Analysis of technical data of Ro-Ro ships

by

Hans Otto Kristensen

HOK Marineconsult ApS
Hans Otto Kristensen

The Technical University of Denmark
Harilaos Psaraftis

Project no. 2014-122: Mitigating and reversing the side-effects of environmental legislation on Ro-Ro shipping in Northern Europe
Work Package 2.3, Report no. 02
July 2016

HOK Marineconsult ApS

Technical University of Denmark

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Technical data and other design parameters for Ro-Ro ships

Introduction

This report contains the results of a detailed statistical analysis of main dimensions and other important design parameters for Ro-Ro cargo ships (number of passengers <= 12) and Ro passenger ships (number of passengers > 12). As part of the statistical analysis mathematical equations have been determined for all these parameters such that they can be used for a detailed computer model for design of Ro-Ro ships such. With such a generic model it is possible to investigate more systematically how these parameters influence the propulsion power demand, such that the energy consumption per cargo unit can be determined.

The propulsion power can be determined by using a well-established empirical method. Such a model has been developed by HOK Marineconsult ApS [Kristensen 2015] and mathematical equations for all the input parameters for this method are given in this report

Following parameters are used in the complete calculation procedure for the combined generic ship design and power prediction program:

L_{wl}	Length of waterline of ship
L_{pp}	Length between perpendiculars
B	Breadth, moulded of ship
T	Draught, moulded amidships (mean draught)
W_L	Lightship weight
D_w	Deadweight of ship
Δ	Displacement mass of ship $(\rho \cdot \nabla = W_L + D_W)$
∇	Displacement volume of ship
S	The wetted surface of immersed hull
A_M	Immersed midship section area
A_{wl}	Area of water plane at a given draught)
D_{prop}	Propeller diameter
V	Speed of ship
Fn	Froude number
C_B	Block coefficient, $(C_B = \frac{\nabla}{Lpp \cdot B \cdot T})$
C_M	Midship section coefficient $(C_M = \frac{A_M}{B \cdot T})$
C_p	Prismatic coefficient $(C_P = \frac{C_B}{C_M})$
C_w	Water plane area coefficient $(C_w = \frac{A_{wl}}{L \cdot B})$
M	Length displacement ratio or slenderness ratio, $M = \frac{L}{\nabla^{1/3}}$
ρ	Mass density of water

Data for the analysis

The data for the statistical analysis are based on four main sources:

- Data from the ShipPax database
- Data from Significant Ships (1990 – 2014)
- Data from DFDS
- Data from Hans Otto Kristensen´s own archive collected during his different jobs in the maritime industry over a period of more than 35 years

These data have been extensively analyzed such that the different parameters have been collected and examined in order to develop formulas for systematic calculations of technical data for Ro-Ro cargo ships (less than 12 passengers) and Ro-Ro passenger ships (more than 12 passengers).

Some of the Ro-Ro cargo ships in the ShipPax database have been excluded in order to obtain a homogeneous data collection, which means that ships with a relative high deadweight have been omitted, typically Ro-Ro ships which are able also to carry a relative large amount of containers, multi stacked on the decks, also called ConRo ships. These Ro-Ro ships are mainly used for deep sea routes and a typically example is shown on fig. 1.

Fig. 1: The container Ro-Ro ship (ConRo) *Jolly Verde* - IMO 7931789

Analysis of main dimensions for Ro-Ro cargo ships

Length between perpendiculars (Lpp), waterline length (Lwl) and length overall (Loa)

In the ShipPax database the overall length is given for all the ships, but for some of the ships, the length between pp is not given. As Lpp is the most commonly used length, it is decided to calculate an approximate Lpp value for the ships which do not have this information. For this purpose two empirical formulas are established for either Lpp based on Loa and vice versa. The statistical background is found in Appendix A, Fig. A1 and A2, showing following equations:

$Lpp = 0.945 \cdot Loa – 3.29$

$Loa = 1.047 \cdot Lpp + 4.91$

Lanemeters and Lpp

As the number of lane meters is a typical and driving parameter for Ro-Ro cargo ships, the different parameters will be expressed as functions of the ships maximum lane capacity for trucks and other relatively heavy cargo, which means that lanes for personal cars have been disregarded.

As a few parameters is expressed as function of Lpp one of the most important parameters is Lpp which is given by following equations:

Less than 1402 lanemeters: $Lpp = 20.4 \cdot lanemeter^{0.259}$

More than 1402 lanemeters: $Lpp = 11.18 \cdot lanemeter^{0.342}$

The two equations are developed by carrying out a regression analysis for Ro-Ro cargo ships divided into two separate groups 1) ships with more than 3000 lane meters and 2) ships with less than 3000 lane meters (see Fig. A3 in Appendix A). At 1403 lane meters the two equations gives the same Lpp value (133.24 m)

Deadweight

Another important capacity parameter, and of same importance as the Lpp, is the deadweight of the ship, Dw. In Fig. A4 in Appendix A is shown the deadweight as function of lane meters. As expected the deadweight is directly proportional with the lane meters, but calculating the deadweight per lane meter is more informative and directly useful, when the necessary deadweight and, not less important the, necessary cargo weight has to be calculated.

As ships carry bunkers, fresh water, stores, crew and passengers and finally but not least also some ballast water for trim and stability purposes, a certain percentage of the deadweight is allocated for cargo (payload). For some of the ships analyzed the maximum payload is given and from Fig. A5 in Appendix A, it is seen that the payload is approximately 70 % of the deadweight for Ro-Ro cargo ships.

From Fig. A6 in Appendix A it is seen that deadweight per lanemeter (LM) can be separated in three categories:

Low deadweight: $Deadweight/lanemeter = 74.1 \cdot LM^{-0.383} - 1$ however not less than 3 t/m

Normal deadweight: $Deadweight/lanemeter = 74.1 \cdot LM^{-0.383}$ however not less than 3 t/m

High deadweight: $Deadweight/lanemeter = 74.1 \cdot LM^{-0.383} + 2$

The deadweight density cannot be less than 3 t/m, which means that the two lowest categories become identical for more than 4330 lanemeter. With 3 t/m the payload is 2.1 t/m which is the lowest acceptable value for normal trucks having a length between 12 m and 18.5 m and a total weight between 18 t and 44 t (see Appendix G). The upper limit for the deadweight per lanemeter is the high deadweight density + 15 %.

Breadth, draught and depth

The breadth of Ro-Ro cargo ships are shown in Fig. A7 in Appendix A. Three different breadths as function of the lanemeters are shown, as these 3 different breadth relations are combined with the three different deadweight densities, such that the block coefficient is not too large and within the normal design range for Ro-Ro cargo ships (see later). The same principle is also valid for the draught where three different draught relations are combined with the three different deadweight densities as shown in Fig. A8 in Appendix A.

The breadth, B, is given by following equations depending on the deadweight density (Dw/LM):

Low deadweight:	$B = MIN(0.85 + 0.15/4330 \cdot LM, 1) \cdot 5.49 \cdot LM^{0.192}$	
Normal deadweight:	$B = 5.49 \cdot LM^{0.192}$	
High deadweight:	$B = 5.49 \cdot LM^{0.192} + 0.0005 \cdot LM + 2$	

The lowest breadth limit is the low deadweight breadth – 1.7 m and the highest draught limit is the high deadweight breadth + 2.0 m.

The draught, T, is given by following equations depending on the deadweight density (Dw/LM):

Low deadweight:	$T = 4.88 + 0.000514 \cdot LM$	if LM < 4330
	$T = 5.81 + 0.0003 \cdot LM$	if LM=> 4330
Normal deadweight:	$T = 1.9 \cdot LM^{0.16}$	if LM < 2000
	$T = 5.81 + 0.0003 \cdot LM$	if LM => 2000
High deadweight:	$T = 1.15 \cdot (1.9 \cdot LM^{0.16})$	if LM < 2000
	$T = 1.15 \cdot (5.81 + 0.0003) \cdot LM$	if LM => 2000

The lowest draught limit is the low deadweight draught – 0.8 m and the highest draught limit is the high deadweight draught + 0.8 m.

Depth to uppermost continuous deck (weather deck)

The height of the uppermost continuous deck (weather deck) above the keel, D, is also an important main dimension which characterizes the ship and which will be used in the formula for calculation of the lightship weight. From Fig. A9 in Appendix A, it is seen that this height can be expressed by following formula:

$D = 0.00172 \cdot \text{lanemeter} + 11.42$

Non-dimensional ratios of main dimensions

After the determination of the main dimensions, the following non-dimensional ratios have been calculated and plotted to see if these ratios seem to be representative for Ro-Ro cargo ships: Lpp/B, B/T, Lpp/T and Lpp/D.

All main dimensions for the three deadweight categories have been calculated and are listed in table A1 – A3. The non-dimensional ratios are shown in Fig. A10 – A13 in Appendix A, where it is seen that the 4 ratios look quite representative.

The lightship weight

Lightship data for 49 different Ro-Ro cargo ships have been analyzed to find an empirical formula for determination of the lightship weight. As the lightship weight will be proportional with the three main dimensions, Lpp, B and D, the lightship data have been plotted as function of Lpp · B · D in Fig. A14, from which following empirical equation for the lightship weight WL has been derived:

$W_L = 0.1215\ Lpp \cdot B \cdot D + 562$

Block coefficient

Based on the different equations for the main dimensions, deadweight and lightweight, the displacement as function of lane meters has been calculated for the three different deadweight density ships including the block coefficient and the length displacement ratio which are shown in Fig. A 15 and A16 in Appendix A. From these figures it is seen that the block coefficient and the length displacement ratio are quite representative.

Maximum draught versus design draught

Often a ship is assigned with two draughts, a maximum draught which is the maximum draught the ship is allowed to sail at where all strength and stability requirements are fulfilled and a so-called design draught which is the draught at which the ship is expected most often to operate at. In the ShipPax database only the maximum draught is given, but in the publications Significant Ships (1990 – 2014) the maximum draught and the design draught is given for approximately one third of the ships. In Fig. A17 in Appendix A the difference between the maximum draught and the design draught is plotted and this difference can be approximated by following equation:

Maximum draught – design draught = 0.0026 · Lpp + 0.01

Wetted surface

The wetted surface is normally calculated by hydrostatic programs for calculation of the stability data for the ship. However for a quick and fairly accurate estimation of the wetted surface many different methods and formulas exist based on only few ship main dimensions, as example Mumford´s formula below:

$$\mathrm{S} = 1.025 \cdot \mathrm{L_{pp}} \cdot (\mathrm{C_B} \cdot \mathrm{B} + 1.7 \cdot \mathrm{T}) = 1.025 \cdot \left(\frac{\nabla}{\mathrm{T}} + 1.7 \cdot \mathrm{L_{pp}} \cdot \mathrm{T}\right)$$

In the present project a modified version and more accurate version of Mumford formula has been developed. The equations for this modified version, which have been deducted in connection with the power prediction program [Kristensen 2015], are shown in the table below. The results of the analysis for the wetted surface for single screw Ro-Ro ships, twin screw Ro-Ro ships and twin-skeg Ro-Ro ships are shown in Appendix B.

Single screw Ro-Ro ships	$S = 0.87 \cdot \left(\frac{\nabla}{T} + 2.7 \cdot L_{wl} \cdot T\right) \cdot (1.2 - 0.34 \cdot C_{BW})$
Twin screw ship Ro-Ro ships with open shaft lines and twin rudders	$S = 1.21 \cdot \left(\frac{\nabla}{T} + 1.3 \cdot L_{wl} \cdot T\right) \cdot (1.2 - 0.34 \cdot C_{BW})$
Twin-skeg Ro-Ro ships with two propellers and twin rudders	$S = 1.13 \cdot \left(\frac{\nabla}{T} + 1.7 \cdot L_{wl} \cdot T\right) \cdot (1.2 - 0.31 \cdot C_{BW})$

The formulas for calculation of the wetted surface include the area of rudder(s) skegs and shaft lines. However any additional surfaces, *S',* from appendages such as bilge keels, stabilizers etc. shall be taken into account by adding the area of these surfaces to the wetted surface of the main hull separately.

If the wetted surface, S_1, is given for a given draught, T_1, the wetted surface, S_2, for another draught, T_2, can be calculated by using following formulas, which have been deducted based on an analysis of data for three types of Ro-Ro ship hull forms:

Single screw Ro-Ro ships: $S_2 = S_1 - 3.0 \cdot (T_1 - T_2) \cdot (L_{wl} + B)$

Conventional twin screw Ro-Ro ships: $S_2 = S_1 - 2.6 \cdot (T_1 - T_2) \cdot (L_{wl} + B)$

Twin-skeg Ro-Ro ships: $S_2 = S_1 - 3.0 \cdot (T_1 - T_2) \cdot (L_{wl} + B)$

Also based on a statistical analysis of three types of Ro-Ro ships following relations between L_{wl} and L_{pp} have been found:

Single screw Ro-Ro ships: $L_{wl} = 1.01 \cdot L_{pp}$

Conventional twin screw Ro-Ro ships: $Lwl = 1.035 \cdot L_{pp}$

Twin-skeg Ro-Ro ships: $L_{wl} = 1.04 \cdot L_{pp}$

Non dimensional geometric coefficients (C_B, C_P, C_M and C_W)

The midship section coefficient, C_M, is defined as the immersed midship section area, A_M, divided by the rectangular area of the breadth and draught, i.e. $C_M = A_M/(B \cdot T)$.

C_M has been analyzed for 64 Ro-Ro ships and C_M is plotted as function of the block coefficient, C_B in Fig. C1 in Appendix C, where the relation between C_M and C_B is shown as follows:

$$C_M = 0.38 - 1.25 \cdot {C_B}^2 + 1.725 \cdot C_B \text{ and } C_M = 0.975 \text{ for } C_B > 0.68$$

The midship section coefficient, C_M, will slightly decrease for decreasing draft according to following formula:

$$C_{M1} = 1 - \frac{T_0}{T_1} \cdot (1 - C_{M0})$$

where:

C_{M0} is the midship coefficient at draught T_0 and
C_{M1} is the midship coefficient at draught T_1

The water plane area coefficient is important when a new draught has to be calculated based on a given given condition (the full load condition). Of that reason the water plane area coefficient at the initial full load condition is calculated according to following empirical formula (see Fig. C2 in Appendix C):

$C_{W0} = 0.7 \cdot C_{Bpp} + 0.38$

where C_{Bpp} is the block coefficient (based on Lpp) for the full load condition displacement, Δ_0, at draught To

The draught T_1 at a lower displacement, $\Delta_{1,}$ is calculated according to following formula:

$$T_1 = T_0 - \frac{\Delta_0 - \Delta_1}{\rho \cdot C_{Wav} \cdot Lpp \cdot B}$$

where C_{Wav} is the average water plane area coefficient between T_1 and T_0.

