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MODELING OF GENERAL CARGO SHIP'S MAIN ENGINE POWERS WITH REGRESSION BASED MACHINE LEARNING ALGORITHMS: COMPARATIVE RESEARCH

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ABSTRACT
This study, which allows estimating main engine power of new ships based on data from general cargo ships, consists of a series of mathematical relationships. Thanks to these mathematical relationships, it can be predicted main engine power according to length (L), gross tonnage (GT) and age of a general cargo ship. In this study, polynomial regression, K-Nearest Neighbors (KNN) regression and Gradient Boosting Machine (GBM) regression algorithms are used. By this means the relationships presented here, it is aimed to build ships that are environmentally friendly and can be sustained at a lower cost by using the main engine power of the new ships with high accuracy. In addition, the relationships presented here provide validation for computational fluid dynamics (CFDs) and other studies with empirical statements. As a result of the study, polynomial regression gives similar results with other studies in the literature. We also concluded that while KNN regression yields fast results, GBM regression algorithm provides more accurate solutions to estimate the ship's main engine power.

Keywords: *Machine learning, Regression algorithm, General cargo ship, Engine power, Prediction*

1. INTRODUCTION

Seaway is the most efficient transportation method in terms of energy efficiency (Li *et al.* 2020). Therefore, the demand for shipping has increased dramatically since the mid-1990s. Today, 90% of the transportation in the world is made by ships (Kaluza *et al.* 2010). However, this rapid increase in shipping supply has also opened up environmental problems. Although other methods of transportation have been subject to considerable environmental scrutiny, shipping has largely gone unnoticed. As a result of these problems, the International Maritime Organization (IMO) tried to prevent it with the implementation of Annex VI of the International Convention on the Prevention of Pollution from Ships (MARPOL) in 1997. The MARPOL convention sets the limits for the main air pollutants such as nitrogen oxides (NOx), carbon dioxide (CO2), sulfur oxides (SOx), particular matter (PM) in the exhaust gases of ships. The reduction of the amount of these pollutants is directly related to the selection of the main and auxiliary engine of the ships in accordance with the working conditions. In addition to emission, the appropriate selection of the ship main engine power is also beneficial in reducing operating costs. In Stopford's study (Stopford 2008), fuel consumption accounts for about two-thirds of ship's cruising costs and more than 25% of a ship's total operating costs.

Machine learning is a technique that examines the work and systems of algorithms that can predict by performing assumptions using mathematical and statistical methods from the possible inputs. Machine learning, which creates a model by making predictions from sample inputs, is a sub-discipline of artificial intelligence (Gheibi, Weyns, and Quin 2021).

Looking at the research on the application of machine learning on the maritime industry in the literature C. Trozzi (Trozzi 2010) proposed a model based on gross tonnage and ship type to predict the ship main engine power. It also provided a ratio dependent main engine power to estimate auxiliary engine power. Requia *et al.* (Requia, Coull, and Koutrakis 2019) examined and analyzed $PM_{2.5}$ factors with Ordinary King (OK) interpolation, hybrid interpolation and machine learning (forest-based regression) techniques. They determined that the forest based regression model offers the best performance because of the R^2 value is higher than 0.7. Peng *et al.* (Peng *et al.* 2020) examined the energy consumption of ships in Jingtang port of China and denoted their strategies to diminish energy consumption and suggested prediction models. They used Random Forest Regression, the Gradient Boosting Regression, Liner Regression, BP Network and K-Nearest Neighbor Regression machine learning models and analyzed 15 features that have an impact on ships' energy consumption as input. They determined that net tonnage, deadweight tonnage (DWT), actual weight and efficiency of facilities are the four most essential features to foresee the energy consumption of the ships. T. Cepowski (Cepowski 2019) proposed regression models for prediction of main engine power for tankers, bulk carriers and container ships. He concluded that main engine power affected nonlinearly from DWT and TEU (Twenty-foot Equivalent Unit) while the speed effects a linear. Gkerekos *et al.* (Gkerekos, Lazakis, and Theotokatos 2019) performed the ships' fuel oil consumption prediction using with machine learning algorithms Support Vector Machines (SVMs), Random Forest Regressors (RFRs), Extra Trees Regressors (ETRs), Artificial Neural Networks (ANNs), and ensemble methods. They stated that their results may be useful for accurate prediction of ships fuel oil consumption. Also, R^2 of approximately 90% was obtained through the best performing modeling approaches. Yan *et al.* (Yan, Wang, and Du 2020) suggested fuel consumption prediction and fuel reduction model for a dry bulk ship. They set up a fuel consumption prediction model that takes into account the ship sailing speed, cargo weight, sea and weather conditions by using the random forest regressor. They concluded that the requested model could reduce ship fuel consumption by 2-7% and the reduction in fuel consumption will also lead to lower CO_2 emissions. Uyanık *et al.* (Uyanık, Karatuğ, and Arslanoğlu 2020) studied that the fuel consumption optimization of a container ship with the help of multiple regression, ridge and lasso regression, support vector regression, tree-based algorithms and reinforcement algorithms. They compared the prediction models and stated that the predictions made by multiple regression and ridge regression yielded more accurate results. In addition, parameters such as main engine speed, cylinder values, cleaning air and shaft gauges were highly correlated with fuel consumption. Jeon *et al.* (Jeon *et al.* 2018) conducted a regression design using an artificial neural network (ANN) with big data analysis combining data acquisition, clustering, compression, and expansion to estimate host fuel consumption. In order to obtain a regression model with good predictions, they used various activation functions by changing the number of hidden layers and neurons in the ANN, and investigated the applications of regression analysis on efficiency and performance. Ekinci *et al.* (Ekinci *et al.* 2011) predicted the main design criteria in consequence of different machine learning methods in their studies. In the first part of the study, they determined the best / worst prediction criterion among all design parameter estimations.

There are many techniques in the literature that are used to calculate the total resistance or resistance components of ships. CFD (Computational Fluid Dynamics), panel methods, other numerical techniques, model experiments, experimental and statistical approaches are among the leading methods of these methods. In addition to these methods, the machine learning technique is also widely used in the literature to estimate ship main engine power. Some of these studies are summarized above. The most important feature that distinguishes this study from others is that the proposed algorithms offer acceptable results in more than one ship type. Thanks to the developing computer power, energy efficiency on ships is increasing day by day. The use of ship age within the entries will contribute to the preservation of the validity of the results in the future. This situation has been omitted in many studies in the literature. In addition, machine learning methods together with the inputs used make this study privileged

In this study, we use different machine learning-based regression methods in order to estimate the main engine power of the ships. The success of regression methods was determined with three different error methods: Root Mean Squared Error (RMSE), Mean

Absolute Error (MAE) and R-squared (R^2). In the next stage of work, they found which parameter was the most effective in estimating the main engine power and which machine learning method was the most successful. They stated that the best approximate parameter is length (LBP) and the worst is the velocity (V) and the most successful method is Model Trees (M5P).

2. MATERIALS AND METHOD

2.1. Data Set

In this study, data containing information from 2286 different general cargo ships were used. The data of the ships were collected by the authors. The dataset contains gross tonnage, year of manufacture, length, and the main engine power for each ship. While 80% of these data of these ships are used to train the model, 20% of them are used for testing. The gross tonnage of the ships varies between 74 and 162960. The oldest ship was produced in 1925, while the newest ship was built in 2018. The lengths of the ships were kept in a wide range from 18.25 m to 368 m. The main machine power and auxiliary machine power to be estimated vary between 147-72240 kW and 37-9600 kW, respectively. Table 1. provides statistical data on the ships.

Table 1. Statistical data of the data set

	Gross Tonnage	Length	Age	ME Power
Minimum	386	40.00	2	202
1St. Qu.	2811	95.63	11	1324
Median	5087	118.22	20	2880
Mean	11140	131.26	20.05	4226
3rd. Qu	16041	166.49	34	6480
Maximum	194817	333.00	56	36560

2.2. Accuracy control of predictions

The accuracy of the model's predictions is computed by comparing the actual power values of the main engine with the corresponding predicted values. Ten-fold cross-validation was used to as objectively and accurately evaluate the performance of the model. The dataset was randomly divided into ten parts. Nine of the detached parts were used to train the model, and one was used for testing. This process was repeated ten times, with each piece subject to testing. The predictive ability of the model is evaluated as the average performance of the model in all replicates. The Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and R-squared (R^2) were used to determine the performance of the improved regression models.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \tag{1}$$

As shown above, y_i and $\hat{y}_i$ respectively represent the actual power values and estimated power values. It is a quadratic metric that measures the magnitude of the error, often used to find the distance between the predictor's predicted values and the actual values of a machine learning model. RMSE is the standard deviation of prediction errors (residues). That is, residues are a measure of how far away the regression line is from data points. The RMSE value can vary from 0 to ∞, and the fact that its value is zero means that the model does not make any errors.

Average absolute error is an error measurement method used to control the difference between two continuous variables. The MAE controls the average vertical distance between the values predicted by the regression model and the best fit line between the actual values. Since the MAE value can be easily interpreted, it is frequently used in regression and time series problems. The MAE is a linear score reflecting the average magnitude of errors within a range of predictions, and all individual errors are equally weighted regardless of whether they are positive or negative. The MAE value can range from 0 to ∞. Negative focused scores i.e. lower valued estimators perform better. Analytical statement is as follows:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|y_i - \hat{y}_i\right| \tag{2}$$

R-squared measures the rate of variation in your dependent variable (Y) explained by your independent variables (X) for the regression model. Adjusts the adjusted R-squared statistic according to the number of independent variables in the model. The R^2 correlation coefficient is used to evaluate the performance of the models and is given as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{\sum_{i=1}^{n}(y_i - \overline{y}_i)} \tag{3}$$

$\overline{y}_i$ represents the mean value of y_i. It is a measure showing how close each data point is to the regression line with the R-Squared value. It is always positive and between 0 and 1.

2.3. Polynomial Regression

Regression is a method used to understand the relationship between one or more independent variables with a dependent variable. The dependent variable can be expressed with only one parameter, or it is possible to express it with more variables. If expressed in a model based on a single parameter, it is called a single regression, when expressed in two or more parameters, it is called multiple regression. Arguments do not always have to establish a linear relationship with the dependent variable. Some arguments can be expressed exponentially to increase the reliability of the model. Polynomial regression is used in such cases. For multiple exponents of the argument, the polynomial model is constructed as in Eq. (4).

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2{}^2 + \dots + \beta_p x_n{}^p + \varepsilon \quad (4)$$

In the equation, p refers to the polynomial degree of the independent variable, n refers to the number of independent variables.

In this part of the study, the polynomial degrees of the independent variables were investigated by using the data from the entire data set without any test-train distinction. Polynomial levels of the effects of three different independent (Length, Gross Tonnage, Age) variables on machine power were examined between one and five. Mean squares of error of polynomial levels were used to decide on the final model. Figure 1 also shows the mean square error of polynomial degrees. The expressions i, j and k are the polynomial levels of length, gross tonnage and age, respectively.

When figure 1 is examined, 2.nd degree polynomial is suitable for length, 5.th degree for gross tonnage and 2.nd degree for age. Table 2 contains RMSE, R^2, MAE errors about the polynomial model's train and test sets.

