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The analysis of recreational vessel groundings in Croatian waters of the Adriatic Sea

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ABSTRACT

Recreational vessel accidents during summer seasons in Adriatic Sea frequently occur when seasonal traffic significantly increases. In this paper, the database containing data on recreational vessel groundings from 2013 up to 2019 has been analyzed. Data distributions have been calculated, and characteristic patterns are noted. Statistical auto-regressive model SARIMAX has been used to create existing grounding data time-series, and to forecast trends for the next five years. The findings show that majority of groundings happen during night hours, suggesting that dominant causes of those accidents are human error related. Weather conditions have also been detected as one of causes of groundings, particularly north-east winds and thunderstorms. The slowly increasing trend of annual groundings is forecasted and recommendation to improve skipper's education and training has been given to mitigate future increase.

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1 Introduction

During summer season, maritime traffic in Croatian waters increases substantially because of tourism activity. With vastly increased amount of yachts and other recreational vessels navigating within area, also the frequency of maritime accidents increases [8]. Grounding has been detected to be among the most common type of accidents of these vessels [12]. Frančić [5] also found that grounding is the most common type of accident in Croatian waters among passenger vessels. They also grouped accidents by type of vessel and found that the majority of accidents happen among small recreational vessels and only minor percentage is assigned to larger passenger and cargo vessels as well as fishing vessels.

The causality relationships and risk factor analysis of accidents has not been discussed much in Croatian scientific literature. The risk of grounding has been analyzed for generally larger vessels [1, 8, 14] but the data used do not account for small recreational vessels. In those studies, locally high traffic volume and human factor are generally recognized as the primary cause of accidents, as well as propulsion/steering system failure for large vessels.

Similar studies have been conducted in other Mediterranean areas. Paper [4] analyzed maritime accidents in Turkish waters and found that 60 % of accidents result from human error, but contrary to [12], found that fire and sinking are more common accidents among yachts than grounding. These statistical differences might be explained by different environmental risks like complexity of area for the navigation, or different climate conditions. Otamendi [13] analyses and discusses accidents of recreational vessels in Spain and finds that improper passage planning is the most common cause of accidents.

McKnight [10] analyzed US Coast Guard database and found that human error, alcohol consumption, failure to look for obstructions ahead and not keeping distance to other vessels are the most common causes of accidents in recreational boating.

In this paper authors analyzed risk factors for groundings of recreational vessels, based on existing search and rescue data. In addition, statistical modeling has been performed and possible future trends based on such established model are calculated.

2 Data and methodology

SAR (Search and Rescue) data are acquired from Maritime Rescue Coordination Centre Rijeka (MRCC) about all recorded groundings of recreational vessels within Croatian waters from year 2013 up to 2019. MRCC SAR database does not represent all accidents because of several reasons. Many charter companies have contracts with private SAR organizations like "EmergenSea" [3, 14] or "Sea-Help" [17]. Those organizations are usually the first to be called in case of minor accidents. In addition, some accidents are not reported to anyone, as vessel crew successfully resolves the situation on their own, or with assistance from nearby vessels. The trend of under-reporting of maritime accidents and accident data quality in general is well known [6, 15]. With all that in mind, the MRCC data should be viewed as a sample, rather than complete accident database.

The time-series of SAR data (Fig. 1a) has been analyzed by using statistical methods to get closer insight into data distributions. Data has been grouped by the day of year to get insight about grounding distribution during the year (Fig. 1b) and by the hour of day to find our daily distribution of accidents (Fig. 1c). Distribution of groundings during year is also presented in form of box-plot for monthly number of accidents as given in Fig. 1d.

Accidents are further grouped according to day or night time. To determine if an event happened during daylight, the Sun altitude above horizon has been calculated for each event using astronomical ephemerides of Sun, accident latitude and longitude, and time of the accident.

$$Alt_{Sun} = \arcsin\left(\sin(lat) \cdot sin(\delta_{Sun}) + \cos(lat) \cdot \cos(\delta_{Sun}) \cdot \cos(LHA_{Sun})\right) \quad (1)$$

$$LHA_{Sun} = GHA_{Sun} + lon \quad (2)$$

where *lat* is latitude of accident, δ_{Sun}, is declination, GHA_{Sun} and LHA_{Sun} are Greenwich hour angle and local hour angle of the Sun at time of the accident, respectively [7]. The Sun declination and Greenwich hour angle are taken from the ephemerides for each accident.