For four different Ro-Ro ships the water plane area coefficient is shown as function of the relative displacement in per cent (see Fig. C3 in Appendix C). The water plane area coefficient, C_{W1}, at draught T_1 is calculated according to following formula (see Fig. C4 in Appendix C):

$$C_{W1} = C_{W0}\,(0.0025 \cdot (\frac{\Delta_1}{\Delta_0} \cdot 100)^2 + 0.048 \cdot \frac{\Delta_1}{\Delta_0} \cdot 100 + 70.3)/100$$

The average water plane area coefficient C_{Wav} is then calculated according to following formula:

$$C_{Wav} = C_{W0} \cdot 0.5 \cdot (100 + (0.0025 \cdot (\frac{\Delta_1}{\Delta_0} \cdot 100)^2 + 0.048 \cdot \frac{\Delta_1}{\Delta_0} \cdot 100 + 70.3))/100$$

Service speed for Ro-Ro cargo ships

The service speed is given in the ShipPax data base and in Significant Ships (1990 – 2014) and the service speed for Ro-Ro cargo ships is plotted as function of lane meters in Fig. D1 in Appendix D. Comparing the service speed in the ShipPax database with the speed in Significant Ships it seems quite evident that the speed in Significant Ships is also the service speed. From Fig. D1 following equation has been obtained for determination of the service speed for Ro-Ro cargo ships:

Service speed = $5.04 \cdot \text{lanemeter}^{0.173}$

Propeller diameter

D_{prop} is the propeller diameter. If not known the following approximations can be used to calculate D_{prop} as function of the maximum draught (see Appendix E for statistical analysis):

Single screw Ro-Ro ships (cargo and pass): $D_{prop} = 0.56 \cdot \text{max. draught} + 1.07$

Twin screw Ro-Ro cargo ships: $D_{prop} = 0.71 \cdot \text{max. draught} - 0.26$

Twin screw Ro-Ro passenger ships: $D_{prop} = 0.85 \cdot \text{max. draught} - 0.69$

Analysis of main dimensions for Ro-Ro passenger ships

The statistical background for Ro-Ro passenger ships is found in Appendix F

Low and high cargo capacity

The results of an analysis of the lane meter per passenger and deadweight per passenger are shown in Fig. F1 – F4 in Appendix F. It is seen that a large part of the Ro-Ro passenger ships have a moderate specific cargo capacity of 0.5 – 1.5 lane meter per passenger and 1 – 6 t deadweight per lane meter for the whole passenger range up to 3200 passengers. It is also observed that some of the Ro-Ro passenger ships have a relative large specific cargo capacity of more than 1.5 lane meter per passenger up to 14 lane meter per passenger and a deadweight of more than 6 t per passenger up to 38 t per lane meter. The maximum number of passengers in this group is approximately 1500 passengers, but with a majority below approximately 1000 passengers.

Based on the above mentioned observation the total number of Ro-Ro passengers have been separated in two groups:

1. Ships with low cargo capacity which means less than 1.5 lane meter per passenger and less than 6 t deadweight per passenger

2. Ships with high cargo capacity which means more than 1.5 lane meter per passenger and more than 6 t deadweight per passenger

The statistical analysis is done for each of these two subgroups. Further ships with less than 400 lane meters have been excluded in the analysis, as the small ships are not considered to be representative for this analysis. The data shown in Fig. F2 and F4 are without the ships less than 400 lane meters.

Length between perpendiculars (Lpp), waterline length (Lwl) and length overall (Loa)

Based on Fig. F5 and F6 in Appendix F, following equations have been obtained for length calculations:

Lpp = 0.922· Loa – 0.95

Loa = 1.078 · Lpp + 1.93

Passenger capacity and Lpp

As the number of passengers is a typical and driving parameter for Ro-Ro passenger ships, the different parameters will partly be expressed as functions of the ships passenger capacity and partly as function of the length between perpendiculars, which is given by following equations:

Ro-Ro passenger ships with low cargo density: $Lpp = 22.5 \cdot passengers^{0.255}$

Ro-Ro passenger ships with high cargo density: $Lpp = 81.4 \cdot passengers^{0.113}$

The two equations are developed by carrying out a regression analysis for Ro-Ro passenger ships with more than 400 lane meters and up to 5600 lane meters (see Fig. F7 in Appendix F).

Breadth and draught

The breadth and draught are calculated as functions of the length of perpendiculars as shown in Fig. F8 and F9 in Appendix F.

Ships with low cargo density: $B = 0.116 \cdot Lpp + 7.5$

Ships with high cargo density: $B = 0.083 \cdot Lpp + 11.64$

The lowest and highest breadth limits are the breadth according to the above mentioned formulas plus/minus 3 m respectively.

Ships with low cargo density: $T = 0.0284 \cdot Lpp + 1.7$

Ships with high cargo density: $T = 0.0191 \cdot Lpp + 3.01$

The lowest and highest draught limits are the breadth according to the above mentioned formulas plus/minus 0.75 m respectively.

Depth to uppermost continuous deck (weather deck)

The height of the uppermost continuous deck (weather deck) above the keel, D, is also an important main dimension which characterizes the ship and which will be used in the formula for calculation of the lightship weight. From Fig. F10 in Appendix E, it is seen that this height can be expressed by following formula:

$D = 0.05 \cdot Lpp + 6.94$

The lightship weight

As mentioned earlier the lightship data for 49 different Ro-Ro cargo ships have been analyzed to find an empirical formula for determination of the lightship weight. Also for Ro-Ro passenger ships the lightship weight will be proportional with the three main dimensions, Lpp, B and D. The lightship data have been plotted as function of Lpp · B · D in Fig. F11 in appendix F, from which following empirical equations for the lightship weight WL has been derived:

$W_L = 0.176 \cdot Lpp \cdot B \cdot D + 6$ for low cargo density Ro-Ro passenger Ro-Ro ships

$W_L = 0.185 \cdot Lpp \cdot B \cdot D - 1617$ for high cargo density Ro-Ro passenger Ro-Ro ships

Lane meters

The number of lane meters are determined as a function of the number of passengers for each cargo category as follows (see fig. F12 in Appendix F):

Ships with low cargo density and less than 800 lane meters: $LM = 1.015 \cdot passengers + 105$

Ships with low cargo density and less than 800 lane meters: $LM = 1.015 \cdot passengers + 105$

Ships with high cargo density: $LM = 89.4 \cdot pass.^{0.474}$

Deadweight and payload

In Fig. F13 in Appendix F is shown the deadweight as function of lane meters. As expected the deadweight is directly proportional with the lane meters, but calculating the deadweight per lane meter is more informative and directly useful, when the necessary deadweight and, not less important the, necessary cargo weight has to be calculated.

As the ship carries bunkers, fresh water, stores, crew and passengers and finally, but not least, also some ballast water for trim and stability purposes, only a certain percentage of the deadweight is allocated for cargo (payload).

For some of the ships analyzed the maximum payload is given and from Fig. F14 in Appendix F, it is seen that the maximum payload is varying from approximately 35 % up to approximately 85 % of the deadweight for Ro-Ro passenger ships, however with a majority between 45 % and 75 % of the deadweight. As a rough mean value the maximum payload for Ro-Ro passenger ship with low cargo density is 60 % of the maximum deadweight and 65 % of the maximum deadweight for Ro-Ro passenger ships with high cargo density. These values are in line with the payload for Ro-Ro cargo ships which is approximately 70 % of the maximum deadweight.

From Fig. F13 in Appendix F it is seen that deadweight per lanemeter (LM) can be separated in two categories:

Ships with low cargo density: $Deadweight/lanemeter = 12.4 \cdot LM^{-0.185}$

Ships with high cargo density: $Deadweight/lanemeter = 138 \cdot LM^{-0.494}$

Using the above mentioned formulas the deadweight is calculated based on the ships lanemeter capacity but in addition to this weight the passenger weight has to be added, assuming 100 kg per passenger including luggage (according to CEN standard 16258).

Non-dimensional ratios of main dimensions

After the determination of the main dimensions, the following non-dimensional ratios have been calculated and plotted to see if these ratios seem to be representative for Ro-Ro passenger ships: Lpp/B, B/T, Lpp/T and Lpp/D.

All main dimensions for the three deadweight categories have been calculated and are listed in table F1 and F2. The non-dimensional ratios are shown in Fig. F15 – F18 in Appendix F, where it is seen that the 4 ratios look quite representative.

Block coefficient and length displacement ratio

Based on the different equations for the main dimensions, deadweight and lightweight, the displacement as function of passengers has been calculated for the two different cargo density ships. The resulting block coefficient and the length displacement ratio are shown in Fig. F19 and F20 in Appendix F. From these figures it is seen that the block coefficient and the length displacement ratio are quite representative, including some statistical scatter as expected.

Maximum draught versus design draught

In the publications Significant Ships (1990 – 2014) the maximum draught and the design draught are given for approximately one third of the ships. In Fig. F21 in Appendix F the difference between the maximum draught and the design draught is plotted and this difference can be approximated by following equation:

Maximum draught – design draught = 0.55 - 0.0015 · Lpp

Number of berths

The total number of berths is shown in Fig. F22 in Appendix F. As expected some of the Ro-Ro passenger ships are day ferries with no passenger cabins. Below approximately 500 passengers most of the ferries with low cargo density have no berths, while most of the ferries with high cargo intensity have berths as they generally are sailing on longer routes. The number of berths is given by following formulas:

Ships with low cargo density: Berths = Max(0, 0.735 · passengers – 410)

Ships with high cargo density: Berths = 0.6 · passengers + 17

These two formulas for the number of berths are expected to represent an average berth capacity and the ship dimensions and lightweight characteristics already described are therefore associated with the average berth capacity. If a ship has less or more berths, necessary adjustments have to be carried out mainly with regard to the lightweight, which will influence the displacement of the ship.

The adjustment of the light weight due to change in number of berths is calculated by following formula:

Light weight change per berth: 13 · 0.2 = 2.6 t/berth assuming that the associated structural weight and interior cabin weight is 0.2 t/m^3 and that each berth corresponds to an accommodation volume of 13 m^3 [Kristensen and Hagemeister 2011].

In order to keep the block coefficient within an acceptable range adjustments of the main dimensions (length, breadth and draught) has most probably to be carried out, and these adjustments will also change the lightweight which can be calculated by the previous mentioned formula for the lightweight, where $Lpp \cdot B \cdot D$ is the main parameter.

Gross tonnage GT

The Gross tonnage is proportional with the displacement, however not linearly. The gross tonnage per tons displacement is shown In Fig. F23 in Appendix F where it is shown that the gross tonnage per ton displacement can be expressed as linear functions of the displacement as follows:

Ships with low cargo density: GT/t displacement = 0.0000352 · displacement + 1.14

Ships with high cargo density: GT/t displacement = 0.0000156 · displacement + 1.16

Using the above mentioned formulas the gross tonnage has been calculated and compared with the real gross tonnage for the sample of Ro-Ro passenger ships which have been used in the deduction of the formulas for GT calculation. The comparison is shown in Fig. F24 in Appendix F, where it is observed that there is a good correlation between the real and the theoretical GT value.

Service speed for Ro-Ro passenger Ships

The service speed for Ro-Ro passenger ships is plotted as function of Lpp in Fig. D2 and D3 in Appendix D. Comparing the service speed in the ShipPax database with the speed in Significant Ships it seems quite evident that the speed in Significant Ships is also the service speed. From Fig. D2 and D3 following equations have been obtained for determination of the service speed for Ro-Ro passenger ships:

Low cargo density ships: Service speed = 0.085 · Lpp + 8.98

High cargo density ships: Service speed = 0.0695 · Lpp + 10.16

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Appendix A – Main dimensions of Ro-Ro cargo ships

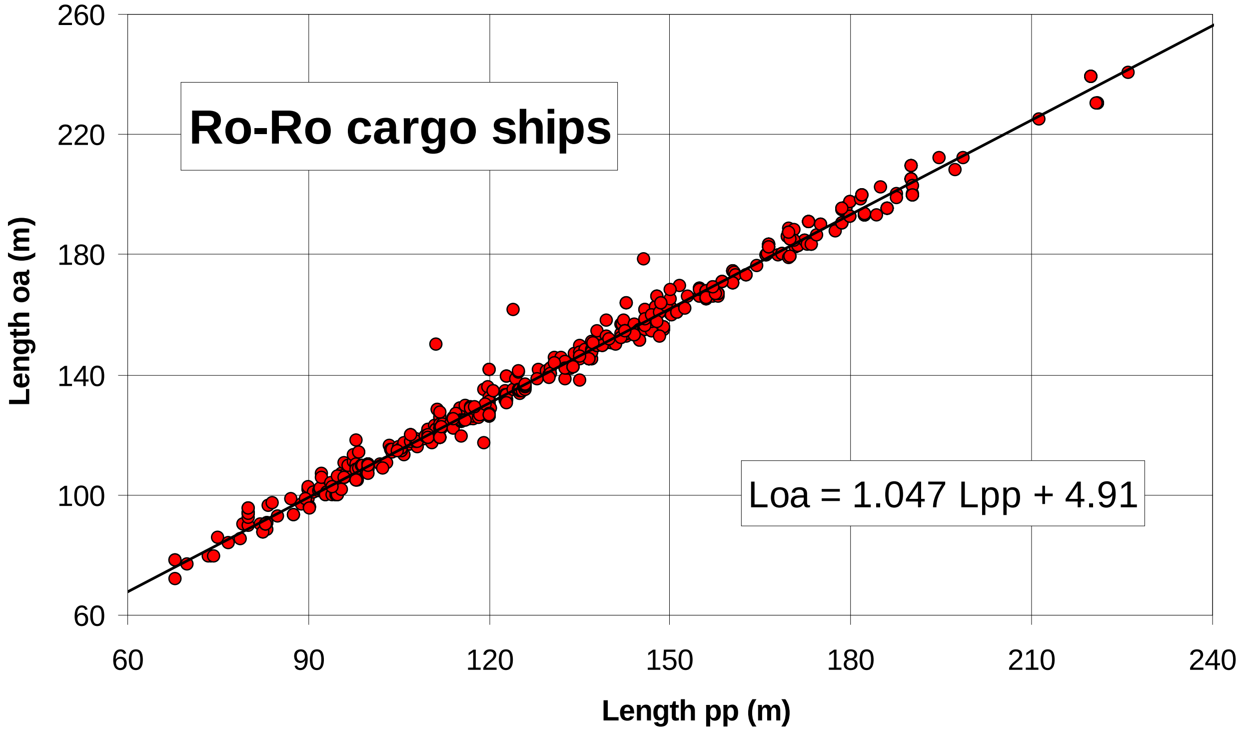

Fig. A1 Length over all, Loa, as function of length between perpendiculars, Lpp, for Ro-Ro cargo ships (ShipPax database and Significant Ships (1990 – 2014))

