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Ship service speeds and sea margins

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Abstract

When designing a transport vessel, one of the most important parameters assumed by the owner is the service speed of the ship. Service speed and motor power are calculated as an approximation of the ship's speed in calm water (i.e., the contract speed) with the addition of the sea margin (SM). In current design practice, the addition of SM is not dependent on weather parameters occurring in liner shipping. This paper proposes a new method for establishing the value of SM depending on the type and size of the vessel and the average statistical weather parameters occurring on various shipping lines. The results presented in this paper clearly demonstrate that further research is needed to determine the precise relationship between the shipping and vessel type and the weather parameters on a shipping line.

Preliminary design of the ship

Designing vessels is reduced in the first instance to determining the basic dimensions (length, beam, draft, side depth), displacement, and block coefficient, and on the basis of fixed dimensions, the theoretical lines of the ship's hull. Then the propulsion power, the volume and surface of the hull, stability, freeboard, damage stability, sea keeping, range and autonomy, and the cost of the ship's construction are determined. All subsequent parameters of the designed ship and its properties depend on the main dimensions, which are determined in the preliminary design phase. The design process is performed iteratively, and thus it is divided into respective stages. Of the all of the design stages, the preliminary design phase (which includes analysis of the assumptions of the owner, development of the basic dimensions of the main development of the concept and preliminary design) is the most important initial stage, because at this stage (Figure 1), the designer has the greatest possible freedom in decision-making. However, at this point, knowledge of the planned ship is the least complete, and although it is the lowest cost phase to implement, errors generated at this stage have the greatest consequences.

Therefore, in order to, on the one hand, reduce the number of iterations leading to the optimal solution, and on the other, reduce the possibility of errors in the operating project, mathematical models have been developed that are functions of certain properties or parameters of the designed ship dependent only on these basic dimensions and, most recently, on the environmental conditions in which the designed ship will be operated.

During design, the designer seeks an optimal solution to meet the assumptions (requirements) of the owner, which are mainly concerned with the operating speed and load capacity of the ship and meeting technical criteria (contained in certain regulations) such as buoyancy, stability, and subdivision.

One of the major tasks carried out at the preliminary design stage is determining the propulsion power for the assumed service speed at which the ship will be sailed by the owner. Propulsion power, in addition to the predetermined speed, has a crucial

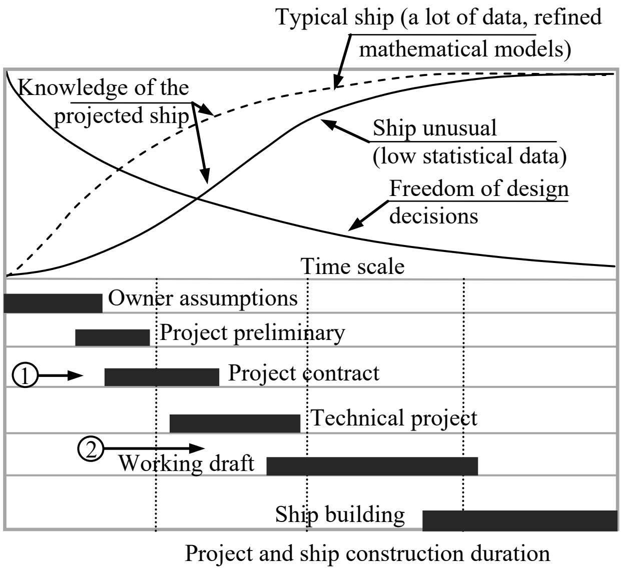

Figure 1. The importance of the next stages of the design for knowledge of the planned ship [own study based on (Chądzyński, 2001)]; ① – at this stage dimensions of the vessel and the propulsion for the established service speed should be defined, ② – in the current design process, ship resistance and propulsion power are determined after signing the contract, based on model tests of these studies and the attached sea margin (SM) is calculated service speed

impact on the shape of the ship's hull and the parameters of its propeller – the geometry of the ship's hull and propeller also impact the overall efficiency, which should be maximized.

The aim of the design process is therefore to choose the design parameters (e.g., the basic dimensions of the main ship) to achieve the desired result, which is a ship project guaranteed to achieve the assumed speed at the assumed capacity with the least propulsion power and the lowest ship construction costs. The owner can then expect to profitably operate the designed ship.

The solution thus defined the design task using mathematical models containing compounds between the geometry of the hull and the propeller and service speed, power propulsion and weather conditions occurring on the shipping line on which is the ship is operated.

