 \Delta Y_{t-1} + \beta_2 \Delta X_{t-1} + \mu_t \quad (2)$$

In this case, in Equation 1 the dependent variable represents changes in Stock Y's price with past values of changes in Stock Y and X as independent variables. The significance of coefficient α2 can tell us if changes in X lead to a change in Y. The reverse direction of causality can be assessed using Equation 2. The significance of β1 can tell us if a change in Y leads to a change in X. Similar but longer forms of these equations will be used to assess the flows of information between rail, maritime, and trucking stock prices.

A limitation of Equations 1 and 2 is that they only account for short-term associations between X and Y and they do not account for any long-term relationship between the two variables. It may be the case that the two stocks exist in stable long-term relationship known as cointegration (Yin et al., 2017; Engle and Granger, 1987). If this is the case, it means that the distance between the two stocks has a long-term relationship that reverts to the mean. In this case, if two stock prices diverge too far from the equilibrium relationship, then the stocks are expected to move closer to each other in future periods to return to the equilibrium.

As a hypothetical example of cointegration, Stock X and Stock Y might both be moving in a random pattern that has no apparent relationship to each other. But in the long run there may exist an equilibrium where their prices cannot move too far from each other. An example of equilibrium might be that Stock X must be twice the price as Stock Y due to the interrelationship between these stocks. Therefore if Stock X is trading for $10 and Stock Y is trading for $5, they are at an equilibrium. If the price of Stock X goes up to $12, either it must drop back to $10, or Stock Y must increase to $6 (or meet somewhere in between). Tests for cointegration examines whether stocks revert back to an equilibrium ratio over time.

If an equilibrium ratio is found, this ratio can also be used for causal assessment. Suppose Stock Y increases to $7. If Stock X later increases to $14 to return the equilibrium of being twice the price as Stock Y, it is evidence that Stock Y is leading (or causing) movements in Stock X. On the other hand, if Stock Y drops back to $5, then it is evidence that Stock X is the lead stock and Stock Y is the follower (or lags Stock X). If Stock X and Stock Y might be in the same industry or be customers of each other, so their fates may be intertwined, and their prices cannot drift too far from each other.

In order to perform a meaningful analysis of our stock price time series, it is important to check for the statistical properties of this data. Tests for cointegration and Granger causality presume the data is stationary, i.e. it is well-behaved data with a constant mean and variance over time. It is well known from prior studies that stock prices are non-stationary and follow a random walk or similar process (Danthine and Donaldson, 2014). However, by using changes in stock prices (first differences) the time series will become stationary, as the mean change in stock prices over time is usually close to zero and remains constant over time.

To test for stationarity the Phillips and Perron (1988) test was used. This is a widely used test for stationarity and it controls serial correlation through non-parametric methods. This test involves fitting the following regression model:

$$Y_t = \alpha + \theta_t + \Phi Y_{t-1} + \epsilon_t \quad (3)$$

Here Y_t is a given time series at time period regressed on the previous period's lagged value Y_{t-1}, α is a constant, θt is a time trend, Φ is the slope of the regression line. The Phillips-Perron test has an alternative hypothesis that Φ has an absolute value less than one, which implies that the series will converge back to the mean over time and the series will have a constant mean consistent with a stationary series. The null hypothesis of this test is that Φ has a unit root (an absolute value of one), which means that convergence to the mean will not occur and the series will be non-stationary with a time-varying mean and variance.

In addition to testing for stationarity of the individual stock prices, it is also necessary to test whether or not the long-term relationship between the different stock prices is also stationary. Stationarity of this equilibrium in this case means that the stock prices do not stray too far from each other and thus exhibits cointegration. To test for cointegration, the Johansen (1995) test was used. This test is commonly used, including in related maritime studies similar to this one, such as Su et al., (2019), Schramm and Munim (2021), and Kasimati and Veraros (2018). This test is similar to the Phillips-Perron test, except that it tests for stationarity across a series of variables rather than a single variable.

A vector error correction model was used to assess how each maritime stock price reacts when a rail or truck stock price moves away from a long-term equilibrium between the three stocks. To estimate the long-term relationship between these stocks, the following cointegrating equation was estimated:

$$lnM_t = \beta_0 + \beta_1 lnR_t + \beta_2 lnT_t + \beta_3 lnBDI_t + ECT_t \quad (4)$$

M refers to the maritime stock price, R to the rail stock price, T to the truck stock price, and BDI to the Baltic Dry Index. The natural log of stock prices was used as is the common practice for time series studies, as this transforms the data into a normal distribution for stock prices (Navin, R., 2007). The coefficient β1 represents the equilibrium ratio of a rail stock price to a maritime stock price. For example, if $\beta_1 = 2$ then rail stock prices must be twice as high as the maritime stock price to be at an equilibrium. If the rail stock price goes up more than twice as much as the maritime stock price, then either the maritime stock price must increase or the rail stock must go down to reach an equilibrium. Similarly, β_2 and β_3 represent the equilibrium ratios for truck stocks and the BDI respectively.

ECT is the error term for this regression, which is referred to as the *error-correction term* for the purposes of this analysis. It measures the extent to which the stocks are out of the equilibrium estimated in Equation 4. If the stocks are in perfect equilibrium, then ECT will be zero. But if ECT is large, then it means the stocks are out of equilibrium and at least one stock will move to bring the stocks back to equilibrium. Since the goal is to see how stocks move in the future to past values of ECT, lagged values of ECT are estimated as follows, using the estimated values of β coefficients from Equation 2:

$$ECT_{t-1} = lnM_t - \beta_0 - \beta_1 lnR_{t-1} - \beta_2 lnT_{t-1} - \beta_3 lnBDI_{t-1} \quad (5)$$

ECT_{t-1} indicates the previous month's deviation from the equilibrium between the stocks. If ECT_{t-1} equals zero, then all stocks are at their equilibrium price. But if ECT_{t-1} is greater than or less than zero, then its impact on stock prices in the next period can be assessed. ECT_{t-1} can be used to predict future values of maritime stock prices in the following equation:

$$\Delta lnM_t = \alpha_0 + \alpha_1 \Delta lnM_{t-1} + \alpha_2 \Delta lnR_{t-1} + \alpha_3 \Delta lnT_{t-1} + \alpha_4 \Delta lnBDI_{t-1} + \alpha_5 ECT_{t-1} + \mu_t \quad (6)$$

ΔlnM_t in this equation is the logged first difference of the maritime stock price for month t, which is a close approximation for the percentage change over the previous month. By including $\Delta lnMT_{t-1}$ as an independent variable in this equation, the impact of the previous month's percentage change in the maritime stock price on future changes in this stock price can be assessed. Similarly, by including the percentage change in rail and truck stock prices along with the BDI as independent variables, the degree to which changes in these prices can predict future maritime stock prices can be assessed.

The coefficients α_1 through α4 represent the sensitivities to how much current maritime stock prices change in response to a previous period's stock price changes. These are short-term changes, just for one month. ECT_{t-1} represents a long-term variable in that it represents deviations from a long-run equilibrium that covers years rather than months of stock price movements. The α_5 coefficient for ECT_{t-1} represents the maritime stock's long-term relationship with the other stock prices. A negative and significant α_5 would mean that the maritime stock is responsive to long-term changes in the other stock prices and would move back towards its equilibrium ratio.

Whereas Equation 6 examines whether or not past changes in stock prices can predict future changes in maritime stock prices, for the purposes of this study it is also necessary to examine whether or not maritime prices can predict rail or truck stock prices. Equations 7 through 9 are very similar to Equation 6, except that rail, truck, and the BDI change places with maritime stocks and become the dependent variable. They are variations of Equation 4 except with the dependent variables changed, but demonstrating the same independent variables:

$$\Delta lnR_t = \alpha_0 + \alpha_1 \Delta lnM_{t-1} + \alpha_2 \Delta lnR_{t-1} + \alpha_3 \Delta lnT_{t-1} + \alpha_4 \Delta lnBDI_{t-1} + \alpha_5 ECT_{t-1} + \mu_t \quad (7)$$

$$\Delta lnT_t = \alpha_0 + \alpha_1 \Delta lnM_{t-1} + \alpha_2 \Delta lnR_{t-1} + \alpha_3 \Delta lnT_{t-1} + \alpha_4 \Delta lnBDI_{t-1} + \alpha_5 ECT_{t-1} + \mu_t \quad (8)$$

$$\Delta lnM_t = \alpha_0 + \alpha_1 \Delta lnM_{t-1} + \alpha_2 \Delta lnR_{t-1} + \alpha_3 \Delta lnT_{t-1} + \alpha_4 \Delta lnBDI_{t-1} + \alpha_5 ECT_{t-1} + \mu_t \quad (9)$$

Hence Equation 4 through 7 tests whether or not maritime stock prices, rail stock prices, truck stock prices, and the BDI respectively can be predicted. The direction of causality between these variables can be tested, both one-way causality as well as bidirectional causality.

5. RESULTS AND DISCUSSION

Results from the Phillips-Perron unit root and stationarity test can be shown in Table 3 below. Each stock was tested one at a time for the presence of stationarity, both for levels and first differences. For all stock price levels (in logs) the test statistic is not significant at the 5% level. Hence the null hypothesis of a unit root and non-stationarity cannot be rejected. However, for first differences the null hypothesis of a unit root was rejected at the 1% level in every case. This result implies stationarity for all series.

Table 3.
Stationarity Tests.

Variables	Levels	First-Differences
lnMAERSK	-2.18	-14.438**
lnEVERGREEN	-2.731	-16.721**
lnHLAG	-0.642	-4.844**
lnMITSUI	-1.922	-13.468**
lnNYKA	-2.203	-8.524**
ln YANGMING	-1.722	-13.595**
lnCOSCO	-2.201	-11.948**
lnWANHAI	-2.233	-16.75**
lnHYUNDAI	-0.186	-15.323**
lnK-LINE	-1.669	-13.199**
lnDSV	-2.787	-33.343**
lnCNI	-0.842	-16.192**
lnUNP	0.222	-17.337**
lnJBHT	0.086	-14.986**
lnBDI	-2.501	-12.517**

** Significant at the 1% Level
Significance indicates stationarity

Examples of non-stationarity versus stationarity can be seen in Figures 1 and 2 below. Figure 1 shows the logged stock prices of JBHT over time. JB Hunt's stock price has a steady upward increase over time, which is shown by the purple line. On the other hand, the monthly change in JBHT can be seen on the blue line. Instead of an upward trend, the monthly stock price change goes up and down in wide swings, but still always reverts to its mean which is slightly above zero. The black line shows the trend for monthly increases or decreases in JBHT.

Figure 2 shows the same pattern for UNP. Both UNP and JBHT have upward trends. In a regression between UNP and JBHT, one might find a strong correlation but this correlation might be due to pure chance as on average most stocks show an upward trend. The method used in this study focuses on changes rather than levels. While the blue lines for stock price changes show a much more random-looking pattern than the purple lines for stock price levels, correlations between changes in stock prices are considered far more meaningful than correlations between stock price levels (Fabozzi et al., 2014).

Now that non-stationarity in stock price levels and stationarity in stock price changes has been established, the next step is to test for cointegration – i.e. if the three stocks and the BDI have a long-term equilibrium with respect to each other. The long-term relationships are also estimated. When JBHT and UNP are included, all maritime stocks show a long-term relationship with the other stocks except for YANGMING. These nine stocks are shown in Table 4. When DSV and CNI were included, only five maritime stocks were shown to have a cointegrating relationship. These five stocks are shown in Table 5.

Table 4.
Equilibrium ratios between stocks.

Martime Stock	βi (lnJBHT)	β2 (lnUNP)	β3 (lnBDI)
lnEVERGREEN	0.40**	0.43*	0.33**
lnMAERSK	-1154.35**	539.60	565.52**
lnHLAG	1.90**	-2.89**	-0.13
lnMITSUI	-0.55	0.59	1.19**
lnNYKA	0.57	0.01	0.67**
lnCOSCO	5.10**	-3.70**	1.71**
hWANHAI	-0.18	0.61	0.67**
lnHYUNDAI	12.83**	3.41	-1.51
lnK-LINE	-1.24**	0.38	1.58**

*Significant at the 1% Level,
*Significant at the 5% Level

Table 5.
Equilibrium ratios between stocks.

Martime Stock	βi (lnDSV)	β2 (lnCNI)	β3 (lnBDI)
EVERGREEN	-1.03**	1.37*	0.50**
HLAG	-4.53**	-0.41	-0.30**
YANGMING	-2.15**	2.75**	0.74**
WANHAI	-2.50**	3.42**	0.54*
HYUNDAI	-8.87**	15.02**	2.73**

*Significant at the 1% Level,
*Significant at the 5% Level

Figure 1.
JBHT Stock Price Levels Versus Changes.

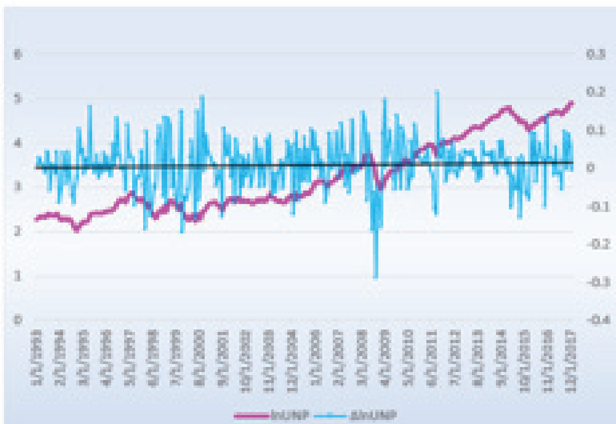


Figure 2.
UNP Stock Price Levels Versus Changes.

Using Equation 2, the equilibrium ratios β1 through β3 between the three stocks and the BDI were estimated. Table 4 shows the ratios between the stocks and the BDI that must hold in order for an equilibrium to hold for each maritime stock. For this case, JBHT and UNP are used as the truck and rail stocks. . Table 5 shows the results when DSV and CNI are used in place of JBHT and UNP.

The interpretation of these equilibrium ratios in Table 4 can be illustrated with EVERGREEN in the first row. The coefficient β1 for EVERGREEN and JBT is 0.4. To be at an equilibrium, JBHT must be 4 the size of EVERGREEN. If the price of EVERGREEN rises, either their price needs to come down or the price of JBHT must go up in order to maintain this ratio. Similarly, the equilibrium ratios between Evergreen and UNP is one to .43 and the ratio with BDI is one to .33. All of these ratios must hold for an equilibrium to exist. While the prices of the stocks will diverge from these equilibrium ratios, since these variables are cointegrated, they will always converge back to these ratios.

Figure 3 presents a visual example of cointegration. This graph shows the interrelationship between HLAG and UNP since HLAG went public in 2015. The axes are scaled so that the left axis shows UNP's stock price. The right axis shows HLAG's stock price scaled four to one, so if UNP's price is 100, then HLAG's price is 25. Thereby anytime the lines cross, they are exactly at a four to one ratio. When UNP's price increases and HLAG's price drops in 2016, they are no longer at a four to one ratio, with UNP hovering above HLAG in the graph. By 2017 they are back at four to one, but later that year they are again out of ratio and HLAG is hovering above UNP. But again, they go back to the four to one ratio. This is an example of what cointegration entails – two series that wander apart, but in the long run move back together at an equilibrium ratio.

Figure 3.
Contegration Between HLAG and UNP.

Using Equations 3 through 6 and the ratios in Table 3, the degree to which each maritime stock diverges from these equilibrium ratios is calculated. These monthly divergences are the error correction terms (ECT) and are used in the next set of regressions, Equations 3 through 6. An example of these regressions is illustrated in Table 6 with MITSUI, the maritime stock shown to have the best explanatory power. Table 6 presents the results of Equations 3 through 6.

For Equation 3, we see that none of the explanatory variables significantly predict ΔlnMITSUIT. It appears that Mitsui's stock is unresponsive to movements in other stocks and cannot be predicted. However, with Equation 4 with ΔlnJBHTT as the dependent variable, it can be seen that JB Hunt's stock can be predicted with past values of other variables. First of all, the coefficient for ΔlnMITSUIT-1 is statistically significant .222 which means if Mitsui's stock price increases by 10% at month T-1, then

JB Hunt's stock will increase by 2.22% in the following month T. In other words, Mitsui's stock price this month can help us predict JB Hunt's stock price next month.

Similarly, ECTt-1 has a statistically significant coefficient at -0.036 in Equation 4. Since ECT represents the deviation from the equilibrium, this means that when the stock prices are out of equilibrium, JBHUNT moves back to equilibrium at a rate of 3.6% per month. Again, JBHUNT can be predicted by examining the prior month's stock prices. The results in Equation 5 are very similar, as they show that UNP can be predicted by looking at pack values of MITSUI, as well as ECT. For Equation 6, BDI is only predicted by past values of BDI. The positive coefficient for ECTt-1 indicates that it does not move back to its equilibrium ratio and instead moves independently. So overall, MITSUI can predict JBHT and UNP, but not BDI. No variable can predict MITSUI, indicating that MITSUI is a variable that leads rather than follows the other ones.

Table 6.
Regression results: Equations 4 through 7.

	(4) ΔlnMITSUIT	(5) ΔlnJBHTT	(6) ΔlnUNPT	(7) ΔlnBDIT
ECT_{T-1}	-0.016 (0.018)	-0.036* (0.015)	-0.027** (0.010)	0.184** (0.036)
$AlnMITSUI_{T-1}$	0.081 (0.074)	0.222** (0.062)	0.100* (0.043)	0.128 (0.147)
$AlniBHT_{T-1}$	0.073 (0.092)	0.059 (0.076)	0.043 (0.053)	0.181 (0.183)
$AlnUNP_{T-1}$	0.053 (0.137)	-0.170 (0.113)	-0.139 (0.078)	0.117 (0.271)
$AlnBDI_{T-1}$	-0.010 (0.036)	-0.016 (0.030)	0.033 (0.020)	0.232** (0.071)
Adjusted R^2	-0.008	0.089	0.104	0.125
Observations	215	215	215	215

**Significant at the 1% level,
* Significant at the 5% level
Standard deviations in parentheses

The same set of regressions was run for each maritime stock, exhibiting a cointegrating relationship, i.e. the stocks listed in Tables 4 and 5. The results of these regressions are shown in Table 7. Long-term lag stocks refer to stocks that have a significant and negative coefficient for ECT_{t-1}, as this indicates that the stock moves back to an equilibrium ratio when other stock prices move. Only three maritime stocks meet this criterion – EVERGREEN, NYKA, and HYUNDAI. This indicates that the other seven maritime stocks cannot be predicted by rail and truck stocks. However, in seven out of nine cases UNP does have a positive ECT_{t-1} coefficient. This indicates that it can be predicted by the other stocks, including the maritime ones.

Short-term lead/lag relationships refer to whether a lagged first difference (percentage change) can predict a change in another stock in the following month. Only three maritime stocks (MAERSK, NYKA, EVERGREEN) could be predicted based on the previous month's stock price of a rail or truck stock. Overall, only NYKA and EVERGREEN were significantly predictable in both the short-run and long-run. Three maritime stocks (COSCO, MITSUI, K-LINE) were able to predict UNP or JBHT. Overall, the results suggest that in the long run UNP can be predicted from maritime stocks and maritime stocks have short-term predictive power for UNP as well. JBHT, however, is more mixed. Sometimes it is a lead variable that predicts maritime stocks such as EVERGREEN or NYKA. But at other times it is a lag variable that can be predicted by other maritime stocks.

Table 7.
Regression results: Summary of long-term and short-term causal relationships.

Maritime Stock	Long-Term Lag Stocks	Martine Short-Term Lead/Lag Relationships
EVERGREEN	EVERGREEN**	JBHT leads EVERGREEN*
MAERSK	UNP*, JBHT**	UNP leads Maersk*
HLAG	UNP**	
MITSUI	UNP**	MITSUI leads UNP**. MITSUI leads JBHT**
NYKA	NYKA**, UNP**	JBHT leads NYKA*
COSCO	UNP**	COSCO leads UNP**, COSCO leads BDI*
WANHAI	UNP*	
HYUNDAI	HYUNDAI*	
K-LINE	UNP*, JBHT*	K-LINE leads UNP**

**Significant at the 1% level.
Significant at the 5% level

The causal relationships between UNP and the maritime stocks are summarized in Figure 4. Based on both long-term and short-term relationships, the overall direction of causality largely goes from maritime stocks to UNP. For six stocks, there is a one-way direction of causality from the maritime stock to UNP, and for one case there is bidirectional causality. Figure 5 summarizes the relationship between JBHT and maritime stocks. The results are more mixed, but in four of the five cases maritime stocks have a causal impact on JBHT. On balance, maritime stocks appear to be able to predict UNP and JBHT much better than these stocks can predict maritime stocks.

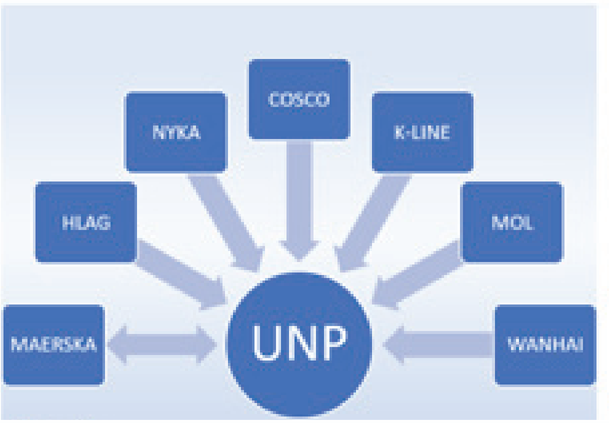


Figure 4.
Direction of causality between UNP and maritime stocks.

