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Model of ferry captain's manoeuvres decision

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Abstract
The paper introduces the results of research concerning modelling of ferry captain's manoeuvres decision. The author's probabilistic model has been validated with real time manoeuvres of the ferry m/f "Polonia" at the Ystad harbour by using Bayesian belief networks. Variables, quality factors, network example, model's suggested settings of propellers and rudder for selected real manoeuvres have also been presented. Comparison to existing methods and models has also been presented. Finally, there are some conclusions concerning the described model. Are also included some proposed practical applications.

Introduction

Ship manoeuvring can be understood as a series of successive and complementary master's decisions taken in given external conditions. During manoeuvres, the captain decides on propellers and rudder settings. The results of research on the safety assessment of manoeuvres lead to the conclusion that hydro and meteorological conditions have fundamental influence on the manoeuvring decisions. One of the main tasks of the ferry captain is to find such a combination of rudder and drive settings to ensure carry out safety manoeuvres. The main goal of construction of model supporting manoeuvring decision of the sea ferry captain is to find a proper combination of settings in accordance with the intentions of manoeuvring.

Model's assumptions

Manoeuvres of the ferry m/f "Polonia" at the port of Ystad was an object of the research. Primary collected database was based on the registration settings of propellers and thrusters that was used during the manoeuvres. Generally registered the response of manoeuvring the ferry captain to different external and internal conditions. However, in contrast to the simulation studies, the subject of the research was real ferry manoeuvres not a deterministic model of manoeuvres based on the classical mechanics and hydrodynamics [1].

Models of ferry moorings manoeuvres decision are based on the assumption that humans are reasonable and capable of solving a problem. In case of many possible decision options and preferences there is relatively high probability of making, reasonably and effectively, the same decision in the same conditions by most of manoeuvring captains. Most of the manoeuvring will choose the same most probable combination settings of bow thrusters, stern thruster, propellers and rudders.

The consequence of this assumption is to build the model supporting the decision of sea going ferry berthing manoeuvres by using statistical methods. Also, it was assumed that it is possible to estimate a priori distributions of all settings of all thrusters, propellers and rudders. To determine these distributions, stored database derived from already registered manoeuvres can be used.

The data of all currently prevailing external conditions, as well as information about the position and movement of the ferry are derived from the present observation of currently executed manoeuvres. On this basis, it is possible for present manoeuvre, using the Bayes' theorem, to obtain the a posteriori distribution of settings thrusters, propellers and rudders. When conditional independence of events for their immediate causes are assumed, to estimate the a posteriori distribution representation of the common probability distribution – Bayesian networks was used. Bayesian networks can be provided by an expert and trained by using experimental data. In case of decision model supporting the sea going ferry berthing manoeuvres, the structure of the network was not known, while assuming the knowledge of all the variables involved in the model. To construct and train Bayesian network and its subsequent verification, software package Powersoft was used [2].

Decision model supporting the sea going ferry berthing manoeuvres

Researches conducted on the ferry m/f "Polonia" equipped with two controllable pitch propellers, two main rudders, in one throttle controlled three bow thrusters and one stern thruster. Primary set of 21 variables was defined that can potentially affect manoeuvring decisions. The data of the model was collected on board of the m/f "Polonia" from 04.07.2009 to 02.07.2010. To record the data, an application was used, part of Ferry Navigation System Anti-Collision System (FNAS) constructed by Institute of Marine Traffic Engineering of Maritime University of Szczecin. The data were recorded from the 152 entering and departure ferry manoeuvring in the port of Ystad for different hydro and meteorological conditions. Ferry different loading conditions represented by draft and also other ships movement in the port were taken into consideration.

The results of studies on the safety assessment of mooring and unmooring manoeuvres m/f "Polonia" ferry [3] made it possible to extract the most difficult phase of all the manoeuvres in the port of Ystad. It was found that the least secure and the most complicated and difficult manoeuvres of the ferry was carried out in the limited area of Ystad internal basin.

During these manoeuvres, the 8 knots linear ferry speed is reduced to zero at a distance of 300 meters. Simultaneously with the deceleration of the speed, the ferry is turning with the rate of turn up to 50 degrees per minute. Then, during continued circulation astern run begins at a speed of about 2 knots. During the manoeuvre, the described hydro technical structures are passed at distances of several meters. Accordingly, for these phases it was decided to build a model supporting berthing manoeuvres. Based on all the 21 variables a learning data base of the model was built. During the construction of Bayesian belief networks, the total number of variables can be reduced to the following without affecting the quality of the initial model:

- true wind direction – dirWind;
- wind speed – spdWind;
- minutes latitude – mnLat;
- minutes of longitude – mnLong;
- gyro course – gyroC;
- true course – trueC;
- rate of turn – ROT;
- true speed – trueS.