The speed and power propulsion in the process of ship design

When designing a vessel to be used for maritime transport, another important consideration is that the ship owner expects to profit from its operation. Thus in addition to technical criteria, the design process includes additional economic criteria (Stopford, 2003). In order to determine whether the vessel will meet the expectations of the owner, economic measures in particular serve to assess the design excellence of the ship. The most commonly used evaluation measures are

- efficiency of transport (Gabrielli & Karman, 1950; Yong et al., 2005; Harries, Heimann & Hochkirch, 2006);
- the design energy efficiency index (EEDI) IMO (in force since 01.01.2013) (GHG-WG, 2009; MEPC.1/Circ.681, 2009; Ozaki et al., 2010);
- economic indicators (Abramowski, 2011).

In all these assessment measures, design excellence is judged by the ship's speed and drive power. This means that the speed of the ship, assumed by the ship's owner as a result of the propulsion power, is one of the most important design parameters. The ship's speed and propulsion power affect fuel (which has an impact on the operating costs of the ship and the owner's profits), emissions (including CO_2 and NO_x), cruise time, and – taking into account the vessel's safety – the shipping route. The ship speed is so important that it is specified in the ship's construction contract. If the ship is operated in calm water with no waves or wind, developing a mathematical model to calculate the speed and propulsion power as a function of the basic geometric parameters of the ship's hull does not constitute a problem. However, if the ship is operating on various shipping lines, which are variable, random parameters characterize the effects of waves and wind. Hence, developing a model of the service speed (and propulsion power) that the ship can attain in real weather conditions is a serious problem.

In current design practice, during the preliminary design phase, propulsion power is determined for the design speed in calm water using very rough dependence (this is equivalent to contract speed) (Figure 1). Only after the project contract has been established and signed (Figure 1) are basin model tests of resistance and propulsion power conducted in calm water (curve 1 in Figure 2). Then, taking into account the sea margin (SM) (standard 10–15%), the nominal engine power N_n and for the projected service speed V_E (Figure 2) is calculated. The SM value does not allow either the precise actual service speed in real weather conditions occurring in the shipping line or determine the propulsion power to guarantee that the assumed service speed will be achieved.

The method of estimating service speed based on ship basin model tests of resistance and drive power shown in Figure 2, is widely used for transport vessels, even though the actual operation of ships that

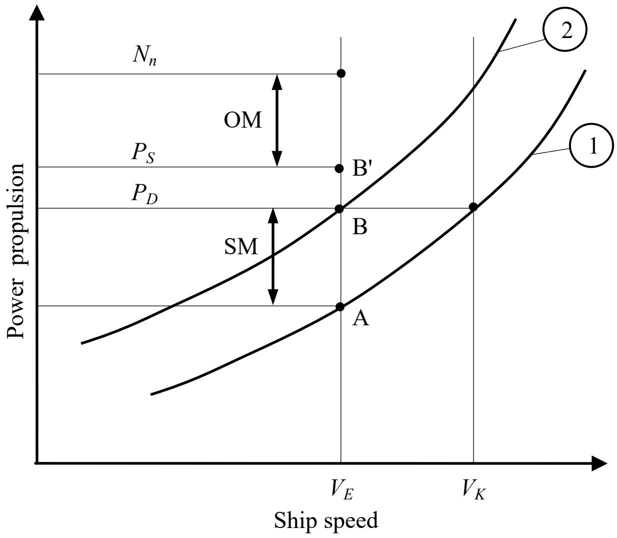

Figure 2. Determination of propulsion power and ship service speed V_E based on model tests of resistance and sea margin (SM). Explanations: N_n – nominal engine power, P_S – power to the shaft line (point B'), P_D – power delivered to the propeller, OM – assumed power reserve (standard 10%), SM – the sea margin (standard 10–15%), B'B – losses resulting from the performance shafting, B – design operating point of the propeller, A – the operating point of the propeller on the calm water, clean hull, V_K – speed contract, V_E – projected service speed, ① – the characteristics of the power propulsion in calm water, clean hull, ② – the characteristics of the power propulsion with the sea margin

reached service speed on different shipping lines does not correspond to the service speed presumed by the ship owner (Figure 3). This means additional shipping taken on some shipping lines is too small and others may be too large (Żelazny, 2005), which means that the power of the drive is either too strong or too weak.

To improve the accuracy of determining ship service speed, the method shown in Figure 2 shows the value SM is dependent on the shipping line, on which there are certain statistical averages weather conditions (i.e., seasonal parameters).

The sea margin for shipping lines

The sea margin it is defined as

$$\mathrm{SM} = 1 - \frac{R_{TS\mathrm{serv.}}}{R_{TS\mathrm{trials}}} = \frac{\Delta R}{R_{TS\mathrm{trials}}} \tag{1}$$

where:
SM – the sea margin (SM < 1);
$R_{TS\mathrm{trials}}$ – the total resistance of the vessel during tests in calm water;
$R_{TS\mathrm{serv.}}$ – the total resistance of the vessel operating in actual weather conditions.

