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# Application of Ship Motion Simulation in Reliability Assessment of Ship Entrance into the Port

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ABSTRACT: The growing number of large container vessels is the reason of port infrastructure modernization necessity and changes of local bylaws in ports. The accessibility studies based on ship motion simulation allow for the assessment of manoeuvring operations safety for the new port designs and reconstructions of the existed infrastructure. Several factors can be used to determine safety of manoeuvring operations. The paper presents an approach to determine the operational reliability which can be included in an accessibility study to determine the best of the possible solutions with respect to the ship entrance into the harbour. The general reliability model has been proposed and an example of reliability of ship entrance into the Port of Gdynia is presented.

## 1 INTRODUCTION

In modern ports due to the economic reasons port manoeuvres of large vessels are commonly performed in conditions closed to the limits related to ship dimensions, under keel clearance, weather conditions and towing assistance. This is mainly caused by the introduction of ultra large container ships (ULCS) over 8,000 TEU (twenty-foot equivalent unit), of 300 – 400 m length, equipped with 2000-3500 kW thrusters and 60 – 80 MW propulsion systems (Hermans & Degens, 2011, Willemset al, 2013) operated i.a. in the direct services Europe – Asia. are Post Panamax Plus of 6000 – 8000 TEU capacity, New Panamax of 11000 – 13000 TEU capacity and Post New Panamax (Suezmax) of 15000 – 19000 TEU capacity, single or twin propeller vessels. They can perform manoeuvres in very tight areas and strong weather conditions, up to port operational limits, using their thrusters and propellers to increase efficiency of manoeuvres assisted by tug boats.

The bottle necks of ships accessibility in most ports are the narrow port entrances and small turning basins (PIANC, 2014). There are several phenomena which should be considered in the risk assessment of error during manoeuvring in restricted waters (Abramowicz-Gerigk&Burciu, 2012; Abramowicz-Gerigk&Burciu; 2014, Gerigk, 2012; Eloot et al., 2010). Ship motion simulation can be used to determine the risk of a particular manoeuvre (Alfredini et al., 2011; Gucma, 2009), safe manoeuvring area and limiting weather conditions combined with experts opinion (Abramowicz-Gerigk &Hejmlich, 2015; Hejmlich, 2014). The action reliability can be included in accessibility study to determine the best of the possible solutions with respect to the manoeuvring tactics of the ship entrance into a harbour.

## 2 RELIABILITY OF SHIP MANOEUVRING OPERATIONS

Operational safety is related to both potential and real hazards of manoeuvring operations performed by a ship master during ship approach and entry into a harbour. The risk management on ship arrival in a port is a decision making process in the area of risk consisting of making optimal decisions with respect to the existed hazards and accepted risk level (Burciu, 2012).

The risk related to manoeuvring operations can be compared to the operational risk – the risk of losses due to incorrect and malfunction internal processes, personnel, technical systems and external events (Hetherington et al., 2006; Mokhtariet al., 2013). This is mainly due to the main influence of human factor on the losses which the operational risk level is dependent on. They are mostly not repeatable and difficult to predict.

The voyage of a vessel which is a transportation task can be considered as an implementation of risk management procedure. Under this assumption the ship entry into a port is the implementation of risk control and monitoring – the last stage of risk management of PMI - Project Management Institute (www.projectinsight).

The operational reliability of ship entering a harbour is the probability of failure-free ship performance during sailing along the approach channel, passing the port entrances, inner port canal and docs, ship turning and berthing manoeuvres. It can be expressed as follows (2.1) and (2.2):

$$K = P(Z = 1) \tag{2.1}$$

$$P(Z = 1|X = 1|) = K_r \tag{2.2}$$

where:
$K$ – is an operational reliability, probability of failure-free task performance,
$K_r$ – is a probability of task performance by a manoeuvring vessel,
$Z$ – the characteristic parameter of the state of the object reliability (1 – operationally reliable (task performed), 0 – operationally unreliable (task not performed),
$X$ – the characteristic parameter of the object reliability (1 – there are no infecting factors as failures, hydrometeorological conditions, ship movement, towing operations, human factor; 0 – there are exiting infecting factors).