Discretization of continuous variables were made. Discretization step of variables was based on observations arising from the seaman practice. Verbal commands are assigned to appropriate settings of bow thrusters, stern thruster, propellers and rudders. In this case the number of propellers settings are limited to 9. For example, for forward main engine commands there is "full", "half", "slow" and "dead slow". Taking into consideration run astern and "stop engine", 9 commands of the main engine are obtained. Based on similar reasoning the alike discrimination are set for the bow thrusters, stern thruster and rudders settings.

Adjustable propellers and thrusters setting are based on a percentage of full ahead or eastern run of the engine (for instance full astern is known as "minus 100%"). Rudders deflection is determined in degrees of angle. The command for helmsman "all to port" for m/f "Polonia" means "45 degrees". Guided by these observations maximum 9th discretization step for engine and rudders was set. If, during the manoeuvres, the full range of settings changes (e.g. for adjustable propeller from "100%" to "100%" 9 steps, which ranges approximately 22.2%) was lower than the maximum (e.g. "50%" to "100%" 9 steps, ranges which 16.7%) then the present discretization of 9 steps always provides better precision of decision model than established for full range.

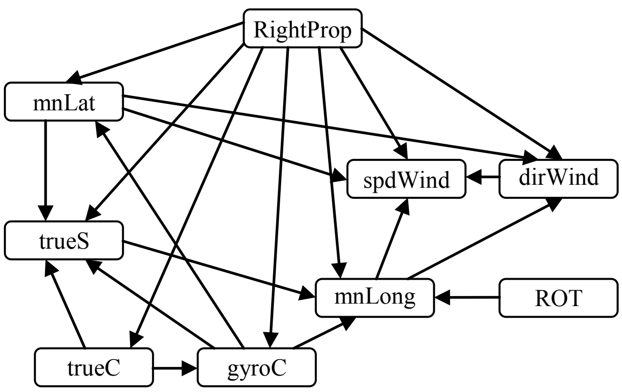

Fig. 1. Bayesian network representing settings for the right propeller

After discretization of selected variables, based on a learning model database, bayesian networks were constructed that inference the settings of the main rudders, thrusters and main engines:

PortRudder, StbRudder, LeftProp, RightProp, BowThruster, SternThruster. Figure 1 shows an example of network representing settings for the right propeller.

Test results of all networks conducted on learning data base carried out at 95% confidence level are shown in table 1. High number of correct assessments allows to formulate the hypothesis that bayesian believe networks can correctly represent manoeuvring decisions. Prove of the truth of this hypothesis required the verification of decision model supporting the sea going ferry berthing manoeuvres by set of test data.

Table 1. Percentage of model's properly verified records of learning data

Settigs	Properly verified records of learning data sets [%]
PortRudder	90.31
StbRudder	90.89
LeftProp	79.43
RightProp	89.45
BowThruster	84.37
SternThruster	82.77

Verification of the model

To verify the model five sets of test data were selected, not used to construct learning the bayesian network. Data to verify this model came from the last 5 registered manoeuvres prior to its construction.

Graphical Verification

Figures 2 and 3 graphically illustrate the operation of the model. Tested and proposed by the model setting for the right propeller have been shown, as well as the right rudder. Both, the rudder and the propeller play significant role during the manoeuvres. The records contain data recorded at intervals of seconds. The model determines the most probable range of settings. For example, for 40th second during the manoeuvre the model suggests setting the right propeller lying between +20 and +32 percent deflection (engine runs forward), assuming that the full range of adjustment of propellers is between –100 and +100 percent.

Until 90th second of manoeuvres the rudder is set to the port, propeller is working forward about 25 of "full ahead" power. Both give a stern movement in opposite clockwise direction. Ferry runs at that time of manoeuvre in the inner harbor in Ystad. After 90th second the rudder is set in the midship position, the propeller is set to astern. For the ferry

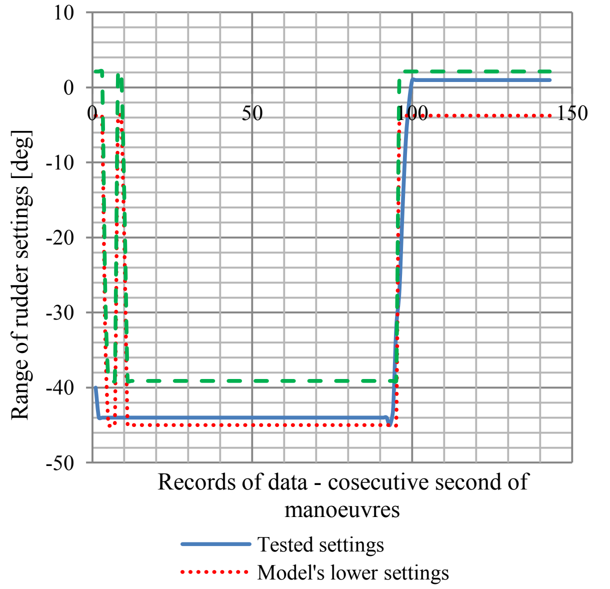

Fig. 2. Model verification of starboard rudder settings in westerly wind force 11 m/s manoeuvres