Therefore, in order to determine what the SM should be, we must know the total resistance of the vessel when it is travelling on a given shipping route, for which there are statistical averages available for (seasonal) weather conditions.

The ship can sail on different shipping lines that run through various reservoirs. In these areas there are weather events, mainly wind and waves (Figure 4), for which numerical values of the parameters of waves and wind occur with varying probability. Waves and wind are also likely to vary depending on the season. Therefore, the total resistance of the vessel will be a random statistical average value of the assumed probability of exceeding.

The total resistance of the ship in real weather conditions is equal to

$$R_{TS\mathrm{serv.}} = R_{TS\mathrm{trials}} + \Delta R \tag{2}$$

where
$R_{TS\mathrm{trials}}$ – resistance of a ship in calm water;

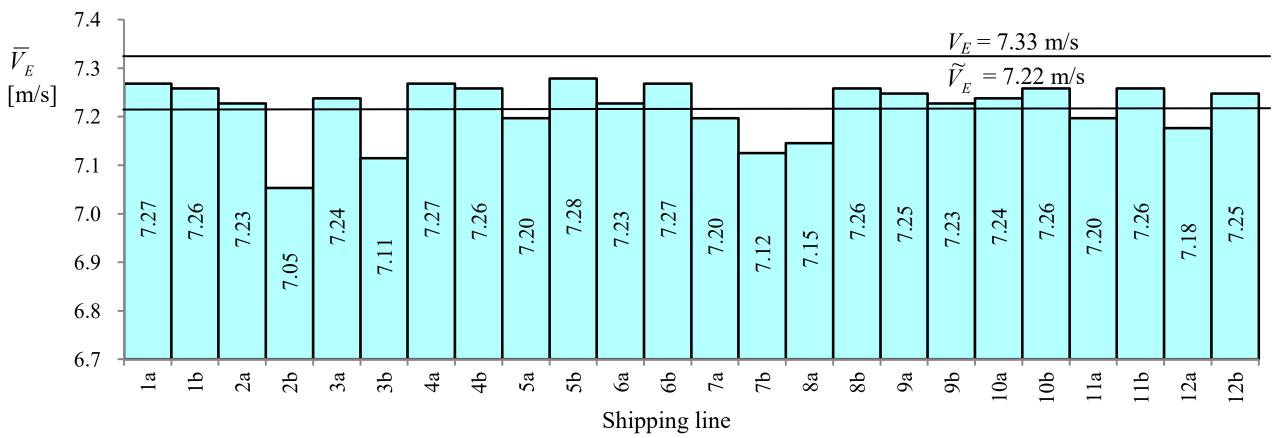

Figure 3. Average long-term service speed $\bar{V}_E$ calculated by (Żelazny, 2005) in liner shipping for bulk carrier M1, VE = 7.33 m/s – assumed by the ship owner service speed for the sea margin SM = 10% ($\tilde{V}_E$ – average service speed for all routes)

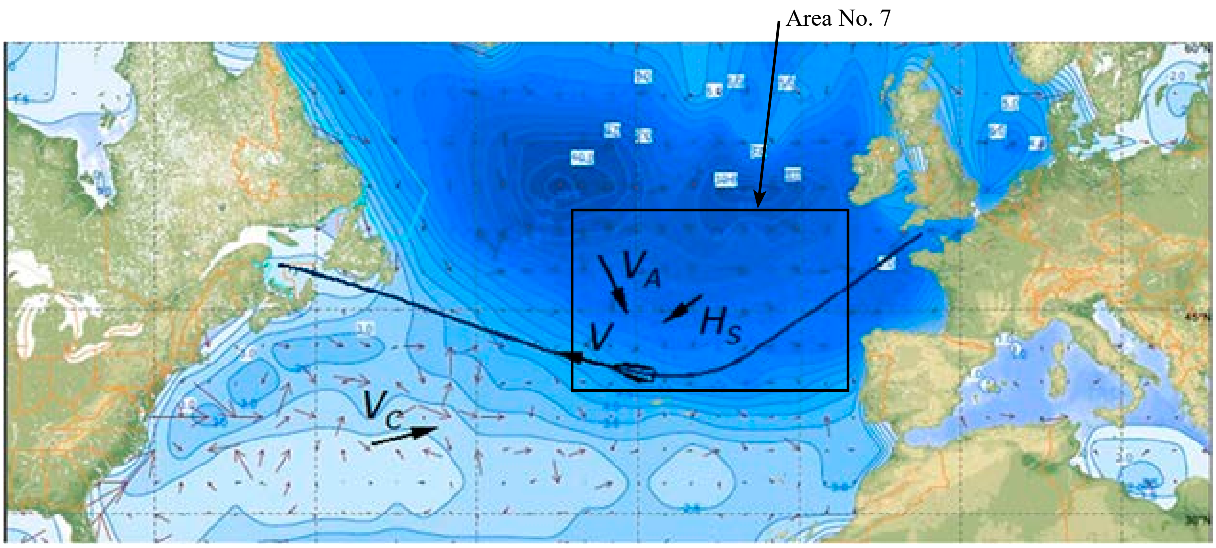

Figure 4. Example of shipping route and directions of impact on the marine environment of the ship