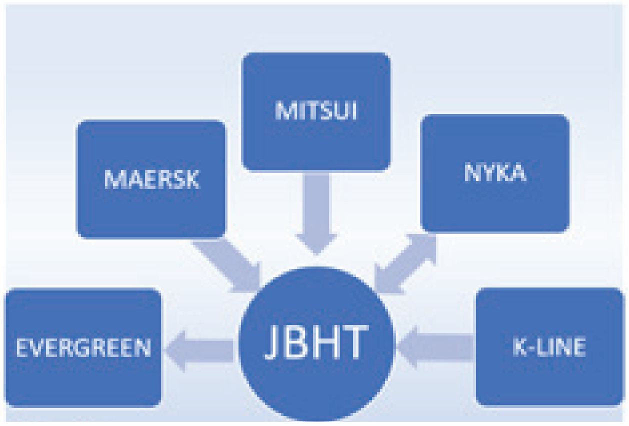


Figure 5.
Direction of causality between JBHT and maritime stocks.

Table 8 presents the regression results with DSV and CNI instead of JBHT and UNP. Since only five maritime stocks showed a significant long-term cointegrating relationship with the other stocks, only the results for these five maritime stocks are shown. The results indicate that in every case DSV has a significant and negative coefficient for ECT_{T-1}, indicating that it responds when other stock prices move out of equilibrium and thus can be predicted by maritime and other stocks. In addition, in every case the maritime stock also has a significant and negative coefficient for ECT_{T-1}. This indicates long-term bidirectional causality between DSV and the maritime stocks, with the implication that one can predict maritime stocks with DSV and vice versa. CNI only has a significant coefficient for ECT_{T-1} in one case, indicating that it is largely unpredictable by other stocks. In terms of short-term causality, DSV was found to significantly predict EVERGREEN and WANHAI. Figure 6 summarizes the causal relationships between DSV and the maritime stocks, indicating a large degree of bidirectionality. Table 9 presents a summary of all the statistical tests used in the analysis.

Table 8.
Regression results: Summary of long-term and short-term causal relationships.

Maritime Stock	Long-Term Lag Stocks	Martine Short-Term LeadiLag Relationships
EVERGREEN	EVERGREEN**, DSV**	DSV leads EVERGREEN**
HLAG	HLAG**, CNI**, DSV**,BDI**	None
YANGMING	YANGMENG**, DSV**	None
WANHAI	WANHAI**, DSV**	DSV leads WANHAI**
HYUNDAI	HYUNDAI**, DSV**	None

**Significant at the 1% level. Significant at the 5% level

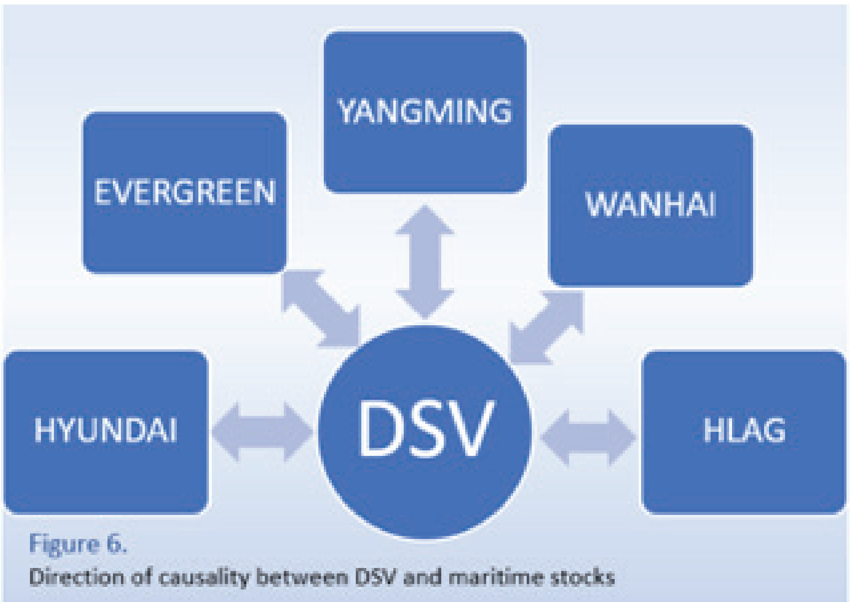


Figure 6.
Direction of causality between DSV and maritime stocks.

Table 9.
Summary of statistical tests.

Test	Purpose	Method	Figure/Equation/Table
Stationarity	To examine if data has a constant mean and variance over time	Phillips-Perron unit root test. See Equation 1, Table 3, and Figures 1 and 2.	Equation 3, Table 3, Figures 1 and 2
Cointegration	To decide if a long-tenn equilibrium ratio needs to be accounted for in the regressions	Johansen test for a linear combination of stock prices that is stationary. See Figure 3.	Figure 3
Granger causality	To examine the potential causal Granger Causality direction or information flow between stock prices	Regresssion of past values of stock price changes on future stock price changes. See Equations 6 through 9 and Table 6.	Equations 1,2, 6-9, Table 6

6. APPLICATION

The most straightforward application of the results of this study is for stock market investing. For example, in Equation 5 in Table 6 we can see the coefficient for Mitsui is 0.222 which is statistically significant. Since the data is in logged first differences, the interpretation is that for every amount Mitsui's stock price increases or decreases, the price of JB Hunt's stock will change by 22.2% of that increase for decrease. This means that if Mitsui's stock price goes up by 10% in one month, JB Hunts stock will go up by 2.22% the next month. Similarly, in Equation 6 we can see the coefficient for Mitsui is .1 which is also statistically significant. This indicates that if the price of Mitsui goes up by 10%, the stock price of UNP will go up by 1%. This is just one example. JBHT, UNP, and DSV all have multiple maritime stocks that can significantly predict their future movement.

A more complex stock trading strategy is through the equilibrium ratios found in Table 4. For example, we see that the log of JBHT must be .4 or 40% of the logged stock price of EVERGREEN. If JBHT's stock price drops below 40% of EVERGREEN, then either JBHT's stock needs to rise to get back to equilibrium or EVERGREEN's stock price needs to drop. In this case, a strategy called pairs trading (Shen et al., 2020) could be used, where you both take a short position in EVERGREEN and a long position in JBHT. If the stock prices return to equilibrium, either the long or short position will give you a positive return. All the statistically significant coefficients in Tables 4 and 5 could potentially be used to execute a pairs trading strategy.

7. CONCLUSION

This paper has shown that the majority of maritime stocks employed in this study can be used to predict three of the four non-maritime transportation stocks that were tested. To a lesser extent, this study has shown that in some cases rail or truck company stocks can be used to predict maritime stocks. These results suggest that investors can potentially apply the methods used in this study to decide which truck and rail companies to invest in. In some cases monthly stock prices can be predicted, such as Mitsui's ability to predict movements in JB Hunt and Union Pacific's stock movements one month in advance. But the majority of the results suggest that only long-run movements in these stocks can be predicted, which could be several months or years. Similarly, previous research has shown that maritime freight rates can impact global markets, but only very gradually (Han et al., 2020). While the methods in this study could be used to make investment decisions, investors should be cautioned that these decisions should be primarily for long-term rather than short-term investments in most cases.

While the cointegration and Granger Causality methods used in this study show us which variables can predict movements in other variables, they are limited in that they do not tell us the precise mechanism by which one variable predicts the other. Maritime stock prices might predict future stock prices, not due to direct causality, but because of other mechanisms. For example, maritime stock prices might contain valuable information about the future direction of the global economy that allows it to predict transportation stock prices. Or it might be a direct mechanism – e.g. maritime shipping might be a complement or substitute for rail and truck shipping, whereby improvements in business for a maritime company might spill over to a rail or truck company.

To further assess the mechanisms which give maritime stocks a predictive power, future research on maritime stocks should be done to see if they also have a predictive power on other economic factors.

Since the BDI has been shown to have a predictive power on such factors as major stock market indices, commodities, and GDP (Bakshi, et al., 2011; Erdogan, et al., 2013), maritime stock prices might have similar predictive power on a variety of economic factors. A positive result would indicate that maritime stock prices predict other transportation stock prices as a result of possessing valuable information concerning the world economic trends.

Another limitation of this study is that only stock price and maritime freight rate data was collected. To further investigate the relationship between maritime, rail, and truck stocks, company data should be collected, not only on stock prices but also on revenue and shipping quantities. This data could be used to see if an increase in revenue or quantity shipped by a company has a negative or positive impact on another transportation company. This would help to explain whether or not the predictive power of maritime stocks on other transportation stocks is due to a direct business impact on other companies or due to other factors.

Abbreviations

ECT: Error-correction term

BDI: Baltic Dry Index

JBHT: JB Hunt

UNP: Union Pacific

CNI: Canadian National Railway

REFERENCES

Abdullah, A. Ç. I. K., Baran, E., & Ayaz, İ. S., 2020. Testing the Efficient Market Hypothesis: A Research on Stocks of Container Shipping Companies, Global Journal of Economics and Business Studies, 9(17), pp. 1-12. Available at: https://dergipark.org.tr/en/pub/gumusgjebs/issue/55948/558942.

Alexandridis, G. et al., 2018. A survey of shipping finance research: Setting the future research agenda. Transportation Research Part E: Logistics and Transportation Review, 115, pp.164–212. Available at: http://dx.doi.org/10.1016/j.tre.2018.04.001.

Alizadeh, A.H. & Muradoglu, G., 2014. Stock market efficiency and international shipping-market information. Journal of International Financial Markets, Institutions and Money, 33, pp.445–461. Available at: http://dx.doi.org/10.1016/j.intfin.2014.10.002.

Bakshi, G.S., Panayotov, G. & Skoulakis, G., 2011. The Baltic Dry Index as a Predictor of Global Stock Returns, Commodity Returns, and Global Economic Activity. SSRN Electronic Journal. Available at: http://dx.doi.org/10.2139/ssrn.1787757.

Beuthe, M., Jourquin, B. & Urbain, N., 2014. Estimating Freight Transport Price Elasticity in Multi-mode Studies: A Review and Additional Results from a Multimodal Network Model. Transport Reviews, 34(5), pp.626–644. Available at: http://dx.doi.org/10.1080/01441647.2014.946459.

Beuthe, M. et al., 2001. Freight transportation demand elasticities: a geographic multimodal transportation network analysis. Transportation Research Part E: Logistics and Transportation Review, 37(4), pp.253–266. Available at: http://dx.doi.org/10.1016/s1366-5545(00)00022-3.

Bildirici, M.E., Kayıkçı, F. & Onat, I.Ş., 2015. Baltic Dry Index as a Major Economic Policy Indicator: The Relationship with Economic Growth. Procedia - Social and Behavioral Sciences, 210, pp.416–424. Available at: http://dx.doi.org/10.1016/j.sbspro.2015.11.389.

Choi, K.-H. & Kim, D.-Y., 2019. The Effect of Baltic Dry Index on the Korean Stock Price Volatility. Journal of Korea Port Economic Association, 35(2), pp.61–75. Available at: http://dx.doi.org/10.38121/kpea.2019.06.35.2.61.

Danthine, J., and Donaldson, J., 2015. Intermediate Financial Theory. Available at: http://dx.doi.org/10.1016/c2010-0-68534-8.

Drobetz, W., Menzel, C. & Schröder, H., 2016. Systematic risk behavior in cyclical industries: The case of shipping. Transportation Research Part E: Logistics and Transportation Review, 88, pp.129–145. Available at: http://dx.doi.org/10.1016/j.tre.2016.01.008.

Drobetz, W., Schilling, D. & Tegtmeier, L., 2010. Common risk factors in the returns of shipping stocks. Maritime Policy & Management, 37(2), pp.93–120. Available at: http://dx.doi.org/10.1080/03088830903533726.

Engle, R.F. & Granger, C.W.J., 1987. Co-Integration and Error Correction: Representation, Estimation, and Testing. Econometrica, 55(2), p.251. Available at: http://dx.doi.org/10.2307/1913236.

Erdogan, O. et al., 2013. Dynamics of the co-movement between stock and maritime markets. International Review of Economics & Finance, 25, pp.282–290. Available at: http://dx.doi.org/10.1016/j.iref.2012.07.007.

Fabozzi, F.J. et al., 2014. The Basics of Financial Econometrics. Available at: http://dx.doi.org/10.1002/9781118856406.

Farooq, O. & Aktaruzzaman, K., 2019. Informational role of ownership concentration: evidence from the Casablanca stock exchange. Journal of Islamic Accounting and Business Research, 10(5), pp.726–735. Available at: http://dx.doi.org/10.1108/jiabr-11-2016-0141.

Finke, C. & Weigert, F., 2017. Does Foreign Information Predict the Returns of Multinational Firms Worldwide? Review of Finance, p.rfw070. Available at: http://dx.doi.org/10.1093/rof/rfw070.

Giannarakis, G. et al., 2017. The effect of Baltic Dry Index, gold, oil and usa trade balance on Dow Jones Sustainability Index World, 7(5), pp. 155-160.

Giannakopoulou, E.N., Thalassinos, E.I. & Stamatopoulos, T.V., 2015. Corporate governance in shipping: an overview. Maritime Policy & Management, 43(1), pp.19–38. Available at: http://dx.doi.org/10.1080/03088839.2015.1009185.

Granger, C.W.J., 1969. Investigating Causal Relations by Econometric Models and Cross-spectral Methods. Econometrica, 37(3), p.424. Available at: http://dx.doi.org/10.2307/1912791.

Granger, C.W.J. & Newbold, P., 1974. Spurious regressions in econometrics. Journal of Econometrics, 2(2), pp.111–120. Available at: http://dx.doi.org/10.1016/0304-4076(74)90034-7.

Grelck, M.B. et al., 2009. Diversification Properties of Investments in Shipping. The Journal of Alternative Investments, 12(1), pp.55–74. Available at: http://dx.doi.org/10.3905/jai.2009.12.1.055.

Harris, R., 1995. Using Cointegration Analysis in Econometric Modelling, Hemel Hempstead: Prentice Hall/Harvester Wheatsheaf.

International Maritime Organization, 2020. Challenges. Available at: http://www.imo.org/en/OurWork/TechnicalCooperation/ITCP/Pages/Challenges.aspx.

Jawadi, F., Jawadi, N. & Cheffou, A.I., 2015. Are Islamic stock markets efficient? A time-series analysis. Applied Economics, 47(16), pp.1686–1697. Available at: http://dx.doi.org/10.1080/00036846.2014.1000535.

Johansen, S., 1995. Likelihood-Based Inference in Cointegrated Vector Autoregressive Models. Available at:
http://dx.doi.org/10.1093/0198774508.001.0001.

Han, L., Wan, L. & Xu, Y., 2020. Can the Baltic Dry Index predict foreign exchange rates? Finance Research Letters, 32, p.101157. Available at:
http://dx.doi.org/10.1016/j.frl.2019.04.014.

Kasimati, E. & Veraros, N., 2017. Accuracy of forward freight agreements in forecasting future freight rates. Applied Economics, 50(7), pp.743–756. Available at:
http://dx.doi.org/10.1080/00036846.2017.1340573.

Khan, M.Z. & Khan, F.N., 2020. Estimating the demand for rail freight transport in Pakistan: A time series analysis. Journal of Rail Transport Planning & Management, 14, p.100176. Available at:
http://dx.doi.org/10.1016/j.jrtpm.2019.100176.

Kyriakou, I. et al., 2017. Freight derivatives pricing for decoupled mean-reverting diffusion and jumps. Transportation Research Part E: Logistics and Transportation Review, 108, pp.80–96. Available at:
http://dx.doi.org/10.1016/j.tre.2017.09.002.

Lin, A.J., Chang, H.Y. & Hsiao, J.L., 2019. Does the Baltic Dry Index drive volatility spillovers in the commodities, currency, or stock markets? Transportation Research Part E: Logistics and Transportation Review, 127, pp.265–283. Available at:
http://dx.doi.org/10.1016/j.tre.2019.05.013.

Manoharan, M. & Visalakshmi, S., 2019. The interrelation between Baltic Dry Index a practical economic indicator and emerging stock market indices. Afro-Asian J. of Finance and Accounting, 9(2), p.213. Available at:
http://dx.doi.org/10.1504/aajfa.2019.099483.

McCullough, G.J. & Hadash, I., 2019. Price Effects in Truck-Competitive Railroad Markets. U.S. Freight Rail Economics and Policy, pp.114–126. Available at:
http://dx.doi.org/10.4324/9780429031120-5.

Merikas, A., Gounopoulos, D. & Nounis, C., 2009. Global shipping IPOs performance. Maritime Policy & Management, 36(6), pp.481–505. Available at:
http://dx.doi.org/10.1080/03088830903346053.

Merikas, A., Gounopoulos, D. & Karli, C., 2010. Market performance of US-listed Shipping IPOs. Maritime Economics & Logistics, 12(1), pp.36–64. Available at:
http://dx.doi.org/10.1057/mel.2009.18.

Mitchell, D., 2010. Australian Intercapital Freight Demand: An Econometric Analysis, Australasian Transport Research Forum 2010 Proceedings, 29, pp. 1-19. Available at:
https://www.australasiantransportresearchforum.org.au/sites/default/files/2010_Mitchell_A.pdf.

Navin, R.L. ed., 2012. The Mathematics of Derivatives. Available at:
http://dx.doi.org/10.1002/9781119197034.

Panayides, P.M., Lambertides, N. & Cullinane, K., 2013. Liquidity risk premium and asset pricing in US water transportation. Transportation Research Part E: Logistics and Transportation Review, 52, pp.3–15. Available at:
http://dx.doi.org/10.1016/j.tre.2012.11.007.

Rich, J., Kveiborg, O. & Hansen, C.O., 2011. On structural inelasticity of modal substitution in freight transport. Journal of Transport Geography, 19(1), pp.134–146. Available at:
http://dx.doi.org/10.1016/j.jtrangeo.2009.09.012.

Schramm, H.-J. & Munim, Z.H., 2021. Container freight rate forecasting with improved accuracy by integrating soft facts from practitioners. Research in Transportation Business & Management, p.100662. Available at:
http://dx.doi.org/10.1016/j.rtbm.2021.100662.

Schwarz, G., 1978. Estimating the Dimension of a Model. The Annals of Statistics, 6(2). Available at:
http://dx.doi.org/10.1214/aos/1176344136.

Shen, L. et al., 2020. An Evaluation of Pairs Trading in Commodity Futures Markets. 2020 IEEE International Conference on Big Data (Big Data). Available at:

http://dx.doi.org/10.1109/bigdata50022.2020.9377766.

Su, C.-W. et al., 2019. Are there bubbles in the shipping freight market? Maritime Policy & Management, 46(7), pp.818–830. Available at:
http://dx.doi.org/10.1080/03088839.2019.1619946.

Syriopoulos, T. & Tsatsaronis, M., 2011. The corporate governance model of the shipping firms: financial performance implications. Maritime Policy & Management, 38(6), pp.585–604. Available at:
http://dx.doi.org/10.1080/03088839.2011.615867.

Syriopoulos, T. & Bakos, G., 2019. Investor herding behaviour in globally listed shipping stocks. Maritime Policy & Management, 46(5), pp.545–564. Available at:
http://dx.doi.org/10.1080/03088839.2019.1597288.

Yazir, D. & Sahin, B., 2017. Linear Regression Approach for the Financial Risks of Shipping Industry. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, 11(4), pp.635–640. Available at:
http://dx.doi.org/10.12716/1001.11.04.09.

Yin, J., Luo, M. & Fan, L., 2016. Dynamics and interactions between spot and forward freights in the dry bulk shipping market. Maritime Policy & Management, 44(2), pp.271–288. Available at:
http://dx.doi.org/10.1080/03088839.2016.1253884.

Tourist's Perception of Safety in the Republic of Croatia in 2019

Rino Rivi Kolombatović, Rea Barbir, Petricija Knežić, Marko Maretić, Katarina Stegić, Dolores Štefanac, Željana Bašić, Ivana Kružić

This research has examined the attitudes and perceptions of tourists that visited the Republic of Croatia (RH) during the summer of 2019 about the perception of safety in RH, especially on general security, as well as food safety, personal safety, epidemic safety, and natural disasters. Also, we have examined the confidence in Croatian services, such as the police, rescue services, medical emergency, etc. Almost all the safety components were above 4, which indicates that the tourists in Croatia feel safe and trust the services. This research could be a significant tool for improving the policies for attracting the tourists during and after the pandemic.

KEY WORDS

~ Croatia, Tourists
~ Safety Perception
~ 2019
~ Food and water safety
~ Natural disasters safety
~ Emergency services
~ Public safety

University of Split, University Department of Forensic Sciences, Croatia

e-mail: zeljana.basic@unist.hr

doi: 10.7225/toms.v10.n02.019

Received on: 09.03.2021/ Revised on: 21.07.2021/ Accepted on: 23.08.2021/ Published: 21.10.2021

1. INTRODUCTION

Tourism is one of the most important branches of the economy of the Republic of Croatia. At the Mediterranean, Croatia is among the most visited countries, and at the world level, it is important to emphasize that Croatia is one of the most desirable tourist destinations because of its historical, cultural, natural, and human features (Vuković, 2006). Also, Croatia has positioned herself on the 27th place according to international competitiveness index, and it has occupied the 32nd place in the world economies with a positive growth (Travel&Tourism, Competitiveness Report, 2019). Croatian tourism has shown high resilience to many factors, which is confirmed by higher growth rates than in the other competing countries (Government of the Republic of Croatia, 2013). For example, Croatia had a better change in score than the first countries on the list, Spain and France (Travel&Tourism Competitiveness Report, 2019). Croatian tourism is supported by the Mediterranean climate, which is characterized by mild winters and warm summers, and in addition, Croatia is rich in natural and cultural heritage (Gluvačević, 2016; Uroević, 2012) . (Plitvička jezera National Park, cultural sites from the UNESCO, etc.) (Kapusta & Wiluś, 2017).