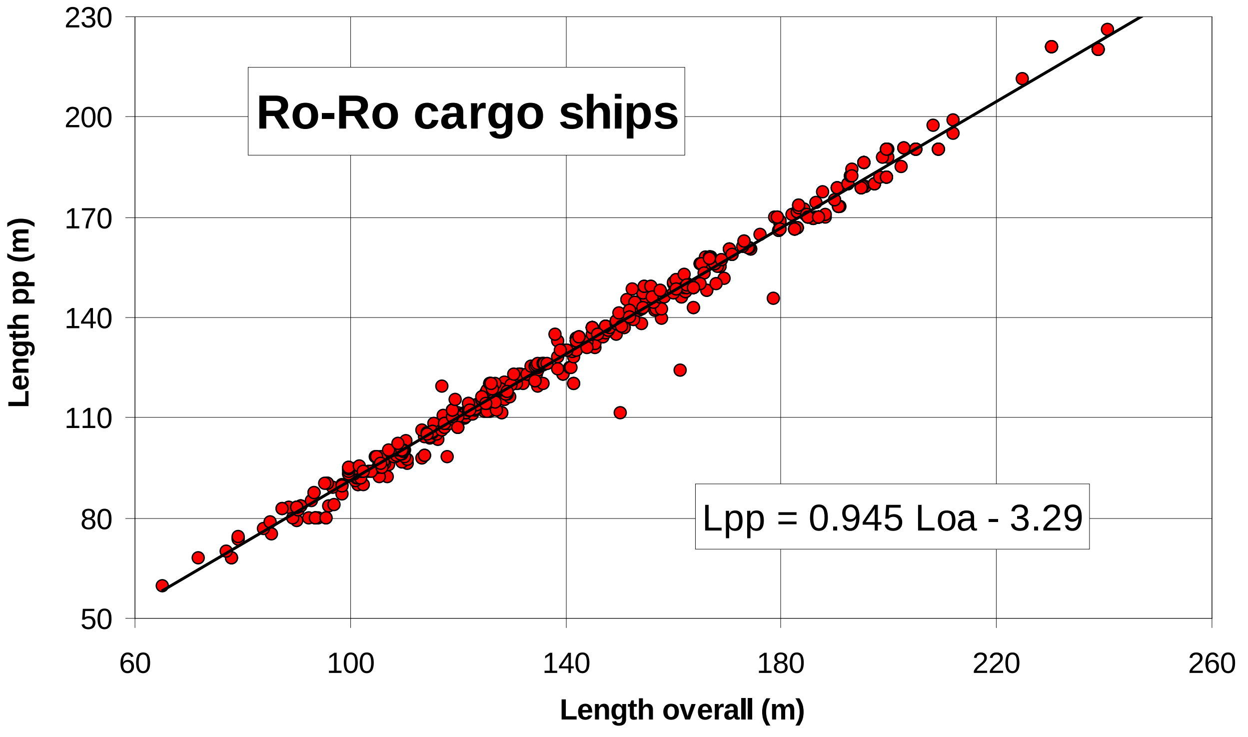

Fig. A2 Length over all as function of Length between pp Ro-Ro cargo ships. (ShipPax database and Significant Ships (1990 – 2014))

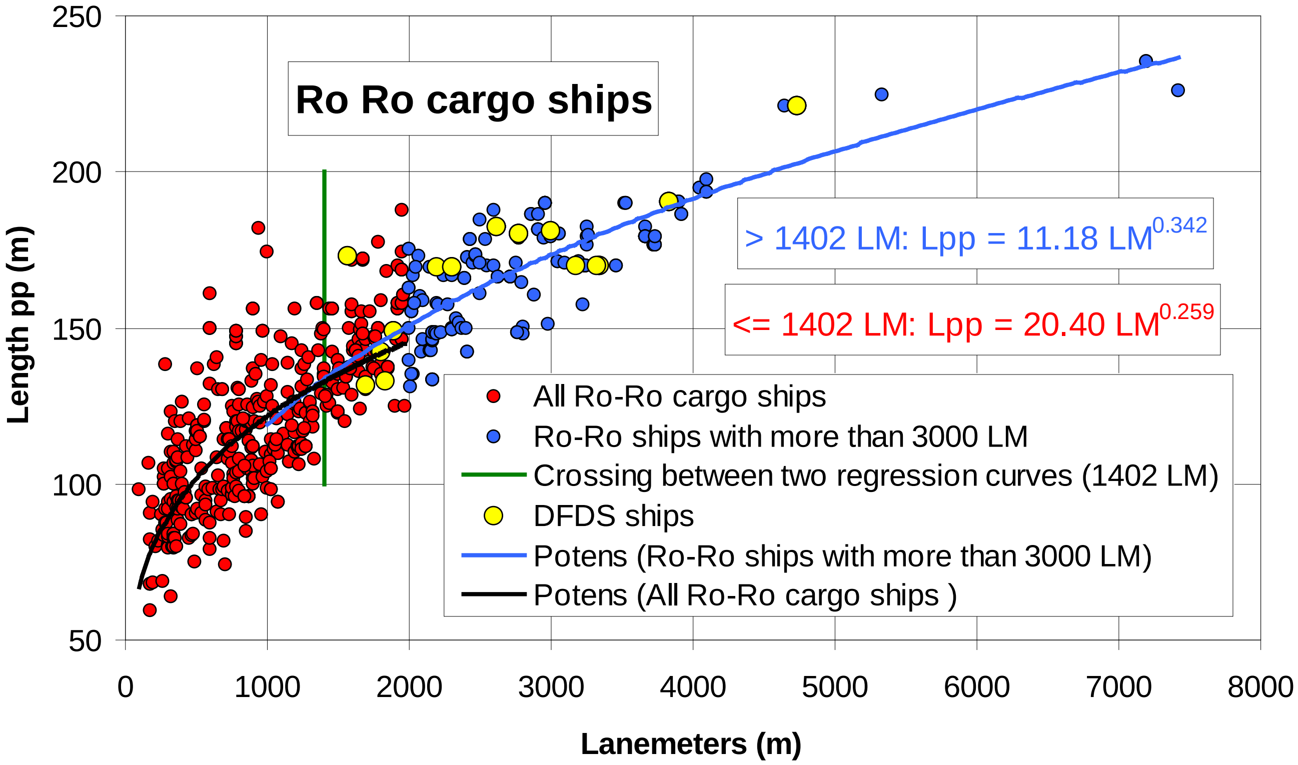

Fig. A3 Length as function of lanemeters for Ro-Ro cargo ships.
(ShipPax database, DFDS and Significant Ships (1990 – 2014))

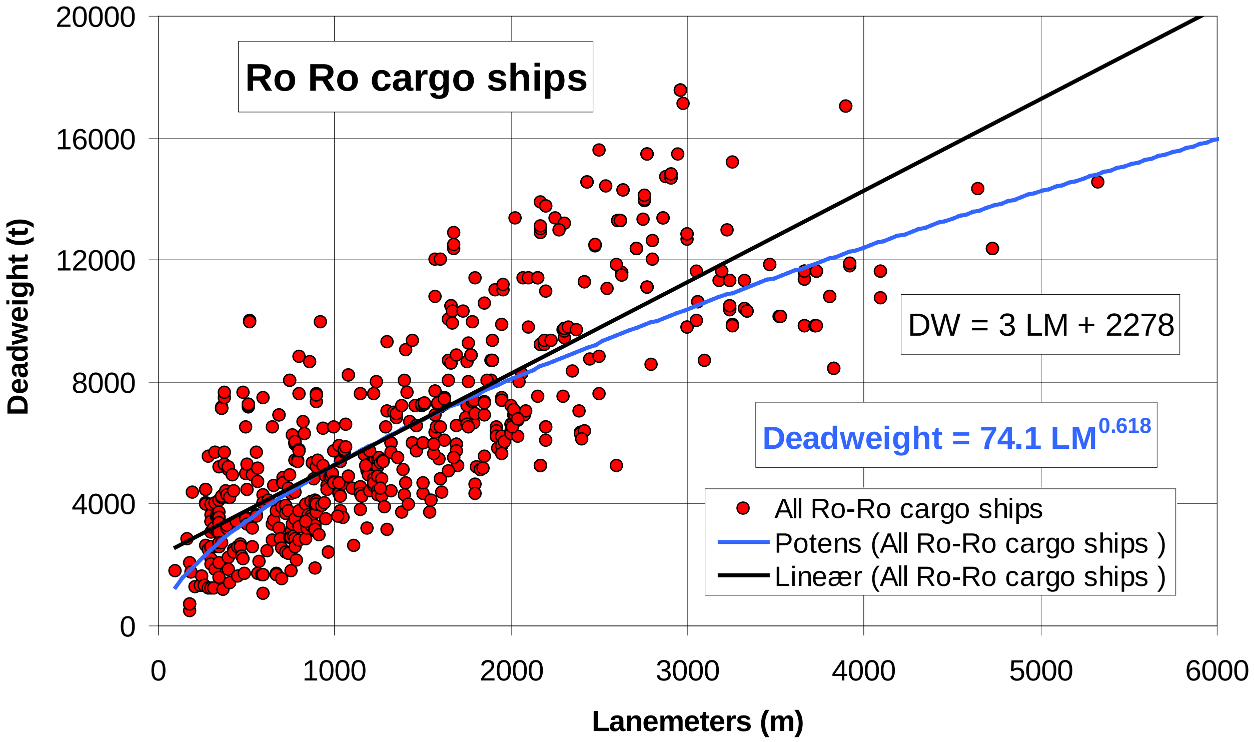

Fig. A4 Deadweight as function of lanemeters for Ro-Ro cargo ships.
(ShipPax database and Significant Ships (1990 – 2014))

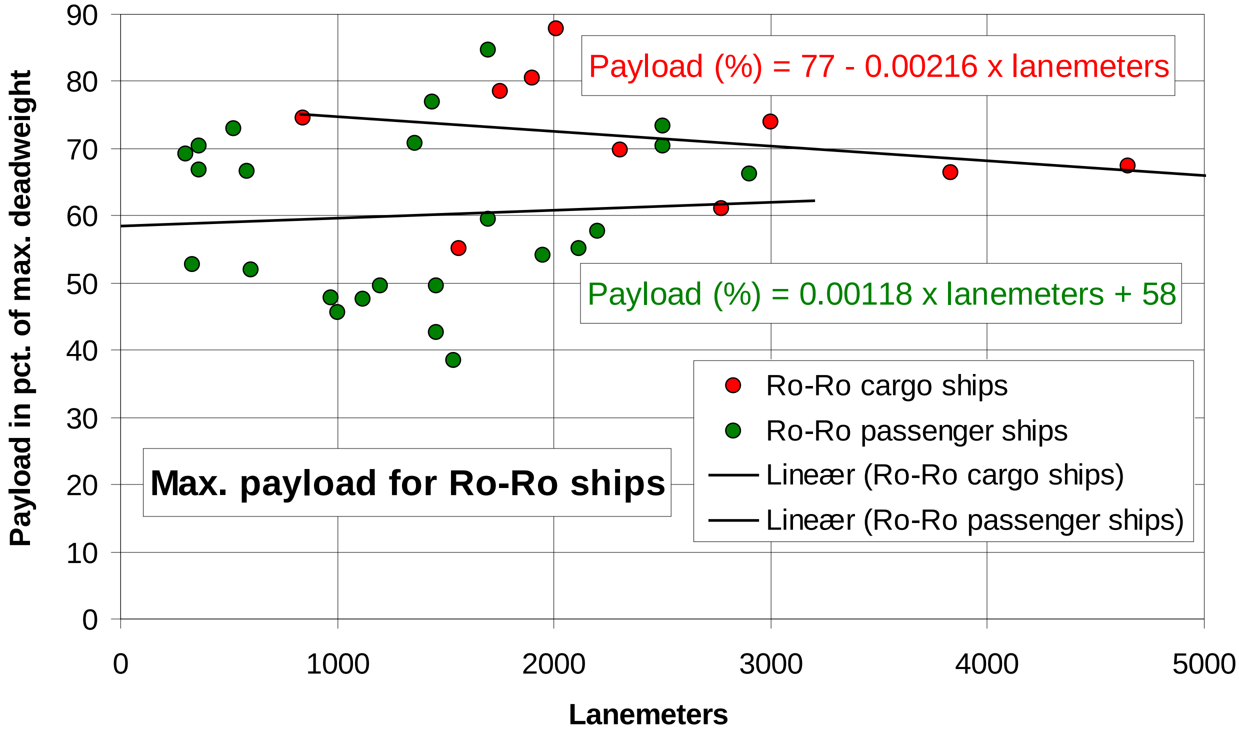

Fig. A5 Payload in percentage of maximum deadweight as function of lanemeters for Ro-Ro cargo ships (DFDS and Hans Otto Kristensen archive).