Table 2. Error values of the polynomial model.

	RMSE	R^2	MAE
Train	5174.02	0.808	3112.52
Test	5006.43	0.800	2955.65

2.4. K Nearest Neighbors – Regression

K-Nearest Neighbors (KNN) is one of the algorithms used for classification and regression in Supervised Learning. It is considered to be the simplest machine learning algorithm. With KNN, basically, the closest points to the new point are searched. K represents the amount of the closest neighbors of the unknown point. We choose k quantities of the algorithm (usually an odd number) to predict the results. KNN was used as a nonparametric technique in statistical prediction and pattern recognition in the early 1970s.

The KNN algorithm is predicted by the majority vote of its neighbors. The closest neighbors are found with a distance function. Eq. 5, 6 and 7 contains distance functions that are frequently used for regression (Chomboon *et al*. 2015)

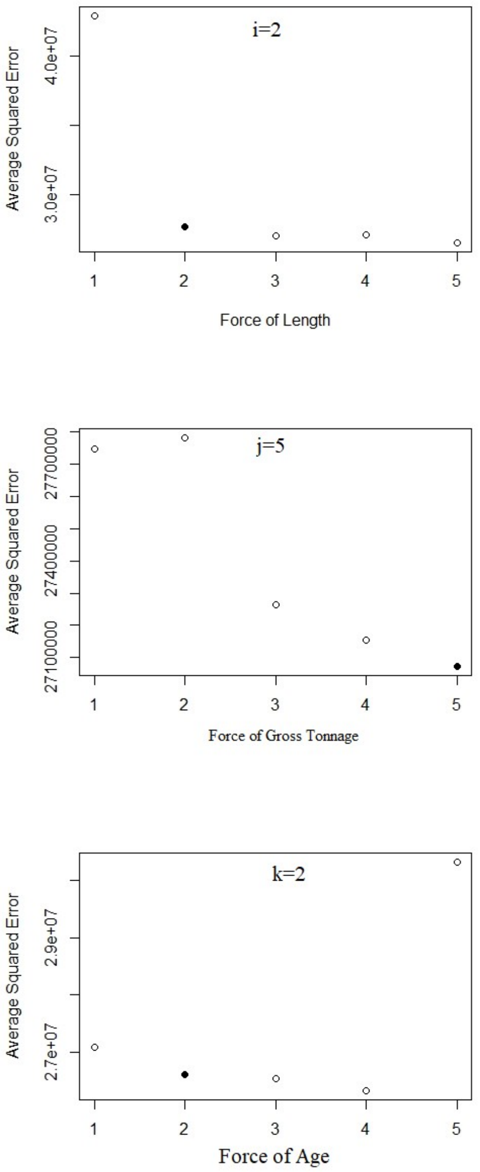

Fig. 1. The forces of independent variables

Euclidean $$\sqrt{\sum_{i=1}^{k}(x_i - y_i)^2} \quad (5)$$

Manhattan $$\sum_{i=1}^{k}|x_i - y_i| \quad (6)$$

Minkowski $$\left(\sum_{i=1}^{k}(|x_i - y_i|)^q\right)^{1/q} \quad (7)$$

The three distance functions expressed in Equations 5, 6 and 7 are distance functions that can only be used in continuous variables. Generally, a large K value is more sensitive as it reduces overall noise, there is no guarantee of time. Cross validation is another way to retrospectively determine a good K value using an independent data set to validate the K value.

In this part of the study, the number of neighbors was determined. Model 2 was designed to be used to estimate ship main engine power. The arguments used to estimate the outputs were not changed. To determine the number of neighbors, the number of neighbors between 1 and 10 were examined and determined according to RMSE values. Figure 2 shows the RMSE values of neighbor numbers.

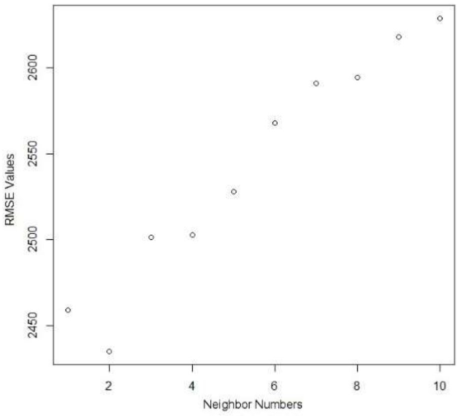

Fig. 2. RMSE values of neighbor numbers.

When Figure 2 is examined, the minimum error value for Model 2 is obtained when the neighbor number is 2. After the suitable neighbors were found, the model was trained with 80% of the data in the version set and tested on 20%. The results obtained were analyzed for both test and train sets with three different error calculation methods.

Table 3. Error values of the KNN model.

	RMSE	R^2	MAE
Train	989.76	0.925	396.36
Test	1536.01	0.839	676.415

2.5. Gradient Boosting Machine (GBM)

Gradient Boosting Machine (GBM) develops the conventional decision tree method by combining a statistical approach called augmentation. The main idea of this technique is to put together a series of "weak" models to create a single "strong" consensus model rather than creating an optimized model. In GBM, new decision trees are created sequentially, minimizing existing residual. Unlike standard regression models, in GBM, new decision trees are created by reducing the residuals at each step. In other words, optimization is made by adding trees in each step to reduce residues.

This method requires the most time as training time. Besides, there is a considerable amount of parameters that need to be determined from the outside. Initially, Model 3 was designed to estimate ship main engine power. Interaction dept, n.trees, shrinkage and n.minobsinnode variables were determined by tuning. Interaction depth 1 through 7 in 2 increments, n.trees between 1000 and 10,000 with 1000 increments, shrinkage value as 0.01 or 0.1 and n. minobsinnode value was searched between 10 and 20. The final values used for the model were n.trees = 3000, interaction.depth = 7, shrinkage = 0.01 and n.minobsinnode = 15. Figure 3 shows the effect of these variables on RMSE.

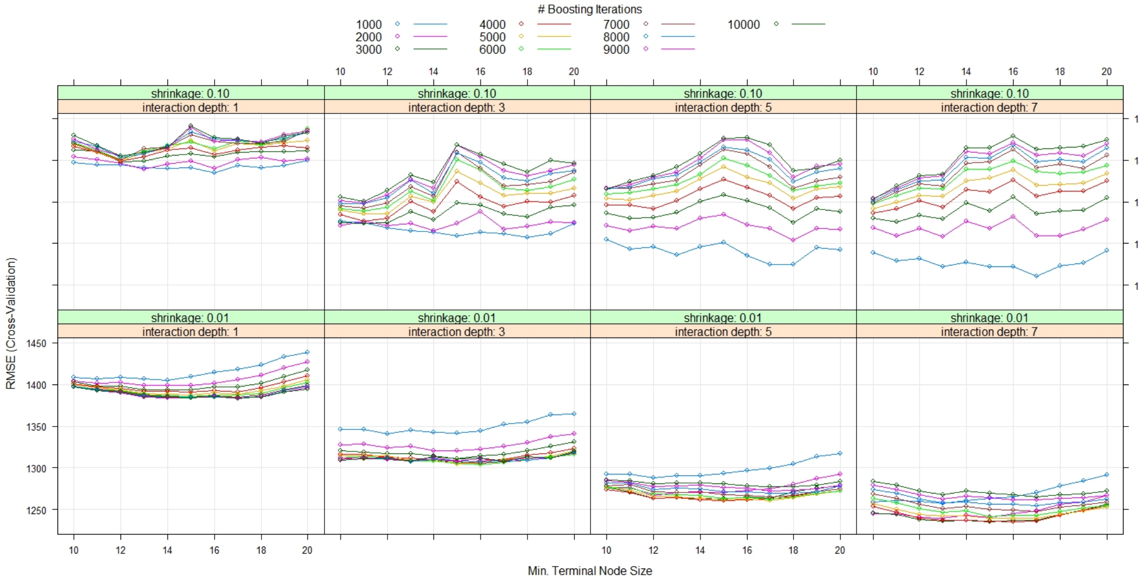

Fig. 3. Effects of variables on RMSE

The error rates for the final models created after the tuning process are listed in Table 4.

Table 4. Error values of the GBM model.

	RMSE	R^2	MAE
Train	408.49	0.987	273.41
Test	415.661	0.991	267.39

3. RESULTS AND DISCUSSION

Based on the length, gross tonnage and age data of 2286 different ships, the main engine power values were estimated in this study. While the gross tonnage values of the ships varied between 386 and 194817, their average was calculated as 11140. The length of the ship with the smallest length in the data set is 40 m, while the average length and maximum length values are 131.26 m and 333 m, respectively. In addition, the newest ship is 2 years old, while the oldest ship is 56 years old as of 2020. As a predictor, three different regression models (Polynomial, KNN and GBM) were studied. Models were trained in 80% of the test set and tested in 20%. The performance of the models was evaluated with ten-fold cross validation and RMSE, MAE and R^2 errors were calculated and interpreted.

In this study, a parametric study has also been done. For polynomial regression, the appropriate polynomial force was chosen for each independent variable. In addition, K value for KNN regression was examined at ten different levels and the optimum K value was determined as number 2. Finally, Interaction dept, n.trees, shrinkage and n.minobsinnode parameters were examined for GBM regression. The final values used for the model were n.trees = 3000, interaction.depth = 7, shrinkage = 0.01 and n.minobsinnode = 15.

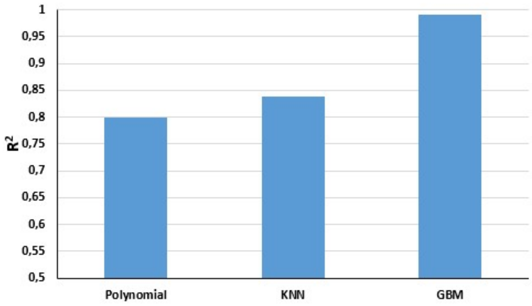

Fig. 4. Coefficients of determination of three models.

Basically, the closer R^2 error value is to one, the higher the success of the model. In Figure 4, the model contains R^2 error values calculated for three different models. As a result of the study, GBM algorithm has made the best approach to estimate main engine power of general cargo ships. The calculated R^2 value for the GBM algorithm is 0.991. However, the GBM algorithm is a method that takes quite a long time because it contains many variables. In addition, polynomial regression, which is a relatively easier method, has yielded results very close to the KNN algorithm and R^2 value is 0.800. Although KNN is quite simple in its application, it is not a suitable method for estimating main engine power of general cargo ships. Although KNN can show better results in small data sets, its success decreases in large data sets. The R^2 value obtained for KNN is 0.839.

Statistically, the mean absolute error (MAE) is a measure of errors between paired observations expressing for the same arguments. If the error value is close to zero, it means the success of the model. In Figure 5, the success of the models is evaluated on the basis of the MAE error value.

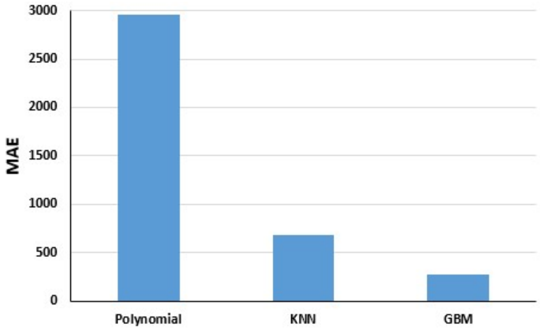

Fig. 5. Mean absolute error values of three models.

