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SEQUENTIAL RISK MODEL FOR SHIP MANOEUVRING OPERATIONS IN THE HARBOUR

ABSTRACT

The paper presents the sequential risk model of ship manoeuvring operations in the harbour. The risk of the sequence of manoeuvring procedures performed by a self-manoeuvring vessel in the harbour during approach, entry into the harbour and berthing inside the docks has been expressed as a function of the conditional probabilities of the sequential operations and their consequences.

Keywords: Navigational Risk, Manoeuvring Operations.

INTRODUCTION

The main tendencies in the improvement of safety are now the effective vessels traffic monitoring and introduction of Harbour Safety Management Systems. The main tools used in the harbour safety management systems are the determination of risk and risk management.

To determine the risk of a self-manoeuvring ship navigating in the harbour area a sequence of manoeuvring tasks should be considered. For this purpose, a sequential approach to navigational risk of harbour operations has been proposed and the sequential risk model has been constructed. The complex navigational task of calling the harbour by a self-manoeuvring vessel can be defined as a following sequence of the manoeuvring tasks: the navigation along the approach channel, entry into the harbour and berthing inside the docks.

The risk model allows for the calculation of the exposure to events classified as hazards, which represent the accident scenarios. The magnitude of the risk is a function of both the probability that the event will occur and its consequences.

Within the safety management systems in ports, four groups of hazards are identified with respect to their consequences [1]. They are related to life, property, environment and port business.
The consequences are defined in dependence on people injuries, financial losses, including the period of the restrictions or closure to navigation (for several days - for major, serious and long term loss of trade - for the catastrophic consequences), time to clean up of the polluted area and community disruption. The proposed sequential risk model is related to the safety of self-manoeuvring vessel.

The holistic risk model, formulated on the basis of the conditional probabilities determined for sequential manoeuvring tasks allows for the global assessment of ship safety during harbour operations. The limitations of the model are the qualitative parameters based on the expert opinion.

SEQUENTIAL HAZARDS IDENTIFICATION

Hazards identification process in the harbour is dependent on the local conditions and it looks at the whole system, including pervious accidents and incidents, personnel opinions and reviewing of the currently used processes.

With respect to the navigational risk of the self-manoeuvring ship calling the particular harbour the factors considered in the compilation of the hazard lists are as follows:

- human factor (qualification, training, working hours of the personnel on board the ship and personnel in port);
- factors related to the ship (general operational characteristics, navigational equipment, communication systems, load type and loading equipment);
- factors related to the port (infrastructure, port – ship communication systems, port facilities, port services - pilot boat, tug boat services, port operational procedures, traffic management, aid to navigation, loading/unloading operations, port emergency services);
- environmental conditions: sea state, wind, tides, currents, fog, rain, light conditions.

In the sequential approach to hazard scenario development the sequence of manoeuvring tasks is considered. The sequential analysis is appropriate to the case when the chain of known sequential factors causes accidents [2].

The fazes of the sequential task of self-berthing ship calling the harbour are as follows:

A – approaching - navigation along the approach fairway,

B – entry into the harbour,

C – transit inside the harbour,

D – berthing inside the docs.

The analysis of the sequential risk is based on the classes of events related to the hazards possible in each phase of the sequential task. The following classes of events related to the ship have been introduced (Table 1).

Table 1. Classes of events with respect to the hazards related to the ship

Phase	Class	Description
A	1	the ship is safely navigating along the approach channel, the ship motion parameters are appropriate for the safe approach to the port entrance
	2	the ship is navigating along the approach channel, some of the ship motion parameters are outside the assumed safety range
	3	operational failure – the manoeuvring task can not be continued
B	1	safe entry into the harbour through the port entrance
	2	safe entry under the condition of slight modification of recommended ship motion parameters or manoeuvring procedures
	3	contact with the entrance heads
C	1	safe and undisturbed transit inside the harbour
	2	safe transit with some of the ship motion parameters outside the assumed safety range for the docks, hazards for other ships or port infrastructure can be generated
	3	collision with another ship or contact with the harbour facilities
D	1	safe performance of berthing operation, permissible berthing parameters are not exceeded
	2	the limits of permissible ship-berth interaction forces are exceeded, small damages of fendering system, ship side shell plating or protective coatings, further safe ship operation is not interrupted
	3	serious damage of ship or berth, termination of ship operation

The transitions from the particular classes of events in the particular phases for classes 1 and 2 can be defined separately for each transition. Class 3, in all phases of the sequential task, is the absorbing event, which absorbs the operational energy of the ship. Every event classified in this class interrupts the performance of the task.

Fig. 1 presents the transitions of events between classes, developed on the basis of experts opinion.

