

Safety of Shipping when Navigating on the PS Class Container Vessel "Emma Maersk" While Approaching DCT Terminal in Gdańsk Port Północny

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ABSTRACT: In this paper author presents the methods that can be used for estimating the safety of shipping (navigational risk) in the restricted sea areas of the Gulf of Gdansk by means of a three-dimensional model of ship's domain specified for the PS Class container vessels "Emma Maersk". The essence of the method suggested in the thesis is the systematic approach to a sea vessel operation in the aspect of estimating its safety while approaching DCT terminal in Gdańsk Port Północny in the divergent exterior conditions.

1 INTRODUCTION

There are numerous criteria that can be used for estimating the safety of navigation in the restricted sea areas. Yet, most of them are not standardized, which can cause problems with distinguishing the sea areas difficult for navigation and the restricted sea areas and classify them as 'easy' or 'difficult' for navigation. It is also hard to present the 'scale of difficulty' in navigating in a given sea area by means of numbers or symbols, as such a system has not been established so far [4].

In this article we try to establish, if possible, the standard, i.e. universal method to classify the sea areas difficult for navigation with regard to the concept of uniform safety system of transport in the sea area restricted by a safety margin, defined by the outline of a three-dimensional domain of a ship [6].

The risk analysis has been prepared for PS Class container vessels "Emma Maersk" from AE10 Far East Asia-Europe Service in the Deep Container Terminal (DCT) Gdansk Port Polnocny. Navigational risk for the ships manoeuvring in the restricted sea area has been estimated with respect to varied outer

interference (average and extreme condition) on the approach to Gdańsk Port Północny DCT terminal alongside the currently exploited eastern fairway by means of a three-dimensional model of ship's domain [6], [7].

2 NAVIGATIONAL RISK ANALYSES WHEN PROCEEDING IN RESTRICTED SEA AREAS

In this chapter we present methods that can be used for estimating safety of navigation (navigational risk) in the restricted sea areas by means of the model of the ship's domain [6], the definition of the navigational risk [7] and the simple ship's domain formulas (from [6]) for estimating the ship's domain parameters (see Fig.1): including the depth of the ship's domain (G_D), the height of the ship's domain (W_D), the length of the ship's domain (D_D) and the beam of the ship's domain (S_D). Then, using all above information by means of the three-dimensional model of the ship's domain and knowing the parameters, we are going to try to establish the navigational risk in a vertical (R_{NG} , R_{NW}) and horizontal (R_{NDz} , R_{NDr} , R_{NSp} and

R_{NSI}) plane for a PS class Container vessel like “Emma Maersk” in the ballast and/or loaded condition when navigating on the east fairway to DCT Terminal in the Gulf of Gdansk (sea area restricted with the overall dimensions 350 meters in breadth, 17 meters in depth and 253,6°-073,6° direction) in the divergent exterior conditions (average and extreme).

According to the ship’s domain definition [6], every ship will be safe (in navigational meaning) as long as she is the exclusive object which can generate danger within her domain.

With reference to a vertical plane OZ of the three dimensional co-ordinates XYZ established down from the central point of the local ship’s reference system, one can affirm unambiguously that every ship will remain safe as long the value of G_D is smaller than the real value of the sea depth h (see Fig.1). Therefore, component R_{NG} of R_N can be referred to as the vertical component of the navigational risk that concerns keeping under keel clearance, or risk concerning under keel clearance. The component mentioned above can be depicted by means of the following formulas:

$$R_{NG} = \begin{cases} 0 & \text{when } h > G_D \\ 0 \div 1 & \text{when } T_{max} < h \leq G_D \\ 1 & \text{when } h \leq T_{max} \end{cases} \quad (1)$$

Formula (1) indicates that the value zero of the navigational risk [7], deriving from factors (objects) A_i , signifies total navigational safety with respect to these factors (objects). Consequently, according to the formula (1), assumption $h > G_D$ can be defined as the guarantee of the safe shipping - navigation with reference to all underwater objects or obstructions immersed on the depth smaller than h . If sea depth h is smaller or equal to the ship’s draft T , that is $h \leq T_{max}$, according to the formula (1) sea passage can be unfeasible¹³ or highly risky. In that situation the value of the navigational risk R_{NG} will equal one (see formula (1)), and in all probability it will signify unquestionable (100%) risk of collision with some underwater objects immersed on the depth less than h .

Furthermore, we can also say that the value of navigational risk R_{NG} for the sea depth h limited between T_{max} and G_D ($T_{max} < h \leq G_D$) will be limited between zero and one ($R_{NG} \in [0,1]$) (see formula (10) the middle line). General formula, which can be used to estimate navigational risk R_{NG} , depending on h factor from the range ($T_{max} < h \leq G_D$), is presented below:

$$R_{NG} = \frac{G_D - h}{G_D - T_{max}} \quad (2)$$

Similarly, risk analyses that refer to all objects hanging in the air above the water (see Fig.1) can be carried out just as it was done in case of all underwater objects i.e. obstructions. Therefore, component R_{NW} of the navigational risk R_N (let’s call it the vertical component of navigational risk that

concerns keeping air draft clearance, or shortly risk concerning air draft clearance) can be depicted by means of the following formulas:

$$R_{NW} = \begin{cases} 0 & \text{when } H_o > W_D \\ \frac{W_D - H_o}{W_D - H_N} & \text{when } H_N < H_o \leq W_D \\ 1 & \text{when } H_o \leq H_N \end{cases} \quad (3)$$

where:

H_o - distance between water level and the height of the nearest objects hanging above the water (for bridge vertical clearance above HW (high water), [m]; H_N - ship’s air draft, (distance between waterline to the highest point on the ship’s hull), [m].