The MAE error values calculated for polynomial, KNN and GBM regressions are 2955.65, 676.41 and 267.39, respectively. The success criterion obtained in the R^2 error value did not change in the MAE. While GBM is the most successful algorithm in predicting the main engine power of general cargo ships, the weakest results are obtained by polynomial regression.

Another comparative criterion used in the study is RMSE, and similar to MAE, the success of the model increases as the error values approach zero. In Figure 6, the comparison of RMSE errors of the three models is visualized.

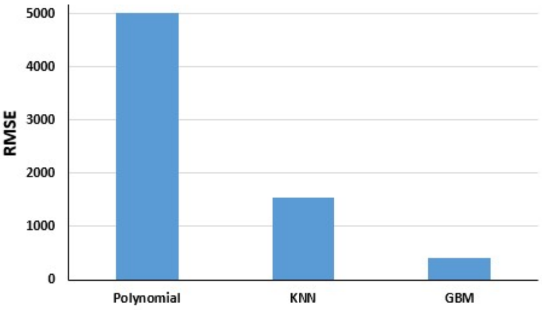

Fig. 6. Root mean squared error values of three models.

The relationship between the estimation data made with three different models and the actual data is given in Figure.7.

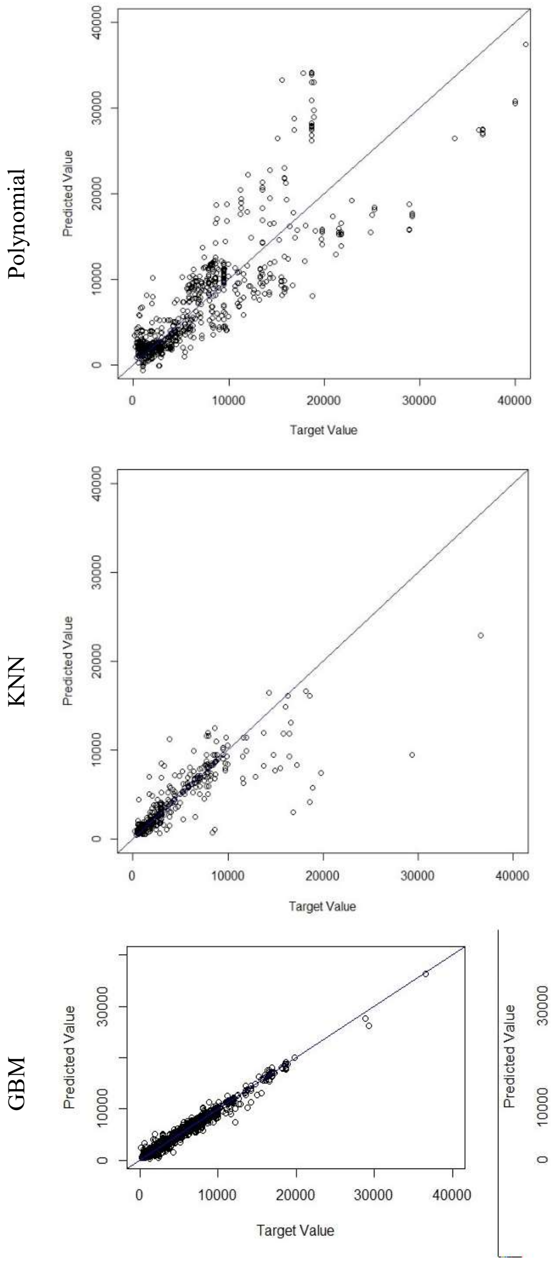

Fig. 7. Difference between target values and forecast values.

When Figure 7 is examined, it is seen that the points move away from the blue line when the predictive power of the models decreases. Also, Figure 7 provides information about the main engine power distribution of the ships in the data set.

Differences between actual values and estimated values are called residuals. The residual analysis method plays an important role in the validation of regression models, and enables the visualization of residuals. The difference between the values calculated with the help of models and the actual values is in Figure 8.

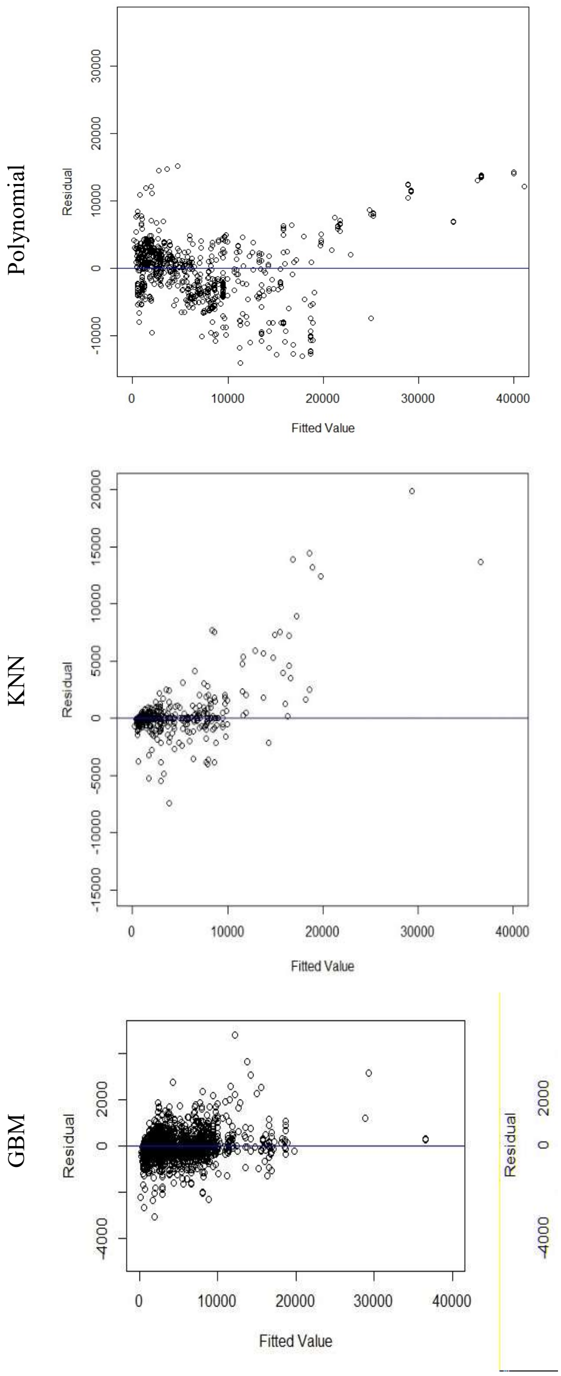

Fig. 8. Residuals.

In Figure 8, it is seen that the residuals increase away from the zero line in polynomial regression where the error rates are high. On the other hand, it is seen that GBM and KNN algorithms are located closer to the zero line thanks to their relatively high precision.

4. CONCLUSION

In this study, regression based algorithms (Polynomial, KNN, GBM) are used to estimate ship main and auxiliary engine powers. For each method, there are data preprocessing, data distribution determination, regression and performance evaluation steps, which are important stages of machine learning.

K-cross validation method was used to compare the performance of the models. Five different polynomial forces were investigated for each independent variable in the polynomial regression model. In addition, analyzes were performed to determine the optimum neighbor number for KNN regression and the optimum neighbor number was determined as number 2. In the study of 2286 general cargo ship samples, GBM was the algorithm that best predicted ship main engine power compared to R^2, RMSE and MAE. Although this method provided good results in the study, the excessive number of parameters to be determined externally and the time consuming nature appeared as the negative side of the method. Polynomial regression was revealed for three different error detection methods that it is not suitable for this data set. KNN regression could not exhibit the expected performance due to the large data set. The GBM regression is the optimum method for estimating the main engine power of general cargo ships, and it has proved highly sensitive.

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Research Article

MOBILE PHONE-BASED PHOTOGRAMMETRY FOR 3D MODELING OF SHIP HULLS

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ABSTRACT
Currently, maritime transportation constitutes the biggest part of world trade. For this reason, ships have a great importance and are effectively used throughout the world. Shipbuilding and ship repair industries frequently utilize engineering processes such as design, manufacture, repair, research and development, quality and control etc. In all the mentioned processes, digital data and CAD drawings of the ships are regularly used by engineers. While all these documents are usually included in the inventory of most ships, there are cases where these documents are lost or unavailable. Reverse engineering studies allow the reconstruction of digital data and CAD drawings of already existing ships. Ships are structures that are difficult to measure due to their sizes, complex geometries and curvature natures. For this reason, measurements are mostly made by advanced technological devices, not by human hands. Photogrammetry and terrestrial laser scanning are two of the most utilized methods contributing to ship surveys. In this study, a mobile phone-based photogrammetric survey method was utilized with the aim of obtaining the digital CAD data of a boat's hull. Data acquisition, post-processing, accuracy analysis, and results are presented in the study.

Keywords: *3D modeling, Photogrammetry, Hull modeling, Reverse engineering*

1. INTRODUCTION

Transport demand has risen sharply in recent decades, at or above the rate of gross domestic product (GDP) growth, and maritime trade has evolved as the most important type of cargo transportation. Maritime transport accounts for nearly 90% of global goods transported today, and it accounts for over 90% of the European Union's external trade and 43% of its domestic trade (Andreoni *et al.* 2008).

The shipping industry is an important part of international trade, as well as a significant factor for citizens and economies all over the world. The industry transports the majority of the world's goods, and thus serves as a cornerstone for global trade and the value generated by it (Holm and Kalinovs 2017).

Shipbuilding and ship repair industries frequently utilize engineering processes such as design, manufacture, repair, research and development, quality and control etc. In all the mentioned processes, digital data and CAD drawings of the ships are regularly used by engineers.

Since it usually refers to a product with geometrically complex freeform shapes, measuring and modeling such a component with traditional measurement methods is very difficult. The use of scanned data in the form of point clouds enables the designer of a seagoing watercraft to produce a detailed CAD 3D model, which can then be used for determining manufacturing quality, CAE system-based redesigning, engineering and simulation tests, and many more (Deja *et al.* 2019).

This digital model could not exist or be destroyed in many cases. As a result, implementing a reverse engineering technique which is capable of recreating a digital hull design is critical, and in some cases, the only wise choice (Athanasios 2021). Sometimes the literature provides no established design lanes for ship hull's variables, so engineers or researchers use reverse engineering techniques in order to obtain these variables, and then create 3D CAD model of ship surfaces (Winyall *et al.* 2012). When no product information exists (anymore) or when such information is considered inaccurate, re-engineering can be needed. Post-production shape validation, shape retrieval for damage repairs, safety evaluation (stability, strength) of ill-documented vessels, and interior refurbishment are examples of typical applications (Koelman 2010).

Traditional manual surveying instruments, mechanical machines, laser scanners, and photogrammeters are the key measurement techniques used in the marine industry for shape data acquisition (Koelman 2010).