In 2019, Croatia had an increase of 5% in tourist arrivals, almost 21 million of them, and 2.4% more overnight stays were recorded (Ministry of Tourism of the Republic of Croatia, 2020). According to the eVisitor system, in 2019 the number of foreign tourist arrivals was 18,267,166 (an increase of 4.4%), while 2,424,455 domestic tourist arrivals were recorded (an increase of 9.0%). In the same period, 94,812,813 overnight stays of foreign tourists were realized (growth of 1.7%), as well as 13,830,741 overnight stays of domestic tourists (growth of 7.6%) (Rihelj, 2020). Growth in the number of arrivals and overnight stays is registered from distant markets of China, the USA and Canada, as well as Ukraine, Spain, Austria, Bosnia and Herzegovina, France, Italy, Hungary, Germany, Russia, Slovenia, Slovakia, Switzerland, the UK, and domestic market. Markets recording growth in arrivals with a slight decline in the number of overnight stays are Belgium, Denmark, Finland, and Poland. South Korea recorded a decline in arrivals with an increase in overnight stays. Markets that are declining in overnight stays and arrivals are the Czech Republic, Japan, the Netherlands, Norway and Sweden (Rihelj, 2020). The total turnover in 2019 (overnight stays) is dominated by the German market (19.5%), followed by the domestic market (12.7%), Slovenia (10.1%) and Austria (7.1%) (Rihelj, 2020).

Every year, the Ministry of Tourism of the Republic of Croatia prepares a strategic plan for the next two years. In that plan, they present goals and plans for the upcoming period, define projects and strategies. The following text describes part of the strategic plans for the period from 2018 to 2022 related to security in tourism. "The general goal of the strategic plan is to raise the competitiveness of Croatian tourism with the affirmation of Croatia as one of the leading international tourist destinations, i.e., the special goal implies the improvement of the tourist quality and contenst of the tourist product and the affirmation of Croatia on the international tourist market through effective promotion." (Ministry of Tourism, 2018).

As part of the special goal of improving the tourist quality and contents of the tourist product, the creation of prerequisites for a safe stay in our country is implied, because safety is one of the basic requirements for a successful conduct of tourist activity. Therefore, the Ministry of Tourism co-finances the costs of additional medical teams in destinations with a significantly increased number of tourists. Furthermore, it supports and co-finances training programs for organizers of tourist facilities, direct preventive action and other activities of the Croatian Mountain Rescue Service in order to ensure quality and safe implementation of special forms of tourism. It also participates in the Safe Tourist Season project. The international police cooperation has been implemented since 2006, with dozens of police officers from European Union countries and the region, as well as China and South Korea, who contribute towards a greater sense of security of their fellow citizens (Ministry of Tourism, 2018).

At the time of conducting this research no comprehensive study of the perception of safety of tourists in the Republic of Croatia has been published. Thus, we have conducted the research in the area of the city of Split. This research was conducted before the pandemic of the COVID-19 virus and could be extremely important after the end of the pandemic to create strategic frameworks and a return of tourists to Croatia.

The research of the tourist safety is extremely important for countries that want to maintain and improve their touristic offer. This kind of survey gives an insight into potential problems and possibilities for improvement. Similar research in the world has already been conducted in numerous countries. For example, in Kuala Lumpur, where the issue of safety and security among women travellers was examined. What the researchers have highlighted as the most important safety issues are: personal safety and a sense of vulnerability and illness, accidents and political violence (Amir, Ismawi, 2015). According to a research conducted in Malaysia, including the citizens of India, China, Australia, France, and Indonesia, it was found that most tourists perceive earthquakes, tsunamis, SARS, terrorist attacks, and epidemics as risks and avoid travelling to the exposed countries. A similar study has been conducted in the Turkish province of Gaziantep, which found that respondents do not worry about terrorist attacks and food security, the reason for this being that most of them come from developed countries where such problems do not exist. Another study conducted in Turkey, has shown that natural disasters are the biggest risk for tourism, but also, on the one hand, they slow down the development of tourism and, on the other hand, attract people because of a sense of solidarity. They believe that the only solution for such situations is to develop management for dealing with crisis situations (Genç, 2018). In another survey, conducted in South Africa, tourism development is seen as an opportunity to overcome many socio-economic barriers that South Africa faces. The research focuses on and analyzes the poor perception of international tourists about personal safety in the period from 1997 to 1998. The main reason for such perception is the high crime rate observed through six most important factors: public violence, rape, murder, and aggravated attacks, burglaries, robberies, and motor vehicle thefts, which were used to analyze the general pattern of crime (Ferreira, Harmse, 2012). Also, natural disasters affect the tourism significantly, which varies from one type of the disaster to another, for example the most negative impact have volcanic eruptions, whilst the folds and storms have the least impact (Rossello et.al., 2020). Not only that safety of the destination matters, but also the nationalities of the tourist, for example, one study has shown that the tourists coming from some countries (Israel, Ireland, USA) or a specific age groups are more likely to be sensation seeking tourists and that the marketing should also aim to the group of tourists depending on this type of the tourist offer (Pizam et al., 2004). Also, it seams that the nationality of the tourists also affects their readiness to visit destinations after major catastrophes, e.g., some nationalities are less worried when visiting such destinations (Kovačić et al., 2020). One study has shown the importance of the effect of the stress causing risk factors for the tourists and the necessity to adjust the marketing strategies according to analysis of such data (Lepp&Gibson, 2003).

Considering all the stated above, the aim of this paper is to examine the tourist's perception of safety in Croatia, in the context of their sense of security in general, regarding the danger of a terrorist attack, food and water safety for consumption, flood and fire danger, considering the threat to fundamental human rights, awareness of culture and laws, given the level of trust in the police and health services and the risk of viral epidemics. The results of this research could be a good guidance for the improvement of Croatia as a tourist destination, as well as for creating the politics for the return of the tourists to Croatia after the COVID-19 pandemic ends.

2. MATERIALS AND METHODS

The research has been conducted using a survey questionnaire. The questionnaire consisted of basic demographic questions (gender, nationality, employment status, marital status, number of visits to the Republic of Croatia), while the second part of the questionnaire consisted of 22 questions related to a sense of security in Split / Croatia, and trust in the police and other institutions in the Republic of Croatia, food safety, etc., which had to be assessed with Likert scale (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree). The questionnaire was been filled in by adult foreign nationals residing in the city of Split. The sample size was been determined using the sample size calculator available at https://www.surveysystem.com/sscalc.htm. The input variable was the number of visitors in the city of Split a year before the survey (2018), with a confidence interval set at 95%. The data was analyzed in SPSS (version 18; SPSS Inc, Chicago, IL, USA), with the significance level set at $P \leq 0.05$.

The survey was conducted in the period from 2019-06-15 to 2019-08-15. Foreign citizens who visited the city of Split were randomly interviewed. After the survey, a database with all collected samples was created, and the obtained data was statistically processed.

3. RESULTS

Out of the total number of respondents, 193 persons were female, and 161 persons were male.The average age of the female population was 31.79 years old, and the average age of the male population was 33.44 years old. The median age of the respondents was 32.72 years.

Table 1.
Average safety ratings of tourists, by gender.

	Average rating - women (1-5)	Average rating - men (1-5)	P
Personal safety influences my decision to travel.	4.13 (1-5)	4.19 (1-5)	0.20
I think that a terrorist attack in Croatia will most likely not happen.	3.96 (1-5)	4.05 (1-5)	0.16
I feel safe in the late hours in Croatia.	4.13 (1-5)	4.06 (2-5)	0.21
I think personal belongings in a hotel or private accommodation are safe.	4.1 (2-5)	4.19 (1-5)	0.15
I have confidence in the Croatian rescue services.	4 (2-5)	4,11 (1-5)	0.02
I have confidence in the Croatian health services.	3.76 (1-5)	3.82 (1-5)	0.10
I have confidence in the Croatian police service.	3.89 (1-5)	4 (2-5)	0.07

There were no statistically significant differences between males and females.

Considering the distribution of the participants by country, the number of countries represented by their participants was 40, and on Figure 1 the countries represented by more than 10 participants are shown.

The total number of respondents by country with more than 10 respondents is 279, which makes a total of 79%. The remaining 21% or 73 respondents belong to nationalities with less than 10 respondents and were not considered when comparing scores based on the comparison of average scores of statements related to "Tourist Safety in the Republic of Croatia" by nationality base.

By dividing the nationalities by continents, those that will be compared, the following data was obtained (Russia in this case was assigned to the continent of Asia since 77% of Russia's territory is located in Asia). The results are shown in Figure 2.

In Table 2 the average rating of tourists by the continent is shown.

On the Figure 3 the work status of the respondents is shown.

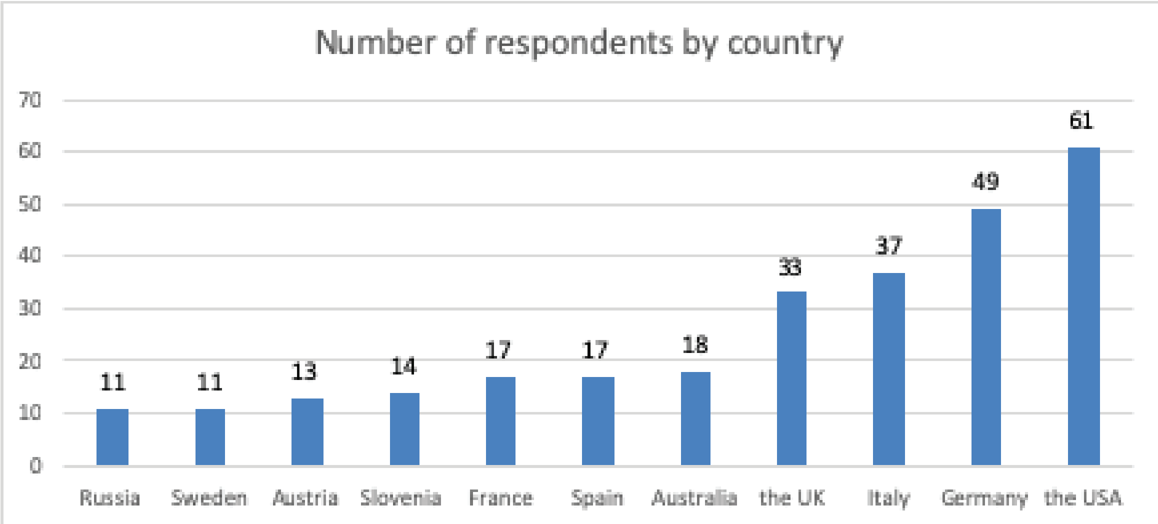


Figure 1.
Overview by countries with more than 10 respondents.

Table 2.
Average ratings of tourists by continents.

	Average rating - residents of Europe (1-5)	Average rating - residents of Asia (1-5)	Average rating - residents of Australia (1-5)	Average rating - residents of North America (1-5)
I believe that Croatia is a safe country.	4.13 (2-5)	4.18 (3-5)	4 (1-5)	4.34 (3-5)
In my case, Croats do not discriminate against others on national, racial, religious grounds, etc.	4.04 (1-5)	4.36 (3-5)	3.72(2-5)	3.84 (2-5)
I feel safe in the late hours in Croatia.	4.15 (1-5)	4.54 (3-5)	3.89(2-5)	4.03 (3-5)
I have confidence in the Croatian rescue services in case of natural disasters.	4.19 (3-5)	4.27 (3-5)	3.5 (2-5)	4 (2-5)
I am not afraid of a serious viral epidemic in Croatia.	4.1 (1-5)	4 (3-5)	3.89 (2-5)	3.80 (1-5)
I had no unpleasant experiences with the Croatian police.	4.35 (2-5)	4.27 (3-5)	4.39 (3-5)	4.31 (3-5)

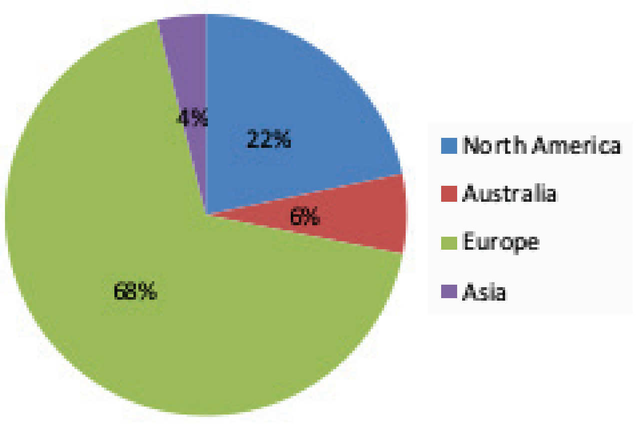


Figure 2.
Number of respondents by the continent.

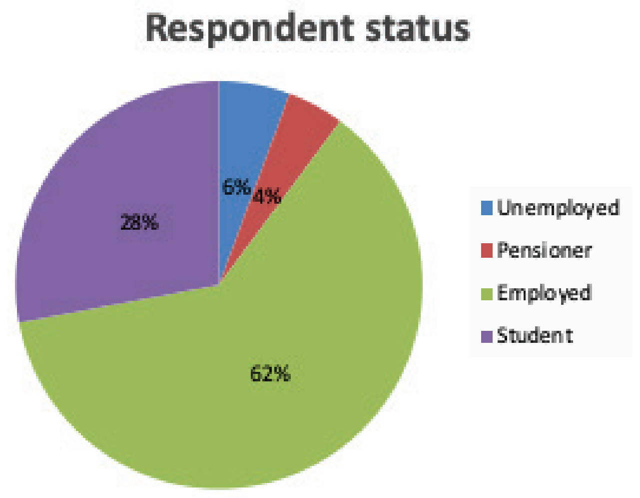


Figure 3.
Respondents by the work status.

The average students' score of the impact of personal safety when deciding on a trip is 3.73, employed respondents 4.06, pensioners' 3.9 and unemployed respondents' 3,4. The majority of respondents stated that they were not discriminated against on the basis of nationality, religion or race in Croatia. Also, most of them stated that they considered Croatia a safe country and did not fear that they could be victims of kidnapping or some natural disaster. As for the trust in health services, there were no major discrepancies in responses. Out of a maximum of 5, the average score was 3.79. Students and employees had more confidence in the safety of their personal belongings in hotels or private accommodation, for students and employees the average was higher than 4, while for pensioners and the unemployed it was lower, 3.7.

Considering the relationship status of the participants, 206 respondents were in a relationship or married, the other 148 were single, i.e., they had no partners. In terms of the impact of personal safety on their travel decisions, the average score of single respondents was 3.91, while the average score of the married ones or those in a relationship was 3.95. They equally believed that the Republic of Croatia was a safe country. They shared the same opinion on the comparison of the Republic of Croatia with other EU members and believed that it was safer, with an average score of 3.6. Respondents who were married or in a relationship believed that Croats did not discriminate against others based on nationality, race, or religion. They shared the same opinion that there was little possibility for terrorist attacks in the Republic of Croatia and that they could be the victims of kidnapping. It is important to mention that singles felt less safe in the late hours in the Republic of Croatia. Both groups had the same opinion on the water and food safety for consumption in the Republic of Croatia, which made the highest average score (4.33) in the entire questionnaire. The biggest difference between the participants that were not in a relationship or married and those who were was the inconvenience they had experienced with the Croatian police; the first ones trusted the Croatian police less than the people in a relationship, and their presence on the streets had no effect on their sense of safety.

Out of the total number of respondents, 66% had no children. The average scores of respondents with children and those without children differ greatly. Respondents with children agreed more with the fact that the Republic of Croatia was a safe country, with an average score of 4.14, the respondents had an average score of 3.71. There was no difference in terms of the safety of the Republic of Croatia compared to other EU members. Respondents without children believed that Croatia was safer than the country they came from with an average score of 3.97, and the average score of respondents with children was 3.25. Respondents with children agreed more with the fact that it was necessary for the Croatian tourism to make a manual for tourists. Respondents without children believed more to have a small chance of a terrorist attack and to be victims of kidnapping in the Republic of Croatia, and to be safer on the streets in the late hours. The big difference in the average rating of trust in Croatian rescue services in case of natural disasters was that the respondents with children (4.2) believed more than the respondents without children (3.78). This difference is statistically significant ($P = 0.006$). There was a small difference between the fear of serious viral epidemics in the Republic of Croatia, the respondents with children gave an average score of 4.13, while the respondents without children gave 4.04. Distrust in the Croatian police was much higher among the respondents without children, with an average score of 3.61, while the respondents with children trusted the Croatian police more, with an average score of 4.15, and this difference is statistically significant (P = 0.0002).

Regarding the number of trips, half of the respondents stated that they travelled 2-3 times a year, 32% travel once a year, and 18% more than three times a year. When asked about the impact of safety on the decision to travel, all respondents mostly shared the opinion, so the average score for all three groups was 3.93. Also, most of them considered Croatia a safe country and stated that they had not experienced discrimination based on nationality, religion, or race in Croatia. When asked whether they considered Croatia safer than other EU countries, an average score of 3.58 out of a possible 5 was obtained. Most respondents believed that food and water were safe for consumption, also expressing confidence in the Croatian emergency services and were not afraid of being a victim of kidnapping or natural disaster. Respondents stated that they felt safe during the night hours, so the average score was 4.08.

Most of the respondents have visited more than five countries so far, 267 respondents to be precise, which made 75% of the total number of respondents. The average age of respondents who had visited less than five states was 29.31 years, and those who had visited more than five countries before visiting Croatia were, on the average, 33.84 years old. 73.91% of male respondents, and 75.39% of female respondents had visited more than five countries.

Table 3 shows a comparison of the respondents' opinions based on their travel experience.

Table 3.
Average scores of respondents based on their travel experience.

	Average rating given by people who visited less than five countries (1-5)	Average rating given by people who visited more than five countries (1-5)	P
Personal safety influences my decision to travel.	3.91 (2-5)	3.94 (1-5)	0.39
I believe that Croatia is a safe country.	4.18 (3-5)	4.15 (1-5)	0.35
Before coming to Croatia, I was informed about the way of life, culture, history, laws.	3.64 (1-5)	3.71 (1-5)	0.28
I feel safe in the late hours in Croatia.	4.19 (2-5)	4.05 (1-5)	0.07
I think that Croatian food and water are safe for consumption.	4.29 (2-5)	4.34 (2-5)	0.30
I am not afraid of a serious virus epidemic in Croatia.	3.93 (1-5)	3.93 (1-5)	0.49
I have confidence in the Croatian police service.	3.95 (2-5)	3.95 (1-5)	0.48
I had no unpleasant experiences with the Croatian police.	4.29 (1-5)	4.29 (1-5)	0.46

As seen in Table 3, there were no statistically significant differences between the experienced and less experienced travellers. Out of the total number of respondents, 69% visited Croatia for the first time.

Table 4 shows the average ratings of respondents who visited Croatia for the first time (69%) and those who have visited Croatia more than one time.

Table 4.
Average ratings of persons who have visited the Republic of Croatia for the first time and more than once.

	Average ratings given by persons who are in the Republic of Croatia for the first time. (1-5)	Average grade given by persons who visited the Republic of Croatia more than once. (1-5)	P
I believe that Croatia is a safe country.	4.18 (1-5)	4.12 (2-5)	0.15
In my case, Croats do not discriminate against others on national, racial, religious grounds, etc.	3.97 (1-5)	3.64 (1-5)	0.002
I feel safe in the late hours in Croatia.	4.1 (1-5)	4.05 (1-5)	0.31
I have confidence in the Croatian rescue services in case of natural disasters.	4.07 (2-5)	4.1 (1-5)	0.25
I am not afraid of a serious viral epidemic in Croatia.	4 (1-5)	3.77 (1-5)	0.02
I had no unpleasant experiences with the Croatian police.	4.25 (1-5)	4.42 (2-5)	0.04

Statistically significant difference was observed between the two groups in the question of discriminating against others on national, racial, religious grounds, with more positive answers from those being in Croatia for the first time.

4. DISCUSSION AND CONCLUSIONS

The results of the research on a total of 354 respondents has shown that tourists in the Republic of Croatia feel safe. Namely, the overall average safety rating was 4.16. The study involved 193 females and 161 males. Analyzing the answers given by females or males, no major discrepancies were observed in the given ratings. Analyzing the answers in terms of the age of the respondents, we have concluded that there is no significant difference, to most of the questions the same answers were given by the respondents of all age groups. No statistically significant differences were found in their responses.

Every country has its own cultural characteristics and nowhere is it the same. This fact can be best explained by foreigners visiting the Republic of Croatia. Thus, for example, those who have visited more than five countries so far, consider Croatia a safe country and there are no statistically significant differences between respondents who have visited less than five and more than five countries. They share the same opinion when it comes to trust in the Croatian police and fear of a serious viral epidemic in Croatia. They also feel equally safe in the late hours in Croatia and with a high score confirm the absence of unpleasant experiences with the Croatian police.

For example, people in North America think that Croatia is a safe country with an average score of 4.34, while Australians give the lowest average score of 4. That Croatia is not a country of racial intolerance and discrimination is mostly thought by people in Asia, with an average score of 4.36, while Australians still give the lowest average grade of 3.72. Asians have the most trust in Croatian rescue services, with an average rating of 4.27, while residents of Australia, with the average rating of 3.5, have the least trust. As for the fear of a serious epidemic, the average on all the respondents, regardless the continent they are from, is almost the same and ranges from 3.8 to 4.1, which shows that all residents agree the most and believe that there is no excessive fear of an epidemic. A high average score for the absence of unpleasant experience with Croatian police, from 4.27 to 4.35, shows that the participants from all the observed continents agree that they did not have any bad experiences with the Croatian police.

According to marital status, there are no statistically significant differences in average scores. They equally agree that Croatia is a safe country, and that Croatia is safer than other EU members. Analyzing the average scores of those in relationships and the single ones, those in a relationship agree more that they are less likely to be abduction victims, while single respondents gave a lower average score, which means they agree less with this statement. Also, single people had more unpleasant experiences with the Croatian police than those in a relationship, although the difference was not significant. According to the answers given, the highest average score is reflected in the safety of food and beverages in Croatia.

Respondents with children and those with no children show differences in scores. Respondents without children trust rescue services less in the event of a natural disaster, trust the Croatian police less, and feel less secure when they see the police on the street. Also, respondents without children do not agree that the cooperation of the Croatian police with foreign police is of great importance, and the lowest average grade is given for this statement. In terms of safety, respondents with children feel safer in the Republic of Croatia, but not as safe as they feel in the country they come from, and respondents with and without children share the same opinion: that Croatia is a safer country than other EU members.

