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Probabilistic Model of Underkeel Clearance in Decision Making Process of Port Captain

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ABSTRACT: The paper presents practical implementation process of developed probabilistic model of ships underkeel clearance. The model was implemented in “on-line” version and could be used for decision making process of harbour captain in everyday practice. The paper presents the results of validation of the model and the practical guidelines of use in decision making process.

1 INSTRUCTION

Underkeel clearance is most important factor which determines the possibility of ships hull touching the bottom. Maintaining safe clearance is the basic navigator’s responsibility among his other usual duties. Till now method of constant clearances has been used to determine the minimal safe underkeel clearance. This method calculates safe underkeel clearance as a sum of several components. Many factors are taken into account within this method which have constant values for a particular area. In many cases this solution might be too general.

The paper presents model of underkeel clearance with probabilistic method. Uncertainties taken into account within the model are: depth, draught and water level together with their determination uncertainties. The paper presents the hints for practical use of the model. Model presents predicted underkeel clearance distribution. The method allows to determine the probability of ships hull hitting the bottom, which might be helpful to assess whether maximal vessel can or cannot enter to the port.

2 PROBABILISTIC MODEL OF UNDERKEEL CLEARANCE DETERMINATION

The model determinate predicted underkeel clearance for chosen ship and probability of ships hull contact with the bottom. It uses probabilistic method, which shows underkeel clearance distribution.

On the grounds of vessel type and length program gives underkeel clearance for chosen ship, which might be helpful to assess whether maximal vessel can or cannot enter to the port.

Depth measurement uncertainty, uncertainty of draught determination in port, error of squat determination, bottom irregularity, tides and waves influence are deciding factors for underkeel clearance of ships. Program is modelling above mentioned errors using distributions and their parameters (Monte Carlo simulation is used) [Gucma L. 2004a].

Program is iterating to a predefined n_{max}. While $n \leq n_{max}$ calculations are made for randomly selected parameters. If $n > n_{max}$ results are analysed and underkeel clearance distribution is printed.

The following parameters are randomly selected from their distributions:

- depth – hi ,

- sounding error – δ_{BS_i},
- mudding component clearance – δ_{Z_i},
- draught determination error – δ_{T_i},
- ship's heel error – δ_{P_i}.

Length between perpendiculars – L, ship service speed – V_{serv}, ship's block coefficient – C_b are determined on the basis of vessel type and length overall. If given length is outside then alert message will be given. Each iteration consist of 5 main analytical modules.

2.1 *Random draught module*

User-entered draught is corrected for draught determination error value and ship's heel error.

Iterated draught (T_i) is calculated as follows:

$$T_i = T + \delta_{T_i} + \delta_{P_i}$$

where: T – Ships draught [m], δ_{T_i} – draught determination error, δ_{P_i} – ships heel error.

2.2 *Water level module*

Water level PW_i is automatically fed from Maritime Office in Szczecin. For Gdańsk Harbour water level value must be entered manually.

2.3 *Depth module*

Random depth h_i and current water level in port are used to calculate up-to-date depth.

2.4 *Squat module*

Squat in each iteration is calculated in three stages. First module calculates squat with methods used to obtain moving vessel squat (Huusk, Milword 2, Turner, Hooft, Barrass 1, Barrass 2) [PIANC 1997; PIANC 2002]. Next standard errors of each methods are allowed. Squat model selection and their standard errors were verified by GPS-RTK experimental research [AM 2004a; Gucma L., Schoeneich M. 2006]. As a result of the experiment uncertainty of each model was assessed and each squat method assigned weight factor $w_i = \sigma_i/\Sigma\sigma_i$. Method's weights and Bootsrap method are then used to calculate ship's squat.