The possible ways of scenario development, determined on the basis of the classes of events, show that the particular faze of the sequential task can be terminated even if the events in preceding phases were in class 1. The small disruptions can be prevented or mitigated in each phase, if the preceding event belongs to class 2. If one of the subsequent events is anticipated in class 3 the task should be terminated immediately.

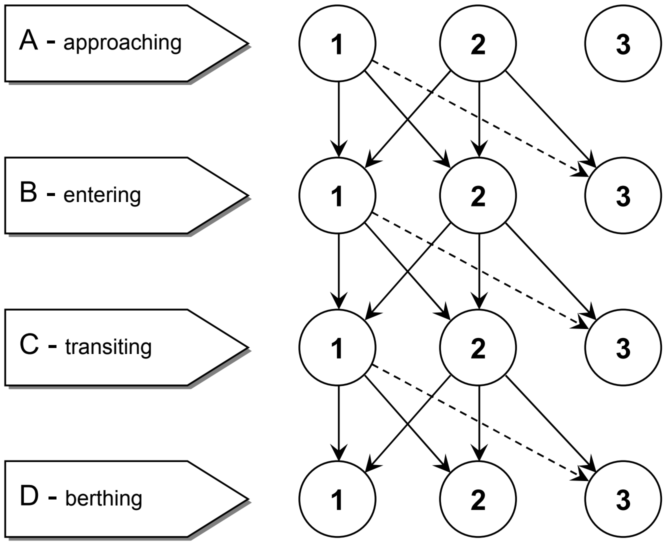

Fig. 1. Transitions of events between classes

Table 2. describes the transitions between classes. The transitions are described by probability distribution functions determined form the ship performance analysis.

Table 2. Transitions of events between classes

Transitions between classes	Description
$1 \to 1$	proper performance of operational procedures, effective online correction of ship motion parameters
$1 \to 2$	small operational errors are cumulated, significant human error or change to worse weather conditions
$1 \to 3$	rare event, unpredictable in time (the exponential distribution in time can be assumed)
$2 \to 1$	improvement of weather conditions, corrections of the operational procedure due to the external assistance (tug boats assistance [3])
$2 \to 2$	not fully effective correction of ship motion parameters, the correction does not keep up the changing external conditions (weather or traffic conditions [4])
$2 \to 3$	errors control failure, change to worse weather conditions

SEQUENTIAL RISK MODEL

The consequences in the sequential risk model are related to the ship operational procedures. In the following classification of the consequences they are considered with respect to the operational parameters. In case of the catastrophe, which results could be sinkage, loss of stability or grounding the significant threats to human life and environment are considered [5]. Description of the classes of consequences is presented in Table 3.

Table 3. Classes of consequences

Classes of consequences	Description
0	insignificant - there are no negative consequences
1	minor - slight damages of the side shell or coatings which do not interrupt normal ship operation
2	moderate - operational time delay
3	major - significant damages of ship construction, eliminating the ship from normal operation
4	catastrophic - sinkage, loss of stability or grounding

The risk of the sequential manoeuvring task (equation (1)) is the product of hazard probability during ship approach, conditional probability of the hazards during ship entry under the condition of safe ship approach along the fairway, conditional probability of the hazard during transit under the condition of safe ship approach along the fairway and safe ship entry, conditional probability of the hazard during berthing under the condition of safe ship approach along the fairway, safe ship entry, safe ship transit inside the harbour and weight factors of the consequences of the hazards respectively: S_{A3}, S_{B3}, S_{C3}, S_{D3}, $S_{A,B,C}$.

$$R_s = \sum_{r=1}^{2} P(A_r) \cdot \left\langle \sum_{k=1}^{2} P(B_k / A_r) \left\{ \sum_{n=1}^{2} P(C_n / Ar \cap B_n) \cdot \right.\right. \\ \cdot \left[\sum_{u=1}^{2} P(D_u / A_r \cap B_k \cap C_u) \cdot S_{A,B,C} + \right. \\ \left.\left.\left. + P(D_3 / A_r \cap B_k \cap C_u) \cdot S_{D_3} \right] + P(C_3) S_{C_3} \right\} + P(B_3) S_{B_3} \right\rangle + P(A_3) S_{A3} \tag{1}$$

CONCLUSIONS

The model parameters should be assessed on the basis of:

- historical data with respect to the hydro-meteorological conditions and traffic data (frequency of calling the harbour by a particular ship),
- operational parameters of the fairways (water depth, width and shape of manoeuvring area),
- permissible trajectories for the safe ship navigation (determined on the basis of ship motion simulation),
- heuristic analysis of ship entry and berthing based on the experts opinion.

The implementation of the model allows for the safety assessment of the sequential navigation task, assessment of the hazards existing in particular phases of the navigational task, online control of ship performance during manoeuvres, enhancement of ship safety, development of risk management tools to break the chain of events and decrease of risk for port infrastructure, operation and environment [6, 7].

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