Analyzing the answers of the respondents regarding their employment status, it can be concluded that employed persons and students decide more to travel, and unemployed persons and pensioners decide this to a lesser extent. Most respondents agreed that they did not experience discrimination based on nationality, religion, and race in Croatia. Also, most of them agreed that they considered Croatia a safe country and were not afraid that they could be victims of kidnapping or natural disaster. The only significant discrepancies in the answers are visible in the issue related to the safety of personal belongings in hotels or private accommodation, where students and employees gave significantly higher grades, i.e., they considered their personal belongings in private accommodation and hotels to be safe.

According to the number of trips, most respondents stated that they travelleed two or three times a year, followed by respondents who travel once a year, and the least of those who travel more than three times a year. All three groups of respondents agreed that the safety of the country affected their decision to travel. Also, most of them stated that they dd not feel discriminated against based on nationality, race, or religion in Croatia. They also gave high scores to questions about food and water safety for consumption and trusted in emergency services. They also state that they feel safe during the night and that most of them have not had an unpleasant experience with the Croatian police.

The period in which the survey was conducted (summer of 2019) will probably serve the best as an orientation about the post COVID pandemic tourism. The survey was conducted only half a year before the outbreak of the COVID pandemic that would, as we have seen, affect tourism, at least for several years. The pandemic 2020 has downgraded Croatia to 20 years ago. Croatia had 64.2% less arrivals and 55.3% less overnight stays (Croatian Bureau of Statistics, 2021). Taking into consideration that Croatia had suffered losses in the tourist industry, in future, post-pandemic years, the authorities should be focused upon attracting even more tourists to compensate the losses. Our survey could be of great importance for strategic planning, as it shows pre-pandemic tourists' attitudes about safety. Improvements in the areas that have been recognized as most worrying and a marketing towards the less prone populations or demographic groups could be one of the strategic goals of Croatian tourism marketing. This study could also direct different marketing strategies in different countries, focusing more upon the issues that worry specific subgroups or populations. Croatia should focus on her strengths and improve her flaws, thereby directly influencing not only the "subjective" perception of the tourists but also the overall quality of the tourist offer in the field of safety.

Overall, this research has shown that Croatia is perceived as a safe tourist destination, and as highlighted by the survey participants, their major confidence lies in the safety of food and water, which could and should be highlighted in the promotion of Croatian as tourist destination. It should be noted that the research was done before the coronavirus pandemic and that now, probably, the results would be significantly different in the perception of the pandemic safety. Given that tourism is a major source of increased human mobility, it is one of the most important factors in spreading of coronavirus, especially in Europe. It should be noted that many countries have suffered heavy losses in the field of economy, as well as the health system, and that the population will not be primarily oriented towards tourism and tourist travel. Although many things will change after this pandemic, this research in the future could be used to study the changes that have occurred and, according to tourists, to discover our strengths and weaknesses, to introduce changes to be better and more successful, and consequently become a more attractive destination for tourists.

REFERENCES

Amir, A.F., Ismail, M.N.I. & See, T.P., 2015. Sustainable Tourist Environment: Perception of International Women Travelers on Safety and Security in Kuala Lumpur. Procedia - Social and Behavioral Sciences, 168, pp. 123–133. Available at: http://dx.doi.org/10.1016/j.sbspro.2014.10.218.

Croatian Bureau of Statistics, 2020. Tourist arrivals and nights in commercial accommodation establishments. Available at: https://www.dzs.hr/Eng/Covid-19/tourism-arrivals_and_nights_2020.html.

Gluvačević, D., 2016. The power of cultural heritage in tourism-example of the city of Zadar (Croatia). International journal of scientific management and tourism, 2(1), pp. 3-24.

Ferreira, S.L.A. & Harmse, A.C., 2000. Crime and Tourism in South Africa: International Tourists Perception and Risk. South African Geographical Journal, 82(2), pp.80–85. Available at:
http://dx.doi.org/10.1080/03736245.2000.9713696.

Genç, R., 2018. Catastrophe of Environment: The Impact of Natural Disasters on Tourism Industry. Journal of Tourism & Adventure, 1(1), pp.86–94. Available at: http://dx.doi.org/10.3126/jota.v1i1.22753.

Kapusta, A. & Wiluś, R., 2017. Geography of Tourism in Croatia. The Geography of Tourism of Central and Eastern European Countries, pp.109–147. Available at: http://dx.doi.org/10.1007/978-3-319-42205-3_4.

Kovačić, S. et al., 2020. What are the Factors affecting Tourist Behavior based on the Perception of Risk? Romanian and Serbian Tourists' Perspective in the Aftermath of the recent Floods and Wildfires in Greece. Sustainability, 12(16), p.6310. Available at: http://dx.doi.org/10.3390/su12166310.

Lepp, A. & Gibson, H., 2003. Tourist roles, perceived risk and international tourism. Annals of Tourism Research, 30(3), pp.606–624. Available at: http://dx.doi.org/10.1016/s0160-7383(03)00024-0.

Pizam, A. et al., 2004. The Relationship between Risk-Taking, Sensation-Seeking, and the Tourist Behavior of Young Adults: A Cross-Cultural Study. Journal of Travel Research, 42(3), pp.251–260. Available at: http://dx.doi.org/10.1177/0047287503258837.

Rihelj, G., 2020. U 2019. godini ostvareno 21 milijuna dolazaka i 108,6 milijuna noćenja. Available at: https://hrturizam.hr/resume-2019-godine-ostvareno-21-milijuna-dolazaka-i-1086-milijuna-nocenja/, accessed on: 15. Feb 2020.

RH, Ministarstvo turizma, 2020. Available at: https://mint.gov.hr/vijesti/u-2019-godini-21-milijun-turista-5-posto-vise-nego-u-2018-nocenja-2-4-posto-vise/20762, accessed on: 15 Jan 2020.

RH, Ministarstvo turizma, 2018. Strateški plan Ministarstva turizma za razdoblje 2019.–2021. Available at: https://mint.gov.hr/UserDocsImages/AA_2018_cdokumenti/180403_strateski-p_mint.pdf, accessed on: 20. Feb 2020.

Rosselló, J., Becken, S. & Santana-Gallego, M., 2020. The effects of natural disasters on international tourism: A global analysis. Tourism Management, 79, p.104080. Available at: http://dx.doi.org/10.1016/j.tourman.2020.104080.

Urosevic, N., 2012. Cultural identity and cultural tourism: Between the local and the global (a case study of Pula, Croatia). Singidunum Journal of Applied Sciences, 9(1), pp.67–76. Available at: http://dx.doi.org/10.5937/sjas1201067u.

RH, Vlada, 2020. Strategija razvoja turizma RH do 2020. godine. Available at: https://narodne-novine.nn.hr/clanci/sluzbeni/2013_05_55_1119.html/, accessed on: 15. Jan 2020.

Vuković, I., 2006. Suvremeni trendovi u razvoju turizma u EU i implikacije na Hrvatsku, pp. 35–55.

World economic forum, 2019. The Travel & Tourism Competitiveness Report 2019. Travel and Tourism at a Tipping Point. Geneva.

Accessible Learning Sources: A Need Analysis on Maritime English Learning Apps

Purnama Nancy Lumban Batu, Antoni Arif Priadi, Wida Cahyaningrum

Maritime English is defined as the English language used by seafarers both at sea and in port and by individuals working in the shipping and shipbuilding industry. The teachers are required to make the students skillful and ready to work in maritime sectors once they graduate. The existing and relevant maritime English learning materials following STCW 2010 curriculum in Indonesia are still rare and limited. This study aims to conduct a need analysis of android and web-based Maritime English apps based on the students' perspectives. This study uses questionnaires shared and completed randomly by 318 students from different majors and at Sekolah Tinggi Ilmu Pelayaran (Maritime Higher Education Institute) Jakarta. The data is gathered and analyzed accordingly to create the essential concept of the MarEng apps design. The questionnaire result indicates that most of the participants need an ME learning platform in order for them to have better access to and to practice the required knowledge and skills. Explicit bilingual instructions and features like video, audio, and text are also preferred to be incorporated. It is suggested to start from the elementary level and cover the four skills, especially listening, speaking, and pronunciation. It is so suggested that the platform can be constructed in easy and fun UI/UX covering the required content.

KEY WORDS

~ Need analysis
~ Maritime English
~ Online learning
~ Learning platform
~ Maritime students

State College of Sailing Jakarta, Indonesia

e-mail: nancy.lumbanbatu@gmail.com

doi: 10.7225/toms.v10.n02.020

Received on: 26.03.2021/ Revised on: 28.07.2021/ Accepted on: 17.08.2021/ Published: 21.10.2021

1. INTRODUCTION

The rising impacts of the Covid-19 pandemic have affected vocational maritime education, especially in terms of teaching and learning Maritime English. In line with the technological advancement that makes the teaching and learning processes more manageable in many ways, educators are required to immediately adapt to the current situation and make vast creative innovations. Teachers are required to make the students skilful and ready to work in maritime sectors once they graduate. The higher demands are not without reason. Mastering the English language skills has been an absolute requirement mentioned in STCW 2010, which is later explained further in the IMO Model Course 3.17 Maritime English (IMC 3.17). However, through his research, Dirgeyasa (2018) concluded that the alumni and the students of maritime education and training (MET) have low English proficiencies, both in oral and written English. He added that the existing and relevant maritime English learning materials following the STCW 2010 curriculum are still rare and limited.

Next, rapid technological changes have been proven to positively impact most areas, including education. Teachers, practitioners, and researchers are aware of expanding technologies to better education (Motteram, 2013; Paulo, 2016). Some studies have proven that it contributes to positive learning experiences for learners and effective teaching and learning processes (Oers, 2015; Peterson, 2016).

Based on the background above, the provision of an independent learning tool integrated with technology or digital platform for maritime students is considered a necessity to meet the required standard of maritime human resources and enhance Indonesia's maritime graduates' quality in terms of maritime knowledge and communication.

Furthermore, the researchers intend to design a prototype of MarEng Android and web-based apps of by doing preliminary research. To sum up, this study aims to conduct a needs analysis of Android and web-based Maritime English apps based on the students' perspectives.

2. LITERATURE REVIEW

2.1. The Nature of Maritime English

Maritime English (ME) can generally be classified as English for specific purposes (ESP). Compared to general English, ESP underlines the teaching of English for vocational or professional purposes. Hutchinson et al. (1987:19) stated: "ESP is an approach to language teaching in which all decisions as to content and method are based on the learner's reason for learning." Dudley-Evans (1997) added that it is defined to meet the specific needs of the learners. That is why ESP is associated with needs analysis. To acknowledge the students' specific purpose and their goals of studying English, a needs analysis helps to determine what is necessary to achieve this.

Accordingly, ME is defined as the English language used by seafarers both at sea and in port and by individuals working in the shipping and shipbuilding industry. It is oriented to individuals who need to be fluent in English for communicating successfully while on board and ashore (Bocanegra-Valle, 2012). Also, it is mentioned that ME has five branches, including English for maritime communications, English for maritime commerce, English for maritime law, English for marine engineering, and English for shipbuilding. Meanwhile, in his research, Dirgeyasa (2018) sums up that ME has to cover maritime and language skills and its features, such as listening and speaking for communication, reading and writing, grammar, applied terminologies, and SMCP content (Dirgeyasa, 2018).

2.2. Online Teaching and Learning

Vast development in technology and education has been positively rooted in integrating digital technologies into the teaching and learning process. Various teaching and learning platforms become another alternative for students to get supplementary learning and interact with other users, such as teachers and their classmates. Salavati (2016) added that it had become a demand and challenge to use digital technologies in the teaching and learning process. Correspondingly, Howard and Major (2004) described a series of specific guidelines in online teaching and learning involving (1) stimulate interaction and be generative; (2) encourage learners to develop learning skills and strategies when they use online English resources; (3) online English resources should link to each other to develop a progression of skills, understandings, and language item; (4) have appropriate instructions; be attractive and flexible. Also, Palz (2003) determined principles of online teaching and learning, which include, (1) Let the students do most of the work (actively involved); (2) Interactivity (within the students and with the instructor/teacher); (3) Strive for presence, including social presence (attendance), cognitive presence (discussion on the topic), or teaching presence (instruction).

2.3. Digital Platform

Digital platforms have broad definitions and scope. Asadullah et al. (2018) explained that it had become a new model of organizing economic and social activities, and somehow it transforms the landscape of several industries such as transportation (e.g., Uber, Grab), hospitality (e.g., Airbnb), and software development (e.g., Google, Android). Also, Koh and Fichman (2014: 977) defined the digital platform as two-sided networks that facilitate interactions between a distinct but interdependent group of users. In other words, digital platforms can be understood as a digital medium that can be integrated with any distinct field which facilitates the organization and interaction of its users. In terms of education, Anderson (2013) explained that apps developers use the methodology to use technology to give personalized study material, feedback and progress report, and distributed practice. It convinces users that learning is more manageable and fun through the apps. He added web-based vs. downloaded translation language proficiency levels as factors that need to be considered for platform development. To create a user-friendly platform, UI (user interface) and UX (user experience) are also essential factors that need to be considered. UI refers to a system and a user interacting with each other through commands or techniques to operate the system, input data, and use the contents (Joo, 2017). Meanwhile, he defined UX as the overall experience related to the perception (emotion and thought), reaction, and behavior that a user feels and thinks through his or her direct or indirect use of a system, product, content, or service.

3. METHOD

This is a preliminary research for designing an apps prototype based on Design and Development Research, or DDR. So, a needs analysis is conducted to find out the requirement for the design. Richey and Klein (2007) describe product development research procedures in conducting a needs analysis, information gathering, designing a product, and evaluating the product. Meanwhile, the needs analysis itself cannot be separated from ESP. It is considered a prerequisite in any course design (Richterich and Chancerel, 1987 in Li, 2014). Li (2014) continued to explain that needs analysis is one of ESP's key stages beside syllabus design, selection and production of materials, teaching and learning, and evaluation.

Furthermore, she explained that need analysis involves gathering information that will be the foundation for developing a curriculum to meet a particular group of learners' learning needs. Nunan (1994, p 54) mentioned that need analysis should include the criteria and rationale for grouping learners, the selection and sequencing of course content, methodology, course length, and intensity and duration. Accordingly, this research implements analysis based on standard guideline (Krippendorf, 2004) and target situation analysis (Hutchinson and water, 1987) for creating ME learning platform or apps for maritime learners

This study uses questionnaires shared and completed randomly by 318 cadets from different majors at Sekolah Tinggi Ilmu Pelayaran (Maritime Higher Education Institute) Jakarta. It was presented in Bahasa Indonesia to avoid misunderstanding. The questionnaire was developed consisting three parts. The first part encompassed general questions about background of the cadets: prior education and current education. The second part of the questionnaire consisted statement and questions about their Maritime English learning experience. In the third part of the questionnaire, the cadets were asked about their needs if there were a Maritime English learning apps designer particularly for the target learners.

The data were examined and arranged based on the most frequent answers. Then, the data and the standard guideline of ME learning were compared and analysed by the researcher to create the essential concept of ME apps design.

4. RESULT AND DISCUSSION

The research results are generated based on the standard guidelines (Krippendorf, 2004) and target situation analysis (Hutchinson and water, 1987). Standard guideline of needs analysis is gathered from a theoretical review from the expert in the field. In this case, it covers research findings, books, and other guidelines for Maritime English learning. Next, Target Situation Analysis (TSA) is defined as a needs analysis that mainly focuses on students' needs at the end of a language course (Robinson, 1991). Data of the needs can be gathered in different ways, including spreading a questionnaire to the target learners. In this context, ME learning content can be gathered by asking the target learners about their target learning and goals.

Table 1.
Representation of the questionnaire result.

Theme	Answer	Representation
Education background		
last education	Non-Maritime high school	78%
current activity	Cadets	98%
ME learning background		
learning experiences	1-4 years	60%
learning media	Book	67%
	YouTube	56%
Needs for ME Apps		
Expected content	to prepare future career in maritime sector	83%
	to improve communication skills	73%
	emphasizing on speaking and listening skills	87%
	emphasizing on pronunciation	76%
UI/UX	emphasizing on audio visual learning	81%
	English-Bahasa Indonesia instructions	78%
Expected subscription price	50,000 rupiah/month	95%

Based on the table above, 78% of the respondents were from non-maritime high school, who did not have any enough background knowledge of ME when they started learning it at higher education level. 60% of the cadets studied Maritime English ranging from one to four years. The learning media they are exposed to are varied: 67% from books and 56% from You Tube learning videos. Their purposes of learning Maritime English are varied: many of them (83%) learn it to prepare for a future career in the maritime sector, while 73% of them want to improve their communication skills. Most of the cadets support a provision of ME learning platform, with more on speaking and listening skills (87%) and pronunciation (76%). Accordingly, 81% of the cadets are more interested to use a learning platform that includes more audio-visual learning material. Next, instructions in Bahasa Indonesian and English are required by many of them (78%). Furthermore, almost all the cadets (95%) agree with a subscription fee of 50,000 rupiah per month.

4.1. The Required ME Learning Platform

Based on the literature review above and the results of the questionnaire spread to the target learners, there are some similarities and requirements of a learning platform for ME, including (1) Stimulate interaction and be generative; (2) Encourage learners to develop learning skills and strategies when they use online English resources; (3) Online English resources should link to each other to develop a progression of skills, understandings, and language item; (4) Have appropriate instructions; (5) Be attractive and flexible; (6) Convinces users that learning is more comfortable and more fun through the apps; (7) Uses bilingual approach (English - Bahasa Indonesia).

4.2. Content of the ME Learning Platform

Based on the guidelines and the questionnaire result, it is found that the target content for ME learning covers: (1) ME Knowledge; Language skills and features such as listening and speaking for communication, reading and writing, grammar, applied terms, and SMCP; (3) Campus and working requirement for maritime knowledge and communication skills; (4) ME for elementary level.

Table 2.
Needs Analysis of the Required Learning Platform.

	Theory	Questionnaire result	Summary
Content	Content (Dirgeyasa, 2018) 1. Knowledge (maritime content) 2. Language skills and features: 3. Listening and speaking (communication) 4. Reading 5. Writing 6. Grammar, applied terminologies 7. SMCP	1. Campus and working requirement for maritime knowledge and communication skills 2. Speaking and listening skills, ME terms, and pronunciation 3. Elementary level 4. Level of difficulty: medium-hard 5. The needs for sufficient reliable sources	1. Maritime content (IMO, STCW, Model course 3.17) 2. Contextual activities covering the four skills; however, still emphasizing speaking and listening skills 3. Grammar: Marlins test specifications 4. SMCP and maritime terminologies 5. Suggested to start with elementary, which covers the level of difficulty from easy to hard.
Platform	1. Stimulate interaction and be generative. 2. Encourage learners to develop learning skills and strategies when they use online English resources. 3. Online English resources should link to each other to	1. The needs of ME learning platform 2. Suggested form: video, audio, text, PPT. 3. Bilingual (English – Indonesia) 4. Proposed price: 50.000 rupiah/month.	1. ME learning platform. 2. Easy, fun UI and UX to motivate learners in learning. 3. Progression record of content and language skills achievement separately. 4. Clear instructions.

	develop a progression of skills, understandings, and language items. 4. Have appropriate instructions. 5. Be attractive and flexible. 6. Convinces users that learning is more comfortable and more fun through the apps.		5. Ranging from easy – hard practices. 6. Suggested form: video, audio, text, PPT. 7. Bilingual 8. Suggested price: 50.000 rupiah/month
Other considerations	Online teaching and learning principles 1. Let the students do most of the work (actively involve). 2. Interactivity (within the students and with the instructor/teacher). 3. Strive for presence: Social Presence (attendance), Cognitive Presence (discussion on the topic), or Teaching Presence (instruction).	1. Maritime cadets (18-21 y.o.). 2. Background: non-maritime vocational school. 3. Been learning English for 1-2 years. 4. Learn from YouTube and book. 5. Averagely can follow the used material resources.	1. Sufficient explanation supporting to give learners meaningful learning experience. 2. Considering adult learner characteristics. 3. Step by step/ continuing practices. 4. Medium for instructor-student/student-student interactions. 5. Record of visit, open discussion medium. 6. Short and clear instructions.

4.2.1. Content

The questionnaire shows that the learners have average interest in and knowledge of ME. However, it could also mean that their knowledge and interest are still not optimal. In terms of the level of difficulty, the learners do not find it too hard to learn. The result above indicates that the learners need more support and encouragement to require apps in which the UI/UX and content can support and motivate them in learning. Next, the content should cover IMO, STCW, Model Course 3.17, Marlins test specification, SMCP, ME terms. It is suggested to start from the elementary level and cover the four skills, especially listening, speaking, and pronunciation. The learners can start from easy to hard explanations and practices. A study revealed that the lack of language skills of a ship's crew could result in ineffective communication, which is identified as the cause of the many accidents (Ziarati et al., 2011). So, the emphasis on listening and speaking skills is needed as the learners have to be able to communicate well for their work in the future. Besides, the communication skills should also represent communicative language training set in the context of real-life situations at sea (Ziarati et al., 2011).

4.2.2. Platform

Based on the result of the analysis, the major participants are aware of their need to improve their ME ability. However, it appeared that they need more support of sufficient and reliable sources to motivate them to learn the knowledge and the communication skills. The questionnaire result indicates that most of the participants need an ME learning platform in order for them to have a better access to and to practice the required knowledge and skills. So, it is suggested that the platform can be constructed in an easy and fun UI/UX covering the required content. Furthermore, the progression records of content and language skills achievement should be separated. Also, factors like explicit bilingual instruction (Bahasa Indonesia – English) and features (video, audio, text, PPT) also need to be incorporated.

In general, ME learning application platforms are essential to optimize ME learning. Learning with apps is considered suitable particularly for adult learners since they are characterized as independent, practical, responsible, voluntary, and motivated learners. In other words, they are more ready to study and explore the respective knowledge actively and are motivated to learn what becomes their immediate needs and requirement

(Kapur, 2015). Beside designing a ME learning platform, the designers/researchers must incorporate the applicable content and platform to bring a successful learning experience to the learners.