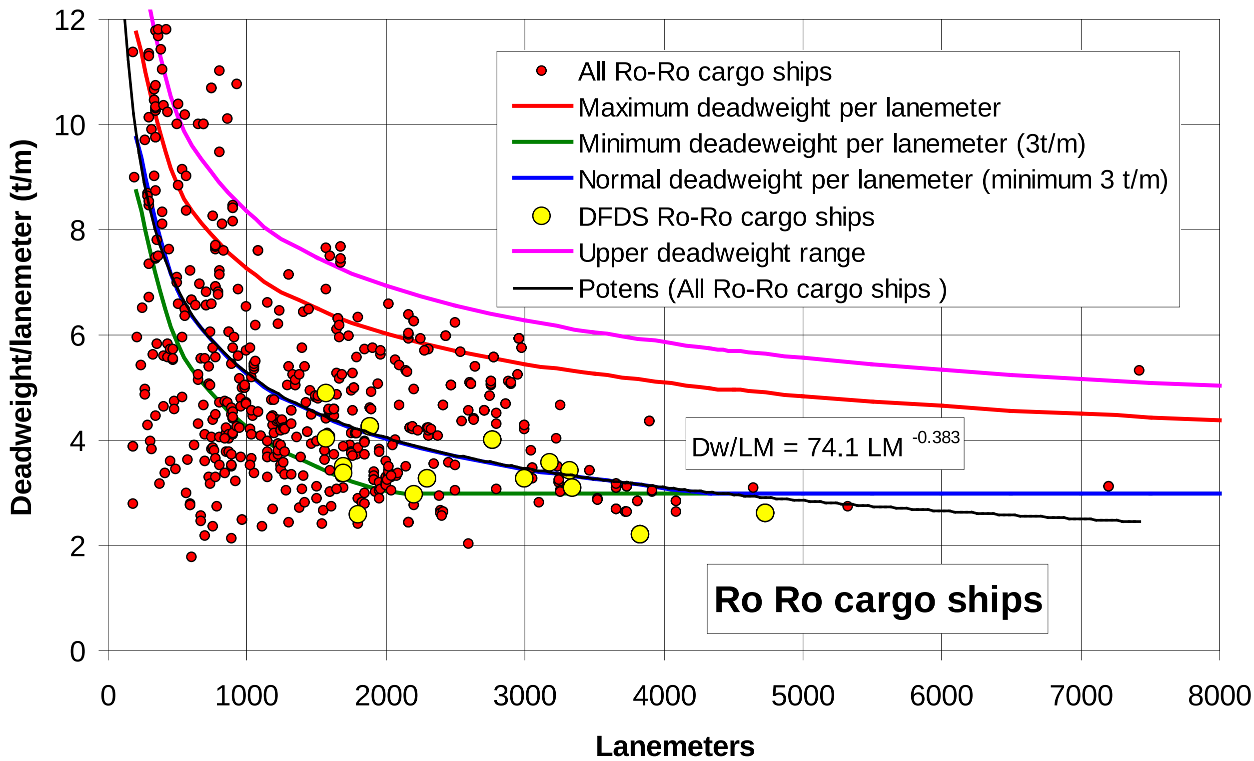

Fig. A6 Deadweight per lanemeter as function of lanemeters for Ro-Ro cargo ships (ShipPax database, DFDS and Significant Ships (1990 – 2014))

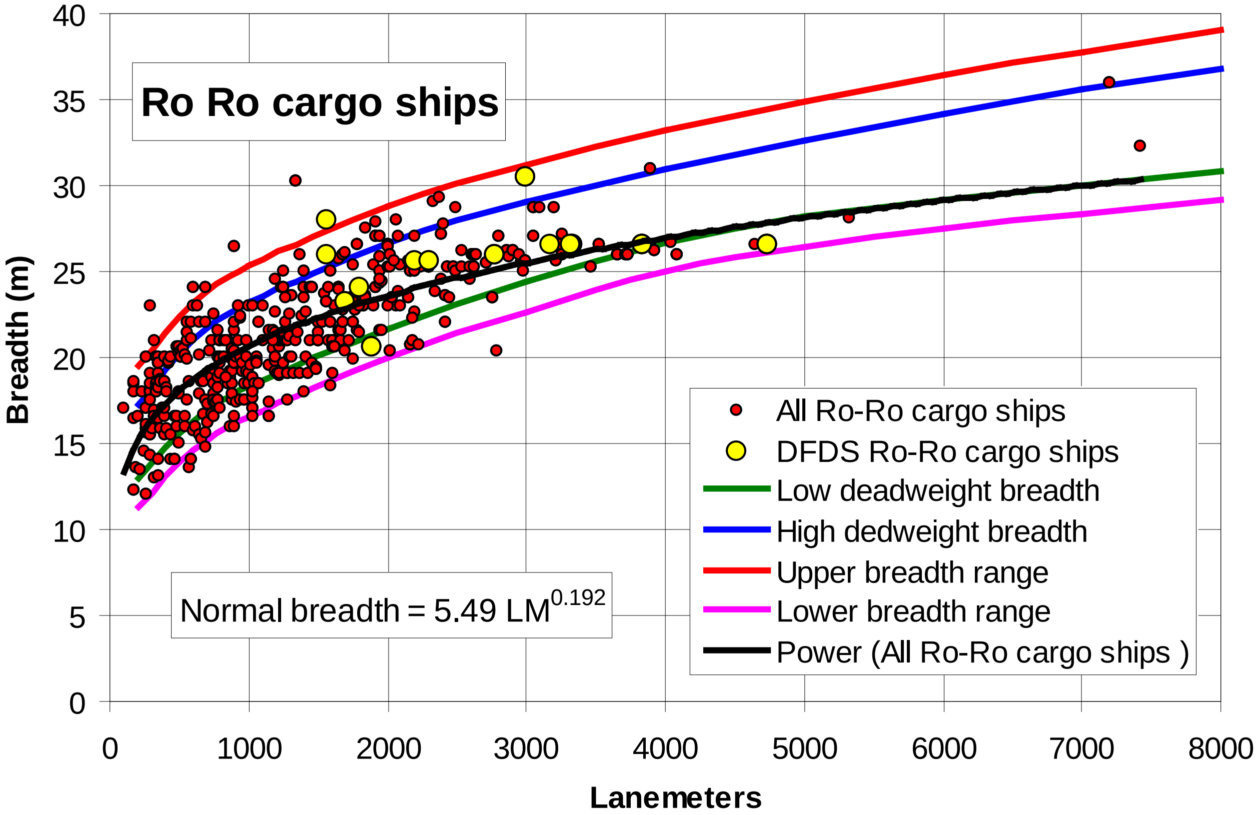

Fig. A7 Breadth as function of lanemeters for Ro-Ro cargo ships.
(ShipPax database, DFDS and Significant Ships (1990 – 2014))

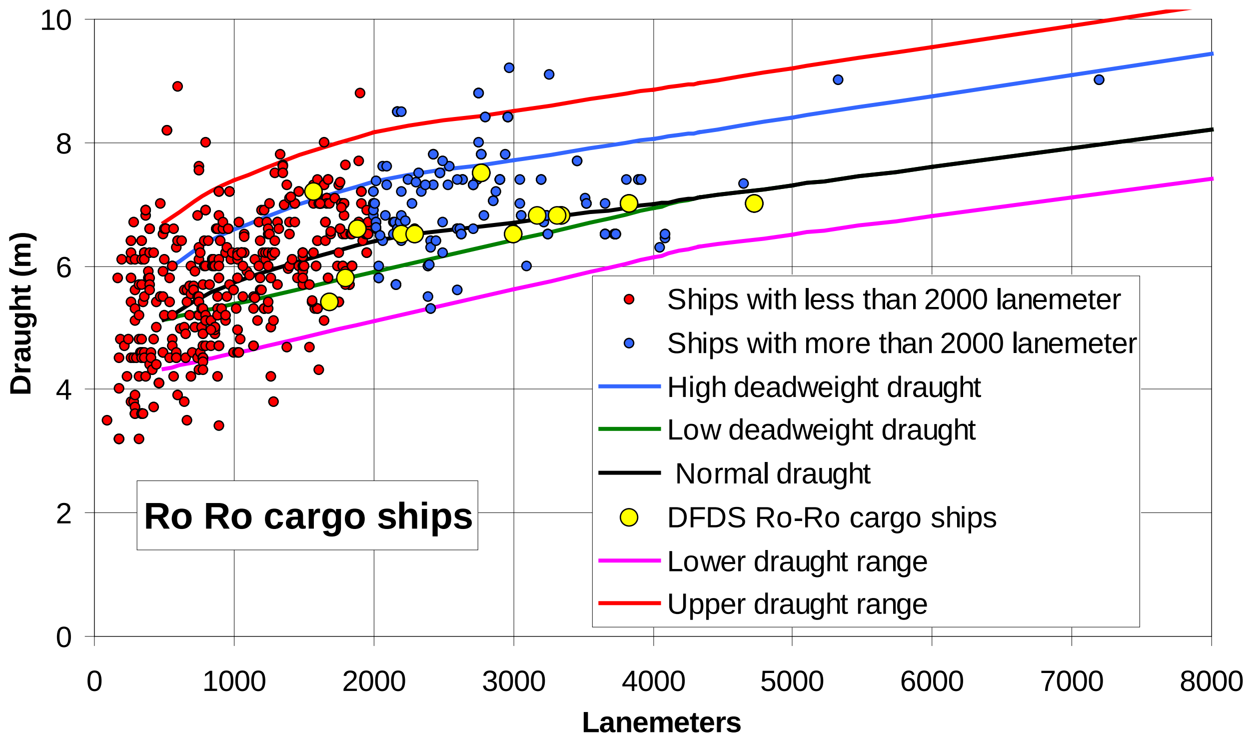

Fig. A8 Draught as function of lanemeters for Ro-Ro cargo ships.

(ShipPax database, DFDS and Significant Ships (1990 – 2014))

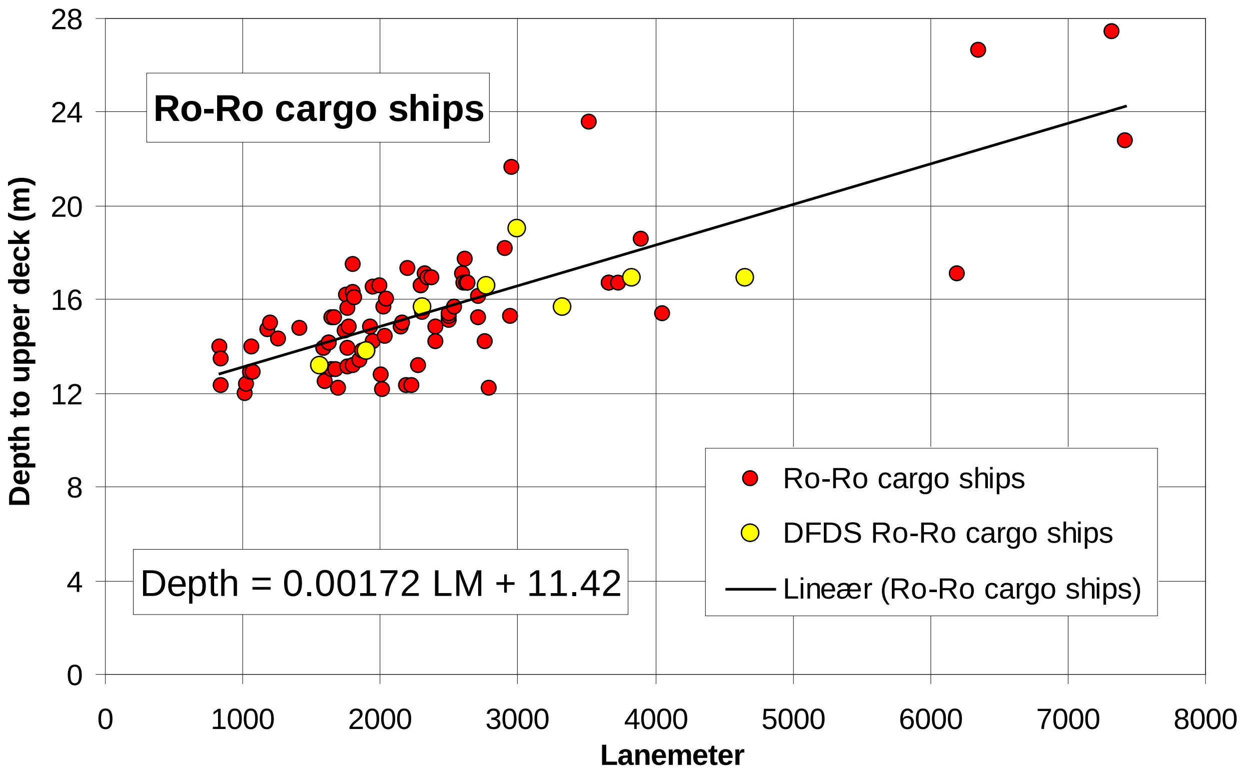

Fig. A9 Depth to uppermost continuous deck (weather deck) as function of lanemeters for Ro-Ro cargo ships. (DFDS and Significant Ships (1990 – 2014)).

Table A1 Low deadweight density ships

LM	Lpp	B	T	D	Lpp/B	B/T	Lpp/T	Lpp/D	C_B	L/Displ. vol.$^{1/3}$
m	m	m	m	m	-	-	-	-	-	-
500	102.01	15.70	5.14	12.28	6.50	3.05	19.85	8.31	0.697	5.70
1000	122.08	18.30	5.40	13.14	6.67	3.39	22.62	9.29	0.679	6.06
1500	136.35	20.16	5.65	14.00	6.76	3.57	24.11	9.74	0.658	6.28
2000	150.45	21.72	5.91	14.86	6.93	3.67	25.45	10.12	0.633	6.53
2500	162.38	23.10	6.17	15.72	7.03	3.74	26.32	10.33	0.642	6.61
3000	172.83	24.36	6.43	16.58	7.09	3.79	26.90	10.42	0.651	6.64
3500	182.19	25.55	6.68	17.44	7.13	3.82	27.26	10.45	0.656	6.67
4000	190.70	26.68	6.94	18.30	7.15	3.84	27.48	10.42	0.660	6.68
4330	195.94	27.40	7.11	18.87	7.15	3.85	27.56	10.38	0.661	6.68
5000	205.82	28.17	7.31	20.02	7.31	3.85	28.16	10.28	0.683	6.70
5500	212.64	28.69	7.46	20.88	7.41	3.85	28.50	10.18	0.698	6.72
6000	219.06	29.17	7.61	21.74	7.51	3.83	28.79	10.08	0.711	6.72
6500	225.14	29.62	7.76	22.60	7.60	3.82	29.01	9.96	0.723	6.73
7000	230.92	30.05	7.91	23.46	7.68	3.80	29.19	9.84	0.735	6.73
7500	236.44	30.45	8.06	24.32	7.76	3.78	29.33	9.72	0.745	6.74

Table A2 Normal deadweight density ships

LM	Lpp	B	T	D	Lpp/B	B/T	Lpp/T	Lpp/D	C_B	L/Displ. vol.$^{1/3}$
m	m	m	m	m	-	-	-	-	-	-
500	102.01	18.10	5.14	12.28	5.63	3.53	19.86	8.31	0.694	5.44
1000	122.08	20.68	5.74	13.14	5.90	3.60	21.28	9.29	0.663	5.74
1500	136.35	22.36	6.12	14.00	6.10	3.65	22.27	9.74	0.653	5.92
2000	150.45	23.62	6.41	14.86	6.37	3.69	23.47	10.12	0.644	6.14
2500	162.38	24.66	6.56	15.72	6.59	3.76	24.75	10.33	0.649	6.31
3000	172.83	25.54	6.71	16.58	6.77	3.81	25.76	10.42	0.653	6.44
3500	182.19	26.30	6.86	17.44	6.93	3.83	26.56	10.45	0.656	6.55
4000	190.70	26.99	7.01	18.30	7.07	3.85	27.20	10.42	0.659	6.63
4330	195.94	27.40	7.11	18.87	7.15	3.85	27.56	10.38	0.661	6.68
5000	205.82	28.17	7.31	20.02	7.31	3.85	28.16	10.28	0.683	6.70
5500	212.64	28.69	7.46	20.88	7.41	3.85	28.50	10.18	0.698	6.72
6000	219.06	29.17	7.61	21.74	7.51	3.83	28.79	10.08	0.711	6.72
6500	225.14	29.62	7.76	22.60	7.60	3.82	29.01	9.96	0.723	6.73
7000	230.92	30.05	7.91	23.46	7.68	3.80	29.19	9.84	0.735	6.73
7500	236.44	30.45	8.06	24.32	7.76	3.78	29.33	9.72	0.745	6.74