Photogrammetry is an age-old technique that has been used in cartography and architecture since the second half of the nineteenth century (Yakar and Yılmaz 2008). Since it is based on the intersection of two or more optical rays, photogrammetry, like theodolites survey techniques, was destined to be used only by specialists with very costly instrumentation (Ackermann *et al.* 2008; Yakar 2009).

Photogrammetry has become an efficient, inexpensive, and simple to use technique as a result of the digital age and modern advances in informatics (both hardware and software) (Yakar *et al.* 2016). As compared to the traditional metric and semi-metric film cameras, digital cameras with high resolution frame sensors are becoming more popular and affordable (Yılmaz *et al.* 2000; Ackermann *et al.* 2008).

In the documentation process, photogrammetry is a stand-alone tool. This method relies on at least two images with overlapping data to ensure that the triangulation process is effective (Unal *et al.* 2004). The aim of digital close-range photogrammetry is to simplify and accelerate the data recording and processing (Yakar and Doğan 2018).

In a study, the researcher had developed reverse engineering algorithms for automated generation of ship hulls from hydrostatic curves and general ship data by using photogrammetry and laser scanning techniques (Athanasios 2020). Another study shows that photogrammetric survey methods make it possible to obtain 3D models of cultural heritages with the aim of documenting them digitally (Yakar and Doğan 2018). With application of photogrammetry-based systems, re-engineering processes such as ship hull shape modeling, hull shape measurements and corrections, damage analyzes and repairing can be carried out efficiently (Koelman 2010). In another study, a housing of the main propulsion propeller shaft for a newly designed vessel had been examined to create 3D CAD model and detect production defects (Deja *et al.* 2019). Another study demonstrates that hull form modeling and screw propeller modeling applications can be completely done by using low-cost and easy-to-apply photogrammetric methods (Ackermann et al. 2008). In addition, photogrammetry can also be utilized for creating 3D CAD datas of a trawler's hull and propeller. After obtaining the digital data, Martelli *et al.* (2015) used them to compare with the production data and to make efficiency evaluation. Another research showed that submarines also can be modeled in 3D by using photogrammetric and terrestrial laser scanning methods (Burdziakowski and Tysiac 2019). Another examination shows that prototypes of a fisherman boat and a catamaran hull vessel were measured by using photogrammetry and laser scanning methods with the aim of determining the accuracy of prototype ship models (Abbas *et al.* 2016). Documentation of maritime heritage is also an appropriate topic to utilize photogrammetric survey. In a study, the 3D modelling of a 3-m-long-scale model of a historic warship, the Indomito, is presented (Menna and Nocerino 2014). Hydrodynamic performance computations can also be made with photogrammetric modeling technique. Martelli *et al.* (2016) showed that overall efficiency assessment of a trawler propulsion system is completed with the aid of photogrammetric survey.

In this study, a mobile phone-based photogrammetric survey method was utilized with the aim of obtaining the digital CAD data of a boat's hull. In addition, lines plan of the boat was created. Finally, basic hydrodynamic calculations were made as a case study. Camera calibration, data acquisition, post-processing, accuracy analysis, and results are presented in the paper.

2. METHOD

2.1. Camera Calibration

A photograph is a central viewpoint that is often associated with a simple device known as a "pinhole camera". Three elements are necessary to fully define perspective in this geometric model: focal distance and the optical axis' intersection point coordinates with the image plane (interior orientation). Nonetheless, due to the nature of a lens that induces optical distortions, such a model is far from the real one (Ackermann *et al*. 2008).

In this study, Samsung Galaxy S10 mobile phone was used to capture images of the boat. The mobile phone has three rear cameras. The main camera of the phone has 12-megapixels with a 5.6x4.2 mm sensor size. Auto-focusing and focusing at infinity settings were applied. The minimum focusing distance of the camera is 0.10 m and the hyperfocal distance of the camera is 3.60 m. The lens of the camera has a focal length of 4.32 mm and (f/1.5) aperture. Focal length (35 mm eq.) is 27.7714 mm. In addition, the lens has a 66.3° horizontal field of view and 52.2° vertical field of view. Magnification factor was 1x for all photos taken.

Camera calibration process was made in Agisoft Metashape Professional software. The chessboard image of the software is utilized to calculate camera calibration parameters. 20 photos of the image were taken. Subsequently, the photos taken were transferred into the Agisoft software. In the final step, camera calibration parameters were calculated by the software automatically.

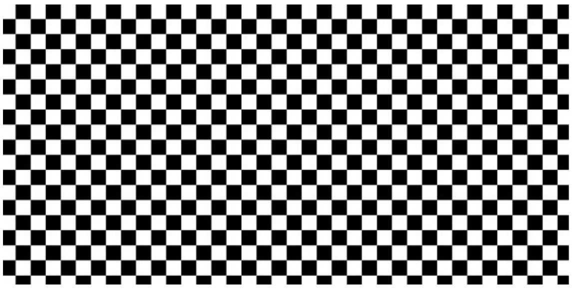

Fig. 1. Chessboard image of Agisoft Metashape Professional software

Table 1. Camera calibration parameters

Focal Length: 4.32 mm/Pixel size: 0.001554 x 0.001554 mm			
f:	2890.202	**cx:**	-43.351
k1:	0.307	**cy:**	11.783
k2:	-1.805	**p1:**	0.0007
k3:	4.087	**p2:**	0.0005
k4:	-3.124	**b1;b2:**	-0.253; -3.33

2.2. Data Acquisition

Fig. 2. Some captured images of the boat

The photogrammetric survey part of the study consists of two phases such as field work and the office work. During the field work, 185 images of the boat were captured by using the mobile phone. A constant focal length during the acquisition and a constant and lighting were utilized as much as possible. Blurry photos, flash light, optical stabilization, digital zoom, and fish-eye lenses were avoided with the aim of producing better results.

Furthermore, 8 measurements were taken on the boat for later verification. Three of these were used in dimensioning, while the rest were used in accuracy analysis. Red double-sided tapes were used to mark the boat.

2.3. Post-processing

After the completion of the field work, the office work phase was initiated. During the office phase of the study, 180 of the images were processed at Bentley's ContextCapture Software.

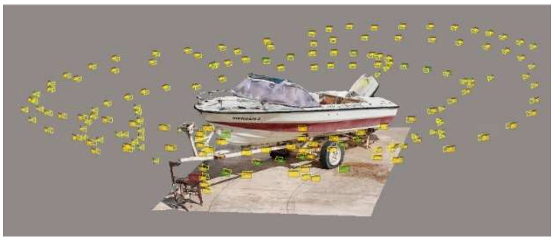

Fig. 3. Camera stations configuration of the boat

In order to use in dimensioning, six attachment points were marked on the model with the aim of defining three previously taken measurements. Six user tie points were marked on the boat to submit an accurate triangulation to the photos. Then, by taking precise measurements on the parts of the boat, predefined positioning and scale constrains were generated with six user tie points that marked before. Generic block type option was selected in order to help the triangulation process. Camera calibration parameters calculated before were imported into aerotriangulation process.

Fig. 4. User tie points and scale constrains – 1

Fig. 5. User tie points and scale constrains – 2

Fig. 6. User tie points and scale constrains – 3

The 3D point cloud data generation phase was started after the aerotriangulation process was completed. Colored point cloud was generated by selecting the options of 1 pixels point sampling, no-compression, and visible colors for color source. The acquired 3D point cloud data was imported into Agisoft Metashape Professional to remove redundant points and create an accurate 3D solid model of the boat.

Fig. 7. Point cloud data obtained by ContextCapture

During the mesh reconstructing process, source data was selected as dense cloud which was imported from ContextCapture. Arbitrary (3D) surface type was selected and high quality face count was applied. Interpolation was enabled and calculate vertex colors option was marked. 66 295 875 points for the boat were processed to obtain the 3D solid model.

Fig. 8. 3D solid model of the boat by ContextCapture

Fig. 9. 3D solid model of the boat by ContextCapture

After the 3D solid model of the boat constructed, accuracy assessment was also implemented. Firstly, a wavefront object (.obj) format of the 3D model was generated to utilize it in ANSYS Aqwa analysis after accuracy assessment step. In order to define the metric performance of the 3D model, 5 distances between selected detail points on the boat were compared with the distances acquired from Bentley's ContextCapture dimensions.

Fig. 10. Detail measurements for accuracy assessment

Before starting ANSYS Aqwa analysis, the 3D model produced was transferred to the Rhinoceros software. In Rhino, surface defects were removed and the surface was smoothed. After the surface treatments were completed, the lines plan for the boat was created by taking sections on the 3D model. As a result of this step, the waterlines, cross sections, buttocks and profile curve belonging to the boat were obtained.

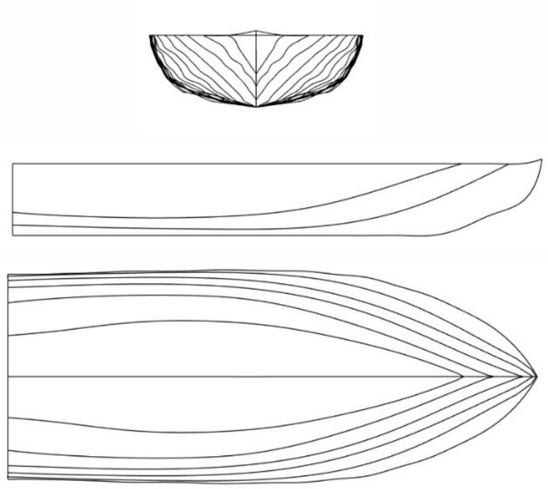

Fig. 11. Lines plan of the boat by Rhinoceros

In the last part of the study, simple hydrodynamic calculations of the boat were made. ANSYS Aqwa software was utilized for analysis. Firstly, the 3D model of the boat has been transferred to the software. Subsequently, boat draft, volume moments of inertia, center of gravity and weight of the boat were defined to the software. These basic hydrostatic values were calculated by using Rhinoceros, and then imported into ANSYS. The next step involved creating mesh and specifying analysis settings. After these were also completed, the analysis was started and the results were examined.

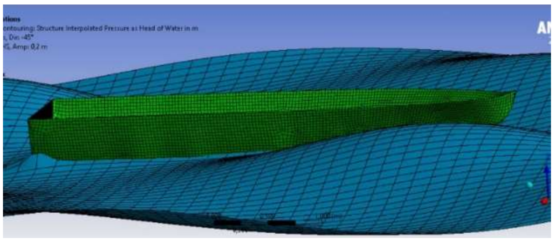

Fig. 12. Free surface and hull mesh image of simulation

3. RESULTS

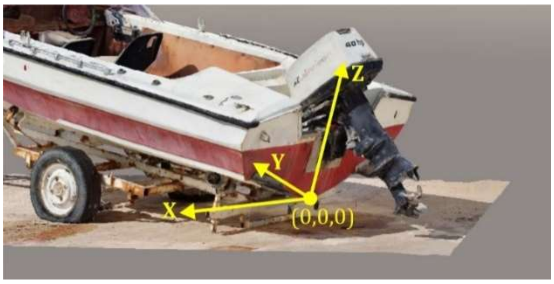

Fig. 13. Coordinate center of the 3D model

All results are presented according to the coordinate system specified in the ''Fig. 13''.