Similarly, with reference to horizontal plane OX (see Fig.1) R_{NDdz} and R_{NDr} components of the navigational risk R_N (let’s call them horizontal components of the navigational risk that concern keeping safe distance from the nearest danger adequately ahead and astern of the ship, or just the risk concerning safe distance ahead and astern) can be depicted by means of the following formulas:

$$R_{NDdz} = \begin{cases} 0 & \text{when } d_{Ndz} > D_{Ddz} \\ \frac{D_{Ddz} - d_{Ndz}}{D_{Ddz} - L_{RD}} & \text{when } L_{RD} < d_{Ndz} \leq D_{Ddz} \\ 1 & \text{when } d_{Ndz} \leq L_{RD} \end{cases} \quad (4)$$

and

$$R_{NDr} = \begin{cases} 0 & \text{when } d_{Nr} > D_{Dr} \\ \frac{D_{Dr} - d_{Nr}}{D_{Dr} - (L - L_{RD})} & \text{when } (L - L_{RD}) < d_{Nr} \leq D_{Dr} \\ 1 & \text{when } d_{Nr} \leq (L - L_{RD}) \end{cases} \quad (5)$$

Interpretation of formulas (4) and (5) will be carried out similarly to the presentation of navigational risk R_{NG} and R_{NW} in case of vertical navigational reserve. Hence, the assumptions $d_{Ndz} > D_{Ddz}$ from formula (4) as well as $d_{Nr} > D_{Dr}$ from formula (5) constitute the guarantee of safety of shipping (navigation) with reference to all objects (obstructions) detected adequately ahead d_{Ndz} and astern d_{Nr} of the ship. When analysing formula (4) one can also notice that the value of navigational risk limited between zero to one ($R_{NDdz} \in (0,1)$) will come into being only if the value of the distance to the nearest danger ahead of the ship d_{Ndz} will be either less or equal to the length of the ship’s domain ahead D_{Ddz} . In all probability, assumption $d_{Ndz} < L_{RD}$ will signify navigational accident or collision with some objects (obstructions) detected ahead of the ship or unquestionable (100%) risk of collision with those objects. A questionable situation concerns those objects that move with some speed and have their own domain, the value of which normally decreases d_{Ndz} parameter.

Similarly with reference to the horizontal plane OY (see fig. 1) distinguishers R_{NSI} and R_{NSp} of the navigational risk R_N (let’s call them horizontal components of the navigational risk that concern keeping safe distance to the nearest danger adequately on port and starboard side of the ship, or, in short, risk of keeping safe distance to port and starboard side) can be depicted by means of the following formulas:

¹³ In our analyses we exclude the situation, when the ship can change her draft due to for example deballasting operation.

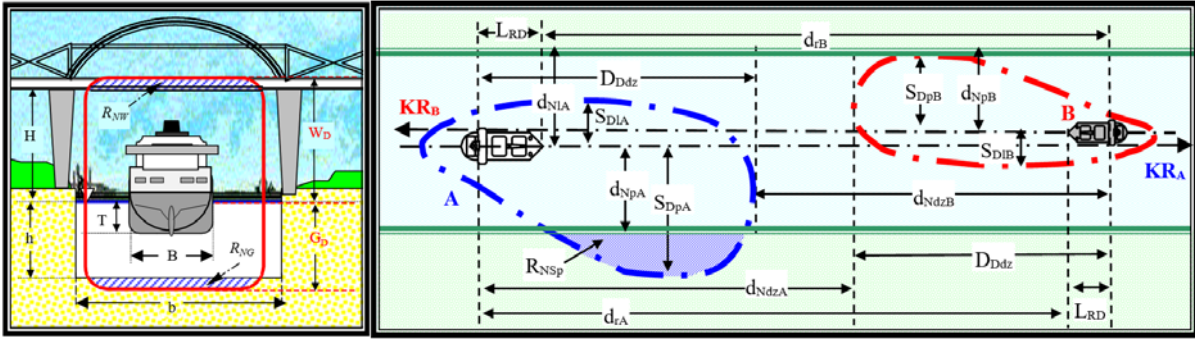


Figure 1. Presentation of navigational risk for ship passing along a narrow fairway (channel) with shallow water and bridge.

Table 1. Navigational parameters and hydro-meteorological factors observed in the Gulf of Gdansk on deepwater easter fairway leading to terminal DCT Gdansk Port Polnocny; the parameters of fairway are: breadth $b=350$ m, depth $h=17,0$ m, direction $KR=253,6^\circ-073,6^\circ$. All data described in this table has been recognized as the representative factors used for the navigational risk assessment in the Gulf of Gdansk for the average and extreme navigational conditions. All data has been collected on the basis of research works and statistical information provided by Hydrographic Office of the Polish Navy (HOPN), Maritime Office in Gdynia, Baltic Pilot Admiralty Sailing Directions (NP20) and VTS service for the Gulf of Gdansk.