Table 1. The number of wave height H_S and the period T_1 for the μ = 0° on the area 7 (Figure 4) for the whole year

H_S [m]	calm	T_1 [s] < 5	6–7	8–9	10–11	12–13	14–15	16–17	18–19	20–21	> 21
0.25		70	1	1	1			1			7
0.5		217	29	7	2						13
1.0		542	225	44	18	6	3	3		2	6
1.5		276	501	143	41	8	4	1			3
2.0		61	334	229	55	18	4				
2.5		25	164	143	76	14	2	2	1		
3.0		3	87	136	61	18	4				
3.5		6	35	96	49	22	8	1	1		
4.0		2	24	41	47	17	7		1		
4.5		3	14	31	27	17	2	2			1
5.0		2	3	4	4	6	1	1			
5.5		3	2	4	8	2	1				
6.0			4	6	6	3	2				
6.5			7	3	6	6		2			
7.0			1	7	1	2					
7.5				2	1		1	2			
8.0			1	4	5	4		2			
8.5				2	1	4	1				
9.0			5	2	1		1	1			1
9.5			2	1	4	1	1				

ΔR – additional ship resistance due to the impact of wind and wave and steering devices

$$\Delta R = R_{xA} + R_{xC} + R_{xW} + R_{xR} \tag{3}$$

R_{xA} – additional resistance from the wind;
R_{xC} – additional resistance from the sea surface currents;
R_{xW} – additional resistance from the waves;
R_{xR} – additional resistance from factors such as steering gear on a given course (interference of the course is also caused by the impact of wind and waves).

Shipping lines run through waters in which the average statistical parameters of waves and wind have been measured and are these are available in weather atlases such as (Hogben, Dacunha & Olliver, 1986; Hogben & Lumb, 1967). Average statistical parameters of waves for the entire year on the waters of the lines in Table 2 are presented in Table 1. In calculating total resistance $R_{TS\mathrm{serv.}}$ for all parameters of waves, including their likelihood of occurring on a given shipping route, a statistical mean value of the total resistance $\bar{R}_{TS\mathrm{serv.}}$ can be calculated for the shipping line. The algorithm for

Table 2. Basic technical parameters investigated ships

Parameter	Bulk carriers M1	M2	M3	M4	Container ships K1	K2	K3
Length of the vessel L [m]	138.0	185.0	175.4	240.0	140.14	171.94	210.2
Ship breadth B [m]	23.0	25.3	32.2	32.2	22.3	25.3	32.24
Draught T [m]	8.5	10.6	12.0	11.6	8.25	9.85	10.5
Block coefficient C_B [–]	0.804	0.820	0.805	0.815	0.641	0.698	0.646
Waterplane coefficient C_{WP} [–]	0.892	0.854	0.873	0.872	0.809	0.828	0.807
Displacement ∇ [m^3]	21 441	40 831	56 396	73 910	17 290	29 900	47 250
Assumed service speed of the ship V_E [m/s]	7.33	7.72	8.20	8.28	8.44	9.62	10.50

calculating the statistical mean value of total resistance of the ship on the shipping line is presented in (Żelazny, 2005).

The results of calculations for the sea margin shipping

Calculations of average statistical sea margins (SM) of two types of vessels (bulk carriers and container ships) whose parameters are shown in Table 2 for the twelve shipping lines listed in Table 3 (appendix shipping was calculated for a cruise ship on the shipping line on one side (a) and on the return side (b)).