Considering the significance of design verification in the overall reverse engineering phase, few, if any, publications on part-to-CAD reverse engineering discuss modeling accuracy (Ingle 1994). After 3D model of the boat was obtained, the accuracy assessment was also applied. The result of the accuracy analysis was shown in the "Table 2".

Table 2. Accuracy assessment of the 3D model [in cm]

Length	Real	Model	V	VV
1	6.80	6.90	0.10	0.010
2	20.28	19.63	0.65	0.423
3	22.75	22.63	0.12	0.014
4	35.65	36.01	0.36	0.130
5	85.80	86.17	0.37	0.137
			RMSE = 0.378 cm	

According to ''Table 2'', the 3D model of the boat has a root mean square error (RMSE) of 0.378 cm.

Table 3. Hydrostatic stiffness of the boat model

	Z	RX	RY
Heave (Z):	-46227.04 N/m	-127.45 N/°	1.02e-5 N/°
Roll (RX):	-7302.51 N.m/m	-753.53 N.m/°	-2.1e-5 N.m/°
Pitch (RY):	5.85e-4 N.m/m	-2.11e-5 N.m/°	-95.975 N.m/°

''Table 3'' shows the hydrostatic stiffness of the boat model. The values on the table indicates the boat's resistance to doing the movements which are heaving, rolling and pitching. For instance, heave Z value was calculated as 46227.043 N/m, and it means that to force the boat into 1 meter heave motion, this amount of force is required. The similar situation is valid for the rotational motions above.

Table 4. Small angle stability parameters of the boat

BG	0.193 m	
GM_X/GM_Y	5.482 m	0.717 m
BM_X/BM_Y	5.675 m	0.911 m
M_X/M_Y	-733.403 N.m/°	-95.975 N.m/°

''Table 4'' indicates the small angle stability parameters of the boat model. BG was calculated as 0.193 m and it represents the distance between center of gravity (CoG) and center of buoyancy (CoB). GM_X and GM_Y are metacentric heights of the boat. BM_X and BM_Y represents the distance between center of buoyancy (CoB) and metacentre point. M_X and M_Y are the restoring moments of the boat at small angles.

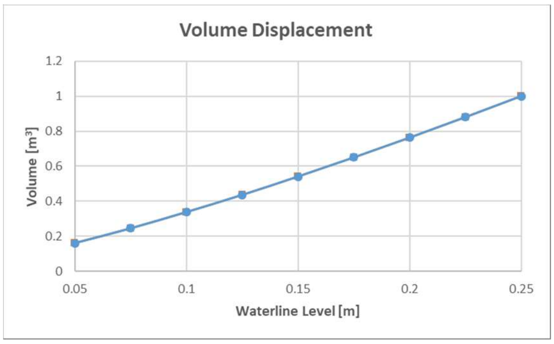

Fig. 14. Volume displacements at different water levels

‘‘Fig. 14’’ shows the displaced volume values in specified units. As the draft increases, the volume values increase as shown in the figure. This stems from the upwardly expanding geometry of the boat.

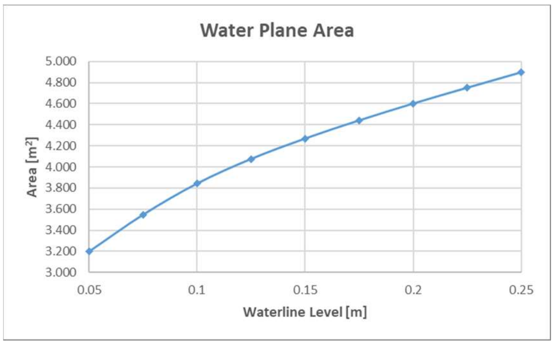

Fig. 15. Water plane areas at different water levels

‘‘Fig. 15’’ indicates the water plane areas of the boat at different waterline levels. As shown in the figure, the increase in waterline level leads to an increase in water plane areas. At small waterline levels the increase in area values is faster, while at the next values the increase is slower. This is again due to the geometry of the boat.

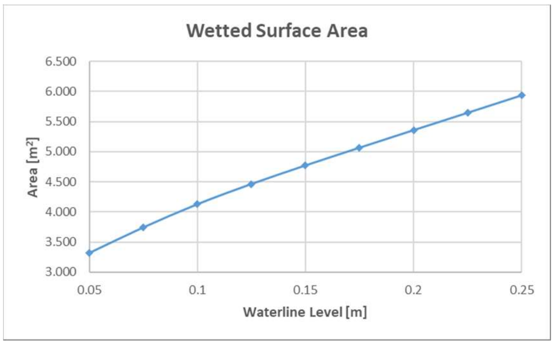

Fig. 16. Wetted surface areas at different water levels

‘‘Fig. 16’’ demonstrates the wetted surface area values of the boat at different water levels. As the waterline level increases, the wetted surface area also increases due to the fact that the boat will sink further into the water.

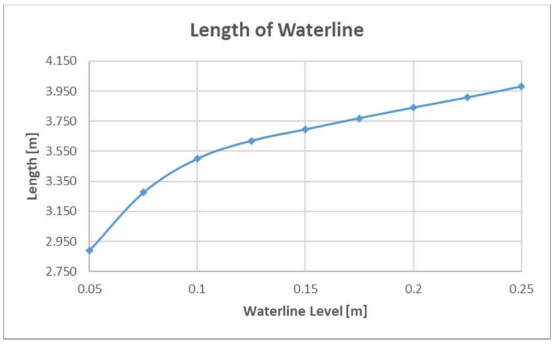

Fig. 17. Waterline lengths at different water levels

‘‘Fig. 17’’ displays the waterline lengths of the boat at different waterline levels. As shown in the figure, the increase in the waterline level gives rise to an increase in the waterline lengths.

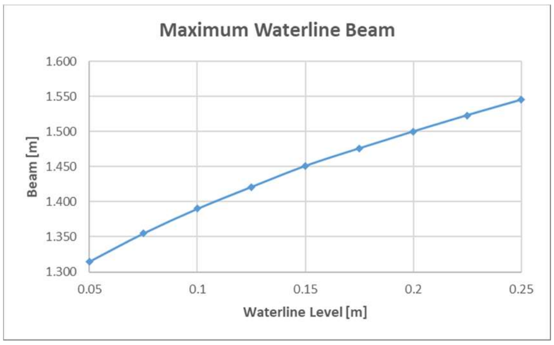

Fig. 18. Max. waterline beams at different water levels

Maximum waterline beam values of the boat at different waterline levels are shown in ‘‘Fig. 18’’. As shown in the figure, the boat's enlargement in the transverse direction is not as rapid as in the longitudinal direction.

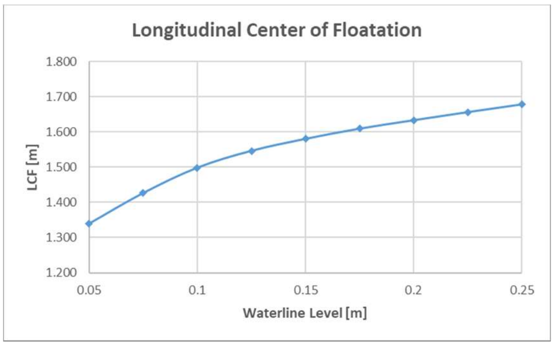

Fig. 19. Longitudinal centers of floatation at different water levels

Longitudinal center of floatation values of the boat at different waterline levels are presented in ‘‘Fig. 19’’. Because of the fact that the aft peak of the boat represents the coordinate center, the values above show the distance from the stern of the boat to the longitudinal center of floatation.

Table 5. Center of buoyancy coordinates at different waterline levels [in meters]

Waterline	X	Y	Z
0.050	0	1.259	0.0215
0.075	0	1.302	0.0357
0.100	0	1.346	0.0499
0.125	0	1.386	0.0641
0.150	0	1.421	0.0782
0.175	0	1.450	0.0923
0.200	0	1.475	0.1065
0.225	0	1.497	0.1205
0.250	0	1.518	0.1346

‘‘Table 5’’ indicates the center of buoyancy coordinates at different waterline levels. All coordinate values are presented according to the coordinate system specified in the ‘‘Fig. 13’’.

4. DISCUSSION

This study shows that 3D models of ships can be obtained with high accuracy by using mobile phone-based photogrammetric survey method which is an easy-to-use, low-priced, and efficient method. Although all processes were done in high quality in the software, the results are satisfactory. Higher accuracy could have been achieved if it was made in ultra-quality.

The results obtained correspond to the aim of the study. Although there are no technical drawings, measurements and details of the boat in the inventory, it is seen that all these can be obtained by using this method.

The results obtained have been added to the boat inventory and can be used in activities such as repair, maintenance, modification and restoration in the future.

The 3D model and drawings reconstructed in the study were acquired by processing the images of the boat. Since the surface is slightly indented in the first data processed, the smoothing process was carried out. If the processes were done with a higher quality, such a step would not be necessary and the surface lines would be modeled exactly.

In future studies, the results can be improved with a hybrid method by using a terrestrial laser scanner in measurements.

5. CONCLUSION

There are various reasons for utilizing reverse engineering. One of the essential purpose of selecting RE as an engineering calculation method is the deficiency of 3D CAD models of the existing parts. As a result of conducting this research, it is clear to be seen that accurate 3D CAD models of existing ships and their engineering calculations can be created/made by using mobile photogrammetric surveys and common engineering softwares.

The aim of this study was to obtain the digital CAD data of a boat's hull using a mobile phone-based photogrammetric survey method. In addition, the boat's lines plan was generated. Finally, as a case study, simple hydrodynamic calculations of the boat were performed.

The findings of this study indicate that mobile photogrammetric methods can provide ships with quick, precise, and accurate 3D documentation. Analysis of the 3D model’s accuracy reported that less than 0.5 cm accuracy can be achieved without difficulty.

This study also presents that many engineering calculations can be made by using 3D models of the ships.

All things considered, for reverse engineering calculations, mobile phone-based photogrammetric survey is an effective, easy-to-use and accurate method.

In future researches, the findings could be developed and expanded by using a hybrid approach that includes measurements with a terrestrial laser scanner.

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Research Article

STATISTICAL ANALYSIS OF MARINE ACCIDENTS IN THE STRAIT OF İSTANBUL USING CHI-SQUARE TEST

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ABSTRACT
The Turkish Straits which comprise the Strait of İstanbul, the Strait of Çanakkale and the Sea of Marmara connect the Aegean and Mediterranean Seas and the Black Sea. The Straits are one of the most hazardous and crowded waterways in the world. The Straits are important from the point of international politics and commerce. The aim of the study is to analyse the accidents that occurred in the Strait of İstanbul from the implementation of the Maritime Traffic Regulations for the Turkish Straits and the Marmara Region in 1994 until 2019 using frequency distribution, Chi Square) and Cramer's V Tests. The main findings of the study have given as follows; the cargo ships were the most involved in the accident; accidents are mostly collision and respectively grounding; the most accident has been occurred in the hours 20:00-24:00, main reason of accidents is human error and a total of 71.5% of the ships involved in the accident have not taken a pilot in the Strait of İstanbul. There is a statistically significant relationship between accident type and accident year; between accident type and the ship types involved in the accident and between accident type and whether the ship involved in the accident had a pilot; relationship between ship type involved in the accident and whether to take a pilot or not. At the conclusion of the study suggestions are proposed to provide safety of environment and navigation in the Strait of İstanbul.