Average Navigational Conditions	Extreme Navigational Conditions
Visibility good, calm sea $h_f \leq 1$ m, wind moderate 3-4° B, current rate $vp \leq 1,0$ kn and direction 090° , vertical oscillation of sea surface established according to Chart Datum (Mean Sea Level) $\pm 0,10$ m ($h=16,90$ m); sea water density $\gamma_1=1,00525$ g/cm ³ , Total deviation (drift) of the vessel less than $\pm 1^\circ$, maximum yawing $\pm 1^\circ$, list $\alpha \leq \pm 1^\circ$	Visibility moderate to restricted, sea moderate in some places agitated ($h_f \approx 3$ m), wind 6-7° B, current rate $vp \approx 3,0$ kn and direction 344° (perpendicular to fairway line), vertical oscillation of sea surface established according to Chart Datum (MSL) $\pm 0,60$ m ($h=16,40$ m), sea water density $\gamma_2=1,00250$ g/cm ³ , Total deviation (drift) of the vessel $\pm 2^\circ$, yawing $\pm 2^\circ$, list $\alpha \leq \pm 5^\circ$

$$R_{NSI} = \begin{cases} 0 & \text{when } d_{NI} > S_{DI} \\ \frac{S_{DI} - d_{NI}}{S_{DI} - 0,5B} & \text{when } \frac{B}{2} < d_{NI} \leq S_{DI} \\ 1 & \text{when } d_{NI} \leq \frac{B}{2} \end{cases} \quad (6)$$

and

$$R_{NSp} = \begin{cases} 0 & \text{when } d_{Np} > S_{Dp} \\ \frac{S_{Dp} - d_{Np}}{S_{Dp} - 0,5B} & \text{when } \frac{B}{2} < d_{Np} \leq S_{Dp} \\ 1 & \text{when } d_{Np} \leq \frac{B}{2} \end{cases} \quad (7)$$

Therefore, the risk analyses R_N is going to be calculated for PS class container vessel "Emma Maersk" when navigating on the Gulf of Gdansk on east fairway leading to DCT Terminal in Gdańsk Port Północny, which is restricted by their draught ($h_1=17$ m) and breadth ($b_1=350$ m) in divergent exterior conditions and other factors.

On the basis of research and longterm observation carried out in the Gulf of Gdansk [1], [3] it has been established, that all navigational parameters and hydro-meteorological factors described in Table 1 can be recognized as the representative factors used for navigational risk assessment in the Gulf of Gdansk for average and extreme navigational condition.

3 NAVIGATIONAL RISK ASSESSMENT WHEN NAVIGATING ON THE PS CLASS CONTAINER VESSEL „EMMA MAERSK”

The PS Container class vessels such as "Emma Maersk" have a carrying capacity about 15000 TEU. They have been appointed to the Far East service AE10 between Asia and Europe for the world-wide Maersk Line operator in the Deep Container Terminal DCT Gdansk Port Polnocny. PS class vessels are recognized as the biggest container vessels that can operate on the Baltic Sea.



Figure 2. PS class container vessel "Emma Maersk" appointed to the AE10 Far East service between Asia and Europe in Maersk Line for DCT terminal in Gdańsk Port Północny. Source: <http://www.maerskline.com>.

The container vessel "Emma Maersk" (IMO 9321483) is characterized by the following data: length over all LOA= 397,60 m, breadth $B=56,40$ m, $C_B=0,598$ coefficient factor, height $H_c=76,50$ m and

maximum draught $T_{max}= 16,02$ m (however service in the DCT terminal in Gdansk is expected with reduced draft $T_{zr}= 14,50$ m), 156907 DWT, displacement 218788 tons, light vessel 61881 t, the masses of segregation ballast water 60338 t, 170794 GT, 55396 NRT and carrying container capacity 14770 TEU. "Emma Maersk" has been equipped with a 80 MW power plant Wartsila Sulzer 14RT-Flex96c (80080 kW, MCR 108877 HP / 68 068 kW, CSR 92545 HP), 5 diesel engine generators MaK 9M32C with power 4140 kW each and 8500 kW steam-gas main engine power unit. The vessel has been equipped with a clockwise fixed propeller, the mass of which is 135 tons. The ship is able to proceed with maximum speed forward $V_{max}= 27,5$ kn (50,9 km/h). However the usual operational speed is about $V_e= 24,5$ kn (45,3 km/h). Two *Rolls*

Royce bow thrusters and two *Rolls Royce* stern thrusters with a pitch propeller and 25 tons pressure, effectively increase her manoeuvring ability. The bow thrusters and the stern thrusters are installed adequately 2,77 m above the keel. The bow thrusters are installed 38,19 m and 44,44 m from a bow line, stern thrusters 38,50 m and 44,72 m from a stern line. In bad weather conditions rolling and pitching can be reduced by using *Litton Sperry Fin Stabilizers*. The Main Engine computer automatically checks 8000 points from the different sensors and indicators. Due to this fact the ship is manned only by 13 crewmembers. "Emma Maersk" is equipped with two anchors, 29 tons each and 2 x 14 shacles (2 x 385 m) anchor chain.