2.5 *Underkeel clearance module*

Underkeel clearance Z_i is determined by using draught, depth, water level and squat results which were calculated before. Underkeel clearance is defined as:

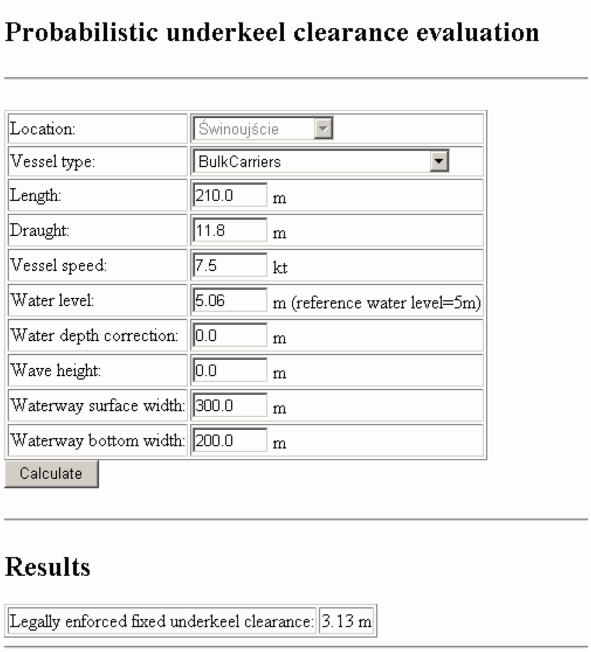
$$Z_i = (h_i + \delta_{Z_i} + \delta_{BS_i}) - (T_i + O_i + \delta_N + \delta_{WP_i} + \delta_F)$$

where: h_i – up-to-date depth in each iteration, δ_{Z_i} – mudding component clearance, δ_{BS_i} – sounding error, T_i – iterated draught, O_i – iterated squat, δ_N – navigational clearance, δ_{WP_i} – high of tide error, δ_F – wave clearance.

The result of method of constant clearances is presented to compare it with the proposed probabilistic method. This method calculates safe underkeel clearance as a sum of several components. Any probabilistic characteristics of underkeel clearance can be taken account. The value of this clearance is calculated in accord with "The guidelines for Designing of Maritime Engineering Stuctures".

3 COMPUTER IMPLEMENTATION OF MODEL

The model was implemented using Python compiler and it is available "on-line" on Maritime Traffic Engineering Institute web site. Figure 1 presents form for entering parameters. It is possible to enter the basic ship and water region data. The remaining necessary data are taken from XML file located from the server.



Probabilistic underkeel clearance evaluation

Location:	Świnoujście
Vessel type:	BulkCarriers
Length:	210.0 m
Draught:	11.8 m
Vessel speed:	7.5 kt
Water level:	5.06 m (reference water level=5m)
Water depth correction:	0.0 m
Wave height:	0.0 m
Waterway surface width:	300.0 m
Waterway bottom width:	200.0 m

Results

Legally enforced fixed underkeel clearance: 3.13 m

Fig. 1. User defined data form for probabilistic model of underkeel clearance (UKC)

Model underkeel clearance is evaluate after running the application. The results are presented as a histogram. Also the numerical value of mean squat and conventional calculated underkeel clearance are presented (Figure 2).

4 EXAMPLE RESULTS

Example entering to the harbours of Świnoujście, Szczecin, Police and Gdańsk were simulated. Maximum draught for these harbours decided of vessels' parameters selection. In the Table 1 harbour and input data are presented. Simulation results are presented on figures 2, 3.

Table 1. Ship parameters used in simulation

Harbour Ships parameters	**Świnoujście**	**Szczecin**	**Police**	**Gdańsk**
Vessel type	Bulk Carrier	General Cargo	Chemical Tanker	Bulk Carrier
L[m]	240	160	170	280
T[m]	12,8	9,15	9,15	15
B[m]	36,5	24,2	23,7	43,3
V[kt]	6	8	8	7

The most important result is the probability that clearance is less than zero. This is the probability of accident due to insufficient water depth. Table 2 presents result of simulations as probability, values of mean squat, conventional calculated underkeel clearance, 5% and 95% percentiles of under keel clearance (UKC).