5. CONCLUSION

Needs analysis is a prerequisite to designing the ME learning platform for ME learners in Indonesia. The required ME learning platforms target study achievement and a better future career in maritime sectors in this context. It suggested starting with the elementary level, which underlines Maritime knowledge and communication skills. Accordingly, the platforms have to be comfortable and fun by considering their UI and UX design. This platform can be useful and beneficial for ME learners in Indonesia. It provides an alternative to teach as well as to teach ME, which will be designed by considering both standard guidelines used in ME and includes learners' perspectives to reach their target learning and goals for a better career in the maritime sector. Learning apps aim to create not only quality and meaningful, but also successful learning experiences that will achieve the desired result of enhancement and changes in the knowledge and skills of the ME learners. Understanding the characteristics and needs of adult learners for ME will help the researchers build the content of ME apps.

REFERENCES

Asadullah, A., Kankanhalli, A., & Faik, I., 2018. Digital Platforms: A Review and Future Directions. Digital Platforms: A Review and Future Directions.

Bocanegra-Valle, A., 2012. Maritime English. The Encyclopedia of Applied Linguistics. Available at: http://dx.doi.org/10.1002/9781405198431.wbeal0746.

Dirgeyasa, I.W., 2018. The Need Analysis of Maritime English Learning Materials for Nautical Students of Maritime Academy in Indonesia Based on STCW'2010 Curriculum. English Language Teaching, 11(9), p.41. Available at: http://dx.doi.org/10.5539/elt.v11n9p41.

Dudley-Evans, T., 1998. Developments in English for Specific Purposes: A multi-disciplinary approach. Cambridge University Press.

Howard, J., & Major, J., 2004. Guidelines for Designing Effective English Language Teaching Materials. Guidelines for Designing Effective English Language Teaching Materials.

Hutchinson, T. & Waters, A., 1987. English for Specific Purposes. Available at: http://dx.doi.org/10.1017/cbo9780511733031.

Joo, H., 2017. A study on understanding of UI and UX, and understanding of design according to user interface change, International Journal of Applied Engineering Research 12(20), pp.9931-9935.

Kapur, S., 2015. Understanding the Characteristics of an Adult Learner. Jamia Journal of Education, Volume 2(1), pp.111-121.

Koh, T. K., and Fichman, M., 2014. Multihoming Users' Preferences for Two-Sided Exchange Networks, MIS Quarterly 38(4), pp.977-996. Available at: https://doi.org/10.25300/misq/2014/38.4.02.

Krippendorff, K., 2004. Content Analysis: An Introduction to Its Methodology (2nd ed.) Thousand Oaks, CA: Sage Publications.

Li, J., 2014. Needs Analysis: An Effective Way in Business English Curriculum Design. Theory and Practice in Language Studies, 4(9). Available at: http://dx.doi.org/10.4304/tpls.4.9.1869-1874.

Motteram, G., 2013. Innovation in learning technologies for English language teaching. Innovation in Learning Technologies for English Language Teaching.

Nunan, D., 2012. Learner-Centered English Language Education. Available at: http://dx.doi.org/10.4324/9780203096888.

Oers, V., 2015. Children's Digital Storymaking.

Pelz, B., 2019. (My) Three Principles Of Effective Online Pedagogy (part 2). Online Learning, 8(3). Available at: http://dx.doi.org/10.24059/olj.v8i3.1819.

Peterson, M., 2016. Digital Video as a Summative Assessment Tool.

Richey, R.C. & Klein, J.D., 2014. Design and Development Research. Available at: http://dx.doi.org/10.4324/9780203826034.

Robinson, P., 1991. ESP Today: A Practitioner's Guide. Hemel Hempstead: Prentice-Hall.

Salavati, S., 2016. Use of Digital Technologies in Education: The Complexity of Teachers' Everyday Practice. Doctoral dissertation, Department of Informatics, Linnaeus University, pp.1-4. Växjö, Sweden: Linnaeus University Press.

Ziarati, M., et al., 2011. Communication And Practical Training Applied In Nautical Studies. Available at: https://www.researchgate.net/publication/263652110, accessed on: 4 July 2014.

Testing of the Model of Creating a Specialized Tourist Product for Post-COVID Time

Neven Šerić[a], Lidija Bagarić[b], Anđela Jakšić Stojanović[c], Nevena Keković[d]

Specialized tourists offer in the post covid time is an important reason in choosing the destination to travel to. A new perception of this offer puts new challenges to those who design such offers. Most specialized offers are the result of entrepreneurial initiative and intuition. Authors have dealt with the creation of such offers as an important destination concurrent factor in their own cross-border cooperation. Based on their findings, they have developed a model of creating specialized tourism products for post covid time by linking core, additional, and expanded contents with brand creation and the marketing strategy. In this paper authors continue their research by testing that model through two platforms: desk research of the latest cognitions related to the repercussions of Covid-19 on tourist mind, and on a convenient sample of connoisseurs. The testing of the model is connected with one case study in which authors cooperate in practice. The findings have been tested through a survey on a sample of experts (representatives of travel agencies) related to their experiences in sales for 2020 and 2021.They have also found important changes in tourist perception of specialized tourist product. The findings offer the answers as to why the basic contents of the specialized tourist offer is no longer sufficient, as well as a way for developing additional and expanded contents, on which the brand and brand management activities in the post corona period should be primarily based, i.e. on what to base the marketing strategies in the post covid time.

KEY WORDS

~ Tourism
~ Model
~ Testing
~ Offer
~ COVID-19

a. University of Split, Faculty of Economics, Croatia
e-mail: nseric@efst.hr

b. University of Rijeka, Faculty of Tourism and Hospitality Management, Croatia
e-mail: lidijab@fthm.hr

c. University of Donja Gorica, Faculty of Culture and Tourism, Montenegro
e-mail: andjela.jaksic@udg.edu.me

d. Superior, Ltd
e-mail: nevena.kekovic@gmail.com

doi: 10.7225/toms.v10.n02.021

Received on: 17.05.2021/ Revised on: 22.09.2021/ Accepted on: 17.10.2021/ Published: 21.10.2021

1. INTRODUCTION

Before the outbreak of the covid 19 pandemic during the last decade there have been changes in the behaviour of tourists when choosing a destination, and changes in preferences towards tourist offers (Cooper, 2021; Baggio, 2020; Buhalis & Sinarta, 2019; Buhalis et al., 2019; Richards, 2019; Nunkoo et. al, 2019; Boes et al., 2016). The authors have come to similar conclusions in their own research (Šerić et al., 2020C; Šerić & Marušić, 2019; Šerić & Batalić, 2018; Šerić et al., 2017). The findings of these studies warn us that the originality of the specialized tourist offer is no longer a sufficient prerequisite for competitiveness. Research conducted during the covid 19 pandemic period related to tourist behavior has also indicated drastic changes in tourist behaviour and consumption (Šerić et al., 2021; Cooper, 2021; Girish, 2020; Šerić et al.,, 2020A). It is evident that the competitiveness of a new specialized tourist product depends on how much it is adapted to the contents and perception of added value of the tourist expectations. The authors have analyzed the tourist behaviour on the coastal riviera of the Republic of Croatia and Montenegro during the main tourist season in 2020 (Šerić et al., 2021). They have exchanged data and information from their research with travel agencies and tourist offices in the Republic of Croatia and Montenegro. They have conducted a survey on appropriate samples of tourists who stayed on the coast of the Republic of Croatia and Montenegro during the main tourist season. The findings of the study warn that the covid-19 pandemic will have long-term repercussions on the behaviour of tourists in choosing a destination and specialized tourism products. According to the findings of the research, it can be concluded that the number of tourists for whom the basic tourist contents of a specific offer (destination, hotel) is no longer crucial in choosing a destination is significantly increasing. Due to the growing possibilities of selection within the category of similar basic contents (destinations, hotels), the decision on the final choice is increasingly made on the basis of additional and expanded contents of the offer. Given this fact, the authors define a research question RQ1: Given the growing importance of additional and expanded contents in choosing a tourist destination, should it be significantly implemented in the marketing strategy and brand of the tourist product?

So far the authors have practiced to develop the brand and marketing strategy of a specialized tourist product towards the basic content of the offer. The originality and differentiation of the specialized tourist product before the covid 19 pandemic were sufficient to attract the attention of tourists (Jafari & Xiao, 2021; Ruhanen et al., 2019; Šerić & Marušić, 2019; Šerić & Batalić, 2018; Šerić et al., 2015). Recent research findings warn that additional and expanded contents of specialized tourist offer has stronger impact on its attractiveness and competitiveness (Šerić et al., 2021; Cooper, 2021; Baggio, 2020; Šerić et al., 2020A; Buhalis & Sinarta, 2019). The authors believe that the additional and expanded contents of a specialized tourism product should have a greater significance in marketing strategy and brand as well. The starting point for the design and implementation of additional and expanded contents of a new specialized tourism product should be its basic feature. In this process the standards of related diversification of the tourist offer should be adhered to. For the purposes of testing the basic research question, the authors will use a specific specialized tourism product in the development of which they participate based on scientific cross-border cooperation between the Republic of Croatia and Montenegro - mini smart eco village Zelenika, Herceg Novi, Montenegro.

2. LITERATURE REVIEW

The adaptation of the specialized tourist offer to the targeted perception value of tourist implies relevant information about their habits during travel, and the way of their choosing a destination and specialized tourist offer (Jafari & Xiao, 2021; McCabe, 2020; Gossline et al., 2020; Hall et al., 2020). Recent findings indicate changes in the perception of the value of specialized tourism products. Perception of value of additional and expanded contents significantly contributes to the final selection. Smart technological and environmental solutions in the offer are increasingly attracting the attention of tourists (Milano, et al., 2019; Ruhanen et al., 2019; Šerić et al., 2019). Ignoring these new insights can have negative consequences on destination competitiveness, receptive tourism entity occupancy and the sale of specialized tourism products (Cooper, 2021; Baggio, 2020; Buhalis & Sinarta, 2019). Specialized tourist products are labour-intensive in case of a year-round offer and the engagement of specialized staff. Premium prices of such offers are based on the perception of added value (Buhalis & Foerste, 2015). The originality and contents of the offer, as well as the resources engaged, contribute towards the perception of the added value of a specialized tourist product. The continuity of the development of specialized tourist products encourages the creation of new jobs, self-employment, and income growth of the local population of the receptive destination (Prorok, 2019). Recent research related to the effects of the covid-19 pandemic on the tourism economy indicates that specialized tourism products are more resilient than seasonal tourism products (Girish, 2020; Hall et al., 2020). Because of that fact, this issue should be given special importance.

More serious changes in the behaviour and consumption of tourists began to occur even before the outbreak of the covid 19 pandemic (WTTC, 2020). New insights should be accepted as a basis for managing the tourist offer. The competitiveness of a new specialized tourism product significantly depends upon the perceived value of the target tourism clientele (Wen et al., 2021; Zhang et al., 2021; WTTC, 2020; UNWTO, 2020). If, in addition to the basic contents, additional and expanded contents becomes evident, the tourist gets an impression of an even greater value of the offer (Šerić et al., 2021). Findings from recent research indicate that tourists rely less and less on previous experiences when choosing a destination and tourist facilities. Preference in choosing a destination and tourist contents is given to the offer that they rate as more meaningful and valuable (Prideaux et al., 2020; Hall et al., 2020; Šerić et al., 2020A; Jakšić Stojanović et al., 2019A and 2019B).

Specialized tourism products significantly contribute to the competitiveness of the destination and the wider tourist zone within which they are offered (Jafari & Xiao 2021; Buhalis & Foerste, 2015). Findings from recent research indicate that existing specialized tourism products need to be upgraded with additional contents in order to maintain their attractiveness. The attractiveness of specialized tourist content significantly contributes to its competitiveness (Šerić et al., 2020A). In the post-covid period, due to the further intensification of competition between receptive tourist countries and destinations, new insights related to the development and management of specialized tourist products have, in addition to application and scientific and wider social significance, opened new possibilities. New findings related to this could have important repercussions on the employment of the local population in tourism and the maintenance of the percentage of tourism income in GDP (UN 2020; Prorok et al., 2019). The development and management of specialized tourism products during recent years have become the subject of scientific consideration (Richards, 2019; Buhalis & Foerste, 2015). The expectations of tourist demand are rapidly changing (Gossling et al., 2020). The steady growth of competition and the recession that will follow the end of the covid-19 pandemic impose the need for new research on this issue (Prideaux et al., 2020).

3. BASIC, ADDITIONAL, AND EXTENDED CONTENTS OF THE SPECIALIZED TOURIST PRODUCT

In the overall structure of the global tourist offer, specialized tourist products have shown a high growth rate over the last two decades. This segment of the tourist offer has increasingly significant repercussions on the growth of national tourism economies (Prorok et al., 2019). Specialized tourist products today represent one of the most dynamic and fastest growing categories of tourist offer. In addition to intensive growth, they are also characterized by encouraging tourists to travel throughout the year, which is why they are an important catalyst for extending the tourist season (Buhalis, Park, 2021). In many receptive tourist countries, specialized tourist products are an important component of the competitiveness of the national offer and an important development factor of the tourist economy (Buhalis, Sinarta, 2019). There are many challenges and dilemmas in relation to the development of specialized tourism products.

Atypical and unusual tourist facilities, adapted to the target tourist segments, are classified as specialized tourist products (Jafari & Xiao, 2021; Šerić et al., 2020A). The creativity of the contents of the specialized tourist offer contributes towards its attractiveness (Jakšić Stojanović & Šerić, 2018). With its total contents, the specialized tourist product combines different tourist needs - adventure, health, gastronomic, cultural, and others (Richards, 2019). Depending on the resources upon which each specialized tourist product is based, there are specific contents complexities. A more complex content enables more pronounced differentiation and greater attractiveness (Jakšić Stojanović et al., 2019A). The more pronounced differentiation of the specialized tourist product is a prerequisite for a higher premium price supplement (Šerić et al., 2020A). In terms of contents, it is possible to consider the basic, expected, additional, and extended contents within the specialized tourist product (Šerić et al., 2020A). The expected content is related to the preliminary impressions of the offer of the targeted tourist clientele, and it is not in the focus of this research. The basic content represents the idea and context of the offer and the marketing story about it. This content is the foundation of its recognizability. Additional content contributes to the attractiveness and allows modifications of the offer during the life cycle of a specialized tourism product. The expanded content represents the potential to attract different tourist segments. The elements of additional and expanded content of a specialized tourist product in practice are developed in the phase of its maturity (high demand) in order to maintain the relevant interest of demand for as long as possible. The perception of a specialized tourist product among tourists changes in accordance with the structure of the basic, additional, and expanded contents (Šerić et al., 2021; Jakšić Stojanović et al., 2019A; Jakšić Stojanović et al., 2019B). Based on this fact, the authors consider that in the new, post covid time, it would be recommended to implement all the components of the contents in its marketing strategy and brand. The differentiation and breadth of content characteristics of a specialized tourism product makes it practical for branding and developing a customized marketing strategy.

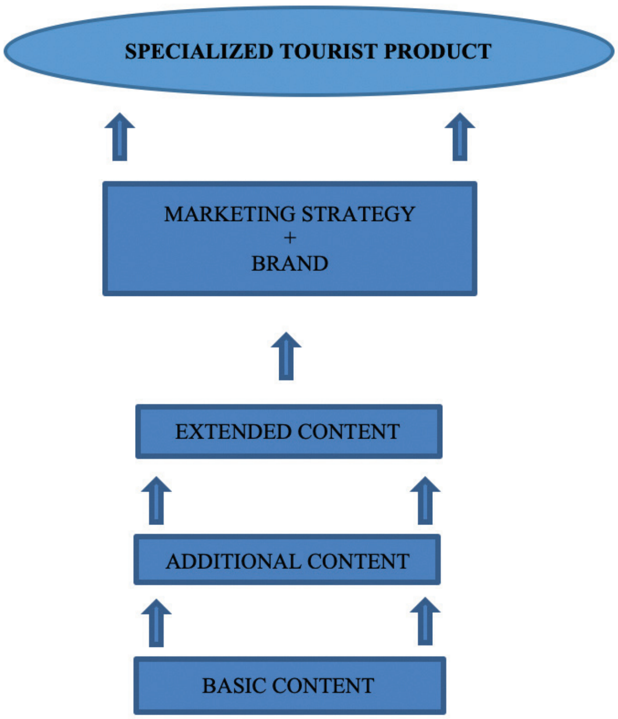


Figure 1.
Recommended model for the development of a new specialized tourism product for post covid time.

The global supply of specialized tourism products is dynamic and continuously growing (Prorok et al., 2019). Acquiring the competitiveness of such tourist facilities depends on their market visibility. In order to increase market visibility and attractiveness of such tourist content, the authors are of the opinion that in addition to the basic content, special importance should be given to additional and expanded content, both in the development process and in the brand and marketing strategy, as shown in Figure 1.

4. THE RESEARCH

The research has been conducted on the example of a specialized family accommodation facility - mini smart eco village. The receptive subject is located in the Montenegro, Zelenika, near Herceg Novi, situated along the coast, below the Adriatic highway. The authors are collaborating on the project development based on cross-border collaboration. The basic content of the offer of the receptive subject is designed in accordance with the previous practice of the author in the development of new specialized tourist products (Šerić et al., 2020A). Additional and expanded content of the offer was developed using SWOT, TOWS, Pestec, Mof and Recoil analysis. This methodology has been selected in order to gain relevant insights into the content possibilities of the offer based on detailed findings of internal and external analysis. Given the specific, pivotal period of the global pandemic and the expected recession that has followed, a multidisciplinary approach was used, and experts from practice (representatives of travel agencies) were consulted in the implementation of the selected methodology and the findings of a survey of authors conducted during 2020 were taken into account (Šerić et al.,2021). The receptive subject has relevant transport infrastructure by road and air (two airports nearby and a regional road). The tourist zone in which it is located is currently frequented by tourists from the surrounding countries and tourists from Russia (by planes). In recent years, two luxury hotels, several high-category catering restaurants and several smaller marinas have been built around the area. Individual promotion of these new tourist entities contributes towards a strengthening the global visibility of the whole tourist zone, which is a prerequisite for attracting tourists from new emitting markets (Jakšić Stojanović & Šerić, 2019; Jakšić Stojanović et al., 2019A; Jakšić Stojanović et al., 2019C; Prorok et al., 2019; Melović et al., 2018; Luković & Šerić, 2009; Šerić & Luković, 2007). These facts and the possibility of diversification of a new, specialized receptive tourism entity, have prompted the idea of devising a concept that would attract smaller tourist groups from different emitting markets throughout the year. In accordance with this goal, basic, additional, and expanded contents have been designed. The idea has been developed on the standards of glamping tourism. Nine (9) small villas are built and equipped in accordance with high environmental standards (building and equipment). Waste selection within the complex has been planned, as well as recycling outside the village (prefabricated recycling yard). Smart technological solutions intended for guests contribute to the high quality and comfort of living with a variety of contents and equipment. The implemented technological solutions are based on high environmental standards. Some have already been confirmed in the authors' earlier tourism projects (Jakšić Stojanović & Šerić, 2020; Jakšić Stojanović et al., 2019; Jakšić Stojanović et al., 2019B; Jakšić Stojanović & Šerić, 2018A; Šerić et al., 2002). The targeted tourist segments are organized groups of employees (from smaller companies) who will stay here for trainings and team building. During the afternoon and evening, the hosts will organize various additional and extended activities (educational, gastronomic, sports, spiritual, health, entertainment, and others) within the complex. User smart solutions have also been implemented: self check in and self check out, smart TV communication platform, tablet management of basic, additional, and extended content of the offer, smart management of the interior atmosphere (light, music, multimedia), offer of special equipment and devices (Alexa, wireless chargers, additional mobile devices equipped with a local SIM card, etc.), concierge video chat (for communication with the reception). New technologies of sound insulation of buildings have been implemented, and the use of energy from renewable sources (sun and wind) has been ensured. Accommodation units are equipped with the highest energy efficiency equipment ECO certified. Energy-saving connections to the water supply network have been installed, and the ecological disposal of hygienic wastewater and its use for watering plantations has been ensured.

Table 1.
SWOT analysis.

STRENGHTS	WEAKNESSES
1)Innovative specialized accommodation offer; 2)Uniqueness of the offer in the tourist zone; 3)Location availability and traffic infrastructure; 4)Attractiveness of the location (proximity to the sea, road access, infrastructure, preserved landscape); 5)Landscape recognizability of the tourist zone; 6)Preserved culture and tradition of the tourist zone; 7)Archaeological and historical heritage of the tourist zone; 8)Favorable microclimatic conditions (average 200 sunny days per year); 9)Experience of investors in construction and installation; 10)Experience in tourism and catering business of the subject; 11)Entrepreneurial experience and initiative of the entity for new projects; 12)Own construction land with enough space for additional facilities; 13)Good financial liquidity and creditworthiness of the entity; 14)Availability of bank capital; 15)Relevant network of partners and outsourcing associates; 16)Experienced management; 17)Economic technologies - lower costs of electricity, water supply and waste disposal; 18)Good image of the subject in the local community; 19)Production of organic food in the tourist zone.	1)Lack of own financial resources for project implementation, required credit indebtedness; 2)Limited accommodation capacity (9 units with 2 - 4 beds); 3)Lack of educated and experienced staff for animation and maintenance of IT applications; 4)Lower solarization of the central open space with the pool due to the height of the whole buildings; 5)Some tourism segments do not accept the digital concept of communication during their stay; 6)The predominant tourist population in the tourist zone (countries of the region) undermines the impression of exclusivity; 7)Higher transportation costs (for building materials and equipment) due to the geographical position of the location; 8)Distance of the location from the highway crossroads; 9)Fragmentation of the offer of content in the nearby tourist zone; 10)Modest promotion and poor visibility of the tourist zone on the global tourist market.
OPPORTUNITIES	**THREATS**
1)Post covid time - restart of tourism; 2)Aspiration of tourists for socialization after months of isolation; 3)The need for re-socialization of employees in companies after the covid pandemic; 4)Existing tourist contacts in the emitting market of Scandinavia and the Russian Federation and opening of new emitting markets; 5)Connecting with professional national associations of target emitting tourist markets; 6)Attracting new market segments; 7)Preferences of tourists for accommodation in smaller receptive facilities in post covid time; 8)Cooperation with maritime concessionaires and supply entities in the area; 9)Popularity of the concept of sustainable ecological tourist offer; 10)Trend of implementation of digital platforms in the tourist offer; 11)Possibility of obtaining a concession for a wider forest belt in the area; 12)Proximity to groomed hiking trails and cooperation with the mountaineering association; 13)Lower prices of construction and execution of the project in its own direction; 14)Positioning in the optimal niche (target tourism segment - organized groups of employees of small companies for education and team building); 15)Attractiveness of location, content and offer - the possibility of attracting different tourist segments; 16)Possibility to organize own guest transfers; 17)Availability before EU accession funds for financing such projects.	1)Prolongation of the covid pandemic; 2)Problems in the purchase of technologically specific equipment; 3)Non-recognition of the added value of the offer (eco and smart standards); 4)Non-recognition of the category of accommodation by the relevant Ministry - inadequate categorization; 5)Seasonality of the tourist visit in the area of the tourist zone; 6)Reducing the attractiveness of the wider environment (tourist zone) due to uncontrolled construction; 7)Employment of local staff in the surrounding countries (seasonal); 8)Financial and other liabilities of the entity in several developing projects; 9)Slow return on investment; 10)Higher cost of communal equipment if the target category of accommodation is not obtained according to the assessment of the relevant Ministry; 11)Increase in interest on other people's funds; 12)Complexity of applying for funds before the accession funds of the European Union; 13)Endangering the landscape and the purity of the sea by the growth of tourist construction in the tourist zone; 14)Emigration of educated young people from the area of the tourist zone (promising tourist staff).