Table 3. List of shipping lines used to calculate the supplement shipping

No. shipping line	Name
1	South America – Western Europe
2	USA East – Western Europe
3	USA East – Gulf of Mexico – Western Europe
4	USA East – Mediterranean Sea – Western Europe
5	Indonesia – Japan
6	Persian Gulf – Japan
7	North Africa – Western Europe
8	North Africa – USA East
9	Persian Gulf – Africa – Western Europe
10	Western Europe – Mediterranean Sea – Persian Gulf – Japan
11	Western Europe – Panama Canal – USA West
12	Western Europe – Latin America

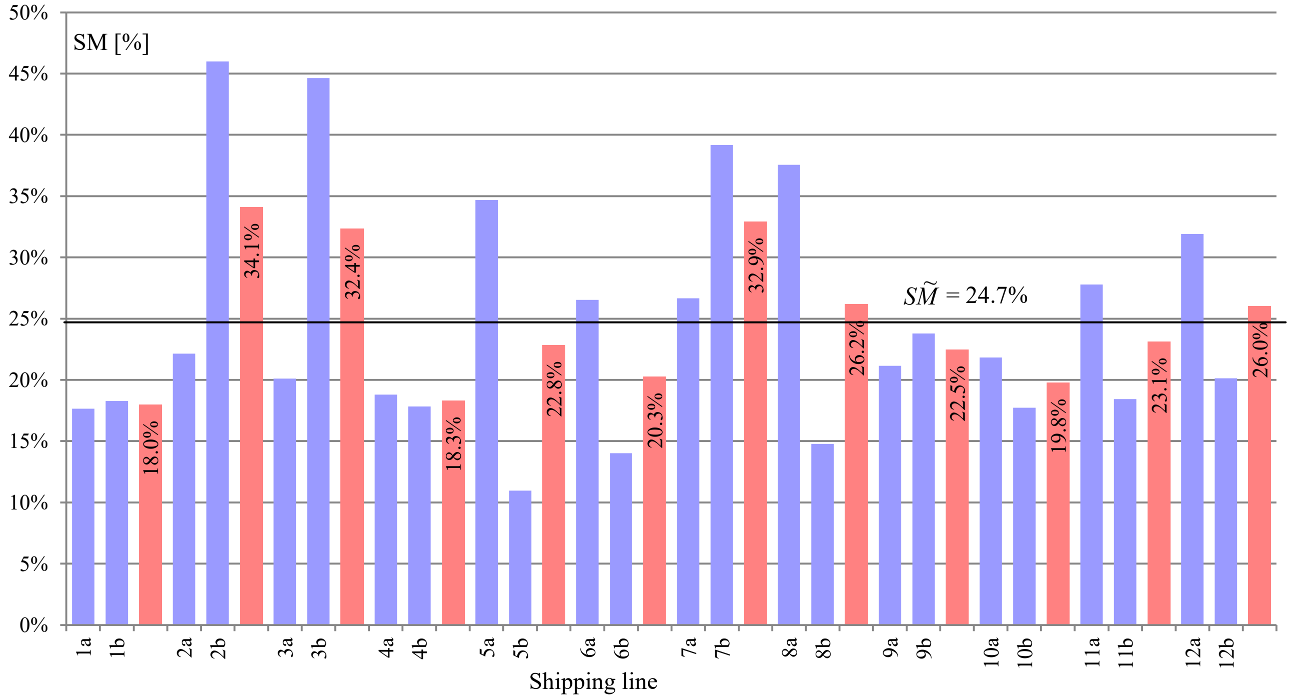

Figure 5. The calculated value of sea margin for a container K1 on different shipping lines

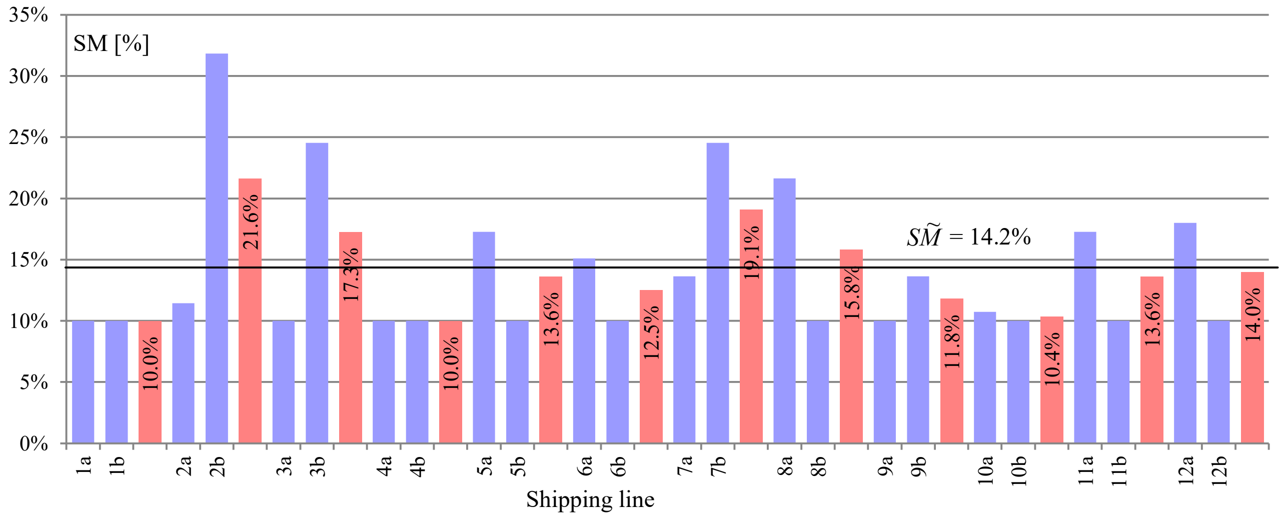

Figure 6. The calculated value of sea margin for a container K2 on different lines shipping