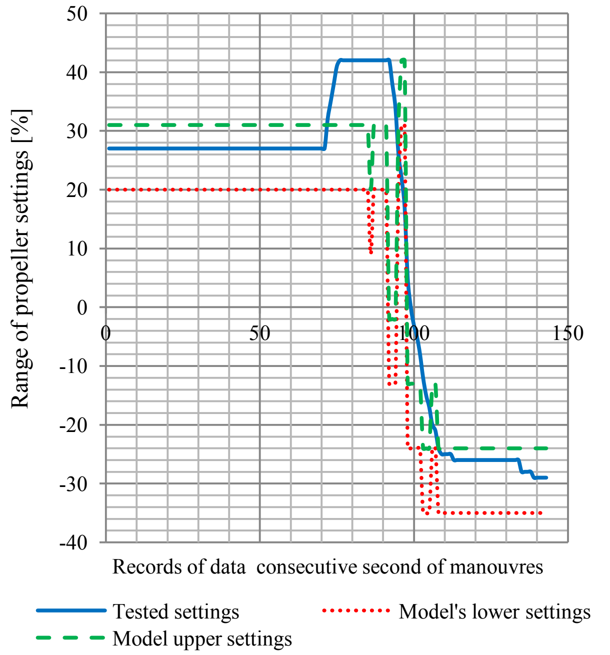

Fig. 3. Model verification of right propeller settings in westerly wind force 11 m/s manoeuvres

movement, this means the end of the turning generated by stern moment of force generated by propellers and rudders. In the same time bow thruster begin the run, as presented on the figure 4 and to the ferry commence approaching to wharf No. 4.

The full results of the verification test for all databases empower to conclude that the decision model in each tested case recreates intentions of manoeuvring captain. At every moment it is possible to prove that settings suggested by the model enable to conduct proper manoeuvre at modeled area.

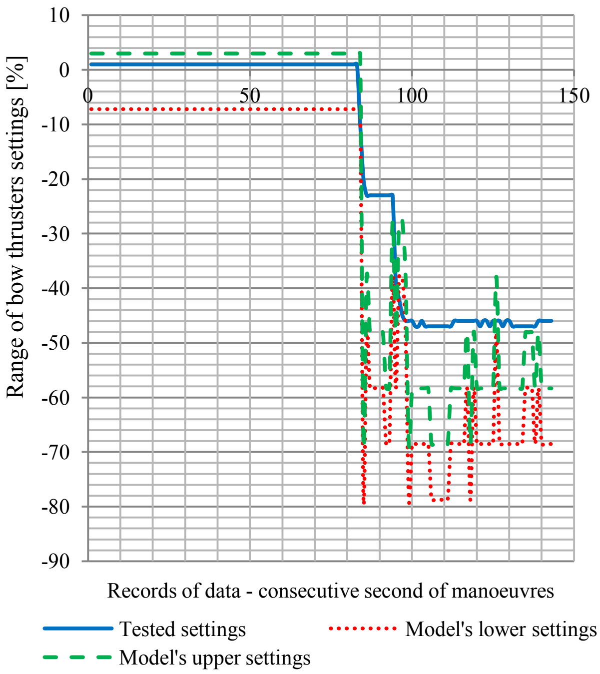

Fig. 4. Model verification of bow thrusters settings in westerly wind force 11 m/s manoeuvres

Analytical Verification

Verification results of the operation of the model for all test databases are shown in table 2. It can be observed that the percentage of correctly identified settings for some cases (setting for bow thrusters in the condition wind E5) is only slightly more than 50%. In fact, the model works much better than the data shown in table 2. The responsibility for this rests on the described previously narrower range of settings used during the manoeuvres included in the determination of nine step method of discretization. For the reported cases, narrowing the full range of the settings and thus reducing the range of accuracy for settings will always entail fewer records verified correctly. Thee good example of this problem shows figure 4 – graphically verification of bow thrusters settings in the same condition as for figures 2 and 3. Here range of model's properly verified setting is narrowed to only 10%. But acceptable by the practitioners of the manoeuvres

Table 2. Percentage of model's properly verified records of testing data sets

Settigs	Properly verified records of the model [%]				
	W 4 [m/s]	E 5 [m/s]	W 11 [m/s]	SW 10 [m/s]	E 9 [m/s]
PortRudder	92.76	93.84	95.10	91.1	91.24
StbRudder	92.76	93.84	92.31	87.67	88.32
LeftProp	90.79	87.67	82.52	71.92	78.83
RightProp	75.66	54.11	76.92	67.12	85.40
BowThruster	57.82	51.37	59.44	65.75	72.99
SternThruster	80.26	83.56	78.32	84.25	84.67

discretization range is 22%. This value give range ⟨–100%, 100%⟩ divided by 9 steps of discretization range. However, from a practical point of view, the model is functioning properly and this is confirmed in the graphical verification of the model and analysis of the model in the operation [4].