Table 2. Simulation results

Harbour Simulation results	**Świnoujście**	**Szczecin**	**Police**	**Gdańsk**
P(UKC<0)	0,02	0,033	0,04	0,006
Mean squat	0,23 m	0,32 m	0,32 m	0,30 m
Constant UKC component method	3,11 m	2,56 m	2,57 m	3,12 m
5% UKC percentile	0,15 m	1,2 m	0,04 m	0,35 m
95% UKC percentile	1,98 m	3,19 m	3,36 m	1,71 m

Results show small values of probability that clearance is less than zero. It is obvious that not all the cases when UKC<0 is ended with serious accident.

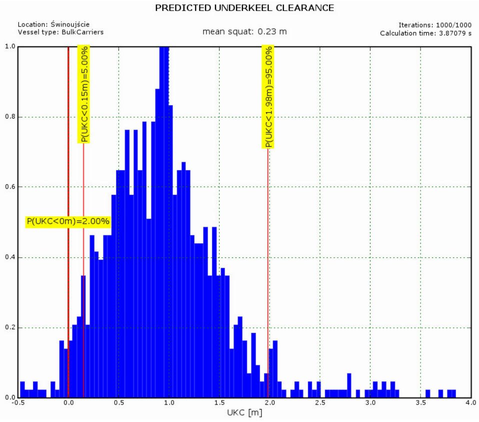


Fig. 2. Underkeel clearance simulation results at the maximum vessel's draught in Świnoujście Port (Górników Wharf)

The distribution have positive asymmetry. Mean underkeel clearance of maximal ships is equal to $UKC_M = 0,9$ m. 95% values are less than 1,98 m when value conventional calculated underkeel clearance is equal to 3,11 m.

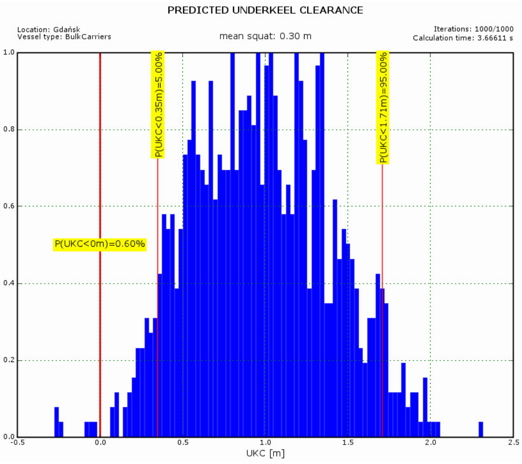


Fig. 3. Underkeel clearance simulation results at the maximum vessel's draught in North Port Gdańsk

In this case the disribution is nearly symmetrical. Mean underkeel clearance of maximal ships is in range <0,5; 1,3>. 95% values are less than 1,71 m when value conventional calculated underkeel clearance is equal to 3,12m.

5 SHIP ENTRANCE DECISION MODEL

Simplified decision model is presented as decision tree in Fig. 2 [Gucma 2004b]. The actions are denoted as *A*, possible state of nature as *P* and outcomes as *U*. The *P* can be understood as state of nature (multidimensional random variable) that could lead in result to ship accident. The main objective of decision can be considered as minimisation of accident costs and ship delays for entrance to the harbour due to unfavourable conditions. The limitation of this function can be minimal acceptable (tolerable) risk level. The expected costs of certain actions (or more accurate distribution of costs) can be calculated with knowledge of possible consequences of accident and costs of ship delays. The consequences of given decision actions expressed in monetary value can be considered as highly non-deterministic variables which complicates the decision model. For example the cost of single ship accident consist of:

- salvage action,
- ship repair,
- ship cargo damages,
- ship delay,
- closing port due to accident (lose the potential gains), etc.

The decision tree can be used also for determination of acceptable level of accident probability if there are no regulations or recommendations relating to it. If we assume that accident cost is deterministic and simplified decision model is applied (Fig. 4) then with assumption that the maximum expected value criterion is used in decision process, the probability p_a^* can be set as a limit value of probability where there is no difference for the decision maker between given action a_1 and a_2. This value can be expressed as follows:

$$p_a^* = \frac{1}{\frac{u_1 - u_3}{u_4 - u_2} + 1}$$

where: $u_1 ... u_4$ – consequences of different decisions expressed in monetary values.