Accidents that happened during twilight time (when the Sun is below horizon but less than 12 degrees), are classified as night accidents.

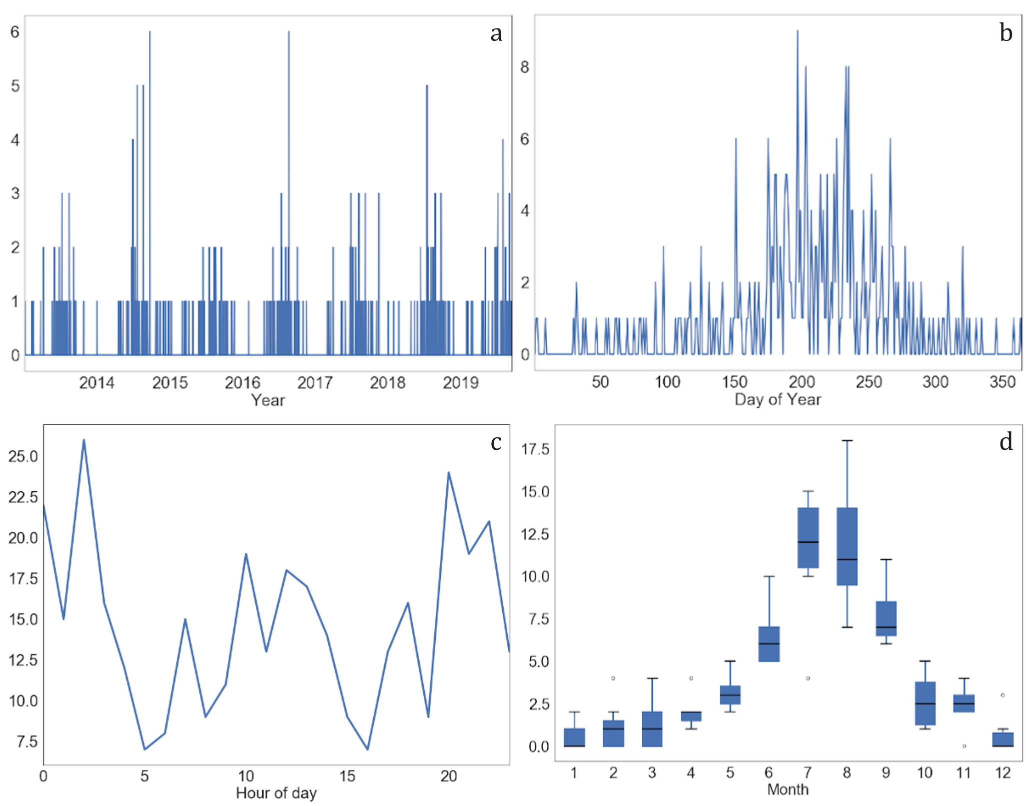

Fig. 1 Time-series of groundings data and its distributions. a) number of groundings per day during observed period, b) total number of groundings per day of year, c) total number of groundings per hour of day, d) box-plot of number of groundings per calendar month.

Source: [9]

We hypothesized that the outlier number of groundings during a particular day can be caused by unfavorable meteorological conditions for navigation. To confirm or reject the hypothesis, weather conditions on days within data-set with 4 or more recorded groundings are examined. The atmospheric data from Croatian Meteorological and Hydrological Service [2] as well as US National Oceanic and Atmospheric Administration model [16] has been used to determine if there were any storm or low visibility recorded in the area during those days that could increase chances of grounding accidents.

As consecutive accident counts are found to be correlated to each other using auto-correlation and partial auto-correlation methods, future groundings can be forecasted based on previous records, if there is no significant change in explanatory variables within the system.

To find and explain regularities in recorded data as well to forecast future accidents based on previous data, time-series has been modeled using auto-regressive integrated moving average (ARIMA) class of models [18, 19]. Due to significant seasonality observed in data (Figs 1a, 1b, 1d), seasonal ARIMA model with support for exogenous variables, SARIMAX has been chosen.

SARIMA is auto-regressive ("AR" term) statistical method, intended to model time-series and account for seasonality within the data ("S" term) where future values are predicted by using moving averages of existing data in time-series ("MA" term).

Contrary to the simpler ARMA model that assumes stationarity within data, instead of predicting time-series of itself, ARIMA predicts differences of time-series from one time-stamp to the previous time-stamp ("I" term). The stationarity within the data means that time-series have constant mean and constant variance over time.