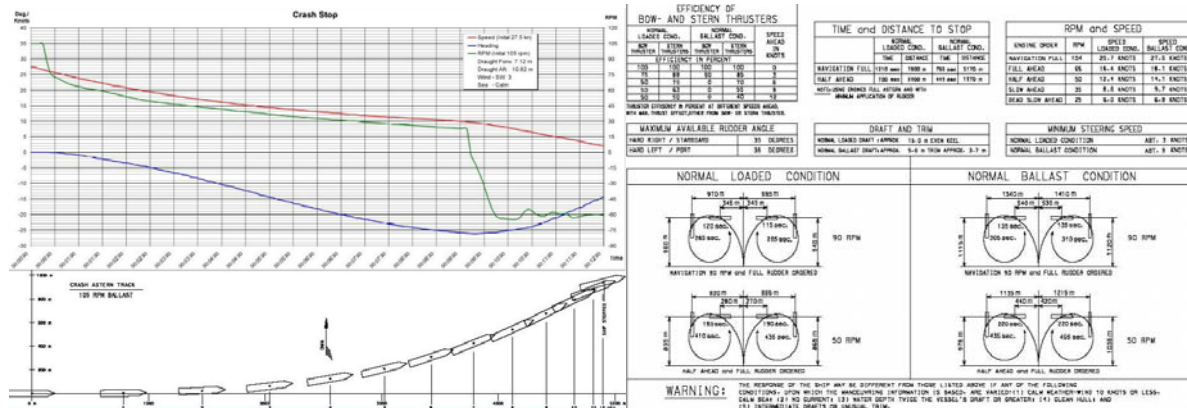


Figure 3. Ship's particulars and a wheelhouse poster from the PS class container vessel "Emma Maersk". All manoeuvres data checked on calm sea (2°), with no current, wind up to 10 kn and sea depth two times bigger than the draft of the vessel. Source: Maersk Line Ship Handling 8.02.01 and Ship Manoeuvrability L203-L210 documentation.

Table 2. Ship's domain estimated for "Emma Maersk" PS class container vessel proceeding on a deepwater eastern fairway to DCT terminal in Gdansk Port Polnocny depending on a ballast or loaded condition and the ship's speed.

EASTERN MAIN FAIRWAY - DIRECTION $253,6^\circ-073,6^\circ$ (fairway parameters: breadth $b= 350$ m and depth $h = 17,0$ m; direction $KR=254^\circ$)

MAIN ENGINE POSITION	LOADED CONDITION (D=156907 t) TD= 14,50 m; TR= 14,50 m; $T_{max} = 14,99$ m for $\alpha \pm 1^\circ$ and 16,90 m for $\alpha \pm 5^\circ$							BALLAST CONDITION (D=122219 t) TD=7,10 m; TR= 10,80 m; $T_{max} = 11,29$ m for $\alpha \pm 1^\circ$ and 13,22 m for $\alpha \pm 5^\circ$						
	V [kn]	G _D [m]	W _D [m]	D _{Ddz} [m]	D _{Dr} [m]	S _{Dp} [m]	S _{Di} [m]	V [kn]	G _D [m]	W _D [m]	D _{Ddz} [m]	D _{Dr} [m]	S _{Dp} [m]	S _{Di} [m]
Average condition	Visibility good, calm sea $h_f \leq 1$ m, wind moderate 3-4° B, current rate $v_p \leq 1,0$ kn and direction 090° , vertical oscillation of a sea surface established according to the Chart Datum (the Mean Sea Level) $\pm 0,10$ m ($h= 16,90$ m) sea water density $\gamma_1 = 1,00525$ g/cm ³ , total deviation (drift) of the vessel less than $\pm 1^\circ$, maximum yawing $\pm 1^\circ$, list $\alpha \leq \pm 1^\circ$													
SFH	25,7	22,32	68,18	9037	1171	232	1741	27,5	17,88	71,14	6215	978	170	1170
FH	16,4	19,18	65,04	5644	861	181	1539	18,1	15,09	68,37	3937	744	141	1041
HH	12,4	18,28	64,14	3680	713	156	1148	14,1	14,27	67,53	2650	614	120	795
SH	8,6	17,68	63,54	1416	458	98	282	9,7	13,63	66,89	1100	427	85	210
DSH	6,0	17,40	63,26	1061	365	87	197	6,8	13,34	66,60	842	347	77	152
STOP	0,0	17,15	63,01	272	205	114	114	0,0	13,08	66,34	272	205	114	114
Extreme condition	Visibility moderate to restricted, sea moderate, in some places agitated ($h_f \approx 3$ m), wind 6-7° B, current rate $v_p \approx 3,0$ kn and direction 344° (perpendicular to the fairway line), vertical oscillation of sea surface established according to the Chart Datum (MSL) $\pm 0,60$ m ($h=16,40$ m), sea water density $\gamma_2 = 1,00250$ g/cm ³ , total deviation (drift) of the vessel $\pm 2^\circ$, yawing $\pm 2^\circ$, list $\alpha \leq \pm 5^\circ$													
SFH	25,7	26,39	67,11	8453	587	2017	3526	27,5	22,05	70,13	5851	615	1330	2330
FH	16,4	22,86	63,58	5226	444	1507	2865	18,1	18,84	66,92	3662	470	1057	1957
HH	12,4	21,85	62,57	3348	382	1245	2237	14,1	17,90	65,98	2445	408	848	1523
SH	8,6	21,17	61,89	1282	323	645	829	9,7	17,16	65,24	1014	340	491	616
DSH	6,0	20,85	61,57	980	283	500	610	6,8	16,82	64,90	790	296	400	475
STOP	0,0	20,57	61,29	257	191	271	271	0,0	16,52	64,60	257	191	271	271