Keywords: *The Strait of İstanbul, Marine accidents, Accident analysis, Collision, Maritime pilot.*

1. INTRODUCTION

The Turkish Straits which comprise the Strait of İstanbul, the Strait of İstanbul and the Sea of Marmara connect the Aegean and and the Black Sea. The Straits are one of the most hazardous and crowded waterways in the world. The Straits have a geopolitic and strategic importance from the points of international politics and commerce. The geographical conditions and navigational constraints of the Strait of İstanbu which is 117 Nautical Miles long, such as currents, several sharp turns, wheather conditions and narrowness cause the accidents in the Straits (Yurtören, 2004 (Akten, 2003). Sharp turns force ships to change course at least 12 times, sometimes turning up to 80 degrees is required (Korçak and Balas, 2020). Nearly, 8.700 tankers annually transit in the Strait of İstanbul carrying a total of 138 million tons of oil and other dangereous cargo (Altan and Otay, 2017; Aslan and Otay, 2021). In 2020, 38.404 ships passed through the Strait of İstanbul, 8,435 of which were tankers and the rate of maritime pilot employed was 65% (UAB, 2021). Nearly 150 ships pass through the Strait of İstanbul every day, of which 27-28 ships carry dangerous goods (Bucak, 2021).

There have been many accidents in the the Strait of İstanbul in the past. Some of these were Independenta-1979 and the Nassia-1994 causing human loss and environment pollution. The legal regime of the Turkish Straits arranged the Montreux Convention in 1936 within the tframework the principle of freedom of passage and navigation with certain formalities for merchant vessels. "Maritime Traffic Regulations for the Turkish Straits and the Marmara Region" entered into force on 1 July 1994. (İnan, 2001). The regulations was revised in 1998 (İnan 2001). "Maritime Traffic Regulations for The Turkish Straits" entered into force on 06.11.1998 to regulate the maritime traffic scheme were adapted in 1998. The regulations shall apply to all vessels entering or navigating within the limits of Turkish Straits. The purpose of Vessel traffic regulations is to ensure safety of navigation, safety of life, property and marine environment by improving the safety of vessel traffic in the Straits. Turkey implemented the traffic separation schemes in the Turkish Straits on 01 July 1994.

The purpose of these Regulations, which shall apply to all ships navigating in the Straits and the Sea of Marmara, is to regulate the maritime traffic scheme in order to ensure the safety of navigation, life and property and to protect the environment in the region. The Vessel Traffic Management and Information System was installed and began to serve as operational on 30 December 2003 (Akten, 2003). Vessel traffic services (VTS) are shore-side systems which range from the provision of simple information messages to ships, such as position of other traffic, meterological hazard warnings, hydrological outlook, to extensive management of traffic within a port or waterway (IMO, 2021).

There were a total of 38.404 ships passed through the Strait of İstanbul, 8,435 of which were tankers in 2021 navigating the Strait of İstanbul (UBAK, 2021). Pilotage service within Turkish Straits is compulsory for vessels carrying nuclear cargo/waste and hazardous and/or noxious goods or waste (IMDG Code-7), for nuclear powered vessels and LPG tankers with length overall (L.O.A.) of 150 meters and above which passes through the Turkish Straits, for contracted and scheduled LNG tankers passing through Canakkale Strait and, foreign flagged vessels calling at or leaving any Marmara port.

The Pilotage Services in the Turkish Straits are carried out by the Directorate General of Coastal Safety in accordance with the principles of TSMTR and operational instructions of TSMTR (KEGM, 2021).

In the study maritime traffic of the Strait of İstanbul was examined and literature review was conducted.The accidents that occurred in the Strait of İstanbul were analysed. from the implementation of the Maritime Traffic Regulations for the Turkish Straits and the Marmara Region in 1994 until 2019 using frequency distribution, Chi Square) and Cramer's V Tests.

2. LITERATURE REVIEW

Uğurlu and e*t al.* (2016) analyzed the marine accidents occurred in the Turkish Straits between the years of 2001 and 2010. The study indicates that employed a pilot on board is the most important measure to decrease the accidents. (Köse *et al.* (2003) developed model to investigate the traffic in the Strait of Istanbul. According to the result of the simulation, waiting time in the Strait would increase the probability of accident in the Straits.

Otay and Tan (1998) determined the probability of ship accidents by developing a stochastic model of tanker traffic. The results of the study are that the most accidents are collision and grounding. The ships proceeding without a pilot are major factor of the reason of accident in the Strait of İstanbul (Akten, 2006). Akten (2006) indicates that the ship accidents occurred in The Strait of İstanbul are the majority being collisions during the period 1953–2002. Koldemir (2009) defined the risk zones to define the accident black points. One of the results of the study is that employment of the pilotage by ships should be encouraged to reduce the accident risk.

Başar and Köse (2006) performed a simulation study for the accidents in the Strait of İstanbul. According to one of the results of the study, further increase of maritime traffic causes waiting times and accidents in the Strait. Ece analyses (2012) the marine accidents occured in The Strait of İstanbul during right-side up scheme period 1982-2010. According the one of the findings of the study the most accident is collision in the Strait.

Bayar et.al. (2008) analyzed the accidents in the Strait of İstanbul in different periods. The findings of the study are that the most accident type occurred in the Strait of İstanbul was collision, the general cargo ships were mostly involved in the accident and the accidents occurred in the Strait decreased after the installation of the VTS System.

Erol *et al.* (2017) analysed the accidents that occured in the Strait of İstanbul by using neuro-fuzzy method. The findings of the study showed that pilotage and the local traffic density are the most reasons which causes the accidents two main factors in the Strait. Altan and Otay (2017) developed a model concerning the collision probability in the waterways. The results of the study show that the collision probability increases in the narrow waterways. Uçan and Nas (2015) analysed the pilotage services in the Strait of Istanbul and indicated that employed pilots is an effective way for navigational safety in the Strait of İstanbul

Görçün and Burak (2015) analysed the accidents in the Strait of İstanbul using Formal Safety Assessment methodology. One of the results of the study, collision is the most common accident in the Strait . Ulusçu *et al.* (2009) performed) risk analysis for trtansit ship maritime traffic in the Strait of İstanbul.The result sof the study is that pilotage and local traffic density are reasons which cause the accident and taking a pilot are extremely important for navigational safety in the Strait to decrease the risks in the Strait.

Uluscu *et.all* (2015) analysed the accidents in the Turkish Straits using various methods, According to the results of the study collision, grounding and contact were the most significant accident types and human error is the most influential factor in the causes of accidents.

Korçak and Balas (2020) created a simulation model to define the probability of collision between the ships in the passage and the domestic ferries in the Strait of İstanbul in 2000-2019. Some of the findings of the study is that there is a significant collision probability between the ships in the passage and the domestic ferries. The collision and contact accidents have by %54 on the accident types in İstanbul Strait (Korçak and Balas, 2020).

Özdemir and Günerioğlu quantitatively evaluated based on expert knowledge and multiple criteria decision-making methodology to investigate the human factor in marittime accidents. The results of this study show that the most important reasons concerning people factor are “ability, skills, knowledge” (8.94%), and “physical conditions” (8.77%). The study indicates that there should be a focus on the types of human errors causing risks onboard a ship and try to enhance the technological infrastructure of merchant ships to reduce marine accident (Özdemir, Güneroğlu, 2015).

3. THE PASSAGE REGIME AND MARITIME TRAFFIC IN THE STRAIT OF İSTANBUL

The legal regime of the Turkish Straits was regulated by the Montreux Convention signed in 20 July 1936. The passage regime through the Turkish Straits is not a transit passage. The transit passage through the Turkish Straits is a sui generis innocent passage since the Montreux Convention (İnan, 2001). According to the The Montreux Convention merchant ships have freedom of passage. They must be subjected with certain formalities. However pilotage and towage remain optional (BASKENT-SAM, 2021; Ece, 2012). Maritime Traffic Regulations for the Turkish Straits and the Marmara Region which apply to all vessels passing in the Turkish Straits entered into force on 01.07.1994 and were implemented to enhance navigation safety, life and property and protection of the environment. The regulations was revised in 1998. (İnan 2001). “Maritime Traffic Regulations For The Turkish Straits” entered into force on 06.11.1998 to regulate the maritime traffic scheme were adapted in 1998.

The purpose of Vessel traffic regulations to ensure safety of navigation, safety of life, property and marine environment by improving the safety of vessel traffic in the Straits. These regulations shall apply to all vessels entering or navigating within the limits of Turkish Straits (Article 1).

Owners, Masters or Agents of the vessels with dangerous cargo or the vessels of 500 GRT and upwards, shall submit "Sailing Plan 1" in writing to the nearest Traffic Control Centers in IMO standard format at least 24 hours prior to entry into the Turkish Straits. After sending SP 1 and assuring himself that the vessel is in compliance with the requirements of Reg. 5, two hours or 20 miles (whichever earlier) before the entrance of the Turkish Straits, the Master shall submit Sailing Plan 2 in IMO standard format as defined by the Administration(Article 6).

All vessels with L.O.A of 20 meters and upwards, shall make a voice radio position report by VHF in IMO standard format to the nearest Traffic Control Station 5 miles before the entrance of the Straits (Article 6).

All vessels with a L.O.A. of 20 meters and upwards while proceeding within the Straits shall make a voice radio call point report by VHF in IMO standard format at the positions defined by Administration to the nearest Traffic Control Station. All vessels must be seaworthy according to the flag state and international legislation and regulations (Article 6).

The System of Turkish Strait Vessel Traffic Services began to serve as operational in accordance with the Turkish Straits Maritime Traffic Regulations on 30 December 2003 to enhance the safety of maritime traffic and environment (KEGM, 2021).

As shown in Table 1, 38.404 ships passed through the Strait of İstanbul, 8,435 of which were tankers and the rate of maritime pilot employed was 65% in 2020 (UAB, 2021). The ships which are greater than 200 m. have taken a pilot at the rate of 100% (Tenker, 2021).

4. METHODOLOGY

The object of the study is to analyse marine accidens occured in the Strait of İstanbul after implementation of “Maritime Traffic Regulations for the Turkish Straits” in 1994-2019. The accident data for the Strait of İstanbul obtained from the Ministry of Transport and Infrastructure of The Republic of Turkey Main Search-Rescue Coordination Cenre and other resources (http://aakkm.udhb.gov.tr, 2016; www.turkishpilots.org, 2004); TurkSail, 2019; Habertürk, 2019 and Independent Türkçe, 2019). ; Turkish Pilots). In the study quantative methods such as frequency distribution, Chi Square Test and Cramer’s V Test have been used to test the null hypothesis (H0) and to determine the statistically significant relationship between the nonparametric data using Statistical Package Programme (SPSS 17). The accidents occured in the Strait of İstanbul data base contains 526 of accidents records including the ship name, year, month and hour of the accident, type and reason of accident, ship type and the ships with/without a pilot involved in the accident.