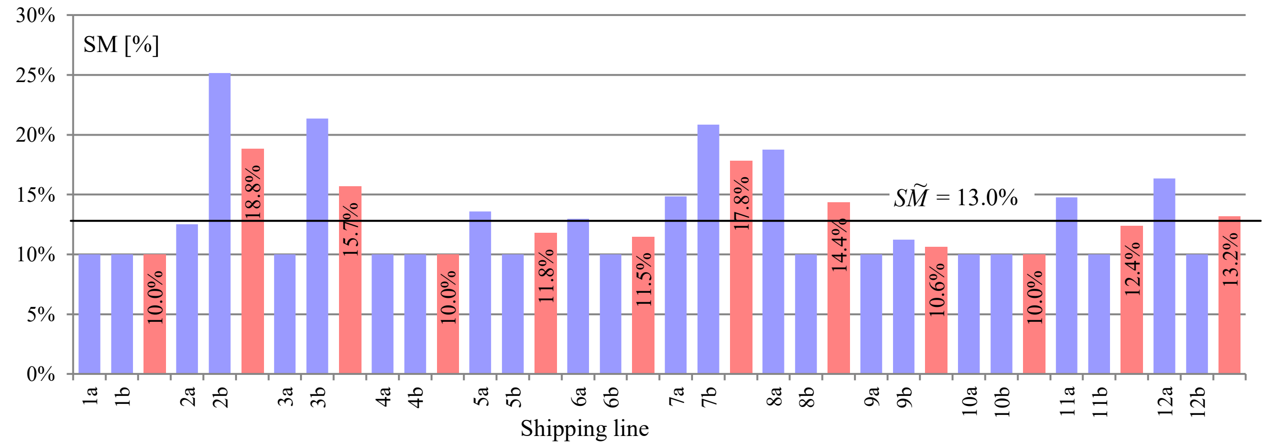

Figure 7. The calculated value of sea margin for a container K3 on different shipping lines

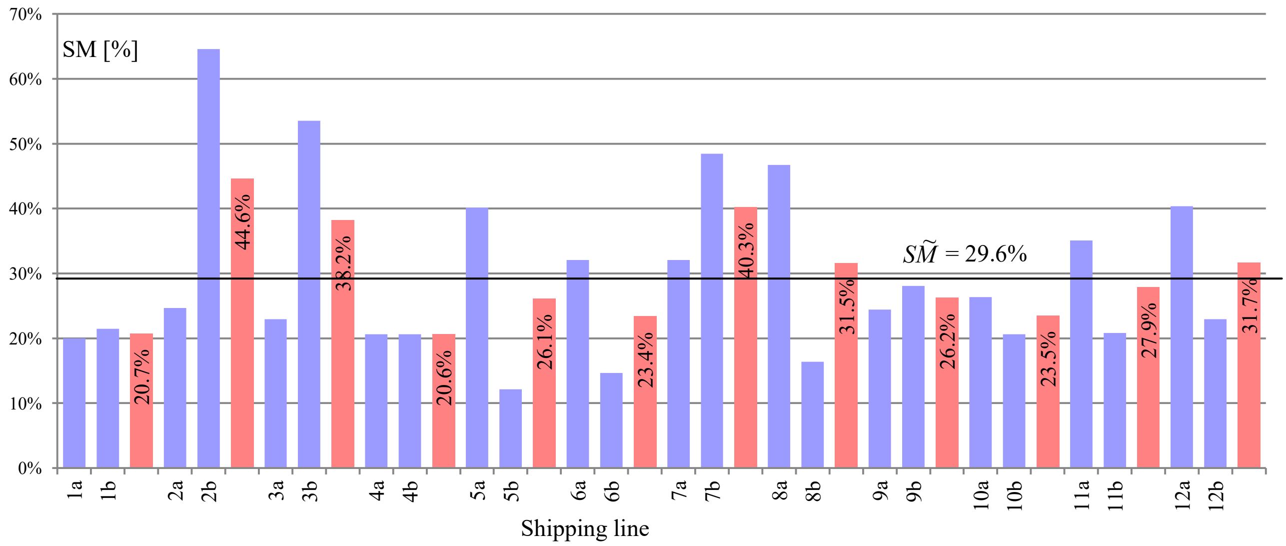

Figure 8. The calculated value of sea margin for a bulk carrier M1 on different shipping lines