REMARKS: In this paper the author established the factors and parameters as follows: $n= 1,1$; $m= 1,0$; $k= 1,0$; $s_D= 1,0$; $s_S= 1,0$; $r_D= 1,0$; $r_S= 1,0$; $L= 976,60$ m; $\Delta L= 25$ m; $B= 56,40$ m; $\Delta B= 25$ m; $L_{RD}= 232$ m; $t_r= 0,5$ ' ; $H_c= 76,5$ m; $p= 1,0$ for the vessel in a loaded and ballast condition (cargo, not dangerous). The Main Engine power = 80080 kW (108877HP), block coefficient factor $CB = \delta = 0,598$.

Table 3. "Crash Stop"/ FSAH-FAS test estimated for "Emma Maersk" in a calm sea, with no current and SW 3°B wind. Source: Maersk Line Ship Handling 8.02.01 and Ship Manoeuvrability L203-L210 documentation.

MAIN ENGINE POSITION RPM	LOADED CONDITION				BALLAST CONDITION			
	V [kn]	T _{stop} [min]	PC [m]	PB [m]	V [kn]	T _{stop} [min]	PC [m]	PB [m]
SFH 104	25,7	20,17'	7800	1509	27,5	12,75'	5170	1000
FH 65	16,4	14,58'	4716	1358	18,1	9,75'	3126	900
HH 50	12,4	11,67'	2900	992	14,1	7,42'	1970	675
SH 35	8,6	5,03'	892	184	9,7	3,42'	607	125
DSH 25	6,0	3,25'	630	110	6,8	2,25'	428	75

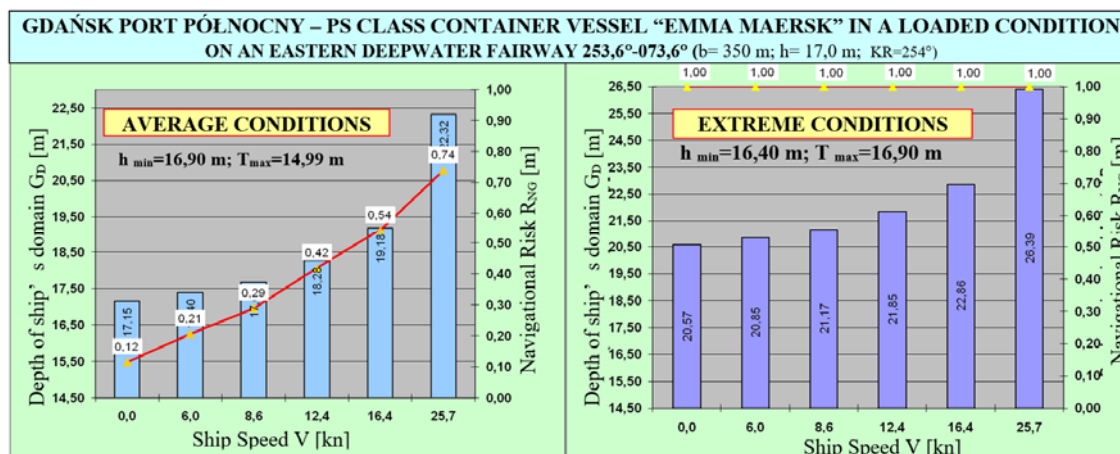


Figure 4. The graphical relation between the ship's speed V, the depth of a ship's domain GD and the navigational risk RNG estimated for the PS Class Container vessel "Emma Maersk" in a loaded condition while approaching the DCT terminal in Gdansk Port Polnocny. Worked out in May 2011.

The ship's domain parameters, estimated by the means of formulae described in paper [6] for the PS class container vessel "Emma Maersk" are presented in table 2. Ship's domain is estimated for the average and extreme weather condition, ship loaded & ship in a ballast condition and ship proceeding with a different speed. The navigational risk assessment R_N is estimated on the basis of formulas 1 to 7 and table 2. The results presented as the factors from the range between 0 and 1 can be used to estimate the navigational risk and consequently estimate the safety of navigation in this area. According to the navigational risk definition [7], we know that the value zero of the navigational risk, deriving from the factors (i.e. objects), signifies a total navigational safety with respect to these factors (objects). Similarly, the bigger the risk (when the factor is approaching value 1) the smaller the safety of navigation. By using this factor, a navigational risk can be presented in a graphical manner.