Table 1. Marine traffic in the Strait of İstanbul

Years	Ship traffic	Tanker traffic	The ships employed a pilot (%)
1994	18,720	-	-
1995	46,954	4,320	38
1996	49,952	4,248	41
1997	50,942	4,303	39
1998	49,304	5,142	38
1999	47,906	4,452	38
2000	48,079	6,093	40
2001	42,637	6,516	41
2002	47,283	7,427	42
2003	54,880	8,107	45
2004	56,606	9,016	41
2005	54,396	8,813	45
2006	54,880	10,153	48
2007	56,606	10,054	47
2008	54,396	9,303	50
2009	51,422	9,299	49
2010	50,871	9,184	51
2011	49,798	9,099	48
2012	48,329	9,028	47
2013	46,532	9,006	50
2014	45,529	8,745	49
2015	43,544	8,633	51
2016	42,553	8,703	52
2017	42,978	8,832	51
2018	41,103	8,587	57
2019	41,112	8,957	65
2020	38.404	8,435	65

Source: UBAK, 2018; UBAK, 2021.

4.1. Frequecy Distribution

Frequency Distribution for quantative data were used to provide informative and summarized data sets. The frequency distributions of the marine accidents by year, month and hours of accident, accident type, ship types and the ships with/without a pilot involved in the accident and reason of accident in the Strait of İstanbul in 1994-2019 have been given in the following tables.

4.1.1. Frequency of ship accidents by years

As shown in Table 2 total of 27.6% of the accidents were occured in the Strait after Maritime Traffic Regulations for the Turkish Straits and the Marmara Region implemented in 1994-1998, 23.0% of the accidents were occurred during the period in Maritıme Traffic Regulatıons for The Turkısh Straits implemented in 1998-2003, 49.4% of the accidents were occurred after The System of Turkish Strait Vessel Traffic Services (TSVTS) implemented on 30 December 2003.

Table 2. Frequency of ship accidents by years

Accident year	Freq.	Percent (%)	Total Cumulative (%)
1994 - 1998	145	27.6	27.6
1999 - 2003	121	23.0	50.6
2004 - 2019	260	49.4	100.0
Total	526	100.0	

4.1.2. Frequency of the marine accidents by accident type

A Total of 45.6% of the accidents occured in Strait of İstanbul were collision and respectively grounding (17.5%), contact (9.5%), fire/ explosion (6.3%), breakdown (5.1%), stranding (3.8%), foundering/capsizing (3.4%) and others (contact fishing nets, local traffic density etc.) (7.2%) as given in Figure 1. In the period 2000-2019, the collision and contact accidents in the Strait of İstanbul 54% (Korçak and Balas, 2020). The ratio of collision and contact accidents occurred in the Strait in 1994-2019 are %55.1.

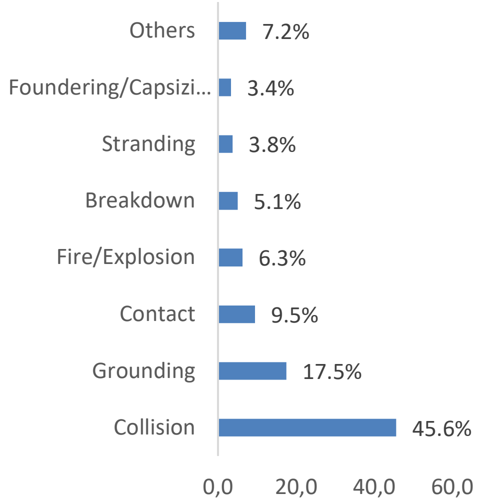

Figure 1. Frequency distribution of the marine accidents by the accident type (1994-2019)

Collision is the most accident type occurred in the Strait of İstanbul. The main reason of collision was human error.

4.1.3. Frequency of ship accidents by reasons

Frequency of the reason of ship accidents occurred in the Straitof İstanbul in 1994-2019 is given in Table 3.

Table 3. Frequency of ship accidents by reasons

Reason of Accident	Freq.	Percent (%)	Cumulative Percent (%)
Unknown	177	33.7	33.7
Human error	157	29.8	63.5
Traffic density	8	1.5	65.0
Bad whether condition/current	53	10.1	75.1
Fire	5	1.0	76.0
Contact fishing nets	34	6.5	82.5
Breakdown	68	12.9	95.4
Others	24	4.6	100.0
Total	526	100.0	

The main reason of accidents is human error (29.8%) and respectively breakdown (12.9%), bad wheather conditions and current (10.1%), contact fishing nets (6.5%) and traffic density (1.5%) in 1994-2019 as given in Table 3.

4.1.4. *Frequency of the ship types involved in the accident*

The cargo ships were mostly involved in the accident (49.8%) and respectively marine vehicles (20%), passenger ships and boats (18.8%) and tankers (9.3%) in 1994-2019 as shown in Figure 2.

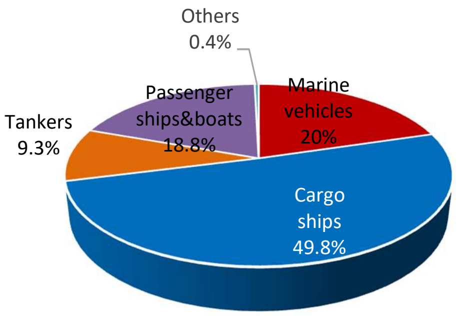

Figure.2. The frequency of the ship types involved in the accident in the Strait of İstanbul in 1994-2019.

4.1.5. *Frequency of marine accidents by accident hours*

The most accident were occured in the hours 20:00-24:00 (19.4%) and respectively 08:00-12:00 (15.8%), 12:00-16:00 (15.6%), 16:00-20:00 ((15.6%), 24:00-04:00 (15.4%), and 04:00-08:00 (12.4%) in the Strait of İstanbul in 1994-2019 as shown in Figure 3.

4.1.6. *Frequency of ships with/without a pilot involved in the accident*

A total of 71.5% of the ships involved in the accident have not employed a pilot. The ratio of ships without a pilot involved in the accident was 28.55% in the Strait of İstanbul as given in Table 4.

The pilotage is a profession which is required special experience and knowledge performed onboard ships in straits, channels, bays, harbors and other narrow. The engagement of a pilot is very important for navigation safety and reducing human error.

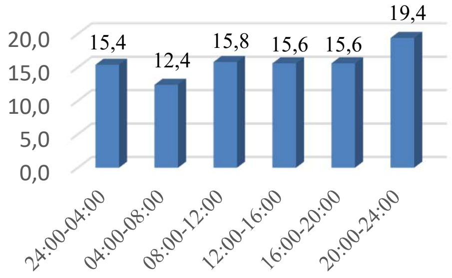

Figure 3. The frequency of marine accidents by accident hours in the Strait of İstanbul in 1994-2019.

Table 4. Frequency of ships with/without a pilot involved in the accident

The ships with/ without a pilot	Freq	Percent (%)	Cumulative Percent. (%)
The ships without a pilot	407	71.5	71.5
The ships with a pilot	162	28.5	100.0
Total	569	100.0	

4.2. The Chi Square (X^2) and Cramer's V Tests

In the study, Chi Square (χ^2) Test and Cramer's V Test were used to define a statistically significant relationship between observed and expected frequencies after implementation of "Maritime Traffic Regulations for the Turkish Straits" in 1994-2019. The Chi Square Test can be safely used when all individual expected counts are 1 or greater and no more than 20% of the expected counts are less than 5 and (Yates, *et all*, 1999). The Chi square (χ^2) Test formula is given as follows:

$$\chi^2 = \sum_{i=1}^{k} \frac{(Observedvalue - Expectedvalue)^2}{Expectedvalue} \qquad (1)$$

Cramer's V Test which dispreads between 0 and 1 determines the relationship between nominal variables for strength test for the Chi-square (www.harding.edu). The formula for the Cramer's Vtest statistic is given as Equation (2) (McHugh, 2013).

4.2.1. *Chi Square Test between accident type and accident year*

The most of the accidents were collision in the period 1994-1998 (38.9%), in 1998-2003 (36.7%) and in 2004-2019 (71.7%) and respectively stranding/contact (25.2%) in 1994-1998, grounding (26.5%) in 1998-2003 and stranding/contact (13.1%) in 2004-2019 as given in Table 5.

Table 5. The crosstabulation between the accident type and accident year

Accident type/ Accident year	Count % within accident type	1994-1998	1999-2003	2004-2019	Total
Unknown	Count	5	2	0	8
	% within accident year	1.9%	4.1%	0.0%	1.5%
Collision	Count	102	18	71	240
	% within accident year	38.9%	36.7%	71.7%	45.6%
Grounding	Count	62	13	8	92
	% within accident year	23.7%	26.5%	8.1%	17.5%
Breakdown	Count	14	3	3	38
	% within accident year	5.3%	6.1%	3.0%	7.2%
Stranding/	Count	66	10	13	121
	% within accident year	25.2%	20.4%	13.1%	23.0%
Others	Count	13	3	4	27
	% within accident year	5.0%	6.1%	4.0%	5.1%
Total	Count	262	49	99	526
	% within accident year	100.0%	100.0%	100.0%	100.0%

Null hypotesis (H_0): There is not a statistically significant relationship between accident type and accident year and Alternatif hypotesis (H_1): There is a statistically significant relationship between accident type and accident year. The Pearson Chi Square value (χ^2) is 42.548 and minimum expected count (min. exp. count) is 1.84 and 16.7% of exp. counts are less than 5 as given in Table 6. Thus, Chi Square Test can be used to test correlated data.

Table 6. Chi-Square Test between accident type and accident year

	Value	df	Asymp. Sig. (2-sided)
χ^2	42.548[a]	10	0.000
Likelihood Ratio (LR)	44.675	10	0.000
Linear-by-Linear Relationship (LLA)	15.010	1	0.000
Cramer's V (Approx. Sig.)	0.201		0.000
Number of Valid Cases	526		

a 3 cells (16.7%) have exp. count less than 5. The min. exp. count is 1.84.

Likelihood Ratio (LR) Test is an alternative procedure to test the hypothesis of no relationship of columns and rows in nominal-level tabular data (Bal, et all, 2009). χ^2= 42.548, LR value is 44.675. P value (0.0000 < α= 0.0005.

Thus, the null hypothesis (H_0) is rejected, alternatif hypothesis (H_1) is accepted. It is concluded that there is a statistically significant relationship between accident type and accident year. Cramer's V value (20.1%) confirms that there is a moderate relationship between accident type and accident year.

4.2.2. Chi Square Test between accident type and ship type involved in the accident

The cargo ships were those most involved in collision (38.9%) and respectively stranding/contact (32.1%) and grounding (23.7%). Tanker&liquid hips were also those most involved in collision (36.7%) and respectively stranding/contact (28.6%) and grounding (26.5%). Passenger shişps&boats were those most involved in collision (71.7)% and respectively stranding/contact (20.2%) and grounding (8.1%) as shown in Table 7.

H_0: There is not a statistically significant relationship between accident type and the ship types involved in the accident, H_1 There is a statistically significant relationship between accident type and the ship type involved in the accident.

χ^2= 80.829 and min. exp. count is not more than 1 (0.33) and 36.7% of exp. counts are less than 5 as shown in Table 8. Thus, Chi Square Test can not be used to test correlated data.