Among many proposed indicators [4] used for an assessment of the model verification, the use of the quality factor of the model – Root Mean Square Error (RMSE) will be described.

$$\mathrm{RMSE} = \sqrt{\frac{1}{T}\sum_{t=1}^{T}\left(y_t - \hat{y}_t\right)^2} \qquad (1)$$

RMSE indicates by how many units, on average, for each time t the compared values taken from real manoeuvres y_t differ from values obtained as a response of model on test data $\hat{y}_t$ (on the plus or minus). RMSE allows to explore the differences between the actual setting used during the test passage and the setting obtained from the Bayesian network. The value of T is defined as the actual full range of manoeuvre duration.

Table 3 shows the values of the calculated RMSE for the 5 sets of test data taken from five different manoeuvres. Root Mean Square Error has the greatest value for the jointly controlled bow thrusters and stern thruster. However, considering the range of the settings in the range of –100% to +100% (giving 200 units of the scope of changes) even for the stern thruster RMSE fluctuates around 0,1 full scale range. Manoeuvring captain, according to his own tactics, sets the power of thruster and observed reaction of the ferry on this force. Operation of the thrusters knob are made roughly without continuously carried out precision reading of the setting on electronic indicators. Taking into account the rules of the use the bow and stern thrusters during manoeuvres it can be concluded that the precision of the model is sufficient.

Table 3. Model's Root Mean Squared Error (RMSE) for testing conditions

Wind [m/s]	T [s]	PortRudder [deg]	StbRudder [deg]	LeftProp [%]	RightProp [%]	BowThruster [%]	SternThruster [%]
E5	146	4.87	4.34	8.85	12.09	20.05	17.34
E9	137	7.18	7.75	3.93	9.35	18.20	21.23
SW10	146	7.32	12.40	2.93	12.86	17.53	18.15
W4	152	6.02	7.62	3.41	15.05	13.34	20.41
W11	143	4.12	8.00	7.57	7.72	10.74	19.71
Mean value of RMSE		5.90	8.02	5.34	11.41	15.97	19.37

Conclusions

The model presented in the article presents the sea ferry captain manoeuvring tactic. Because the data from records are obtained from real manoeuvres, all limitations of manoeuvreability of the ferry are included in the model. The model may find wide range of practical applications. The model can be used by the ferry captain to support manoeuvre decision. The model is a synthesis of knowledge taken from many manoeuvres, therefore it is a set of techniques used for manoeuvring m/f "Polonia" at the port of Ystad.

The conception of model supporting manoeuvring decision of m/f "Polonia" captain allows to continuously and automatically improve its performance by including in the model the data coming from the subsequent manoeuvres. Another advantage of the model is the possibility of continuous improvement in the process of gaining new experience by the manoeuvring themselves. Each successive set of training data derived from the registration of manoeuvres modify the knowledge base for model supporting manoeuvring decision. This system may become part of the sea ferries pilot system.

A limitation of application of the model is the possibility of its use on vessels only engaged in regular voyages, recurrent on the same areas. Bayesian network used for the construction of model supporting manoeuvring decision of sea going ferries allows to update, summarize and represent up to date knowledge necessary for the manoeuvres.

The model may also be used in training of Marine Academy students in the sea ferry manoeuvring. The same trainings are possible for manoeuvring expert level courses of practitioners navigators. In the exercises suggestions for setting of engines, bow thrusters, stern thruster and rudders may be presented. Surely, the proposed manoeuvring decisions will be developed at any time by the most experienced practitioners of manoeuvring – experts in their field. The proposed tactics will always be the most effective while providing maximum safety for manoeuvres.

The next group of users make a profits on decision model is intended for includes maritime administration bodies and sea port managers. Managers and officers in this group are given a tool for simple assessment of ferries' percentage of the propellers power that will be used during different weather conditions. It may be helpful when developing port regulations, especially when we have an attention on safety on one hand of hydro technical infrastructure due to propeller's generated stream and on the other hand safety of the moored vessel on the vicinity of the manoeuvring ferry due to this same stream problem.

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