Therefore, the navigational risk assessment when navigating on the PS class container vessel on the eastern fairway leading to the DCT terminal in Gdansk Port Polnocny restricted by the depth $h=17,0$ m \pm 0,10 m in an average condition and \pm 0,60 m in an extreme condition can be estimated in the following way:

The navigational risk R_{NG} for "Emma Maersk" concerning her under keel clearance in a loaded condition with the draft $T=14,5$ m, which can be increased due to a ship's list $\alpha= \pm 1^\circ$ in an average condition from the wind and the sea waves to $T_{max}=14,99$ m is going to vary between the value 0,12 for a drifting condition to 0,74 for a vessel proceeding with speed SFH (Sea Full Ahead)=25,7 kn.

In that case the vessel proceeding with speed DSH (Death Slow Ahead) = 6,0 kn is going to generate the navigational risk R_{NG} on level 0,21. In order to simplify that method the factor $R_{NG} = 0,21$ can be interpreted similarly as 21 % of probability that we touch the sea bottom and/or destroy the ship's hull on the shallow water or because of the underwater obstructions. The sea passage of "Emma Maersk" in a loaded condition and the extreme passage circumstances (see Table 1 and 2 and Fig. 4) is going to generate the risk on the level 1 regardless of the ship's speed. In this example one should also take into consideration: the maximum fluctuation of the sea water level observed in Gdansk Port Polnocny $\Delta h= \pm 0,60$ m estimated with the reference to a chart datum related to MSL (Mean Sea Level), changes in the sea water density from value $\gamma_1= 1,00525$ g/cm^3 to $\gamma_2= 1,00250$ g/cm^3 and changes in the ship's draft $\Delta T= 2,40$ m due to ship's list $\alpha= \pm 5^\circ$ caused by the wind, sea waves and current in case of the problem with the Fin Stabilizers. Therefore, the sea passage of "Emma Maersk" in that condition is impossible or extremely risky ($R_{NG}=1$). In sea practice there are the situations in which due to the extremely bad hydro-meteorological conditions, e.g. a strong storm, wind, lowering of the sea level or a restricted visibility, the vessels, which have a submersion T_{max} too big with reference to the depth of the sea area h , are sent to the buffer zone in the anchoring place. The ships are expected to wait there until the severe conditions improve, which can enable the ship to cover the given distance.

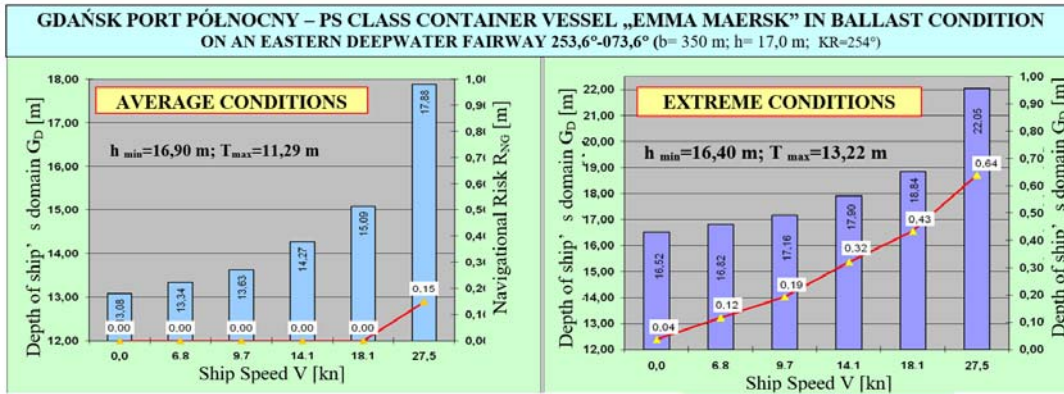


Figure 5. The graphical relation between the ship's speed V , the depth of the ship's domain G_D and a navigational risk R_{NG} estimated for the PS Class Container vessel "Emma Maersk" in a ballast condition while approaching the DCT terminal in Gdansk Port Polnocny. Worked out in May 2011.