According to the findings of the SWOT analysis, the previous experience of investors in the tourism business with the availability of their own and the possibility of using bank's capital is a prerequisite for a successful implementation of the business idea of a specialized tourism product at the planned location. Traffic accessibility and attractiveness of the location are a prerequisite for year-round tourist visits in post covid time. A good image of the subject in the wider tourist zone is a prerequisite for the development of additional and expanded content of the specialized tourist offer, as well as the possibility of tourist commercialization of available resources of the whole tourist zone. The lack of own capital for the realization of the project can be fully compensated by financial by bank capital based on mortgages of own real estate. The organizational accommodation concept of a specialized tourist product limits the total accommodation capacities, which presupposes a premium addition to the price. Maintaining the attractiveness of the offer with a higher price presupposes the development of additional and expanded content of the specialized tourist offer for which there are available resources. The modest promotion of the tourist zone in which the receptive tourist entity will operate, the fragmentation of existing tourist facilities and the predominant actual tourist population do not contribute to the impression of exclusivity. This fact, as well as the distance of the micro-location from the highway crossroads, imposes the need to develop its own channels of promotion and sales with selected entities on the target emitting markets.

Table 2.
TOWS analysis.

STRENGHTS+OPPORTUNITIES	WEAKNESSES+OPPORTUNITIES
1)Post covid time / restart of tourism / innovative offer of specialized accommodation, affirmation of the concept of individuality; 2)Aspiration of tourists for socialization, the need for re-socialization of employees in companies after the covid pandemic, attracting different tourist segments, preferences of tourists for accommodation in smaller receptive facilities; 3)Attractiveness of the tourist zone - preserved landscape, historical heritage, cultural, historical and traditional heritage, favorable microclimatic conditions - perspective for emitting markets with unfavorable climate; 4)Availability and attractions - road and air corridors, proximity to the sea and forests - recreational zone in the area - the possibility of expanding the concession; 5)Good image of the entity, own land, cooperation with supply entities and resource concessionaires in the wider environment - a wide range of additional and supplementary content; 6)Experience of investors in construction and installation, good financial liquidity, availability of bank capital and earmarked funds from the European union; 7)New emitting markets - networking, business experience, contacts on the market of Scandinavia and the Russian Federation, attracting new tourist segments; 8)Connecting with professional national associations of target emitting tourist markets; 9)Global visibility of the promotion of sustainable ecological tourist offer, eco gastronomic offer and digital user platforms on offer; 10)Available insorcing and outsourcing resources, cost-effectiveness of envisaged technical and technological solutions.	1)Insufficient own funds for project implementation, lower cost of project implementation on its own, before European union accession funds and availability of bank capital; 2)Small accommodation capacity, preferences of tourists for accommodation in smaller receptive subjects; 3)Lack of highly educated and experienced staff for hotel animation and for maintain IT applications, education of own staff; 4)Distance of the location from highway crossroads, higher costs of transport and tourist transfers, the possibility of self-organization; 5)The fragmentation of tourist facilities and the predominant tourist population undermines the impression of exclusivity, attracting new tourist segments and organized groups of company employees; 6)Modest promotion and poor visibility of the tourist zone on the global tourist market, restart of tourism - growth of demand for unknown destinations, promotion of the concept of sustainable ecological tourist offer; 7)Some tourism segments do not accept the digital concept of communication, opening new emitting markets and connecting with professional national associations (small companies - organized work and team building stays to re-socialize employees), promotion to tourism segments that prefer eco-sustainable tourism and digital technologies with clear defined high pricing strategy; 8)Spatial and content limitations, cooperation with land concessionaires in the area and the possibility of expanding one's own concession.

STRENGHTS+THREATS	WEAKNESSES+THREATS
1)Restart of tourism, innovative offer of specialized accommodation, problems in the purchase of technologically specific equipment, prolongation of the covid pandemic; 2)Aspiration of tourists for socialization and accommodation in smaller receptive facilities, the need for re-socialization of employees in companies, attracting new tourism segments, global visibility of promoting sustainable environmental tourism offer, non-recognition of the added value of the offer; 3)Attractiveness of the tourist zone, reducing the attractiveness of the tourist zone due to uncontrolled new construction, threats to the landscape and the sea; 4)Traffic accessibility and attractions of the tourist zone, seasonality of the tourist visit; 5)Available insorcing and outsourcing resources, employment of local staff in the surrounding countries, emigration of educated young people; 6)Good financial liquidity of investors, own experience in construction, availability of bank capital and European union funds, financial obligations of investors in other projects, rising interest rates on other people's funds, complexity of applying for European union funds, slow return on investment; 7)Good image and business networking of investors, problems in the procurement and financing of technologically specific equipment, inadequate categorization due to non-recognition of the category of accommodation by the relevant Ministry - higher costs of utility equipment; 8)Promotion of the year-round innovative offer in various emitting markets where tourist offers based on eco-smart contents are preferred, promotional prices in the off-season, extension of the covid pandemic.	1)Lack of own financial resources to complete the project due to commitments on other projects, problems in the procurement of technologically specific equipment, prolongation of the covid pandemic, delay with the commercialization of the project; 2)Distance of the location from the highway crossroads and higher transport costs (materials and equipment); 3)Necessary credit indebtedness, growth of interest on other people's funds, complexity of applying for EU funds, slow return on investments, difficult servicing of loans; 4)Shortage, seasonal employment in neighboring countries and emigration of locally educated and experienced staff; 5)The predominant tourist population and the fragmentation of the offer in the tourist zone undermines the impression of exclusivity, non-recognition of the added value of the offer by the targeted tourist segments; 6)Modest promotion and poor visibility of the tourist zone in the global tourist market results in seasonality of visits; 7)Limited accommodation capacity, risk of financially unfavorable categorization of accommodation by the relevant Ministry-higher costs of utility equipment, space restrictions for the installation of solar panels; 8)Reducing the attractiveness of the tourist zone due to uncontrolled tourist construction, endangering the landscape and the sea.

Based on the TOWS analysis, the choice of strategy of strengths and possibilities is suggested because the accommodation concept of the specialized tourist offer is adapted to post covid 19 time. The characteristics of the micro-location are a precondition for the development of additional and expanded contents of the specialized tourist offer that would be primarily offered on emitting markets with bad microclimatic conditions. Road and air corridors are a prerequisite for year-round visits and good occupancy, given that this is a smaller accommodation capacity that will be offered to businesses in a targeted manner for the organized stay of their employees in business training and team building. The available recreational zone in the environment of the receptive subject and the possibility of obtaining a concession are prerequisites for offering a variety of additional and expanded contents. The existing good image of the investor in the environment, property of the land, established cooperation with supply entities and resource concessionaires in the wider environment are also a prerequisite for the development of additional and supplementary contents. The existing contacts and partners in several emitting tourist markets will simplify communication and promotion of a specialized tourist product given the growing interest in tourist facilities based on sustainable environmental standards, eco gastronomic offer, and implementation of digital user platforms in the offer. The cost-effectiveness of the planned technical and technological solutions in the project with the available insourcing and outsourcing resources also lead to the selection of a strategy of strengths and opportunities in the implementation of the project.

Table 3.
PESTEC analysis.

Market environment segment	Features	Strength of influence	Significance	Overall rating
Political	State subsidies for the application of environmental solutions (renewable energy sources and waste disposal) and EU funds for eco-sustainable tourism offer.	+3	7	+21
	Current political instability at the national level and constraints due to epidemiological circumstances.	-3	5	-15
	Subtotal			+6
Economic	Profit margin	+4	10	+40
	Return of investment	-2	8	-16
	Subtotal			+24
Social	Post covid tourist behavior	+3	6	+18
	Perception of tourist zone exclusivity	-2	7	-14
	Subtotal			+4
Technological	Technological smart equipment	+3	8	+24
	Costs, purchase and maintenance of smart technological equipment	-1	7	-7
	Subtotal			+17
Geo – climatic	Microclimatic conditions	+5	10	+50
	Climate changes	-2	5	-10
	Subtotal			+40
Cultural	Resources / attractions	+3	6	+18
	Global trends	-3	8	-24
	Subtotal			-6
Sum				+85

The findings of the Pestec analysis should be observed, taking into account the limitation of the selection of two (key / strategic) aspects for each analyzed feature of the environmental segments. In order to ensure the relevance of the assessment despite this fact, the application of this method has selected opposite characteristics, which have then been evaluated by the strength of influence and significance in order to know the quantitative positive and negative assessment of each of the five key environmental characteristics. Quantification has been performed using a multidisciplinary focus group. The final quantitative assessment (+85) argues the perspective of the assumed specialized tourist offer, but also warns of the need to adhere to the defined standards, both in the technical implementation of the project and its contents. The specialized tourist offer of the basic content, taking into account all aspects of the environment, has no economic perspective without additional and expanded contents. The additional and expanded content should be clearly visible in the offer, which means their implementation in the strategy and brand of a specialized tourism product.

Table 4.
MOF analysis.

Marketing	
Strengths and opportunities	Weaknesses and limitations
- Originality and eco friendly offer; - Experience and available staff for e-marketing especially through social networks, originality of the offer - potential for international publicity; - Possibility to expand the content; - Existing business communication with certain emitting tourist markets; - Positioning the offer in the niche of small businesses-for educational and team building organized stays of employees.	- Negative image of receptive country given the number of sick and dead from covid-19 per 100,000 inhabitants; - Negative perception of the country in terms of transport accessibility, legal security (not a member of the European union); - The receptive subject and his brand are completely unknown in the global tourist market.
Operations	
Strengths and opportunities	Weaknesses and limitations
- Project management experience and business competencies; - Assumed organizational and logistical business model; - Potential for continuous development of additional and supplementary content of the offer.	- Distance of the location from the highway crossroads-distance from the large emitting tourist markets of Europe; - Most airlines to the nearest airports (Tivat, Dubrovnik) do not have a year-round continuity.
Finance	
Strengths and opportunities	Weaknesses and limitations
- Good current liquidity and previous business of investors; - Good creditworthiness and established cooperation with banks; - Available and vacant real estate for mortgage loans.	- Insufficient own funds for self-financing of the project; - Adverse loans; - Business disruptions during the covid 19 pandemic; - Expected global recession after the end of the covid pandemic.

The findings of the MoF analysis have confirmed the possibility of technical realization of the project of a specialized tourist product with the share of the necessary additional financial indebtedness. The consequences of the covid 19 pandemic will have an impact on the dynamics of the return on the investment, so the cost of bank borrowing should be taken into account. The currently reduced volume of airlines to the two airports in the area will be normalized as the epidemiological situation calms down. In the meantime (due to lower travel intensity) the propulsion of road corridors will be increased. This indicates the balance of transport logistics in the current situation and in the future. The future primary orientation towards airlines imposes a need for organization of own transfers to airports. The findings of previous project analyses have indicated the same. The current negative image of the receptive country, given the ratio of the number of sick and dead per 100,000 inhabitants of the covid 19 pandemic, is expected to be removed by the normalization of the health situation. A change in perceptions of the country's transport accessibility and legal security is also to be expected, as the local population is oriented towards membership in the European Union. But the fact that the receptive subject and his brand are completely unknown to the global tourism market imposes a need for aggressive promotion in which additional and expanded content due to originality and environmental standards represent a usable perspective, provided they are fully implemented in marketing strategy and brand of a specialized tourism product.

Table 5.
RECOIL analysis.

R- resources	E - experience	C0 - control	I - ideas	L - leadership
- Equity reserves and experience in financial planning; - Experienced management; - Good external image of the subject; - Own construction and assembly capacities, own land on a location desirable for the planned content; - Marketing competencies for development and brand management.	- Previous experience in tourism business; - Existing offer of tourist accommodation of the company; - Adapting to market changes; - Cooperation with tourism entities in the country and abroad; - Cooperation with business entities in the environment.	- Marketing planning; - Business forecasting in projects; - Proactive management of new projects; - Monitoring the experiences of foreign and domestic competition; - Use of modern technologies in monitoring and analysis of markets and business.	- Innovative offer; - Adapting the content to the needs of tourist groups; - Smart-eco concept of supply; - Authenticity of the offer and strengthening the perception of the value of the tourist offer; - Development and brand management of the receptive subject.	- Authority and creditworthiness of project owners and managers in the receptive market and with foreign partners; - A family business with clearly defined responsibilities; - Commitment to business continuity optimization; - Commitment of all family members to the project.

Finally, the findings of the Recoil analysis argue the justification of the project. Experience in entrepreneurship, tourism, and construction with available resources, primary land property and sources of own and bank capital, are a prerequisite for the implementation of the project within the planned deadlines. Marketing competencies for brand development and management are a prerequisite for an appropriate implementation of additional and expanded contents of the offer in the strategy and brand image of a specialized tourism product. A good image of the investor in the business environment is a prerequisite for the development of cooperation with business entities, which in turn is a prerequisite for the development of additional and expanded contents. The existing cooperation with tourism entities in the country and abroad is useful in strengthening the visibility of the future brand. The practice of monitoring the situation in the receptive and some emitting markets enables the prediction of trends and adaptation to future market changes. Orientation of the basic content of the specialized tourist offer towards modern technologies will contribute to its additional attractiveness, but also to the monitoring and analysis of business and monitoring of the situation on the target tourist markets. The implementation of modern technologies in the offer enables an easier adaptation of various contents to the needs of tourist groups, and the smart eco concept of the offer is also a current tourist trend. All this contributes towards the authenticity of the specialized tourist product and the impression of added value. The basic, additional, and expanded contents of the specialized tourist offer designed in this way inspires the implementation of various brand management activities. Finally, the authority and business creditworthiness of the project holder company are a prerequisite for establishing cooperation with partners who can contribute to the implementation of the project and the inclusion of new entities in the supply chain. The fact that the project will be realized by a family company with experience in tourism business and the commitment of all members of the extended family to the projects are a prerequisite for the rational and responsible realization of the set mission and vision of the project.

5. CRITICAL REVIEW OF RESEARCH FINDINGS

Although it is difficult to predict the end of the covid-19 pandemic, the population of countries where the disease is under control are re-engaging in tourist migration. Innovative tourist facilities in destinations that are perceived as safe for health are selected. The pleasant micro-climate is also associated with the desirability of the destination. Finally, the diversity of tourist facilities is another feature that contributes to the competitiveness of the offer. The findings of the research have proved the importance of the originality of the additional and expanded contents of the offer for its attractiveness. Additional and expanded content simplifies maintaining the competitiveness of the tourist offer, also representing a prerequisite for attracting a larger number of tourist segments and a growth of annual tourist visits. The availability of the location of the receptive subject to large emitting tourist markets and good transport connections with attractive and favourable microclimatic conditions also positively contribute towards the growth of tourist visits. The diversity of available resources is a prerequisite for a variety of basic, additional,s and expanded content of the tourist offer. The implementation of additional and expanded contents in the marketing strategy and brand of a specialized tourist product contributes to its global visibility and a more intensive response of tourists. Assumed smart technologies, in addition to positive repercussions on future business costs, will also contribute to the attractiveness of a specialized tourism product. The concept of tourist offer and available land are a limit to the number of accommodation units. But this should be used in the context of the exclusivity of the offer. The fragmentation of the tourist offer in the environment encourages the valorization of all available resources, and the development of additional and expanded contents. The modest national tourism promotion of the receptive country results in poorer global visibility. This fact suggests a more aggressive strategy and intensive brand positioning activities of the specialized tourist offer. The originality of the strategy and the attractiveness of the brand are further enhanced by the breadth and diversity of the contents of the offer. The additional and expanded contents are imposed as important components of marketing strategy and brand. The post covid time imposes a different approach to creating and managing a specialized tourism product, marketing strategy and brand. Positioning in a niche of safe, ecological and active content in landscape-attractive locations with various additional and expanded contents are prerequisites for attracting a larger number of tourist segments in the post-covid time. The possibility of obtaining state subsidies and grants from earmarked funds of the European Union reduces the financial risks of commercialization of the project. The originality and attractiveness of the contents of the tourist offer are a precondition for a higher profit margin, given the expected slower return on investment during the first years of commercialization of the project. The adaptation of the specialized tourist product to post covid time is evident, but one should be aware of the existing impression of lower exclusivity of the tourist zone in which the project is being implemented. The pursuit of the exclusivity of the offer and the receptive subject implies more intensive marketing, especially when choosing a marketing strategy, and selective brand management activities. As much as technological smart solutions and such equipment contribute to the attractiveness of the specialized tourist offer, the cost and complexity of maintaining it with possible procurement problems could have negative repercussions during the first years of business. Favourable microclimatic conditions in the geographical commercialization zone of the project diminish the impression of global climate change. The variety of resources can be valorized through the additional and expanded contents of a specialized tourism product and is expected to have positive repercussions on the recognizability of the offer on the global market. Taking into account all the findings of the conducted research, the choice of a strategy that will use the strengths and possibilities of the project becomes imperative. The commitment to this strategy, in addition to the TOWS analysis, is also imposed by the findings of the MOF analysis. The currently negative image of the receptive country should be borne in mind, given the statistics of patients and deaths from the covid-19 pandemic, as well as the fact that Montenegro is not yet a member of the European Union. The original concept of a specialized tourism product, the modest global visibility of the receptive country, destination and receptive tourism entities lead to aggressive marketing strategies and complex brand management activities, which the authors will address in more detail in a new research. Weakness due to the distance of the receptive subject's location from the highway hub will diminish the renewal of numerous airlines to surrounding airports in the post covid time. Entrepreneurial experience, positive business, ownership of the land on which the receptive subject is located and the possibility of using their own real estate as a collateral for a mortgage loan, are the arguments that encourage the realization of the project. All the findings from the research suggest the inclusion of additional and expanded contents of a specialized tourism product in the marketing strategy and brand.

The limitation of the research is the smaller number of analyzed features in the PESTEC analysis. In order to offset it, reducing it to an acceptable level, conflicting characteristics have been selected for evaluation. The attractiveness of certain features of a specialized tourist product could not be tested on tourists since it is not yet possible to receive tourists. Therefore, market testing has been conducted through focus groups in which representatives of travel agencies and tourist offices in the Republic of Croatia and Montenegro have participated.

Based on the research findings, it can be concluded that the concept of mini smart eco village in Zelenika Bay near Herceg Novi on the Montenegrin coast will attract the target tourist population due to wide possibilities of additional and expanded contents - organized groups of company employees who would hold trainings and team building programmes. Available resources and local traditions provide a wide range of attractive educational, gastronomic, sports, spiritual, health, entertainment, and other contents with the receptive subject. The envisaged user smart solutions will contribute to the originality and efficiency of various programmes and the attractiveness of a specialized tourism product. The use of energy from renewable sources, the implementation of energy efficiency standards and eco-certification are prerequisites for securing part of the funds for the implementation of the project from earmarked national and foreign funds. The specific requirements of the post-covid times, changes in the behaviour of tourists when choosing a destination and specialized tourist products offered in tourist areas that do not yet have an exclusive image or good global visibility, undoubtedly necessitate aggressive marketing activities. The additional and expanded contents in the conditions of available diverse resources is imposed as a marketing full-fledged component of the competitiveness of a specialized tourist product. They should be implemented in the same way in the marketing strategy and brand. This knowledge is also the answer to a fundamental research question in the context of testing the presented model of development of a specialized tourist product.