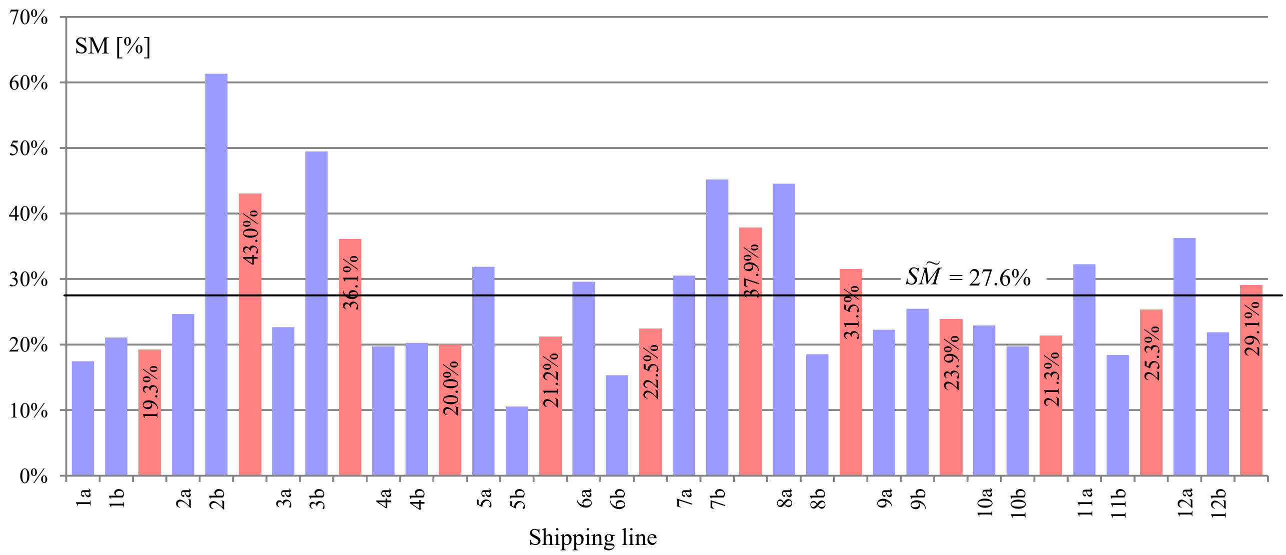

Figure 9. The calculated value sea of margin for a bulk carrier M2 on different shipping lines

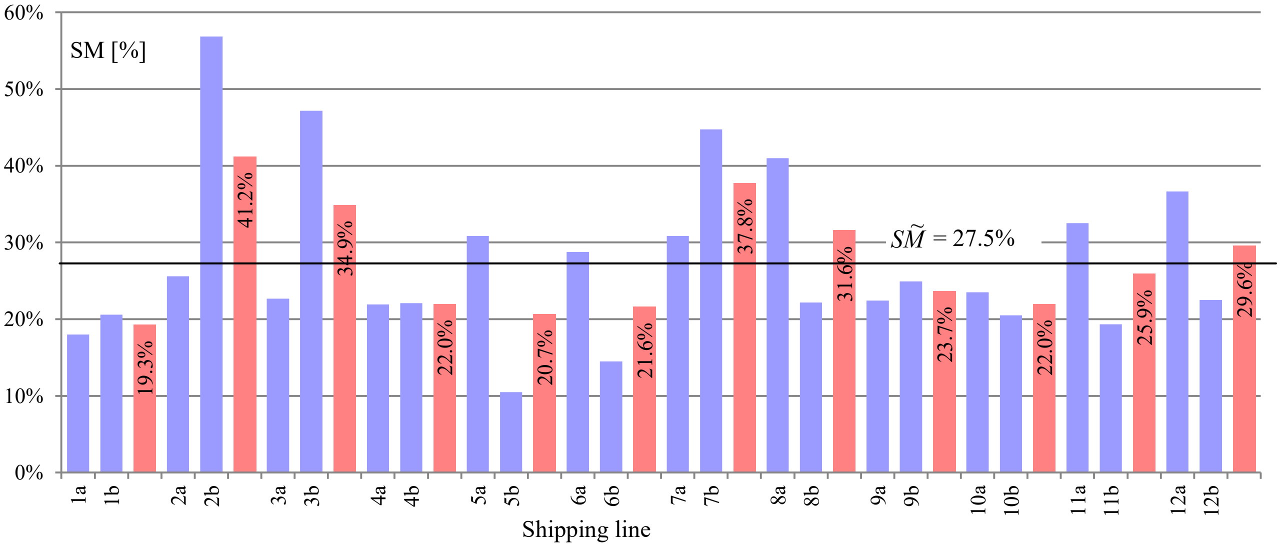

Figure 10. The calculated value of sea margin for a bulk carrier M3 on different shipping lines