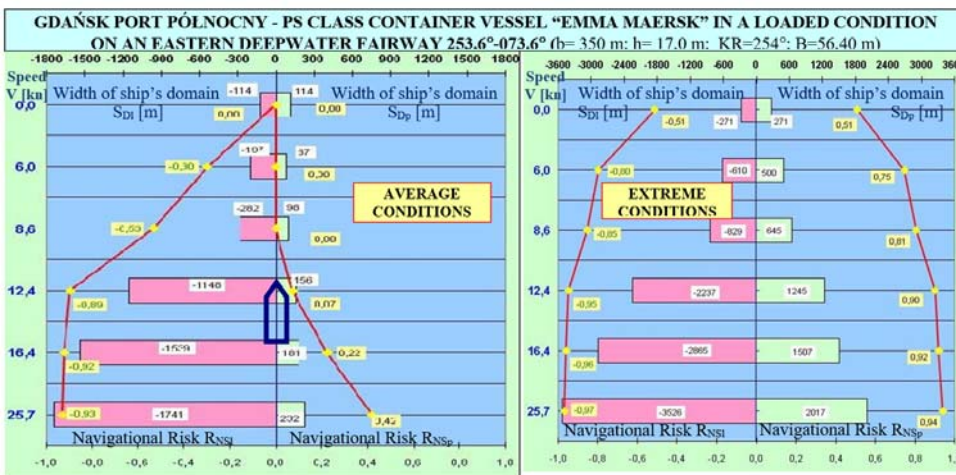


Figure 6. The graphical relation between the ship's speed V , the width of the ship's domain SD_l and SD_p and a navigational risk of keeping a safe distance to a port R_{NSl} and to a starboard side R_{NSp} estimated for the PS Class Container vessel "Emma Maersk" in a loaded condition while approaching the DCT terminal in Gdansk Port Polnocny in the average and extreme external conditions. Worked out in May 2011.

The sea passage of the vessel class "Emma Maersk" in a ballast condition (Fig. 5) proceeding in the average sea conditions specified in table 1 with the speed less than 18 kn generates the navigational risk R_{NG} on the level 0 ($G_D < 15,09$ m; $h_{min} = 16,90$ m, $T_{max} = 11,29$ m, $R_{NG} = 0$). In extreme external conditions her entrance to the port with speed $DSH = 6,8$ kn generates navigational risk R_{NG} on level 12% ($G_D = 16,82$ m; $h_{min} = 16,40$ m, $T_{max} = 13,22$ m, $R_{NG} = 0,12$). Increasing the speed of the ship to $SH = 9,6$ kn can increase a generated risk R_{NG} to value 0,12. Furthermore, if we increase the speed to $SFH = 27,5$ kn, the navigational risk R_{NG} can increase to 64% ($G_D = 22,06$ m; $h_{min} = 16,40$ m, $T_{max} = 13,22$ m, $R_{NG} = 0,64$). In that case the passage of "Emma Maersk" is possible in all conditions with reference to the under keel clearance, however much risky with a higher speed.

Thanks to the analysis of the navigational risk R_{NW} for the container vessel "Emma Maersk" with respect to the objects located on the route, one draws the logical conclusion that the passage is definitely going to be safe and constitutes no threat as there are no on-water objects on the arrival fairway to DCT Gdansk Port Polnocny. The only bridge Oster-Renden which

is located in the Great Belt on the route from the Baltic Sea to the North Sea has the water gap which equals 65 meters ($H_o = 65$ m with respect to MSL). It enables the safe passage of these vessels the domains of which are described as: $W_D \leq 65$ m.

Furthermore, if we assume that "Emma Maersk" proceeds in the axis of the fairway with the speed $DSH \approx 6 \div 6,8$ kn, when the separated gaps between the vessels remain not smaller than $d_N = 0,5$ Nm ($d_N = 926$ m), the navigational risk R_{NDdz} defined in the horizontal plane in front of the bow along the passage reaches the value from 0,13 in the average conditions ($D_{Ddz\ max} = 1061$ m) to 0,06 for the extreme external conditions ($D_{Ddz\ max} = 980$ m) and to value 0 for all conditions in a ballast passage ($D_{Ddz\ max} = 842$ m $< d_N = 926$ m). Paradoxically, in the extreme external conditions, due to the higher resistance from wind, current and sea waves, the vessel needs a shorter distance to reduce the speed using e.g. "the Crash Stop" method; thus the navigational risk R_{NDdz} is smaller. However, if the ship's speed increases in all conditions the navigational risk R_{NDdz} automatically increases.

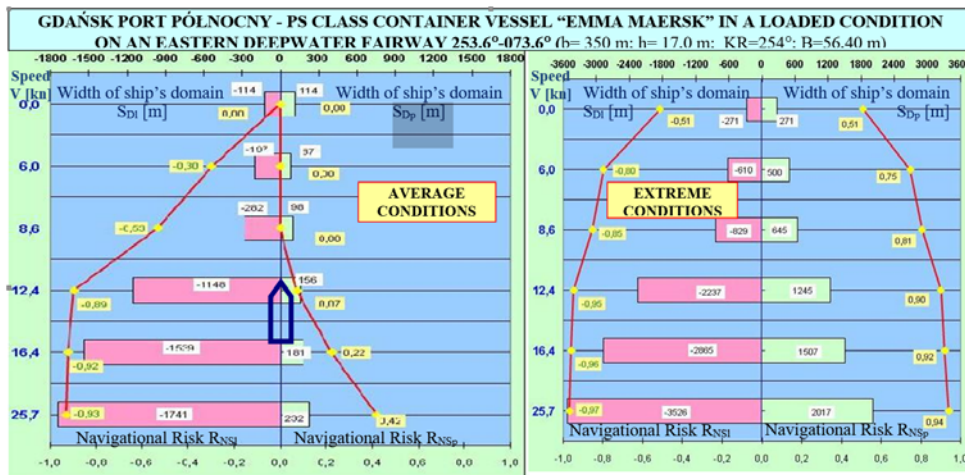


Figure 6. The graphical relation between the ship's speed V , the width of the ship's domain SDl and SDp and a navigational risk of keeping a safe distance to a port $RNSl$ and to a starboard side $RNSp$ estimated for the PS Class Container vessel "Emma Maersk" in a loaded condition while approaching the DCT terminal in Gdansk Port Polnocny in the average and extreme external conditions. Worked out in May 2011.