Table A3 High deadweight density ships

LM	Lpp	B	T	D	Lpp/B	B/T	Lpp/T	Lpp/D	C_B	L/Displ. vol.$^{1/3}$
m	m	m	m	m	-	-	-	-	-	-
500	102.01	20.35	5.91	12.28	5.01	3.45	17.27	8.31	0.643	5.12
1000	122.08	23.18	6.60	13.14	5.27	3.51	18.50	9.29	0.645	5.33
1500	136.35	25.11	7.04	14.00	5.43	3.57	19.37	9.74	0.653	5.44
2000	150.45	26.62	7.37	14.86	5.65	3.61	20.41	10.12	0.656	5.60
2500	162.38	27.91	7.54	15.72	5.82	3.70	21.52	10.33	0.670	5.72
3000	172.83	29.04	7.72	16.58	5.95	3.76	22.40	10.42	0.681	5.81
3500	182.19	30.05	7.89	17.44	6.06	3.81	23.09	10.45	0.690	5.88
4000	190.70	30.99	8.06	18.30	6.15	3.84	23.66	10.42	0.698	5.93
4330	195.94	31.57	8.18	18.87	6.21	3.86	23.97	10.38	0.702	5.96
5000	205.82	32.67	8.41	20.02	6.30	3.89	24.48	10.28	0.710	6.01
5500	212.64	33.44	8.58	20.88	6.36	3.90	24.79	10.18	0.714	6.04
6000	219.06	34.17	8.75	21.74	6.41	3.90	25.03	10.08	0.718	6.07
6500	225.14	34.87	8.90	22.60	6.46	3.92	25.29	9.96	0.723	6.09
7000	230.92	35.55	9.01	23.46	6.50	3.95	25.63	9.84	0.731	6.11
7500	236.44	36.20	9.11	24.32	6.53	3.97	25.96	9.72	0.739	6.12

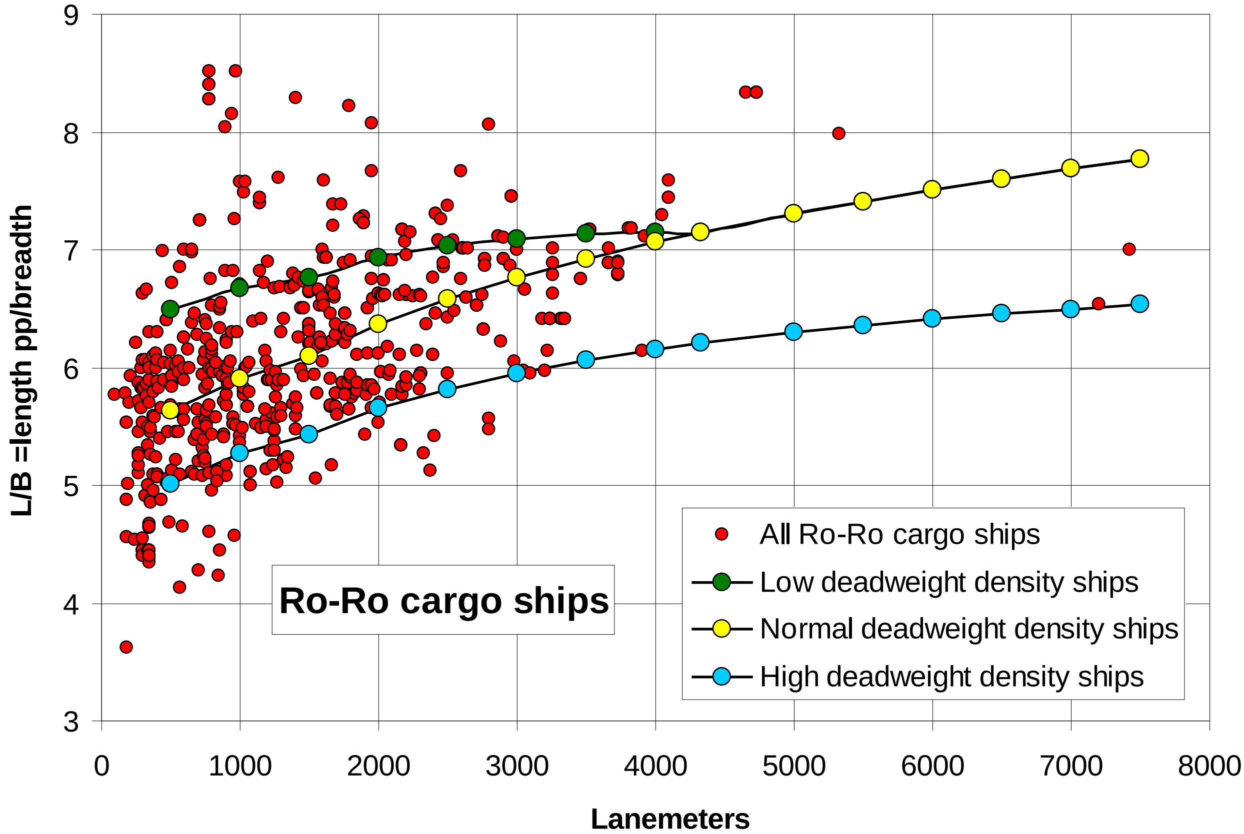

Fig. A10 Length-breadth ratio as function of lanemeters for Ro-Ro cargo ships. (ShipPax database and Significant Ships (1990 – 2014))

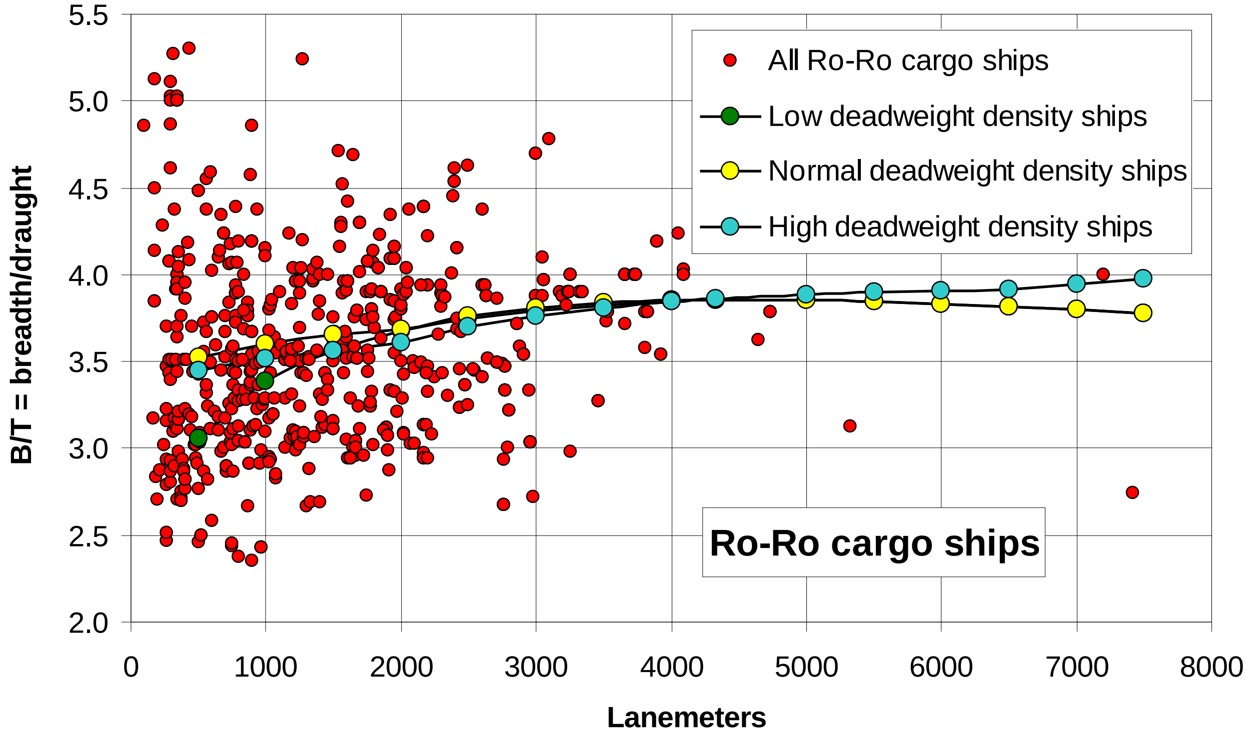

Fig. A11 Breadth-draught ratio as function of lanemeters for Ro-Ro cargo ships. (ShipPax database and Significant Ships (1990 – 2014))

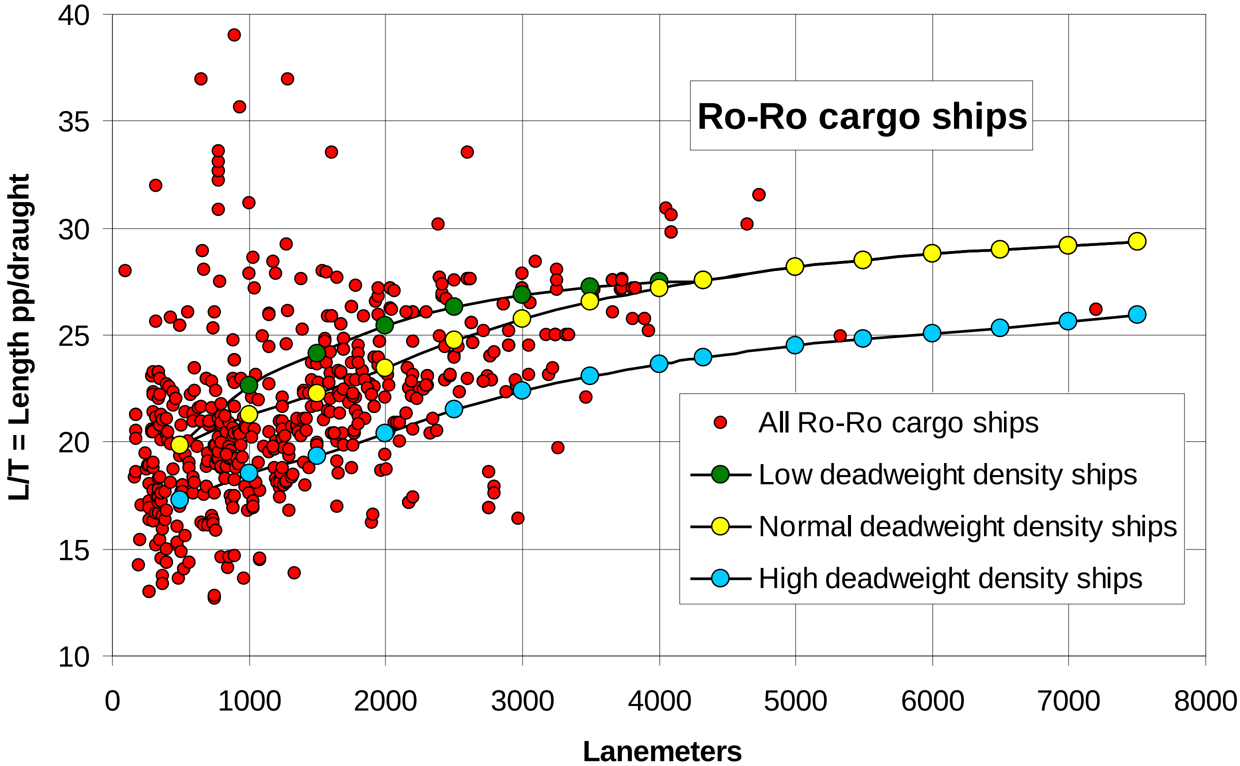

Fig. A12 Length-draught ratio as function of lanemeters for Ro-Ro cargo ships. (ShipPax database and Significant Ships (1990 – 2014))

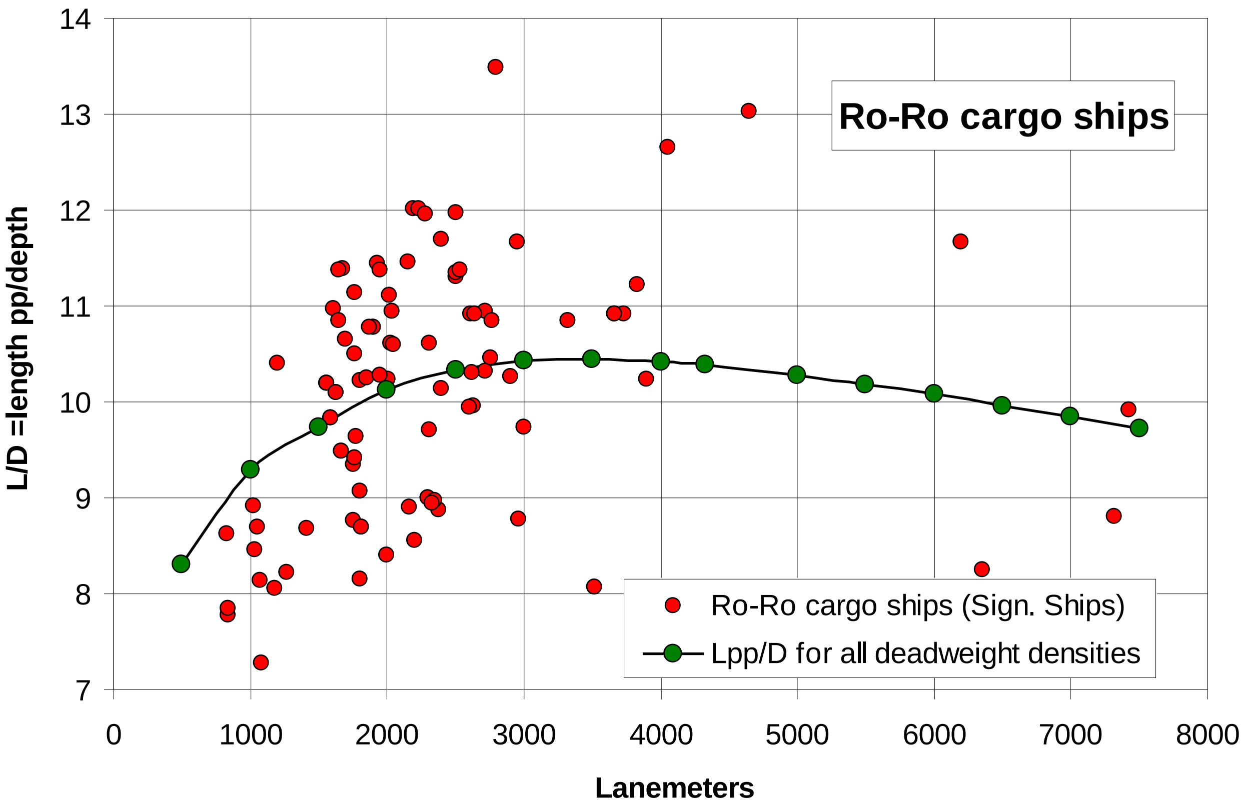

Fig. A13 Length-depth ratio as function of lanemeters for Ro-Ro cargo ships. (Significant Ships (1990 – 2014))