6. CONCLUSION

The consequences of the covid-19 pandemic on the global tourism economy will be evident, not only in the intensity of international arrivals and overnight stays, but also in the choice of destinations and tourist facilities. Safety and purity, and the isolation of the receptive subject are of primary importance in the post covid time. Tourists will travel more often by car, choosing closer destinations, especially the more isolated ones. Due to the tendency to strengthen the body's immunity, tourists will opt more for areas with preserved landscapes and receptive entities in which dispersed accommodation is possible. The tourism economy will recover, but the dynamics of recovery for individual countries, tourist zones and receptive entities will be different. Tourists' awareness of the importance of preserving the environment, striving to get closer to the local population and an increasing interest in the indigenous products suggest that the additional and expanded contents of the specialized tourist offer is more intensively emphasized in the marketing strategy and brand. The same is indicated by changes in social values in the global tourism market. Diversification of specialized tourism products at the level of the national receptive country will contribute towards improving its competitiveness. The wider content of specialized tourist products enables a more moderate consumption of non-renewable resources. Modern technological solutions contribute to the impression of originality and quality of a specialized tourist product. They also contribute to the simplicity of hospitality operations. The digital transformation is incomparable in speed, scope, and impact on receptive subjects with previous experiences. The role of modern technological solutions in specialized tourism products also depends on a defined vision and mission. Nevertheless, the contribution to the automation of the service process, productivity,u and efficiency of the catering service is evident. Artificial intelligence will also play an increasing role in this. Based on the information on the behavior of tourists, it will be possible to predict the business of the receptive subject. Modern technological solutions will contribute towards a lowering the energy and other operating costs of the receptive subject. The focus of marketing activities from the basic contents of a specialized tourism product should be expanded to additional and expanded contents. The Covid-19 pandemic draws tourists' attention to smaller receptive subjects in a preserved natural environment with accompanying outdoor facilities. The importance of the impression of the quality of a specialized tourist product is growing. That impression is easier to maintain on an expanded content. Furthermore, this indicates the need for a more intensive implementation of additional and expanded contents in the marketing strategy and brand of a specialized tourism product. The overall, expanded content of the specialized tourist offer is a precondition for its year-round attractiveness. It should be borne in mind that the end of the covid-19 pandemic will be followed by a recession. Then the maintenance of the intensity of the tourist visit will significantly depend on the adjustment of the offer to the targeted tourist segments. The competitiveness of a specialized tourist product is, in this sense, significantly enhanced by the additional and expanded contents. Tourist zones in the immediate vicinity of the European Union's emitting market have the prospect of increasing visits. Specialized forms of tourist offer, with the creative additional and expanded contents in the preserved landscape with pleasant microclimatic conditions, have a perspective of growth and development. Competitiveness can be maintained by diversification, constant quality improvement, and content expansion. Therefore the implementation of additional and expanded contents of each specialized tourism product in the marketing strategy and brand in the post-covid time is implied. This will also contribute towards strengthening the global visibility of the brand of the specialized tourist product and the receptive subject. The broader impression of the overall contents of the specialized tourist product also enables the opening of new emitting tourist markets and the attraction of new segments of tourists.

REFERENCES

Baggio, R., 2019. The science of complexity in the tourism domain: a perspective article. Tourism Review, 75(1), pp.16–19. Available at: http://dx.doi.org/10.1108/tr-04-2019-0115.

Boes, K., Buhalis, D. & Inversini, A., 2016. Smart tourism destinations: ecosystems for tourism destination competitiveness U. Gretzel, Lina Zhong and Chulmo Koo, ed. International Journal of Tourism Cities, 2(2), pp.108–124. Available at: http://dx.doi.org/10.1108/ijtc-12-2015-0032.

Buhalis, D. & Sinarta, Y., 2019. Real-time co-creation and nowness service: lessons from tourism and hospitality. Journal of Travel & Tourism Marketing, 36(5), pp.563–582. Available at: http://dx.doi.org/10.1080/10548408.2019.1592059.

Buhalis, D. et al., 2019. Technological disruptions in services: lessons from tourism and hospitality. Journal of Service Management, 30(4), pp.484–506. Available at: http://dx.doi.org/10.1108/josm-12-2018-0398.

Buhalis, D. & Foerste, M., 2015. SoCoMo marketing for travel and tourism: Empowering co-creation of value. Journal of Destination Marketing & Management, 4(3), pp.151–161. Available at: http://dx.doi.org/10.1016/j.jdmm.2015.04.001.

Cooper, C., 2021. Essentials of tourism, SAGE Publications Limited.

Prayag, G., 2020. Time for Reset? Covid-19 and Tourism Resilience. Tourism Review International, 24(2), pp.179–184. Available at:
http://dx.doi.org/10.3727/154427220x15926147793595.

Gössling, S., Scott, D. & Hall, C.M., 2020. Pandemics, tourism and global change: a rapid assessment of COVID-19. Journal of Sustainable Tourism, 29(1), pp.1–20. Available at:
http://dx.doi.org/10.1080/09669582.2020.1758708.

Hall, C.M., Scott, D. & Gössling, S., 2020. Pandemics, transformations and tourism: be careful what you wish for. Tourism Geographies, 22(3), pp.577–598. Available at: http://dx.doi.org/10.1080/14616688.2020.1759131.

Jafari, J., Xiao, H., 2021. Encyclopedia of Tourism, Springer.

Jakšič-Stojanović, A. & Šerić, N., 2020. Valorization of Montenegrin Lighthouses as Destination Icons Through Different Forms of Multimedia Arts. Lecture Notes in Networks and Systems, pp.939–946. Available at:
http://dx.doi.org/10.1007/978-3-030-46817-0_106.

Jakšić Stojanović, A., Šerić, N., (2019), Sports and Health as Corner Stones of Tourism Development - Case Study of Montenegro, u Sports Science and Human Health - Different Approaches, Intech Open Limited (www.intechopen.com/about-intechopen), London.

Jaksic-Stojanovic, A. et al., 2019a. Montenegro as High-Quality Sports Tourism Destination- Trends and Perspectives. Sport Mont, 17(1), pp.93–95. Available at: http://dx.doi.org/10.26773/smj.190218.

Jakšić Stojanović, A., Janković, M. & Šerić, N., 2019b. Montenegro as a high-quality health tourism destination: Trends and Perspectives, African Journal of Hospitality, Tourism and Leisure Volume 8 (3), pp. 1 – 9.

Jakšić Stojanović, A., Janković, M., Šerić, N., Vukilić, B., Ibrahimi, A., 2019c. Branding of protected areas and National Parks: A case study of Montenegro, African Journal of Hospitality, Tourism and Leisure Volume 8 (2), pp. 1 – 9.

Jakšić Stojanović, A., Šerić, N. & Perišić, M., 2019. Marketing management of the lighthouse heritage in the function of strengthening the national identity on the global tourism market: Stone Lights (Croatia) and the art of the lighthouses (Montenegro), Proceedings of the Faculty of Economics in East Sarajevo n. 19, pp. 83 – 98. Available at:
http://dx.doi.org/10.7251/zrefis1919083j.

Jakšić Stojanović, A. & Šerić, N., 2018a. The Montenegrin Lighhouses as Destination Icons, University Mediterranean, Podgorica, Montenegro.

Luković, T. &Šerić, N., 2009. Strategic development and changes in legislation regulating yachting in Croatia, Journal of Maritime Studies, 23(2), pp. 357-374.

Melović, B. et al., 2018. Mogućnosti i ograničenja brendiranja Kotora kao crnogorske turističke destinacije, Proceedings of the VII Scientific conference Sustainable tourism and institutional environment, Jahorina, pp. 187 – 194.

Nunkoo, R., Seetanah, B. & Agrawal, S., 2019. Guest editorial. Tourism Review, 74(2), pp.129–137. Available at:
http://dx.doi.org/10.1108/tr-04-2019-209.

Prideaux, B., Thompson, M. & Pabel, A., 2020. Lessons from COVID-19 can prepare global tourism for the economic transformation needed to combat climate change. Tourism Geographies, 22(3), pp.667–678. Available at:
http://dx.doi.org/10.1080/14616688.2020.1762117.

Prorok, V., Šerić, N. & Peronja, I., 2019. Analysis of Overall and Pure Technical Efficiency of Tourism in Europe. Transactions on Maritime Science, 8(2), pp.219–229. Available at:
http://dx.doi.org/10.7225/toms.v08.n02.007.

Richards, G., 2019. Culture and tourism: natural partners or reluctant bedfellows? A perspective paper. Tourism Review, 75(1), pp.232–234. Available at:
http://dx.doi.org/10.1108/tr-04-2019-0139.

Ruhanen, L., Moyle, C. & Moyle, B., 2019. New directions in sustainable tourism research. Tourism Review, 74(2), pp.138–149. Available at:
http://dx.doi.org/10.1108/tr-12-2017-0196.

Šerić, N., Jakšić Stojanović, A. & Bagarić, L., 2021. Model kreiranja specijaliziranog turističkog proizvoda za post covid vrijeme, Proceedings of the X Scientific Conference Jahorina business forum 2021: South east Europe in the vortex of the 2020 crisis, disruptive innovation, policies and measures for sustainable economic growthx, Jahorina, Istočno Sarajevo, pp. 85 – 97.

Šerić, N., Marušić, F. & Peronja, I., 2020a. Upravljanje razvojem specijaliziranog turističkog proizvoda, Redak Split.

Šerić, N., Mihanović, A. & Tolj, A., 2020. Model for the Development of a Specialized Dark Tourist Product. Transactions on Maritime Science, 9(2). Available at:
http://dx.doi.org/10.7225/toms.v09.n02.014.

Šerić, N. & Marušić, F., 2019. Tourism Promotion of Destination for Swedish Emissive Market. Advances in Economics and Business, 7(1), pp.1–8. Available at:
http://dx.doi.org/10.13189/aeb.2019.070101.

Šerić, N. & Batalić, M., 2018. Marketinško upravljanje informacijama u funkciji jačanja privlačnosti turističke destinacije, Podstranska revija XVII br. 36, Ogranak Matice Hrvatske u Podstrani, pp. 12-15.

Šerić, N., Jerković, M. & Bučić, K., 2017. Mogućnosti kreiranja turističke marke zaobalne destinacije Svilaja Moseć, Zbornik radova Župa Ogorje - Putovima života i vjere između Svilaje i Moseća, pp. 467 – 486.

Šerić, N., Ljubica, J., Jerković, M., 2015. Evaluation of the tourist resort strategic management model in the eastern Adriatic littoral, Proceedings of the 11. International Conference Challenge of Europe, Faculty of economics, Split, pp. 273 – 290.

Šerić, N. & Luković, T., 2007. Primjena BPD (Build Primary Demand) modela razvoja tržišne strategije tranzicijskih tržišta, Ekonomska misao i praksa, 1, pp. 99 – 110.

Šerić, N., Ikač, M. & Vidović, Z., 2002. Disposal of waste water in ecologically sensitive environment of lighthouse¸ Conference proceedings 44th International Symposium ELMAR, Zadar, pp. 135-139

UN, 2020. Ending Poverty. Available at: https://www.un.org/en/sections/i.

UNWTO, 2020. World Tourism Barometer May 2020, Special focus on the impact of Covid-19, Madrid. Available at: https://webunwto.s3.eu-west-1.amazonaws.com/s3fs-public/2020-05/Barometer%20-%20May%202020%20-%20Short.pdf.

Wen, J. et al., 2020. COVID-19: potential effects on Chinese citizens' lifestyle and travel. Tourism Review, 76(1), pp.74–87. Available at:
http://dx.doi.org/10.1108/tr-03-2020-0110.

WTTC, 2020. To Recovery / Beyond: The Future of Travel & Tourism in the Wake of Covid-19, WTTC - Oliver Wyman, September 2020. Available at: https://wttc.org/Research/To-Recovery-Beyond/moduleId/1707/itemId/18.

Zhang, H. et al., 2021. Forecasting tourism recovery amid COVID-19. Annals of Tourism Research, 87, p.103149. Available at:
http://dx.doi.org/10.1016/j.annals.2021.103149.

CONTRIBUTION

NAŠI ŠKOJI

Pere Ljubić

Ko da su veliški, usidreni brodi
Daleko od krâja na moru široken,
stojidu, mučidu nâši škúri škoji,
a obloci gredu po nebu visoken.

Jedân do drugega usidreni škoji:
široki i úski, i mâli i veli,
a po njima legla pod bârdima mista
iz kojih se dvižu bili kampaneli.

Po kanálih rávnih dí i dí su jidra…
Pomâlo se miču od škoja do škoja,
priko svítlih pútih, iz vâle u vâlu,
po ravnicah pústih tega modreg poja.

OUR ISLANDS

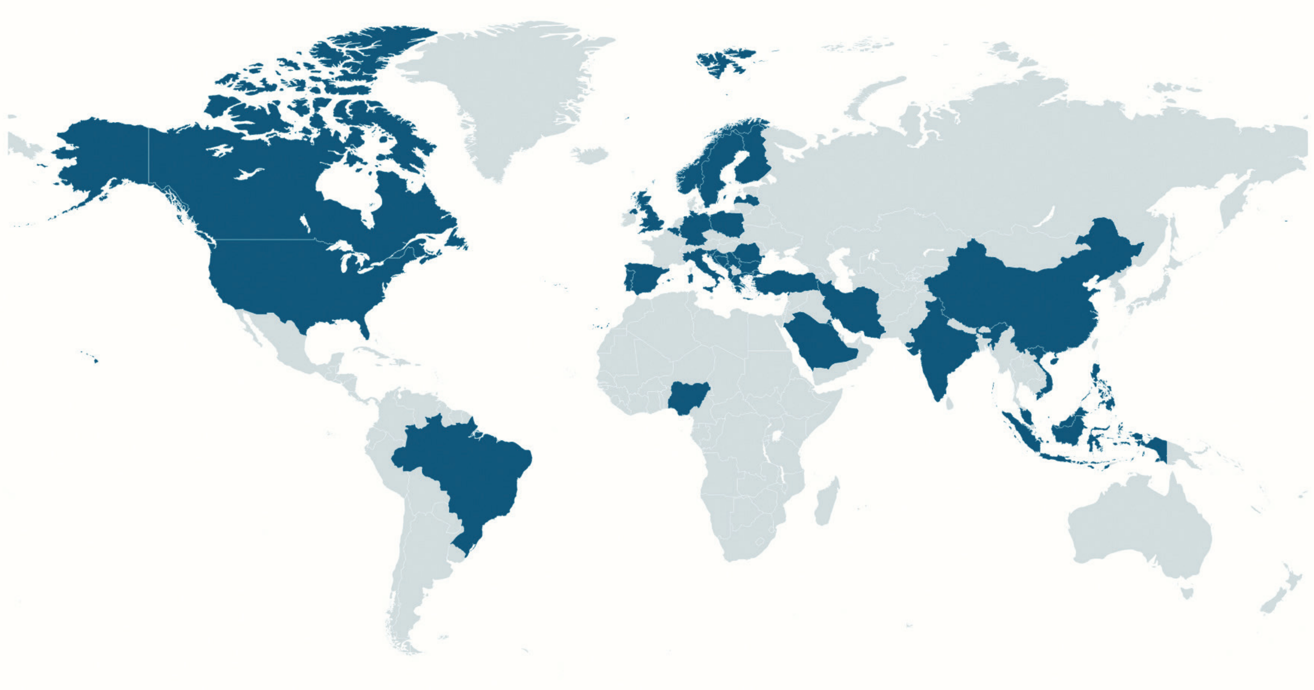
trans. by Mirna Čudić Žgela

Resembling great big ships,
Far away from the mainland, anchored in a wide, wide sea,
Our dark and gloomy islands stand silent and quiet,
While clouds are sailing across the high, high sky.

Next to one another, our islands are anchored:
Both wide and narrow, both small and big,
And on them, on slopes and beneath hills, lie our villages,
From which white church towers rise.

Across the wide channels, here and there sails emerge …
Slowly moving from island to island,
Along bright paths, from bay to bay, from cove to cove,
Across the vast plains of this blue, blue field.

List of reviewers



Adam Weintrit, Poland
Agung Pambudi, Indonesia
Aleksandrs Pavlovičs, Latvia
Alen Jugović, Croatia
Ana Perić-Hadžić, Croatia
Andrea Russo, Croatia
Andrej Androjna, Slovenia
Andrzej Grządziela, Poland
Anh Tuan Hoang, Vietnam
Anita Gudelj, Croatia
Arjit Seth, Hong Kong
Arshad Jamal, Saudi Arabia
Axel Luttenberger, Croatia
Aznida Abu Bakar Sajak, Malaysia
Bangar Raju Totakura, India
Barış Özsever, Turkey
Beatriz López-Bermúdez, Spain
Beatriz Tovar, Spain
Biljana Stamatović, Serbia
Blagovest Belev, Bulgaria
Borislav Savković, Serbia
Branko Žitko, Croatia
Carmine Aveta, Italy
Cezary Specht, Poland
Charléne Guillaumot, Belgium
Danko Kezić. Croatia
Dario Ban, Croatia
Dario Medić, Croatia
Dean Sumić, Croatia
Dejan Dragan, Slovenia
Devran Yazır, Turkey
Didem Özer Çaylan, Turkey
Dionysios Polemis, Greece
Dursun Balkan, Turkey
Đorđe Dobrota, Croatia
E. Pérez Marcos, Germany
Edvard Tijan, Croatia
Egemen Ertürk, Turkey
Elen Twrdy, Slovenia
Eli Marušić, Croatia
Elmas Güldem, Trukey
Ergün Demirel, Turkey
Fauziah Ab Rahman, Malesia
Federico Martin Palmer, Spain
Fırat Bolat, Turkey
Floris Goerlandt, Canada
George Theocharidis, Sweden
German De Melo Rodríguez, Spain
Goksel Ulay, Turkey
Goran Belamarić, Croatia
Goran Vukelic, Croatia
Gordana Jovanovska Kaplan, Turkey
Hans Rummel, Germany
Hrvoje Dodig, Croatia
Hrvoje Jakopović, Croatia
Husna Sarirah Husin, Malaysia
Ignacio de la Peña Zarzuelo, Spain
Igor Vujović, Croatia
Ivana Golub Medvešek, Croatia
Ivana Ognjanović, Montenegro

Ivica Pavić, Croatia
Ivica Skoko, Croatia
Izabela Kotowska, Poland
Jagan Jeevan, Malaysia
James J. Corbett, USA
Jasem Albanai, Kuwait
Jasenko Marin, Croatia
Jinhai Chen, China
Josipa Ferri, Croatia
Joško Dvornik, Croatia
Joško Šoda, Croatia
Kjell Ivar Øvergård, Norway
Konstantinos N. Anyfantis, Greece
Krešimir Malarić, Croatia
Krešimir Trontl, Croatia
Kristina Čižiūnienė, Lithuania
Kristofor Lapa, Albania
Krzysztof Wróbel, Poland
Krželj Maja, Croatia
Kyongsu Yi, South Korea
Lada Maleš, Croatia
Ladislav Vrsalović, Croatia
Lea Vojković, Croatia
Lech Murawski, Poland
Lia Dragojević, Croatia
Liane Roldo, Brasil
Lidija Bagarić, Croatia
Maciej Denc, Poland
Maja Perčić, Croatia
Marhana Mohamed Anuar, Malaysia
Marija Jović, Croatia
Marija Opačak, China
Marija Pijaca, Croatia
Marina Zanne, Slovenia
Mariusz Specht, Poland
Marko Hadjin, Croatia
Marko Katalinić, Croatia
Marko Vukšić, Croatia
Maximo Q. Mejia Jr, Sweeden
Md. Ratul Amin, Malesia
Merica Slišković, Croatia
Michael Baldauf, Sweeden
Mihai Ciprian Mărgărint, Romania
Mina Tadros, Portugal
Mirjana Bonković, Croatia
Miroslav Drljača, Croatia
Mladen Jardas, Croatia
Mohd Azzeri Md Naiem, Malaysia
Mohd Najib Abdul Ghani Yolhamid, Malaysia
Muhammad Salman Siddiqui, Norway
Murat Aydın, Turkey
Nanthini Sridewi, Malaysia
Nenad Đurđević. Croatia
Nenad Leder, Croatia
Nenad Vulić, Croatia
Neven Šerić
Nguyen Van Viet, UAE
Niklas Kühl, Germany
Nikola Mandić, Croatia
Nikola Papac, BIH
Nikša Nikolić, Croatia
Norshaheeda Mohd Noor, Malesia
Nur Afiqah Rosly, Malesia
Olgun Konur, Turkey
Olja Čokorilo, Serbia
Paolo Diviacco, Italy
Pero Škorput, Croatia
Peter Ralph Galicia, Philippines
Piotr S. Szulczewski, Malaysia
Purnama Nancy Lumban Batu, Indonesia
Rafał Gralak, Poland
Ran Yan, Hong Kong
Ranka Petrinović, Croatia
Ranko Vojinović, Montenegro
Rino Bošnjak, Croatia
Robert Pomeroy, USA
Rozaimi Che Hasan, Malaysia
Roziyani Rawi, Malaysia
Ruwaida Ramly, Malaysia
Ryszard Wawruch, Poland
Saifful Kamaluddin Muzakir, Malaysia
Sandro Nižetić, Croatia
Sanja Steiner, Croatia
Sanjin Valčić, Croatia
Sarah Isnan, Malaysia
Sayed Aziz Sayed Hussin, Malaysia
Senka Šekularac Ivošević, Montenegro
Shahidatul Arfah Baharudin, c
Stanivuk, Tatjana, Croatia
Suresh Thanakodi, Malesia
Špiro Ivošević, Montenegro
Tatjana Dalbač, Montenegro
Tin Matulja, Croatia
Tommi Inkinen, Finland
Tonćo Marušić, BIH
Umut Tac, Turkey
Uzoma Gregory Okoro, Nigeria
Vaira Vignesh Ramalingam, India
Vanja Krajinović, Croatia
Venkaiah Chowdary, India
Vesna Skorupan Wolff, Croatia
Victor Bolbot, UK
Violeta Jurković, Slovenia
Violeta Roso, Sweden
Vlatko Knežević, Croatia
Xuan Phuong Nguyen, Vietnam
Yuri Walter, Brasil
Zaloa Sanchez Varela, Croatia
Zdeslav Jurić, Croatia
Zlatko Nedelko, Slovenia
Zurab Mushkudiani, Iran
Zvonimir Lušić, Croatia
Želimir Dulčić, Croatia
Željana Bašić, Croatia
Željko Domazet, Croatia

About ToMS: Ethics, Conflict of Interest, License and Guides for Authors

The Journal is published in English as an open access journal, and as a classic paper journal (limited edition).

ToMS aims at presenting the best maritime research primarily, but not exclusively, from Southeast Europe, particularly the Mediterranean area. Papers will be double-blind reviewed by 3 reviewers. With the intention of providing an international perspective at least one of the reviewers will be from abroad. ToMS also promotes scientific collaboration with students and has a section entitled Students' ToMS. These articles also undergo strict peer reviews. Furthermore, the Journal publishes short reviews on significant papers, books and workshops in the fields of maritime science.