In practice, the navigational risk analysis from the starboard $RNSp$ and the port side $RNSl$ of the ship (see Fig. 6 and 7) is reduced to the comparative analysis of the ship's domain parameters SDp and SDl with the fairway breadth b_f , the water lane breadth b_a , and the distance to the nearest hazard d_N , detected respectively at the starboard and the port of the vessel.

Hence, if we assume that the ship is going to proceed within the eastern fairway with the speed DSH , in the axis of the fairway the breadth of which equals 350 m ($b_f=350$ m), the navigational risk $RNSp$ defined in the horizontal plane on the starboard is going to range: from 0 for the average external conditions regardless of the loaded or ballast ship's condition (Fig.6 and Fig.7) and from the value 0,68 for speed $V=6,8$ kn in a ballast condition (Fig.7, $SDp=400$ m, $d_{Np}=(350m-56,4m)/2=146,8$ m, $RNSp=0,68$) to 0,75 for the loaded ship proceeding with speed $V=6$ kn (Fig.6, $SDp=500$ m, $d_{Np}=146,8$ m, $RNSp=0,75$) in the extreme external conditions (e.g. a strong wind, or the current transverse to the fairway axis).

The navigational risk $RNSl$, defined in the sector on the port side in the eastern fairway for the ship's speed DSH , is going to range from: 0.04 for the ballast condition (Fig.7) in case of the normal passage circumstances ($SDl=152$ m) to 0.80 for the loaded condition and the extreme passage circumstances ($SDl=610$ m). For the loaded condition (Fig.6) and the average passage circumstances the navigational risk $RNSl$ oscillates in range of 0,30 ($SDl=197$ m).

4 CONCLUSION

Thus, the analysis of the navigational risk $RNSp$ and $RNSl$ proves that the PS class container vessel "Emma Maersk" proceeding in the axis of the eastern fairway would be able to carry out properly neither the circulation manoeuvre nor the emergency manoeuvre of stopping by the engine operation full astern with the fishtailing, as those two manoeuvres would involve crossing the boundaries of the given fairway.

Furthermore, the arrival fairway to DCT Gdansk Port Polnocny for "Emma Maersk" ought to be treated as the restricted sea area both with respect to its breadth (narrow passage) and its depth (shallow area). Generally speaking, this particular sea area is treated as the area difficult for navigation for the vessels similar to "Emma Maersk". It seems to be reasonable or even indispensable to maintain a special navigational supervision such as the VTS service as well as the obligatory pilotage for this sea area including the tug assistance with minimum one tug forward and one tug aft. The optimal speed, which can assure the adequate manoeuvrabilities of the vessel with the acceptable level of risk R_N ranges between 3,5 kn to 6,0 kn. The further speed reduction without the assistance of the tugboats can increase the drift, especially in case of the strong wind and the current acting in a transverse direction to the fairway axis.

The approaching speed on the eastern fairway should range between 3 and 6 kn. The minimum steering speed for the PS class container vessel similar to "Emma Maersk" in a loaded and/or ballast condition is established on the level of about 3 kn (5,6 km/h). The passage speed in case of the towing operation with a towing line should also range between 3 to 6 kn. The navigational passage for all inbound and all outbound PS class container vessels in the loaded conditions are recommended in good and/or in average weather conditions within the visibility up to 1 Nm and a wind force up to 7thB. All manoeuvres on a turnover area in port of Gdansk are recommended with the wind force less than 6thB. It that conditions a navigational risk R_N can be accepted. Similarly, a navigational passage in bad and/or extreme weather condition (see table 1) is impossible or extremely risky due to the high value of the navigational risk R_N .

The high risk operation e.g. due to the extremely bad weather conditions such as the wind force 7thB or more should be done with a tug assistance. The recommended towing configuration is to have at least two tugs aft and two tugs forward, two tugs fast and two tugs in assistance. If the wind force increases to

8°B and more from NE and SE direction the vessel should be removed from the port in advance and sent to the buffer zone in the anchoring place. The ships are expected to wait there until the severe conditions improve, which can enable the cargo and/or manoeuvres operations. The final decision is made by the captain of the vessel who consults the Captain of Port of Gdansk and the top management from the DCT terminal in Gdansk.

Taking into consideration "Emma Maersk" dimensions, the main engine force and the location of all bow and stern thrusters, the entire mooring and unmooring operation needs to be done with the special precaution and a tug assistance to avoid washing away the sand from the jetty and the sea bed inside the port. This kind of problem can be eliminated in the DCT terminal when the sea bed is secured by some tarpaulin. Having analysed the navigational risk of the PS class container vessel „Emma Maersk” during her passage to DCT Gdańsk Port Północny, one can unanimously state that the three-dimensional model the ship's domain can constitute the appropriate criterion for estimating the safety structures of the sea transport as well as the structures that classify the sea areas.

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