Mathematically, the seasonal auto-regressive moving average model takes the form

$$\phi_p(B)\ \Phi_P(B^s)\ (1 - B)^d\ (1 - B^s)^D\ z_t = \theta_q(B)\Theta_Q(B^s)\varepsilon_t \qquad (3)$$

where

$\phi_p(B)$ and $\theta_q(B)$ are non-seasonal auto-regressive and moving average lag polynomials;

$\Phi_p(B^s)$ and $\Theta_Q(B^s)$ are seasonal auto-regressive and moving average lag polynomials;

$(1 - B)^d$ and $(1 - B^s)^D$ are difference (or integrated) components

ε_t is white noise process or stochastic error parameter that cannot be modeled.

Therefore, the general model used in this paper to fit time-series is denoted as

$$ARIMA(p,d,q) \times (P,D,Q)_s \qquad (4)$$

The p, d and q, also known as model hyper-parameters, denote the orders of non-seasonal components of the ARIMA model and P, D and Q hyper-parameters denote the orders of seasonal components of the model.

Model optimization has been done by searching for the combination of p, d and q, as well as P, D and Q hyper-parameters that predict time-series with least mean squared error (mse) value. The procedure in statistics and machine learning known as the grid search has been used for hyper-parameter selection for the final ARIMA model. Every combination of hyper-parameters from 0 up to 3 has been evaluated (4096 combinations) and mse for time-series prediction has been calculated. The combination with least mse has been selected as the operational ARIMA model. During preprocessing of data, time-series were re-sampled to monthly number of groundings, so the seasonal parameter in ARIMA equals 12. Overall, the chosen operational model with lowest mse value of 2.347 groundings/month is denoted as:

$$ARIMA(3,1,3)\times(3,1,1)_{12} \qquad (5)$$

or using mathematical notation it becomes

$$\phi_3(B)\Phi_3(B^{12})(1 - B)^1(1 - B^{12})^1\ z_t = \theta_3(B)\Theta_1(B^{12})\epsilon_t \qquad (6)$$

The prediction quality of model has been verified using train/test split of whole time-series in order to avoid forecasting over data that has been already seen by the training process of model. Training part of data-set consisted of all data points up to January 1st, 2018, and a test part of data-set contained the rest of data-points of original time-series. The model has been trained using train part of time-series and forecast is created for the test part of time-series. The results are statistically analyzed.

Finally, after verifying prediction quality of model, whole time-series have been used to train operational model. A final forecast is created for future 5 years. In addition to forecast, decomposed trend of the forecast has been calculated as well as 95 percent confidence interval of the forecast.

3 Results

The calculation of the height of the Sun over or under horizon in the time of accident show that from total of 353 recorded grounding events, 169 (47.9 %) happened during day and 184 (52.1 %) events took place after sunset/before sunrise. The distribution of day and night accidents over the year is given on Fig. 2.

Days within data-set with 4 groundings or more are examined according to the prevailing weather. The results are presented in Table 1.

Results of the seasonal ARIMAX(3,1,3)X(3,1,1)$_{12}$ model trained with data-set up to Jan 1st 2018 and verified on test data-set from that date up to the end of available data are plotted on Fig. 3. The forecast successfully captured seasonal fluctuations of accidents during 2018 and available

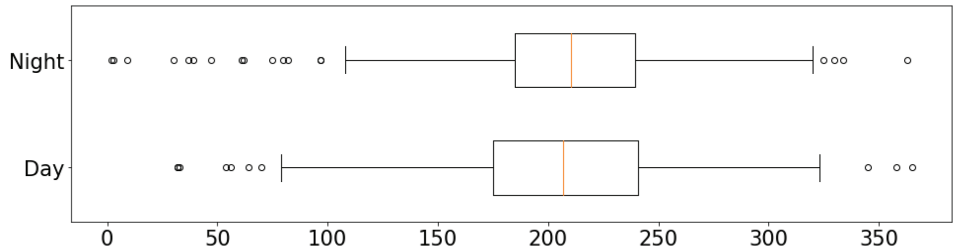

Fig. 2 Distribution of groundings over the year for day and night accidents separately, showing day of year on x-axis.