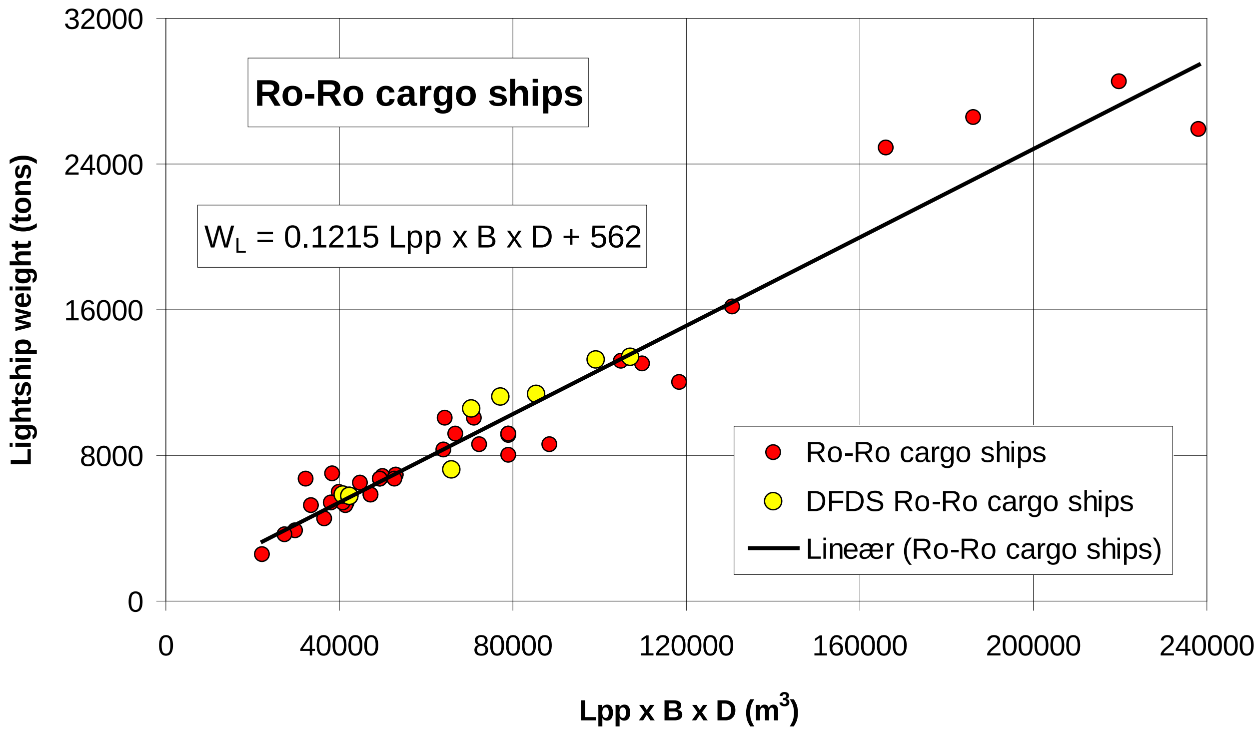

Fig. A14 Lightship weight as function of Lpp · B · D for Ro-Ro cargo ships.
DFDS and Significant Ships (1990 – 2014)

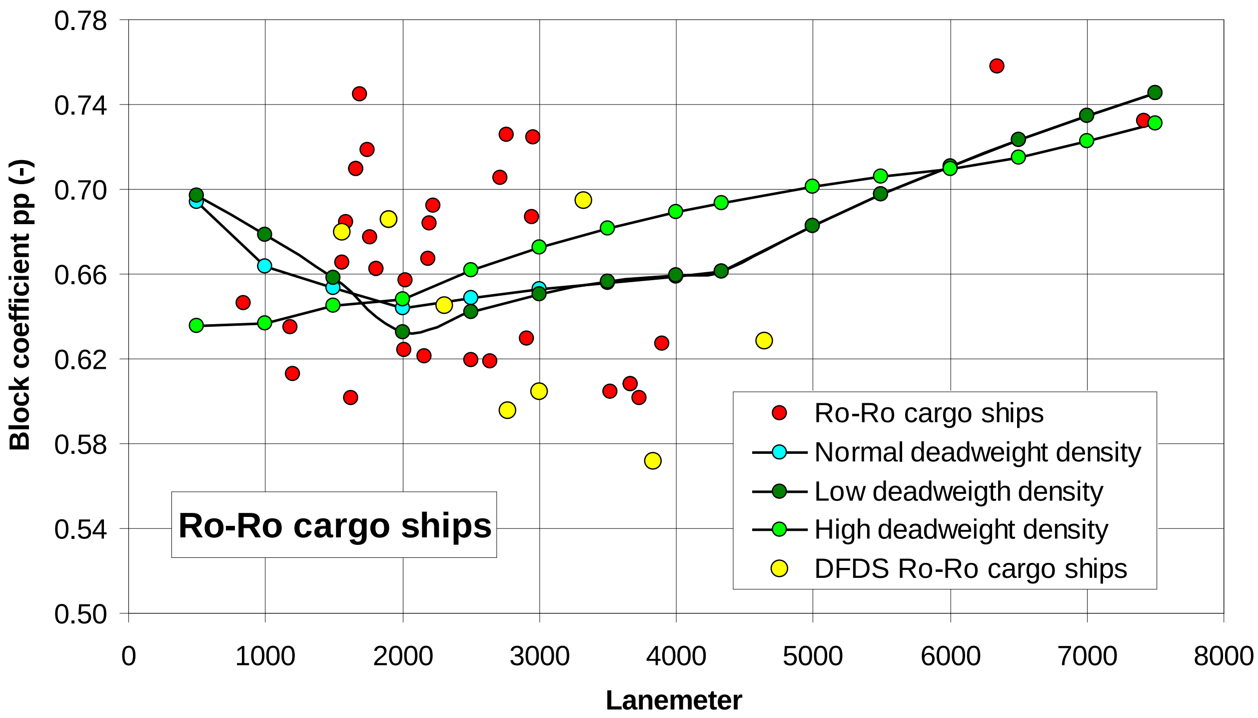

Fig. A15 Block coefficient as function of lanemeters for Ro-Ro cargo ships.
DFDS and Significant Ships (1990 – 2014)

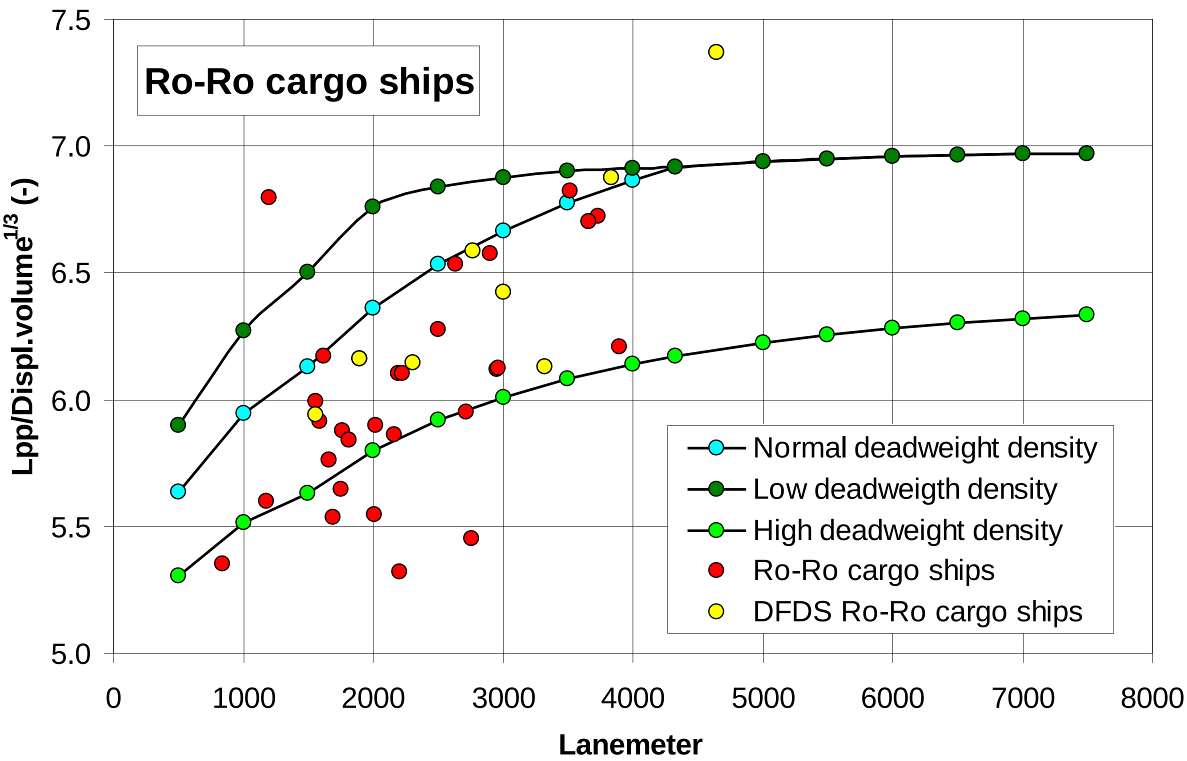

Fig. A16 Length displacement ratio as function of lane meters for Ro-Ro cargo ships. DFDS and Significant Ships (1990 – 2014)

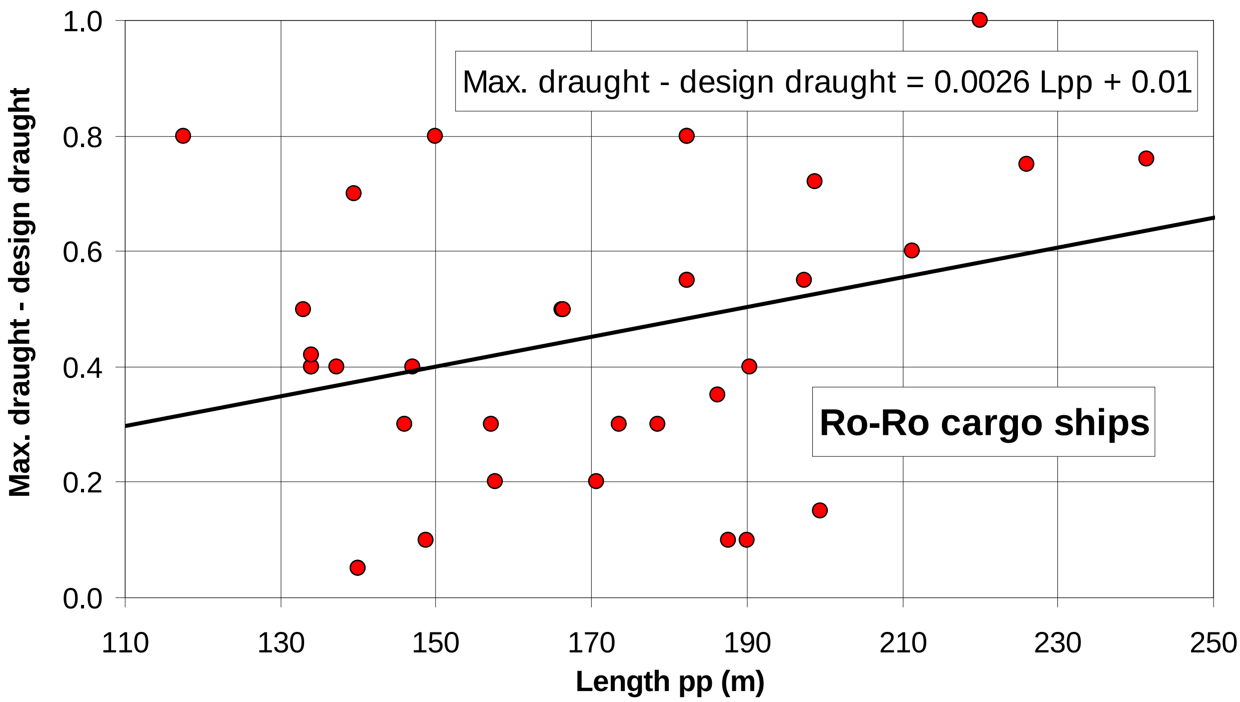

Fig. A16 Difference between maximum draught and design draught as function of Lpp for Ro-Ro cargo ships. Significant Ships (1990 – 2014).

Appendix B – Wetted surface of Ro-Ro ships

The equation used for calculation of the wetted surface in the present project is Mumfords formula according to [Harvald 1983, p. 131]:

$$S = 1.025 \cdot L_{pp} \cdot (C_B \cdot B + 1.7 \cdot T) = 1.025 \cdot \left(\frac{\nabla}{T} + 1.7 \cdot L_{pp} \cdot T\right)$$

An analysis of wetted surface data of 52 different Ro-Ro ships (of different type as well as size) shows that the wetted surface according to the above mentioned version of Mumford´s formula can be up to 15 % too small or too high (Fig. B6 and B7). Therefore it has been analysed if the formula can be adjusted to increase the accuracy.