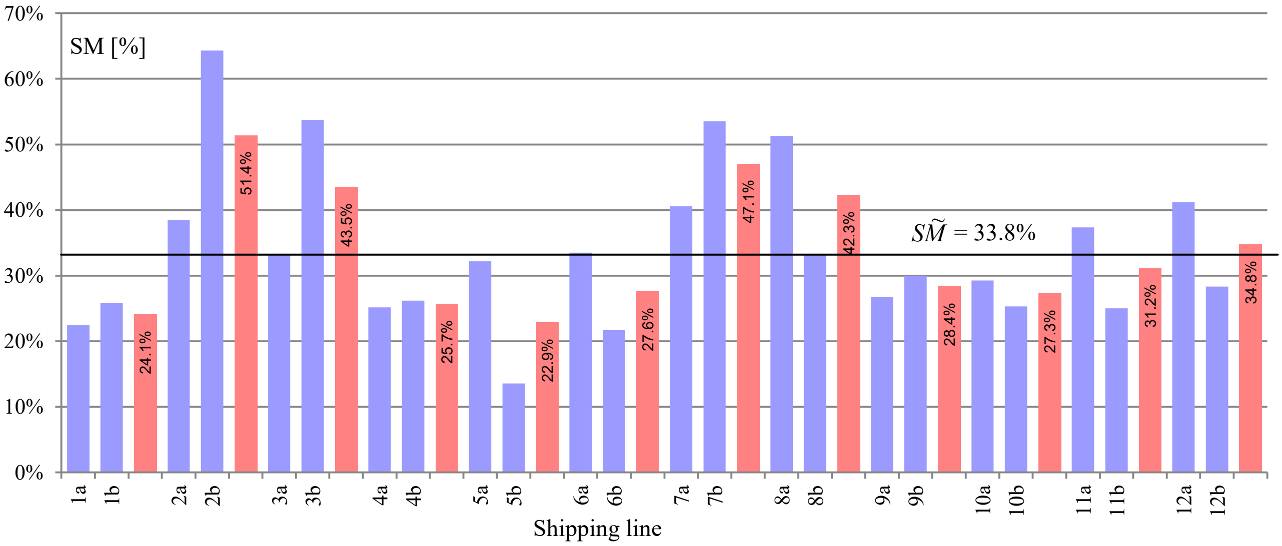

Figure 11. The calculated value of sea margin for a bulk carrier M4 on different shipping lines

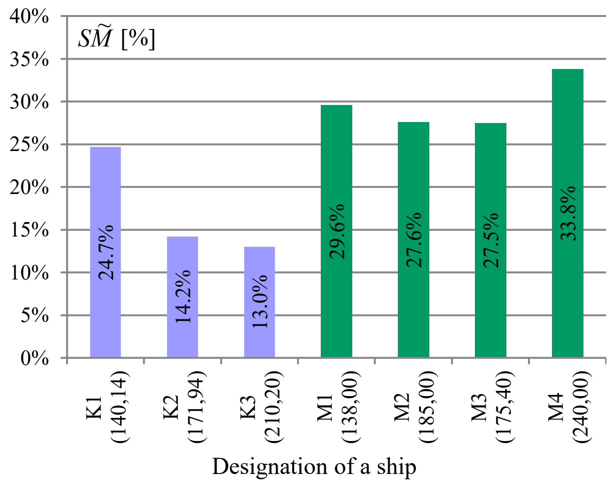

Figure 12. The average value addition shipping lines for selected ships

The calculated values for each additional shipping vessel on various shipping lines are shown in Figure 5–12 (red color – the average value of the SM for the route in both directions).

Conclusions

The sea margin (SM) for each vessel (Table 2) was calculated based on the assumption that the expected service speed would be maintained on each shipping line (Table 3) with probability $P_{VE} = 0.95$.

For the calculation of total resistance to shipping, accepted long-term statistical average parameters (i.e., annual seasonal values) for wind and waves were used (Hogben, Dacunha & Olliver, 1986).

For each vessel the calculated average sea margin was $\widetilde{SM}$ on all shipping lines. If the ship sailed on only one specific shipping line, the calculated sea margin (SM) (and propulsion power) would guarantee that the assumed service speed would be achieved with a certain probability of its maintenance.

The results presented here are preliminary, and calculating sea margins for particular types of ships and shipping lines requires further study. However, these calculations show that it was easier to maintain the assumed service speed for containers than for bulk carriers.

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