## 3 EXAMPLE OF RELIABILITY ASSESSMENT OF SHIP ENTRY INTO THE PORT OF GDYNIA

Port of Gdynia is a universal modern port specializing in handling unitized cargo transported in the lo-lo and ro-ro systems, based on the network of multimodal connections including hinterland, Short Sea Shipping Lines and ferry connections. It is an important link in the Corridor VI of the Trans-European Transport Network (www.port.gdynia.pl).

The previously performed accessibility study of ULCS based on ship motion simulation carried out in the environment of an interactive Full Mission Simulator SimFlex Navigator 4.6 confirmed the port accessibility for the ultra large container ships under particular conditions. The numerical model of navigational area of Port of Gdynia has been developed by Ship Operation Department of Gdynia Maritime University in two variants of port infrastructure - the existed and after a possible reconstruction. The data bases of the terrain were developed using specialized programming tools compatible with Simflex Navigator Area Engineer for Full Mission Ship Handling Simulator SimFlex Navigator version 4.6 based on Nebula Device 2.

The main bridge of Full Mission Simulator SimFlex Navigator 4.6 and Port of Gdynia visualization is presented in figure 1.

Figure 1. Port of Gdynia visualization in the environment of main bridge of Full Mission Simulator SimFlex Navigator 4.6

Full mission simulation creates the environment of real navigational and working conditions including collaboration between ship master, pilot, tug master and vessel traffic services and is the best tool for the operational safety and reliability studies of ship manoeuvring in restricted waters (Gong et al., 2006).

The reliability assessment of ship entry into the port has been performed taking into account 3 stages of ship entry: A, B, C, D related to the particular areas and necessary course changes:

A. Navigation along the approach channel:
   - approach channel width at the sea bed: 150 m, minimum water depth: 14.1 m,
   - maximum ship draft 13 m at medium or high waters,
   - distance between „G1-G2” buoys – the approach channel gate to the main entrance 2780 m = 1.5 Nm,
   - width of the „G1-G2” gate: 185 m.

B. Passing the main entrance:
   - width of the main entrance: 150 m,
   - maximum ship draft 13 m.

C. Passing the inner entrance:
   - distance between main entrance and internal entrance: 980 m,
   - width of the internal entrance 100 m,

– maximum ship draft 13 m.

D. Navigation along the inner port canal.

Every stage of ship entry (A,B,C,D) requires 3 course changes in leading lines in the restricted area. The required course changes are presented in figures 2 and 3 - for a ship not turned on arrival and for the ship turned on arrival in Turning Basin No. 2 - respectively.

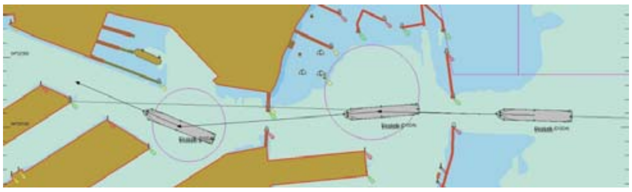

Figure 2. Ship entrance into the Port of Gdynia without turn on arrival.

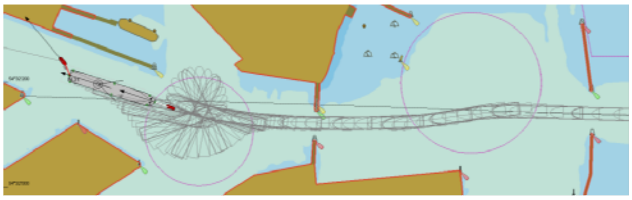

Figure 3. Ship entrance into the Port of Gdynia – ship turned in the turning basin on arrival

For the ship following the sequential leading lines during entry into the port the risk R of the manoeuvring error during ship entry is a function of the events related to the ship courses $KR_i$, i=1, 2, 3 corresponding to the leading lines and can be presented as follows (3.1):

$$R = R(\{KR_1, KR_2, KR_3,\}) \quad (3.1)$$

For the assumed minor faults in course keeping of the $i^{th}$ course $KR_i$, $i$=1, 2, 3 which can be corrected in the next stage of the ship entry, the total probability of a failure during the sequence of four events A, B, C, D:

- $KR_A=KR_B=Kr_1$,
- $KR_C=Kr_2$,
- $KR_D=Kr_3$

can be determined using the chain rule - equation (3.2).

$$P(KR_A \cap KR_B \cap KR_C \cap KR_D) = P(KR_A) \cdot P(KR_B|KR_A) \cdot P(KR_C|KR_A \cap KR_B) \cdot P(KR_D|KR_A \cap KR_B \cap KR_C) \quad (3.2)$$

The risk of failure during ship entry into the port is dynamic in nature as it is the result of fast organizational changes in ship command-control and environment (Khakzad et a., 2012). It can be determined applying the consequences of ship failure, expressed in qualitative or semi-quantitative values related to i.e. the safe distances from the port infrastructure (Abramowicz-Gerigk, 2012).

The counteraction to the hazards existed during sequential stages of ship entry into the port (A, B, C, D) in the particular time and at absolute level of acceptable risk can be called risk management of ship entrance manoeuvres - the system of methods and actions (throttle settings, course corrections) aiming to keep the axis of a fairway to keep the vessel on the designated course during A, B, C, D events.

The operational reliability of ship manoeuvring during taking and keeping the course in A, B, C, D events is called the course reliability.

It is defined as an operational characteristic of a ship determining that the ship can safely perform the task of entry into the port on $K_{A,B,C,D}$ courses in particular weather conditions. The course reliability can be expressed in the form of equation (3.3).

$$R(^o) = P_R(\Delta A \geq |\Delta\alpha|) \quad (3.3)$$

where:

R(°) – is course reliability during the ship entry stages A,…,D;

Δα - is a sector of the safe ship courses in a particular ship entry stage,

*ΔA* – is a sector of safe courses for keeping in the heading line.

For example the course reliability for $KR_A$ the assumed sector 5° (+/-2.5°) can be determined as follows*:*

$$\Delta A = 2.5^o$$

$$R(^o) = P_R(2.5^o \geq |\Delta\alpha|)$$

Course reliability enhancement options for ship entrance into the harbour

The course reliability enhancement can be obtained by the implementation of several options:

- decision support systems,
- changes of the port infrastructure layout:
  - widening of inner entrance,
  - building an outer port.

An example of a decision support system for the ship entry into the port called Ship Virtual Mask (VSM) has been introduced in (Abramowicz-Gerigk&Burciu, 2010). VSM allows determining a complex safety measure for the manoeuvring operations along the approach channel.

It is based on the real time information about weather and traffic along with the prediction models. Statistical emulator provides the necessary estimates determining the most probable circulation patterns from the actual atmospheric forcing field.

The models of ship motion of higher accuracy than the generally accepted models used in applications dedicated for design and training include stochastic transfer functions for wind and current forces generated on a hull.

Ship entry into Port of Gdynia - navigation along the approach channel under the wind and unexpected, wind generated, transverse surface current in front of main entrance is presented in figure 4.

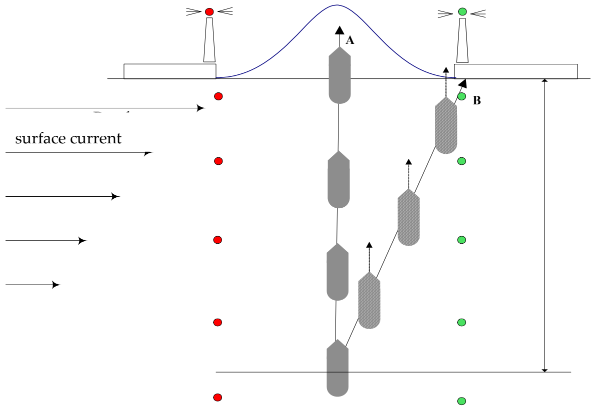


Figure 4. Ship entry into Port of Gdynia – navigation along the approach channel under the wind and unexpected, wind generated, transverse surface current in front of main entrance

Ship entry into Port of Gdynia – navigation along the approach channel under the wind and unexpected, wind generated, transverse surface current in front of main entrance - allision with the entrance head is presented in figure 5.