Analysis of ship geometry data has shown that the wetted surface can be calculated according to following modified Mumford formulas:

$S = X \cdot \left(\frac{\nabla}{T} + 2.7 \cdot L_{wl} \cdot T\right)$ for single screw Ro-Ro ships

$S = X \cdot \left(\frac{\nabla}{T} + 1.3 \cdot L_{wl} \cdot T\right)$ for twin screw Ro-Ro ships

$S = X \cdot \left(\frac{\nabla}{T} + 1.7 \cdot L_{wl} \cdot T\right)$ for twin-skeg Ro-Ro ships

The X- value for the three different ships types are show in Fig. B1

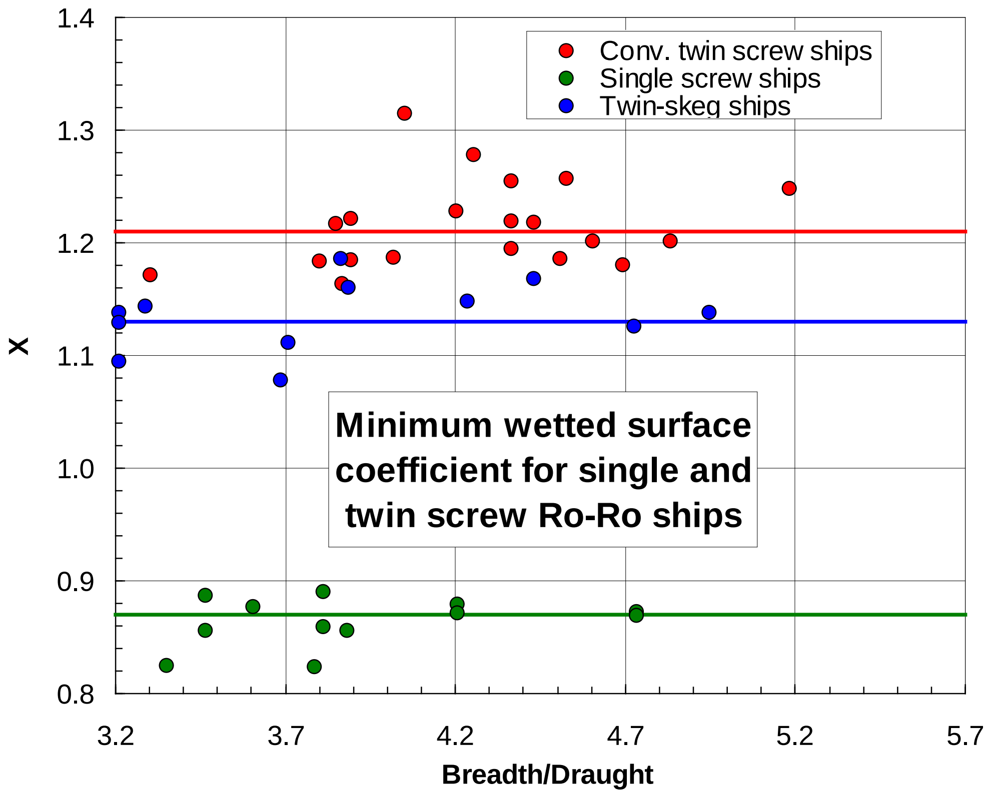

Fig. B1 Constant X is the modified Mumford formula

Using the modified Mumford formulas increases the accuracy of calculation of the wetted surface. However a further analysis reveals that the block coefficient also has an influence on the wetted surface, which can be seen by comparing the actual wetted surface with the wetted surface calculated according to the revised Mumford formula.

The results of this comparison are shown on Fig. B2 – B4. Based on the correction factors following equations for calculation of the wetted surface have been deducted:

Single screw Ro-Ro ships	$S = 0.87 \cdot \left(\frac{\nabla}{T} + 2.7 \cdot L_{wl} \cdot T\right) \cdot (1.2 - 0.34 \cdot C_{BW})$
Twin screw ship Ro-Ro ships with open shaft lines and twin rudders	$S = 1.21 \cdot \left(\frac{\nabla}{T} + 1.3 \cdot L_{wl} \cdot T\right) \cdot (1.2 - 0.34 \cdot C_{BW})$
Twin-skeg Ro-Ro ships with two propellers and twin rudders	$S = 1.13 \cdot \left(\frac{\nabla}{T} + 1.7 \cdot L_{wl} \cdot T\right) \cdot (1.2 - 0.31 \cdot C_{BW})$

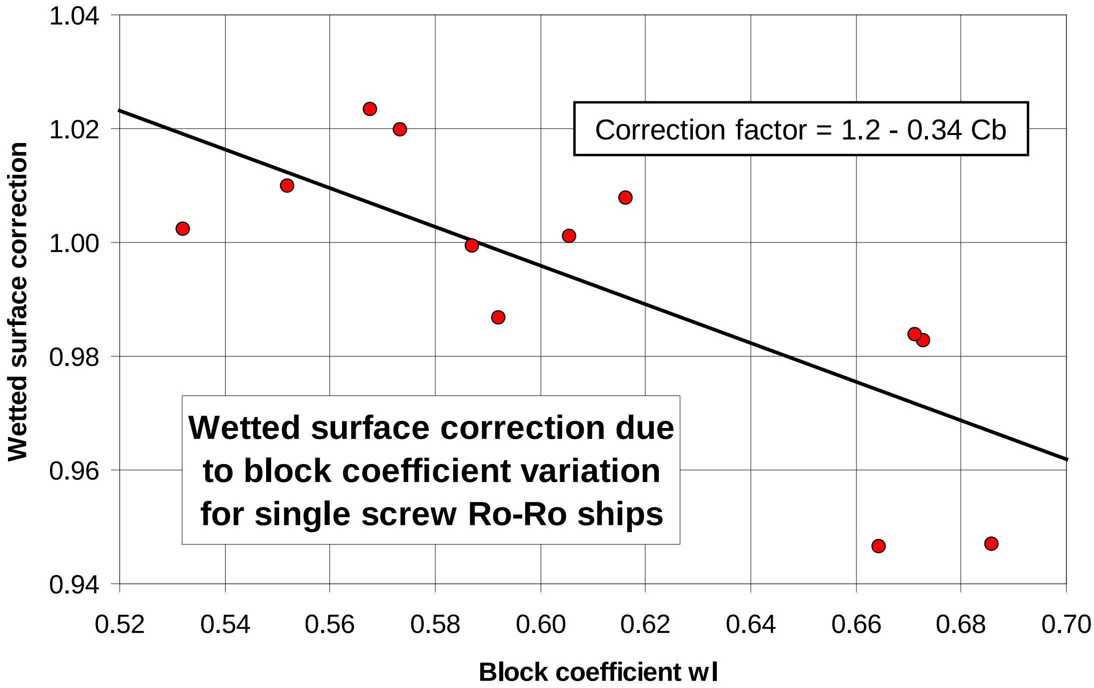

Fig. B2 Wetted surface correction for single screw Ro-Ro ships

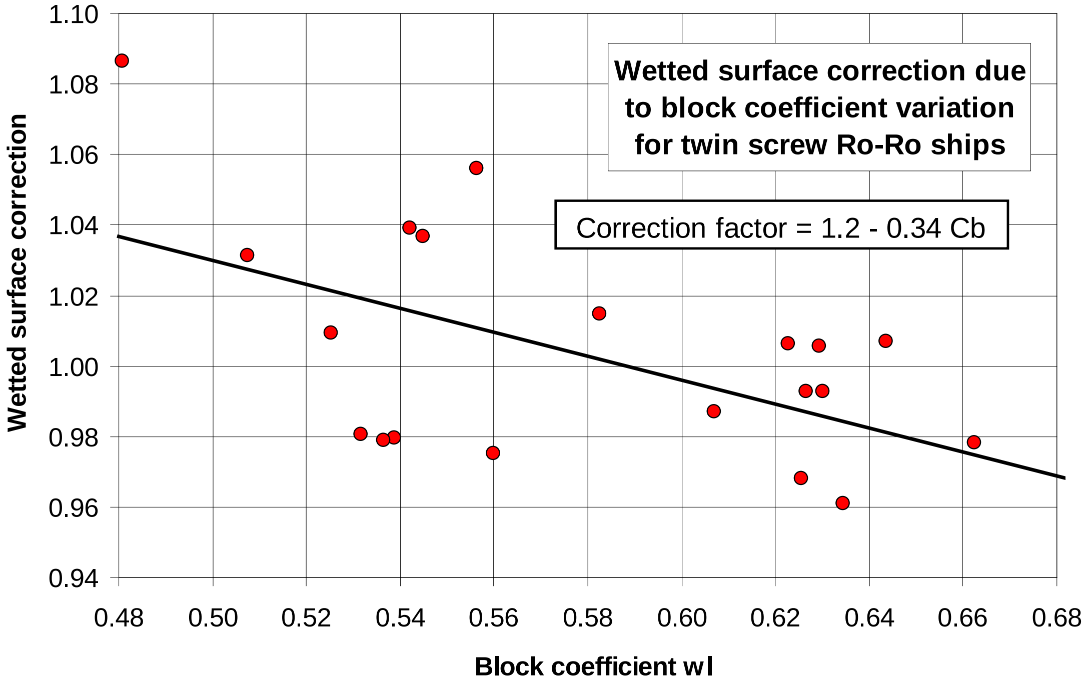

Fig. B3 Wetted surface correction for twin screw Ro-Ro ships

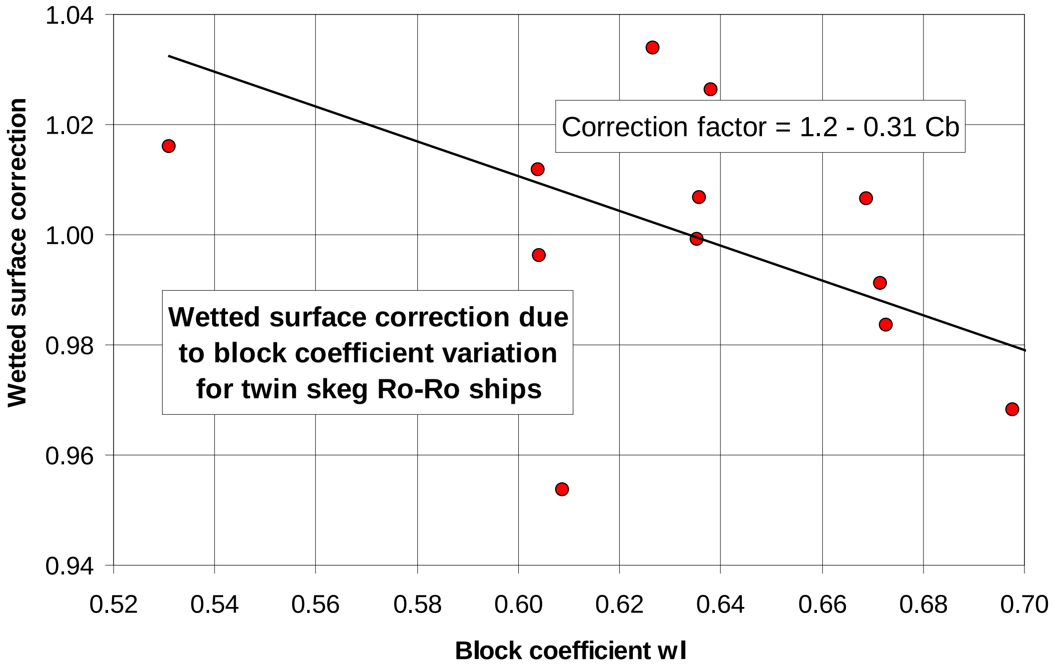

Fig. B4 Wetted surface correction for twin-skeg Ro-Ro ships

Comparisons of the wetted surface using the different formulas with the actual wetted surface are shown in Fig. B5 – B7. It is seen that the modified versions of Mumfords formula increases the accuracy considerable – with the smallest difference using the formula with block coefficient correction. It is seen that the difference is less than 3 % for 86 % of the single screw ships and 69 % of the conventional twin screw ships. For the twin-skeg ships the accuracy is even better as the difference is below 2 % for 79 % of these ships.

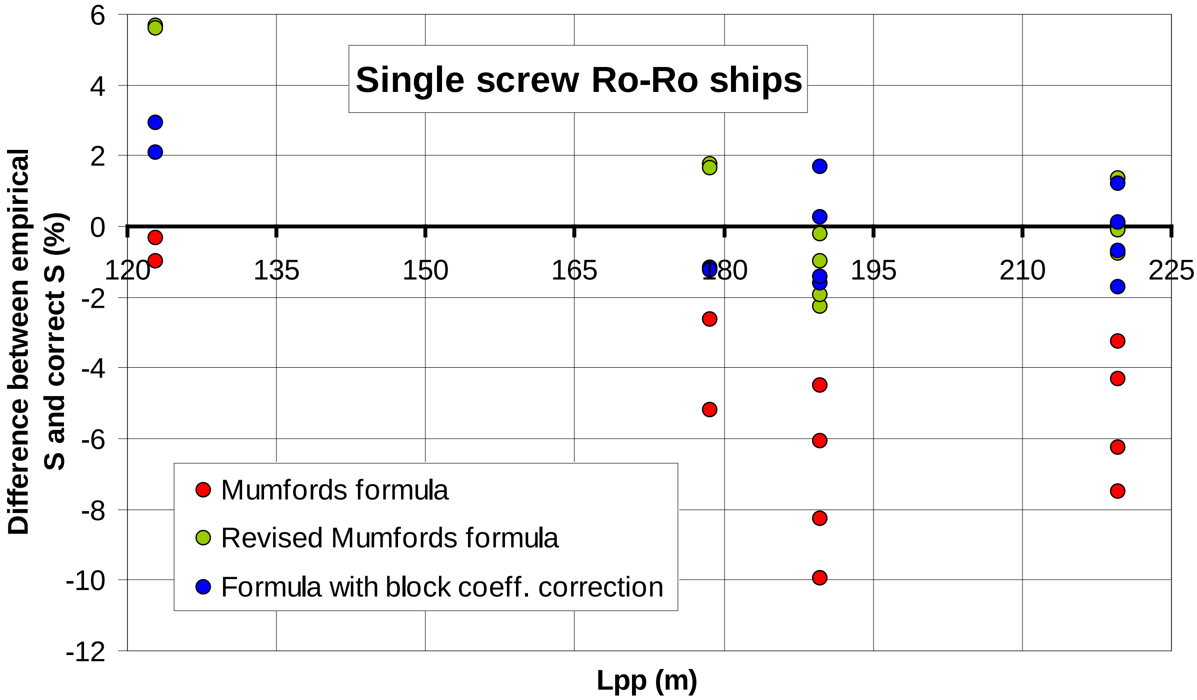

Fig. B5 Difference between the wetted surface according to different versions of Mumfords formula and the actual wetted surface for single screw Ro-Ro ships