Our interest lies in general fields of maritime science (transport, engineering, maritime law, maritime economy) and the psychosocial and legal aspects of long-term work aboard.

1. PUBLICATION ETHICS

Ethical Policies of ToMS

Plagiarism is arguably the most complicated ethical issue. Our policies define plagiarism as "taking material from another's work and submitting it as one's own." ToMS *holds authors — not the Publisher or its editors and reviewers — responsible* for ensuring that all the ideas and findings included in a manuscript are attributed to the proper source. We also refer to our role as steward of what constitutes ethical conduct. Ethical misconduct is the reason for our commitment to continue to strive to educate all the parties in the publishing process how to handle this matter. As a member of Crossref, ToMS has a powerful weapon – iThenticate system, which is not perfect.

"Even if there were reliable and sensitive plagiarism detection software, many issues would remain to be addressed. For example, how much copying is legitimate? Clearly, the reuse of large amounts of others' text constitutes plagiarism. But what should one think about copying short passages from the author's own earlier work, such as commonly occurs in the Methods section? In the Nature article it is suggested that some journals set a quantitative limit whereby the amount of text that can be reused is limited to about 30 percent. This may be utilitarian, but it seems curious and arbitrary that 25 percent of copied text might be deemed acceptable whereas 30 percent might not. Indeed, two authors who copied the same number of words could find themselves on opposite sides of that border if one author simply was more verbose and thus diluted their plagiarized content below the threshold! No, this is not a simple issue at all." [cited from: ASPB Newsletter]

Expectations for Publishing in ToMS

Faculty of Maritime Studies expects authors submitting to and publishing in its journals to adhere to ethical standards to ensure that the work they submit to or publish in the journal is free of scientific misconduct. Authors must:

- Take credit only for work that they have produced.
- Properly cite the work of others as well as their own related work.
- Submit only original work to the journal.
- Determine whether the disclosure of content requires the prior consent of other parties and, if so, obtain that consent prior to submission.
- Maintain access to original research results; primary data should remain in the laboratory and should be preserved for a minimum of five years or for as long as there may be reasonable need to refer to them. All authors of articles submitted for

publication assume full responsibility, within the limits of their professional competence, for the accuracy of their paper. Instances of possible scientific misconduct related to papers submitted to or published in the ToMS will be addressed by following the procedure outlined below.

2. CONFLICT OF INTEREST

The authors, reviewers and other participant are obligated to clearly state possible conflict of interest. Editor-in-chief, senior editor and/or executive editors board decide on actions based on conflict of interest (COI).

Editors' Duty

Disclosure and Conflicts of Interest: The editor cannot use unpublished materials, disclosed in submitted manuscript for his/her own research, without prior written consent of the author(s).

If author(s) of submitted paper is a member of editorial board or editor-in-chief, the submission, review and decision process is carried by the highest ranking editor who is not the author.

Reviewers' Duty

All reviewers should have no conflict of interest with respect to the research, the authors and/or the funding bodies.

3. MALPRACTICE

Procedure for addressing allegations of scientific misconduct or other ethical violations

Scientific misconduct in publishing includes but is not limited to:

- Data manipulation;
- Data falsification;
- Fraud: fabricating a report of research or suppressing or altering data;
- Duplicate publication;
- Plagiarism and
- Self-plagiarism.

Procedure for handling allegations of misconduct

- All allegations of scientific misconduct or ethical violation will be referred to the editor for research integrity or to the editor-in-chief. All allegations should be made in writing.
- Editor for research integrity will report the case in the meeting of the Editorial board and recommend the actions in 30 days.
- Except redraw of the paper, punishment could be inclusion in the black list of the journal and prohibition of further publishing in ToMS.

Submission declaration

Submission of an article implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere including electronically in the same form, in English or in any other language, without the written consent of the copyright-holder.

4. OPEN ACCESS LICENSE

Articles are freely available to both subscribers and the wider public with permitted reuse.

All articles published Open Access will be immediately and permanently free for everyone to read and download. Permitted reuse is defined by Creative Commons Attribution (CC BY) license, which: lets others distribute and copy the article, to create extracts, abstracts, and other revised versions, adaptations or derivative works of or from an article (such as a translation), to include in a collective work (such as an anthology), to text or data mine the article, even for commercial purposes, as long as they credit the author(s), do not represent the author as endorsing their adaptation of the article, and do not modify the article in such a way as to damage the author's honor or reputation.

For further details see the Creative Commons website.

5. PUBLICATION ETHICS AND MALPRACTICE STATEMENT

Unethical behavior is unacceptable and Transactions on Maritime Science does not tolerate plagiarism in any form. Authors who submit articles affirm that manuscript contents are original. Furthermore, authors' submission also implies that the manuscript has not been published previously in any language, either fully or partly, and is not currently submitted for publication elsewhere. Editors, authors, and reviewers, within the Transactions on Maritime Science are to be fully committed to good publication practice and accept the responsibility for fulfilling the following duties and responsibilities, as set by the COPE Code of Conduct for Journal Editors (http://publicationethics.org/resources/guidelines).

5.1. Duties of the Authors

Reporting Standards: Authors should accurately present their original research, as well as objectively discuss its significance. Manuscripts are to be edited in accordance to the submission guidelines of the proceedings.

Originality: Authors must ensure that their work is entirely original.

Multiple, Redundant, or Concurrent Publications: Authors should not concurrently submit the same manuscript for publishing to other journals, or conference proceedings. It is also expected that the author(s) will not publish redundant manuscripts, or manuscripts describing the sameresearch in several publishing venues, after the initial manuscript has been accepted for publication.

Acknowledgement of Sources: Author(s) should acknowledge all sources of data used in the research and cite publications that have influenced their research.

Authorship of the Paper: Authorship should be limited only to those who have made a significant contribution to conceiving, designing, executing and/or interpreting the submitted study. All those who have significantly contributed to the study should be listed as co-authors. The corresponding author should also ensure that all the authors and co-authors have seen and approved the final submitted version of the manuscript and their inclusion as co-authors.

Data Access and Retention: Authors should retain raw data related to their submitted paper, and must provide it for editorial review, upon request of the editor.

Disclosure of Financial Support: All sources of financial support, if any, should be disclosed.

Fundamental errors in published works: When an author discovers a significant error or inaccuracy in his/her submitted manuscript, the author must immediately notify the editor.

5.2. Duties of Reviewers

Confidentiality: Manuscript reviewers, the editor and the editorial staff must not disclose any information regarding submitted manuscripts. All submitted manuscripts are to be treated as privileged information.

Acknowledgement of Sources: Reviewers of manuscripts must ensure that authors have acknowledged all sources of data used in the research. Any similarity or overlap between the considered manuscripts, or with any other published paper, which is in personal knowledge of reviewer, must be immediately brought to the editor's notice.

Standards of Objectivity: Review of submitted manuscripts will be conducted objectively. The reviewers shall express their views clearly, with supporting arguments.

Promptness: If a reviewer believes it is not possible for him/her to review the research reported in a manuscript within the designated guidelines, or within stipulated time, he/she should notify the editor, so that the accurate and timely review can be ensured...

Conflict of Interest: All reviewers should have no conflict of interest with respect to the research, the authors and/or the funding bodies.

5.3. Duties of the Editor

Publication Decisions: Based on the editorial board's review, the editor can accept or reject the manuscript or can send it for modifications.

Review of Manuscripts: The editor ensures that each manuscript is initially evaluated by the editor, who may make use of appropriate means, to examine the originality of the contents of the manuscript. After the manuscript passes this test, it is forwarded to two reviewers for double-blind peer review, and each of whom will make a recommendation to publish the manuscript in its present form or to modify or to reject it. The review period will be no more than30 days.

Fair Review: The editor ensures that each manuscript received is evaluated on its intellectual content without regard to authors' sex, gender, race, religion, citizenship, etc.

Confidentiality: The editor must ensure that information regarding manuscripts submitted by the authors is kept confidential.

Disclosure and Conflicts of Interest: The editor cannot use unpublished materials, disclosed in submitted manuscript for his/her own research, without prior written consent of the author(s).

6. GUIDELINES FOR AUTHORS

The Journal is published in English as an open access journal, and as a classic paper journal (limited edition).

ToMS aims at presenting the best maritime research primarily, but not exclusively, from Southeast Europe, particularly the Mediterranean area. Papers will be double-blind reviewed by 3 reviewers. With the intention of providing an international perspective at least one of the reviewers will be from abroad. ToMS also promotes scientific collaboration with students and has a section entitled Students' ToMS. These articles also undergo strict peer reviews. Furthermore, the Journal publishes short reviews on significant papers, books and workshops in the fields of maritime science.

Our interest lies in general fields of maritime science (transport, engineering, maritime law, maritime economy) and the psychosocial and legal aspects of long-term work aboard.

6.1. Before you Begin

6.1.1. Ethics in publishing

For information on Ethics in publishing and Ethical guidelines for journal publication see Publication Ethics

6.1.2. Conflict of interest

All authors are requested to disclose any actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work.

6.1.3. Submission declaration

Submission of an article implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere including electronically in the same form, in English or in any other language, without the written consent of the copyright-holder.

6.1.4. Changes to authorship

This policy concerns the addition, deletion, or rearrangement of author names in the authorship of accepted manuscripts:

Before the accepted manuscript is published in an online issue: Requests to add or remove an author, or to rearrange the author names, must be sent to the Journal Manager from the corresponding author of the accepted manuscript and must include:

a. the reason the name should be added or removed, or the author names rearranged and

b. written confirmation (e-mail, fax, letter) from all authors that they agree with the addition, removal or rearrangement. In the case of addition or removal of authors, this includes confirmation from the author being added or removed. Requests that are not sent by the corresponding author will be forwarded to the Journal Editors and to the corresponding author, who must follow the procedure as described above.

Note that:

- publication of the accepted manuscript in an online issue is suspended until authorship has been agreed.

After the accepted manuscript is published in an online issue:

Any requests to add, delete, or rearrange author names in an article published in an online issue will follow the same policies as noted above and result in a corrigendum.

6.1.5. Copyright

Upon acceptance of an article, authors will be asked to complete an 'Exclusive License Agreement'. Permitted reuse of open access articles is determined by the Journal Open Source License (CC-BY).

6.1.6. Role of the funding source

You are requested to identify who provided financial support for the conduct of the research and/or preparation of the article and to briefly describe the role of the sponsor(s), if any, in study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication. If the funding source(s) had no such involvement then this should be stated.

6.1.7. Open access

Articles are freely available to both subscribers and the wider public with permitted reuse. All articles published Open Access will be immediately and permanently free for everyone to read and download. Permitted reuse is defined by following Creative Commons user license:

Creative Commons Attribution (CC BY): lets others distribute and copy the article, to create extracts, abstracts, and other revised versions, adaptations or derivative works of or from an article (such as a translation), to include in a collective work (such as an anthology), to text or data mine the article, even for commercial purposes, as long as they credit the author(s), do not represent the author as endorsing their adaptation of the article, and do not modify the article in such a way as to damage the author's honor or reputation. For further details see the Creative Commons website.

6.2. Guidelines for Authors: Manuscript Preparation and Submission

Authors are required to use the template (Microsoft Office) that can be downloaded from: https://toms.com.hr/img/toms_template_2021.dot.

6.2.1. Organization of the manuscript

First (title) page

The first page should carry:

a. the paper title;

b. full names (first name, middle – name initials, if applicable), and last names of all authors;

c. names of the department(s) and institution(s) to which the work should be attributed. If authors belong to several different institutions, superscript digits should be used to relate the authors' names to respective institutions. Identical number(s) in superscripts should follow the authors names and precede the institution names;

d. the name, mailing address and e-mail of the corresponding authors;

e. source(s) of research support in the form of financial support, grants, equipment or all of these.

Last page

The last page should carry:

a. ethical approval, if required;

b. authors' declarations on their contributions to the work described in the manuscript, their potential competing interests, and any other disclosures. Authors should disclose any commercial affiliations as well as consultancies, stock or equity interests, which could be considered a conflict of interest. The details of such disclosures will be kept confidential but ToMS urges the authors to make general statements in the Acknowledgement section of the manuscript.

c. a list of abbreviations used in the paper (if necessary);

Other pages

Each manuscript should follow this sequence:

- title page;
- abstract;
- text (Introduction, Methods, Results, Conclusions/ Discussion);
- acknowledgments;
- references;
- tables (each table complete with title and footnotes on a separate page);
- figures and figure legends, and the last page.

6.2.2. Text organization and style

6.2.2.1. Abstract

The second page should contain the Abstract. ToMS requires that the authors prepare a structured abstract of not more than 250 words. The abstract should include (at least) four sections: Aims, Methods, Results, and Conclusion, not necessarily separated.

Aim. State explicitly and specifically the purpose of the study.

Methods. Concisely and systematically list the basic procedures, selection of study participants or laboratory/ experimental/simulation setup, methods of observation (if applicable) and analysis.

Results. List your primary results without any introduction. Only essential statistical significances should be added in brackets. Draw no conclusions as yet: they belong in to the next section.

Conclusion. List your conclusions in a short, clear and simple manner. State only those conclusions that stem directly from the results shown in the paper. Rather than summarizing the data, conclude from them.

6.2.2.2. Main text

Do not use any styles or automatic formatting. All superscripts or subscripts, symbols and math relations should be written in MathType or Equation editor.

Introduction

The author should briefly introduce the problem, particularly emphasizing the level of knowledge about the problem at the beginning of the investigation. Continue logically, and end with a short description of the aim of the study, the hypothesis and specific protocol objectives. Finish the section stating in one sentence the main result of the study.

Results

Key rules for writing the Results section are:

a. the text should be understandable without referring to the respective tables and figures, and vice versa;

b. however, the text should not simply repeat the data contained in the tables and figures; and

c. the text and data in tables and figures should be related to the statements in the text by means of reference marks.

Thus, it is best to describe the main findings in the text, and refer the reader to the tables and figures, implying that details are shown there. The formulations such as "It is shown in Table 1 that the outcome of Group A was better than that of Group B" should be replaced by "The outcome of Group A was better than that of Group B (Table 1)."

The need for brevity should not clash with the requirement that all results should be clearly presented.

Discussion/Conclusions

The discussion section should include interpretation of study findings in the context of other studies reported in the literature. This section has three main functions:

a. assessment of the results for their validity with respect to the hypothesis, relevance of methods, and significance of differences observed;

b. comparison with the other findings presented in the relevant literature; and

c. assessment of the outcome's significance for further research.

Do not recapitulate your results, discuss them!

6.2.2.3. Tables

Information on significance and other statistical data should preferably be given in the tables and figures. Tables should not contain only statistical test results. Statistical significances should be shown along with the data in the text, as well as in tables and figures.

Tables should bear Arabic numerals. Each table should be put on a separate page. Each table should be self-explanatory, with an adequate title (clearly suggesting the contents), and logical presentation of data. The title should preferably include the main results shown in the table. Use tables in order to present the exact values of the data that cannot be summarized in a few sentences in the text.

Avoid repetitive words in the columns: these should be abbreviated, and their explanations given in the footnotes. Present data either in a table or a figure.

Each column heading for numerical data given should include the unit of measurement applied to all the data under the heading. Choose suitable SI units.

Place explanatory matter in footnotes, not in the heading.

Explain in footnotes all nonstandard abbreviations that are used in each table.

6.2.2.4. Figures

Figures should be numbered in sequence with Arabic numerals. Legends to figures should be listed on a separate page, in consecutive order. Minimum resolution for all types of graphics is 300 dpi and 600 dpi is recommended. The legend of a figure should contain the following information:

a. the word "Figure", followed by its respective number;

b. figure title containing major finding (e.g. Manuscripts which follow Guidelines for Authors had higher acceptance rate, and not Relationship with manuscripts style and their acceptance rate).

Use simple symbols, like closed and open circles, triangles and squares. Different types of connecting lines can be used. The meanings of symbols and lines should be defined in the legend.

Each axis should be labeled with a description of the variable it represents.

Only the first letter of the first word should be capitalized. The labeling should be parallel with the respective axis. All units should be expressed in SI units and parenthesized. Make liberal use of scale markings.

Graphs, charts, titles, and legends in accepted manuscripts will be edited according to ToMS style and standards prior to publication.

Preferred format for graphs or charts is xls. Graphs and charts saved as image (raster) files such as JPG, TIF, or GIF and imported or copied/pasted into Word or Power Point are not acceptable.

The resolution for photographic images should be at least 300 dpi, and minimum image width should be 6 cm. Please submit files in RGB format. For published manuscripts, image files will be posted online in their original RGB format, maintaining the full color of your original files. Note that we will still need to convert all RGB files to CMYK for printing on paper and color shifts may occur in conversion. You will not receive a CMYK proof. You can view an approximation of print results by converting to CMYK in Adobe® Photoshop® or Adobe® Illustrator®.

6.2.2.5. Authorship statement

All contributing authors must fill out and sign these statements and submit them to the Editorial Office. Accepted manuscripts will not be published until signed statements from all authors have been received.

6.2.2.6. Acknowledgments

Technical help, critical reviews of the manuscript and financial or other sponsorship may be acknowledged. Do not acknowledge paid services, e.g. professional translations into English.

6.2.2.7. References

References cited in the manuscript are listed in a separate section immediately following the text. ToMS uses Harvard citation and reference style. The authors should verify all references. Usage of DOIs is mandatory. You can check/find DOI links for specific references on the official CrossRef Metadata Search webpage.

Examples of citation in text:

It is well known fact (Strang and Nquyen, 1997; Antoniou, 2006) that FT is not an appropriate tool for analyzing nonstationary signals since it loses information about time domain.

First group of authors (Vetterli and Gall, 1989) proposed Multiresolution Signal Analysis (MRA) technique or pyramidal algorithm. Second group (Crochiere et al., 1975; Crochiere and Sambur, 1977) proposed subband coding algorithm. Legal acts are cited as in example: The Constitution of the Republic of Croatia (Constitution of the Republic of Croatia, 2010) is the main legal source for this subject matter, as well as any other subject matter relating to the Croatian legal system. References from the Web are cited in the text as (Author(s) last name, year of origin if known (year of accessed in other cases). If the author is unknown, such as in case of company web page, instead of author's name, title of the web page is used.

Examples for reference section:

Journals

Petrinović, R., Wolff, V. S., Mandić, N. and Plančić, B., 2013., International Convention on the Removal of Wrecks, 2007. – a New Contribution to the Safety of Navigation and Marine Environment Protection, Transaction on Maritime Science, 2(1), pp. 49-55., https://doi.org/10.7225/toms.v02.n01.007

Pennec, E. and Mallat, S., 2005., Sparse Geometric Image Representations with Bandelets, IEEE Transactions on Image Processing, 14(4), pp. 423 – 438., https://doi.org/10.1109/TIP.2005.843753

Web links

Donoho, D., Duncan, M. R., Huo, X. and Levi, O., 1999., Wavelab, available at: http://www.stat.stanford.edu /_wavelab/, accessed on: 12 August 2011.

Unknown, Wavelab, available at: http://www.stat.stanford.edu /_wavelab/, accessed on: 12 August 2012.

ToMS home page, available at: http://www.toms.com.hr, accessed on: 12 August 2012.

Books

Mallat, S., 2009., A Wavelet Tour of Signal Processing, 3rd Edition, New York: Academic Press.

Chapter in book

Hymes, D. H., 1972., On Communicative Competence, in: Pride, J. B. and Holmes, J. (eds), Sociolinguistics, Selected Readings, pp. 269-293. (Part 1 if exists), Harmondsworth: Penguin.

Šoda, J., Beroš, S. M., Kuzmanić, I. and Vujović, I., 2013., Discontinuity Detection in the Vibration Signal of Turning Machines, in: Öchnser A. and Altenbach, H. (eds), Experimental and Numerical Investigation of Advanced Materials and Structures, Advanced Structured Materials (serial name if applicable), 41 (volume number if applicable), pp 27-54. (part if applicable), Heidelberg: Springer., https://doi.org/10.1007/978-3-319-00506-5_3

Conference proceedings

Łutowicz, M. and Lus , T., 2013., Effect of Loss of Cylinder Pressure Indicating Channel Patency on Parameters Values Obtained from Indicating Graph, Proc. 5th International Maritime Science Conference, Solin, Croatia, April 22 – 23, pp. 382-389., available at: http://www.pfst.hr/imsc/archive/2013/IMSC2013_proceedings.pdf

Kingsbury, N.G. and Magarey, J.F.A., 1997., Wavelet Transforms in Image Processing. Proc. First European Conference on Signal Analysis and Prediction, Prague, Czech Republic, June 24 – 27, Birkhauser, pp. 23 – 24., available at: http://www.sigproc.eng.cam.ac.uk/~ngk/publications/ngk97b.zip, accessed 12 August 2011.

Regulations, standards or legal acts:

Constitution of the Republic of Croatia, 2010., Narodne novine, 2010(76), pp. (if known).

6.2.2.8. Supplementary materials

Supplementary materials are optional. Authors can submit different types of materials which will be available on-line.

6.2.2.9. Language

Authors may use standard British or American spelling, but they must be consistent. The Editors retain the customary right to style and, if necessary, shorten texts accepted for publication.

This does not mean that we prefer short articles – actually, we do not limit their size - but rather a resection of the obviously redundant material.

The past tense is recommended in the Results Section.

Avoid using Latin terms; if necessary, they should be added in parentheses after the English terms. Real names rather than “levels” or “values” should refer to parameters with concrete units (e.g. concentration).

6.2.2.10. Abbreviations

Only standard abbreviations and symbols may be used without definition and may be used in the title or the page-heading title.

Non-standard abbreviations should not be used in the title or page-heading title. They must be explained in the text in the following way: the term should be written in full when it appears in the text for the first time, followed by the abbreviation in parentheses; from then on, only abbreviation is used in the text. This applies separately to the Abstract and the rest of the text.

6.2.3. Submission of manuscripts

Paper submission via ToMS web page Open Journal System.
www.toms.com.hr