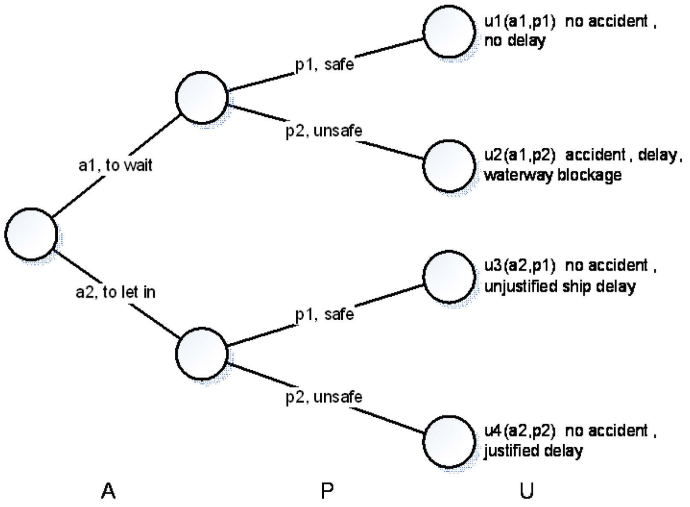


Fig. 4. Simplified decision tree of ship entrance to the port

5.1 *Costs of ships accident and delay*

Usually during the investigation of ship grounding accident on restricted waters it is not necessary to take into consideration the possibility of human fatalities nor injures. The cost of accident *Ca* could be divided into following costs:

$$Ca = Cr + Cra + Cos + Cpc$$

where: *Cr* – cost of ships repair, *Cra* – cost of rescue action, *Cos* – cost of potential oil spill, *Cpc* – cost of port closure.

The mean cost of grounding accident in these researches was calculated for typical ship (bulk carrier of 260m). The mean estimated cost of serious ship accident is assumed as $C_1 = 2.500.000$ zl (around 700.000 Euro) [MUS 2000]. The oil spill cost is not considered. Following assumption has been taken in calculations:

- number of tugs taking part in rescue action: 3 tugs,
- mean time of rescue action.: 1 day,
- trip to nearest shipyard: 0.5 day,
- discharging of ship: 4 days,
- repair on the dry dock: 2 days,
- totel of oil spilled: 0 tons.

Mean cost of loses due to unjustified ships delay according to standard charter rate can be estimated as 90.000 zl/day. It is assumed that after one day the conditions will change scientifically and the decision process will start from the beginning.

5.2 *The decision making process*

The maximization of mean expected value criterion is used to support the decision of port captain. Decision tree leads to only 4 solutions. Each decision could be described in monetary values. The expected results (losses) of given decisions are as follows:

- $u1 = 0$ zl;
- $u2 = - 2.500.000$ zl;
- $u3 = - 90.000$ zl;
- $u4 = 0$ zl.

Taking into consideration the results of grounding probability calculations of example ship entering to Swinoujscie Port (Fig.2) the probability of ship under keel clearance is less then zero equals $p2$=0.02 which is assumed as accident probability. No accident probability in this case is estimated as $p1$=1-$p2$=0.98. We can evaluate the mean expected value of given decisions *a1* and *a2* as:

- $a1 = 0$ zl+(-0.02*2.500.000 zl)= -50.000 zl;
- $a2 = $ -(-0.98*90.000 zl)+0zl= - 88.200 zl;

With use of mean expected value it can be justified to prefer action *a1* (to let the ship to enter the port) because total mean expected loses are smaller in compare to unjustified delay due to decision *a2*.

6 CONCLUSIONS

The paper presents probabilistic method of ships dynamic underkeel evaluation. Previously developed Monte Carlo model was implemented as online program. The program allows to calculate the probability of grounding accident with consideration of several uncertainties.

Simplified decision model based on mean expected value was presented and applied in case study of ships enter to Świnoujscie. Results were discussed.

The model after validation is intended to be used in every day decision making practice of port captains and VTS operators.

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