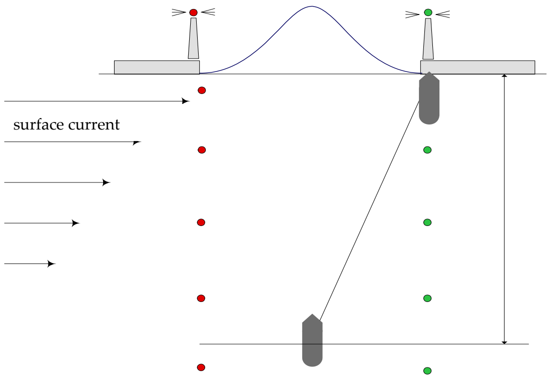


Figure 5. Ship entry into Port of Gdynia – navigation along the approach channel under the wind and unexpected, wind generated, transverse surface current in front of main entrance - allision with the entrance head

The safe ship entry into Port of Gdynia – navigation along the approach channel under the wind and unexpected, wind generated, transverse surface current in front of main entrance – using Virtual Ship Mask System (VSM) is presented in figure 6.

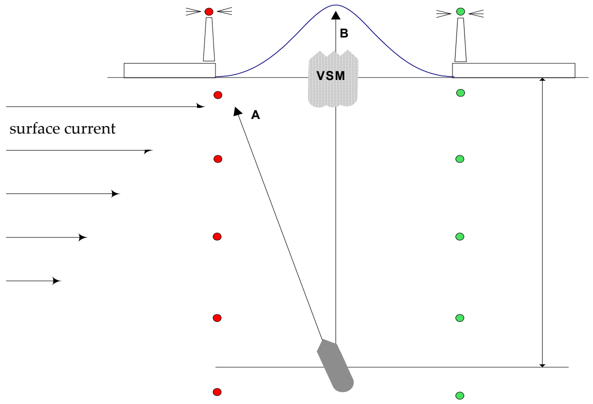


Figure 6. Ship entrance into Port of Gdynia – navigation along the approach channel under the wind and unexpected, wind generated, transverse surface current in front of main entrance – safe entrance using Virtual Ship Mask System (VSM)

The ship entry into Port of Gdynia after the widening of the internal entrance needs only a 1-2° change of ship heading. The navigation light sector of a new leading line is presented in figure 8.

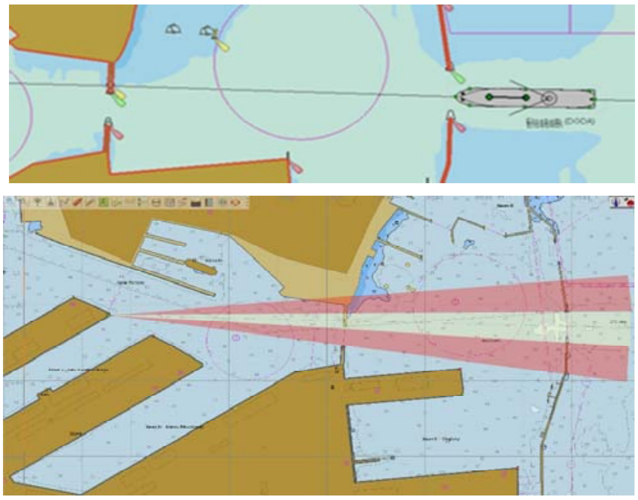

Figure 8. Ship entrance into Port of Gdynia – widened internal entrance, navigation light sectors of a new leading line

A concept design of outer port in Gdynia is presented in figure 8. The new solution allows safe ship entry using only one leading line.

Figure 7. Concept design of outer port in Gdynia

## 4 CONCLUSIONS

Operational reliability usually defined as the probability of failure-free performance of a task over a specified time frame, under specified environmental conditions e.g. quality over the time with respect to the ship course reliability has been expressed in the paper as a quality over the course change, related to the ship course stability and layout of the port infrastructure. The course reliability determined for the successive stages of ship entry into the port allows for the quantitative assessment of different solutions of manoeuvring tactics related to the outline of the a infrastructure.

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