Source: Author's calculation

Table 1 Meteorological remarks for days with 4 or more recorded groundings

Date	# of groundings	Meteorological remarks
2016-08-22	6	Hurricane force gusts of NE wind, following thunderstorms during night hours 21st/22nd Aug.
2014-09-23	6	Widespread thunderstorm activity as cold front passes across the area. Temporary gale force NE winds following front passage.
2018-07-16	5	Significant rain (possibly leading to reduced visibility; all groundings that day happened during night), localized thunderstorms, brief strong NE wind
2014-07-22	5	Night thunderstorm close to position of 4 groundings
2014-08-21	5	Night thunderstorm close to position of 4 groundings
2019-08-02	4	Night thunderstorm close to position of all 4 groundings
2014-06-30	4	Night thunderstorm close to position of all 4 groundings

Source: [2, 16]

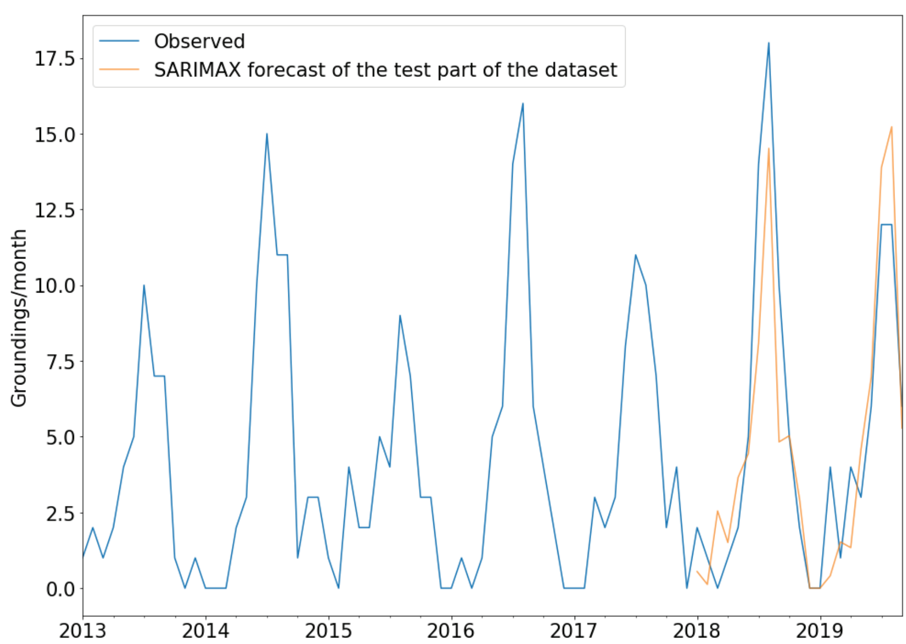

Fig. 3 Comparison of the observed time-series (blue) with forecasted part of the test part of the time-series using seasonal ARIMAX(3,1,3)X(3,1,1)12 model (orange), using train data-set up to Jan 1st, 2018.

Source: Author's calculation

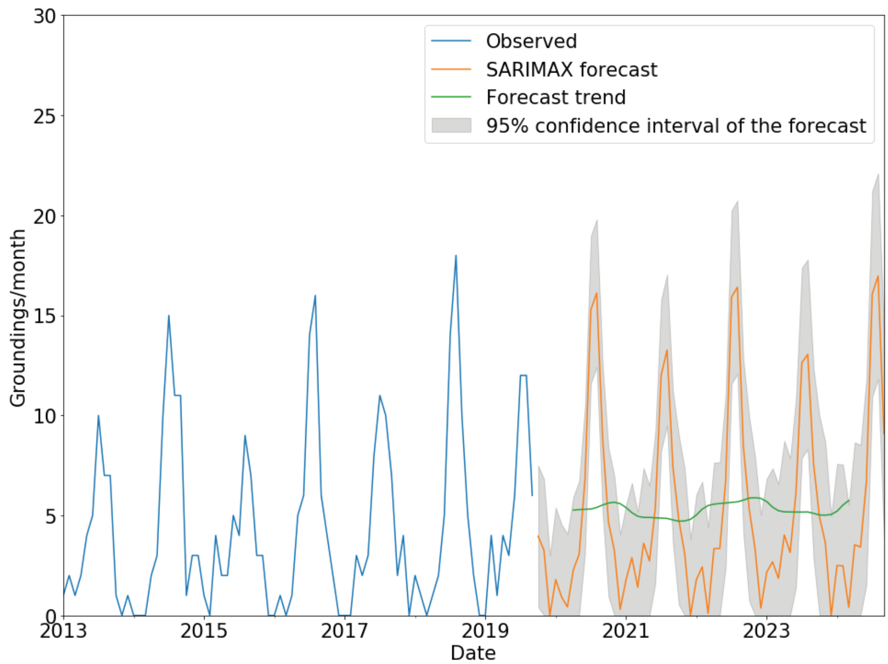

Fig. 4 Observed and forecasted number of monthly grounding accidents using the seasonal ARIMA model.