4.2.3. Chi Square Test between accident type and reason of accident

All types of accidents are mostly caused by human error in The Strait of İstanbul in 1994-2019. The main reason of the collision is human error (54.7%) and respevctively most of the stranding/contact due to human error (22.6%), most of the grounding due to human error (17.6%) as given in Table 9.

H_0: There is not a statistical relationship between accident type and the reason of accident, H_1: There is a statistical relationship between accident type and reason of accident.

Table 7. The Crosstabulation between accident type and ship type involved in the accident

Accident type/ Ship type	Count % within ship type	Unknown	Cargo ships	Tanker&liquid bulk ships	Passenger ships&boats	Others	Total
Unknown	Count	0	5	2	0	1	8
	% within ship type	0.0%	1.9%	4.1%	0.0%	1.1%	1.5%
Collision	Count	12	102	18	71	37	240
	% within ship type	54.5%	38.9%	36.7%	71.7%	39.4%	45.6%
Grounding	Count	1	62	13	8	8	92
	% within ship type	4.5%	23.7%	26.5%	8.1%	8.5%	17.5%
Breakdown	Count	6	1	1	0	0	8
	% within ship type	27.3%	0.4%	2.0%	0.0%	0.0%	1.5%
Stranding/	Count	3	84	14	20	44	165
	% within ship type	13.6%	32.1%	28.6%	20.2%	46.8%	31.4%
Others	Count	0	8	1	0	4	13
	% within ship type	0.0%	3.1%	2.0%	0.0%	4.3%	2.5%
Total	Count	22	262	49	99	94	526
	% within ship type	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 8. Chi-Square Test between accident type and reason of accident

	Value	df	Asymp. Sig. (2-sided)
χ^2	80.829[a]	20	0.000
LR	76.091	20	0.000
LLA	0.014	1	0.904
Cramer's V (Approx. Sig.)	0.196		0.000
Num. of Val. Cases	526		

a. 11 cells (36,7%) have exp.count less than 5. The min. exp.count is 0,33.

Table 9. Crosstabulation between accident type and reason of accident

Accident type/ Reason of accident	Count	Unknown	Human Error	Others	Total
Unknown	Count	4	3	1	8
	% within reason of accident	2.4%	1.9%	0.5%	1.5%
Collision	Count	86	87	67	240
	% within reason of accident	51.2%	54.7%	33.7%	45.6%
Grounding	Count	19	28	45	92
	% within reason of accident	11.3%	17.6%	22.6%	17.5%
Breakdown	Count	1	5	2	8
	% within reason of accident	0.6%	3.1%	1.0%	1.5%
Stranding/	Count	53	36	76	165
Contact	% within reason of accident	31.5%	22.6%	38.2%	31.4%
Others	Count	5	0	8	13
	% within reason of accident	3.0%	0.0%	4.0%	2.5%
Total	Count	168	159	199	526
	% within reason of accident	100.0%	100.0%	100.0%	100.0%

Min. exp. count is 2.42, but 50.0% of exp. counts are less than 5 as shown in Table 10. Thus, the Chi Square Test can not be used to test correlated data.

Table 10. Chi-Square Test between accident type and reason of accident

	Value	df	Asymp. Sig. (2-sided)
χ^2	59.404^a	10	0.000
LR	58.294	10	0.000
LLA	14.380	1	0.000
Cramer's V (Approx. Sig.)	.238		0.000
Num. of Val. Cases	526		

a. 9 cells (50,0%) have min. exp. count less than 5. The min. exp. count is 2,42.

4.2.4. *Chi Square Test* between the accident type and whether the ship involved in the accident had a pilot

The ships without a pilot were those most involved in collision (52.3%) and respectively stranding/contact (20.1%), grounding (14.1%) and breakdown (%7,9) as shown in Table 11.

Table 11. Cross-Tab between the accident type and whether the ship involved in the accident had a pilot

Accident type	Count/ % with/without a pilot	The ships without employed a pilot	The ships with employed a pilot	Total
Unknown	Count/	5	3	8
	% with/without a pilot	1.4%	1.9%	1.5%
Collision	Count/	193	47	240
	% with/without a pilot	52.3%	29.9%	45.6%
Grounding	Count/	52	40	92
	% with/without a pilot	14.1%	25.5%	17.5%
Breakdown	Count/	29	9	38
	% with/without a pilot	7.9%	5.7%	7.2%
Stranding/Contact	Count/	74	47	121
	% with/without a pilot	20.1%	29.9%	23.0%
Others	Count/	16	11	27
	% with/without a pilot	4.3%	7.0%	5.1%
Total	Count/	369	157	526
	% with/without a pilot	100.0%	100.0%	100.0%

H_0: There is not a statistical relationship between the accident type and whether the ship involved in the accident had a pilot, H_1: There is a statistical relationship between the accident type and whether the ship involved in the accident had a pilot.

Table 12. Chi-Square Test between the accident type and whether the ship involved in the accident had a pilot

	Value	df	Asymp. Sig. (2-sided)
χ^2	27.358^a	5	0.000
LR	27.551	5	0.000
LLA	12.520	1	0.000
Cramer's V (Approx. Sig.)	0.228		0.000
Num. of Val. Cases	526	526	

a 1 cells (8.3%) have exp. count less than 5. The min.exp. count is 2.39.

As given in Table 12, 8.3% of of exp. counts are less than 5 and min. exp. count is 2.39 and χ^2=27,358. The test result indicated that since the P-value (0.0000)<0.05). Thus, H_0 is rejected and H_1) is accepted. There is a statistically significant relationship between the accident type and whether the ship involved in the accident had a pilot. Cramer's V value (22.8%) confirms that there is a moderate relationship between the accident type and whether the ship involved in the accident had a pilot.

4.2.5. Chi Square Test between ship type involved in the accident and whether to take a pilot or not

The cargo ships involved in accident without a pilot were those most involved in accident (40.7%) and respectively passenger ships and boats (24.7%) as shown in Table 13.

Table 13. Cross-Tab between ship type involved in the accident and whether to take a pilot or not

Ship type/ the ships with/without a pilot	Count % with/without a pilot	The ships without a pilot	The ships with a pilot	Total
Unknown	Count	17	5	22
	% with/without a pilot	4,6%	3,2%	4,2%
Cargo ships	Count	150	112	262
(Dry bulk, general cargo Ro-Ro, reefer)	% with/without a pilot	40,7%	71,3%	49,8%
Tanker&liquid bulk	Count	31	18	49
	% with/without a pilot	8,4%	11,5%	9,3%
Passenger ships and boats	Count	91	8	99
	% with/without a pilot	24,7%	5,1%	18,8%
Others	Count	80	14	94
	% with/without a pilot	21,7%	8,9%	17,9%
Total	Count	369	157	526
	% with/without a pilot	100,0%	100,0%	100,0%

H_0: There is not a statistical relationship between ship type involved in the accident and whether to take a pilot or not. H_1: There is a statistical relationship between ship type involved in the accident and whether to take a pilot or not.

Table 14. Chi-Square Test between ship type involved in the accident and whether to take a pilot or not

	Value	df	Asymp. Sig. (2-sided)
χ^2	54.906[a]	4	0.000
LR	60.862	4	0.000
LLA	37.314	1	0.000
Cramer's V (Approx. Sig.)	0.323		0.000
Num. of Val. Cases	526	526	

a. 0 cells (0.0%) have exp. count less than 5. The min.exp. count is 6.57.

0% of exp. counts are less than 5 and min. exp. counts are 6.57 and χ^2=54.906. P-value (0.0000)< 0.05 as given in Table 14, Thus, H_0 is rejected and H_1 is accepted. There is a statistically significant relationship between ship type involved in the accident and whether to take a pilot or not. Cramer's V value (32.3%) confirms that there is a moderate relationship between ship type involved in the accident and whether to take a pilot or not.

5. CONCLUSION

The Strait of İstanbul is one of the most risky and narrow waterways in the World due to geographical features, navigational constraints and meteorological factors. In the study, accident analysis has been performed for the accidents occured in The Strait of İstanbul using frequency distribution, Chi Square Test and Cramer's V Test in 1994-2019. The study findings are given below;

Total of 27.6% of the accidents that occured in Strait of İstanbul were occured during "right-side up" scheme and Maritime Traffic Regulations for the Turkish Straits and the Marmara Region implemented in 1994-1998, 23.0% of the accidents that occurred were occurred during the period in Maritıme Traffic Regulatıons for The Turkısh Straits implemented in 1998-2003, 49.4% of the accidents were occurred after implementation of TSVTS in 2004-2019. A Total of 45.6% of the accidents that occured in Strait of İstanbul were collision and respectively grounding (17.5%), contact (9.5%), fire/ explosion (6.3%), breakdown (5.1%), stranding (3.8%), foundering/capsizing (3.4%), others (7.2%). The cargo ships were the most involved in the accident (49.8%) and respectively marine vehicles (20%), passenger ships and boats (18.8%) and tankers (9.3%) in 1994-2019. The most accident were occured in the hours 20:00-24:00 (19.4%) and respectively 08:00-12:00 (15.8%), 12:00-16:00 (15.6%), 16:00-20:00 ((15.6%), 24:00-04:00 (15.4%), and 04:00-08:00 (12.4%) in 1994-2019. The ships without a pilot is the most involved in the accident (71.5) in the Strait of İstanbul. The ratio of human error for ships without a pilot involved in the accident is 28.5%.

The most of the accidents were collision in the period 1994-1998 (38.9%), in 1998-2003 (36.7%) and in 2004-2019 (71.7%) and respectively stranding/contact (25.2%) in 1994-1998, grounding (26.5%) in 1998-2003 and stranding/contact (13.1%) in 2004-2019. Cargo ships were those most involved in collision (38.9%) and respectively stranding/contact (23.7%). Tanker&liquid ships were also those most involved in collision (36.7%) and respectively grounding (26.5%). Passenger shiṣps&boats were those most involved in collision (71.7)% and respectively stranding/contact (20.2%). The main reason of all type of accidents is human error such as collision (54.7%), stranding/contact (22.6%), grounding (17.6%) in The Strait of İstanbul in 1994-2019. All types of accidents are mostly caused by human error. The ships without a pilot were those most involved in collision (52.3%) and respectively grounding (14.1%) and breakdown (7,9%).

There is a statistically significant relationship between accident type and accident year; between accident type and the ship types involved in the accident; between the accident type and whether the ship involved in the accident had a pilot; relationship between the ship type involved in the accident and whether to take a pilot or not in the Strait of İstanbul in1994-2019. The comprehensive risk and accident analysis studies can be conducted by utilizing the findings of the study.

The accidents occurred in the Strait of İstanbul pose a serious risk interms of human life, and property, navigation and environment and cause oil spill. The ships without a pilot were the most involved in the accident occurred in the Strait. The ships passing through Turkish Straits are strongly recommended to take a pilot as per the IMO Resolution A.827 (19). The recommendations to provide safety of human life, and property, navigation and environment in the Strait of İstanbul are: the establishment of The Emergency Response Centre, encouragement of taking a pilot, defining the accident black points for the risky regions, establishment of the naval fire brigade, the establishment of 3D-three dimensional vessel tracking system to enhance situational awareness both from ashore and onboard perspectives, especially during pilotage operations.

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