Source: Author's calculation

part of 2019 with some inaccuracy in forecasting of maximum amplitude of grounding accidents during peak time of year. Mean squared error between observed and forecasted data equals 5.979 groundings/month. Successful verification of ability to forecast seasonality pattern and acceptable forecast of amplitude of the data, using forecast of unseen data during training process, gives us enough confidence that this model can be successfully used to forecast future occurrences, under assumption that no significant change of explanatory variables happens during forecasted period.

4 Discussion

The finding that majority of grounding events happened during night gives important insight into primary reasons for those accidents. As observed data-set consists primarily of chartered and other leisure vessels, it can be assumed that most of them are under way during the day and moored or anchored during night hours. This disagreement between the number of vessels sailing during day/night and the corresponding number of groundings leads to conclusion that much greater probability of grounding exists during night hours.

It may be assumes that the most probable cause is lack of experience of skippers that only occasionally or never sail during night hours, thus lacking skills required to properly determine and monitor vessels position using instrumental methods (visual orientation during night-time is much more difficult than during daylight). Such circumstances lead to frequent deviations from intended routes and eventually to grounding. Also lack of proper passage planning, especially during night, can be important contributing factor of grounding accidents, which agrees with paper [13].

Another reason that can lead to grounding even when vessel is at anchor, is a sudden storm, especially NE winds (Bora) or thunderstorm events. Bora is a katabatic wind from north-east that can quickly reach hurricane force. Although it is more common during colder part of year, it still presents a high-risk during summer season if skippers are found unprepared for it. In addition, summer thunderstorms are quite common in Adriatic area. As it shown (Table 1) in each case of four or more groundings a day, either gale/hurricane force Bura or thunderstorms were present within the area of the grounding accident, so there is very high likelihood that these conditions caused grounding, either during navigation or even at anchorage close to the coastline or shallow water.

Time-series modeling, using the SARIMAX statistical model, shows that similar seasonality pattern of frequency of grounding events is expected in the future, accompanied with slightly increasing trend (Fig. 4).

It is already mentioned that forecast is based on assumption that no explanatory variables change in the future, the most important being traffic density, weather conditions and skipper knowledge, skills and experience.

Traffic density is determined by the level of the tourism activity on the coast during summer season. Based on the Croatian Bureau of Statistics data, a number of tourists is in constant increase from year to year, so it can be extrapolated that this trend will continue, thus causing the traffic density to increase. Finally, it will lead to more accidents in future, which agrees with conclusion given by paper [8].

Weather conditions in future can be viewed through climate changes. According to climate simulations [11], it is estimated that during summer season on Adriatic, the average wind speed will increase by 20-25 percent by year 2040, compared to 1971-2000 period. If so, it will increase the risk of grounding accidents in future.

Human factor is probably the most important variable, and the one that can be influenced the most. Navigational education and training of skippers should be improved in order to provide higher skill levels, improved weather-related awareness, as well as decision making. Without any doubt, this is the single most important way to reduce frequency of accidents on the sea, not only groundings but all types of maritime accidents.

Croatian rules and regulations regulating skipper's mandatory minimal education and training for yacht master up to 100 BT, require 50 hours of education in form of 33 hours of theoretical classes and 17 hours of practical training. However, there is no obligation that any of that is carried out during night conditions. Based on results presented here, the night-time training can be beneficial for reducing frequency of accidents.

5 Conclusion

According to the analysis presented here, most groundings of charter yachts and other leisure vessels happen during night hours, which indicates that primary cause of such accidents are skipper's inadequate skills in practical navigation and vessel control during night time.

Weather conditions like hurricane-force Bora or thunderstorms can also increase risk of yacht accidents, clearly evident in outlier days with more recorded groundings than the average count.

Statistical modeling, as well as analysis of risk factors shows that increase in number of these accidents may be expected in the future. Expected tourism growth and climate changes in next decades are among risk factors that will increase a number of accidents.

As a prevention measure, more efficient education and training, including more work on skipper's practical skills, including night-time training, is proposed.

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