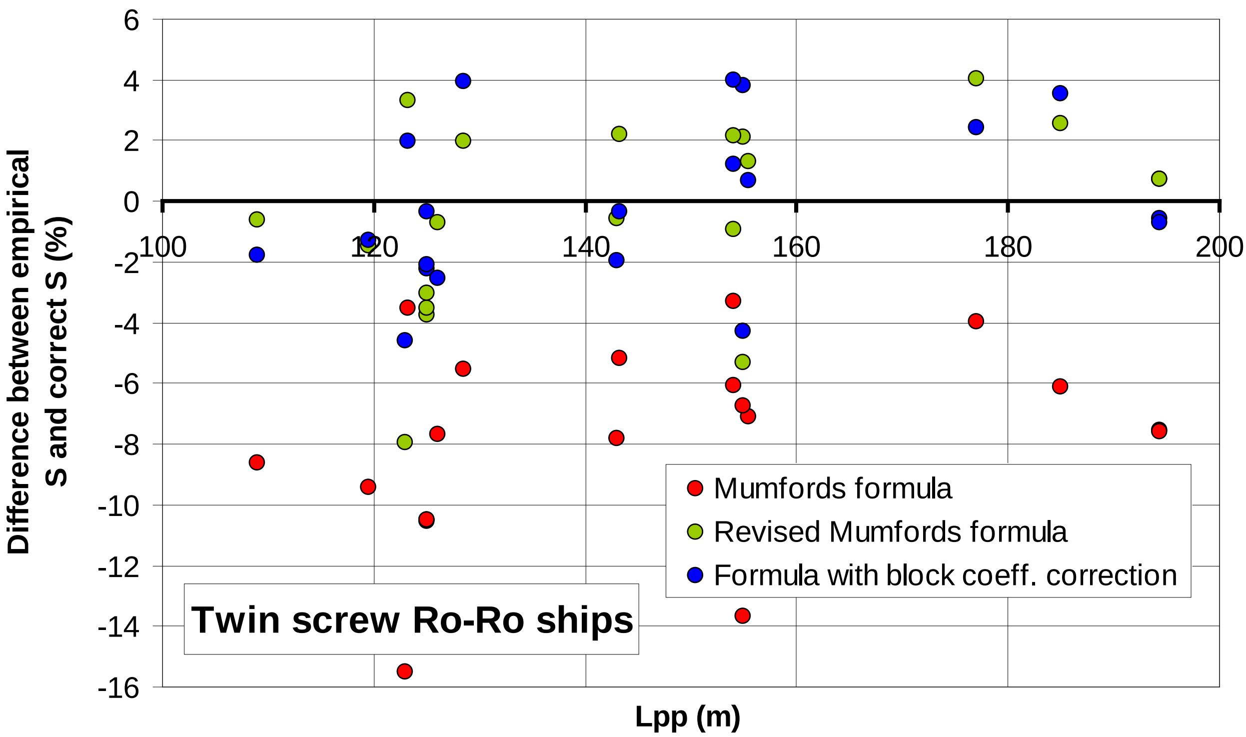

Fig. B6 Difference between the wetted surface according to different versions of Mumfords formula and the actual wetted surface for conventional twin screw Ro-Ro ships

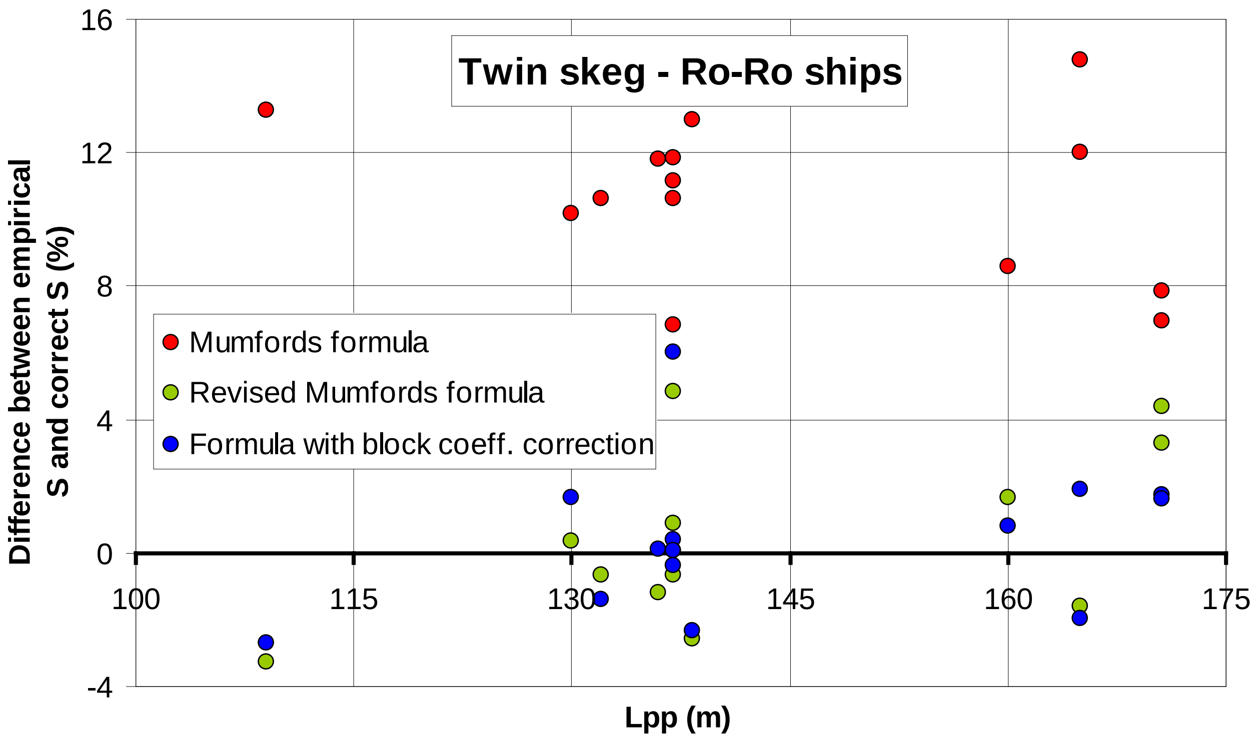

Fig. B7 Difference between the wetted surface according to different versions of Mumfords formula and the actual wetted surface for twin-skeg Ro-Ro ships

Table B1 Average difference in % between the wetted surface according to different versions of Mumfords formula and the actual wetted surface for Ro-Ro ships

Ship type	Original Mumford formula	Modified Mumford formula	Modified Mumford formula with block coefficient correction
Single screw ship	4.94	1.86	1.34
Conventional twin screw ship	5.80	2.80	2.53
Twin-skeg ship	10.68	2.15	1.65

Appendix C - Non dimensional geometric coefficients (C_B, C_P, C_M and C_W)

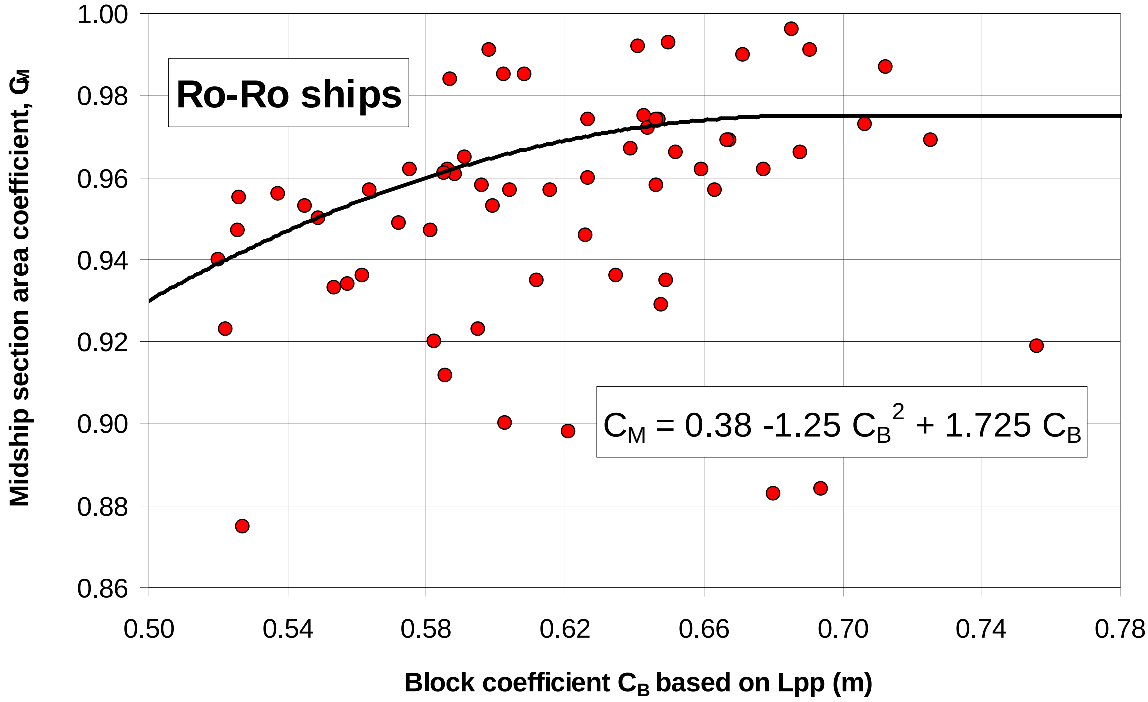

Fig. C1 Relationship between midship section area coefficient and block coefficient for Ro-Ro ships. Hans Otto Kristensen archive.

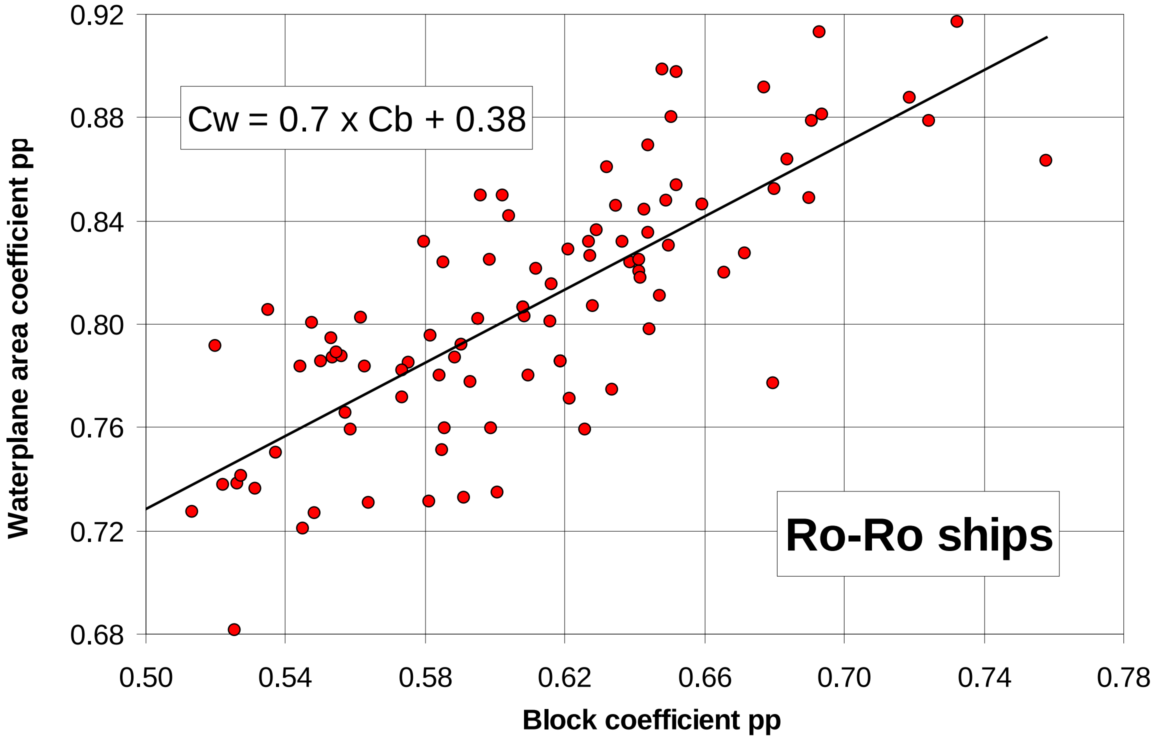

Fig. C2 Relationship between waterplane area coefficient and block coefficient for Ro-Ro ships. Significant Ships (1990 – 2014) and Hans Otto Kristensen archive.

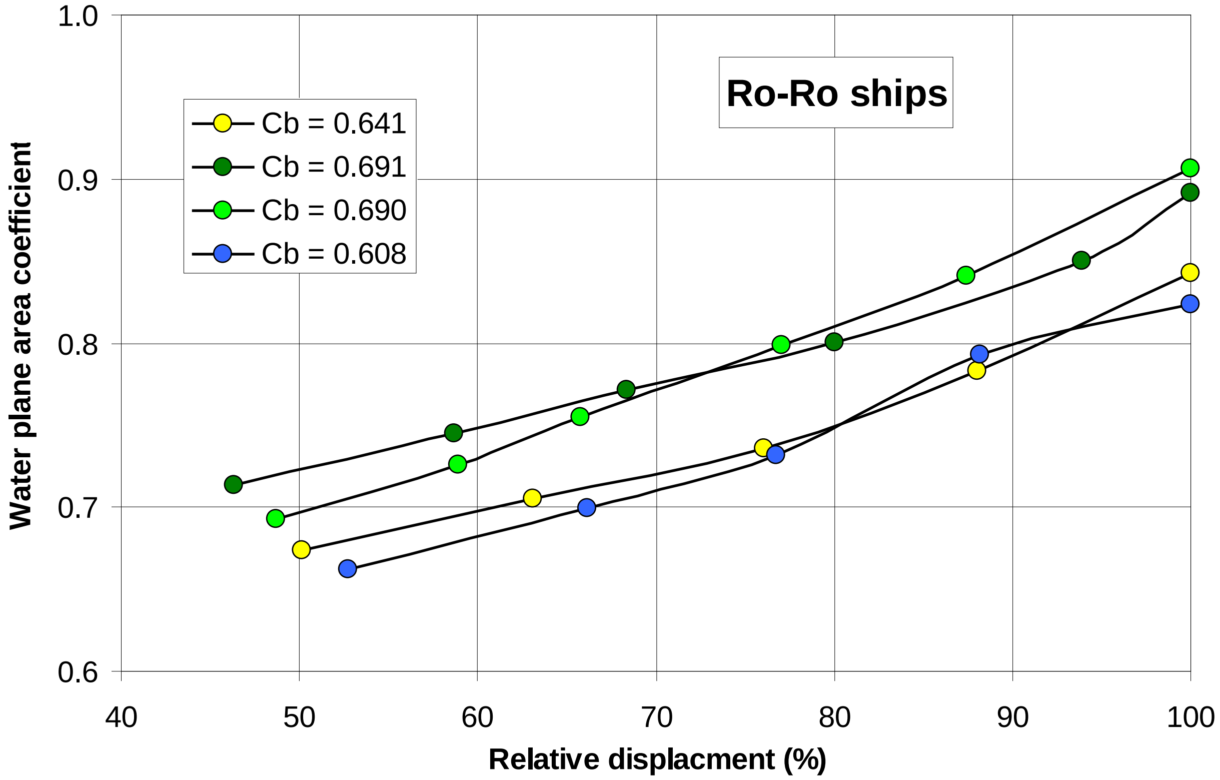

Fig. C3 Relationship between waterplane area coefficient and relative displacement for 4 Ro-Ro ships. DFDS data.

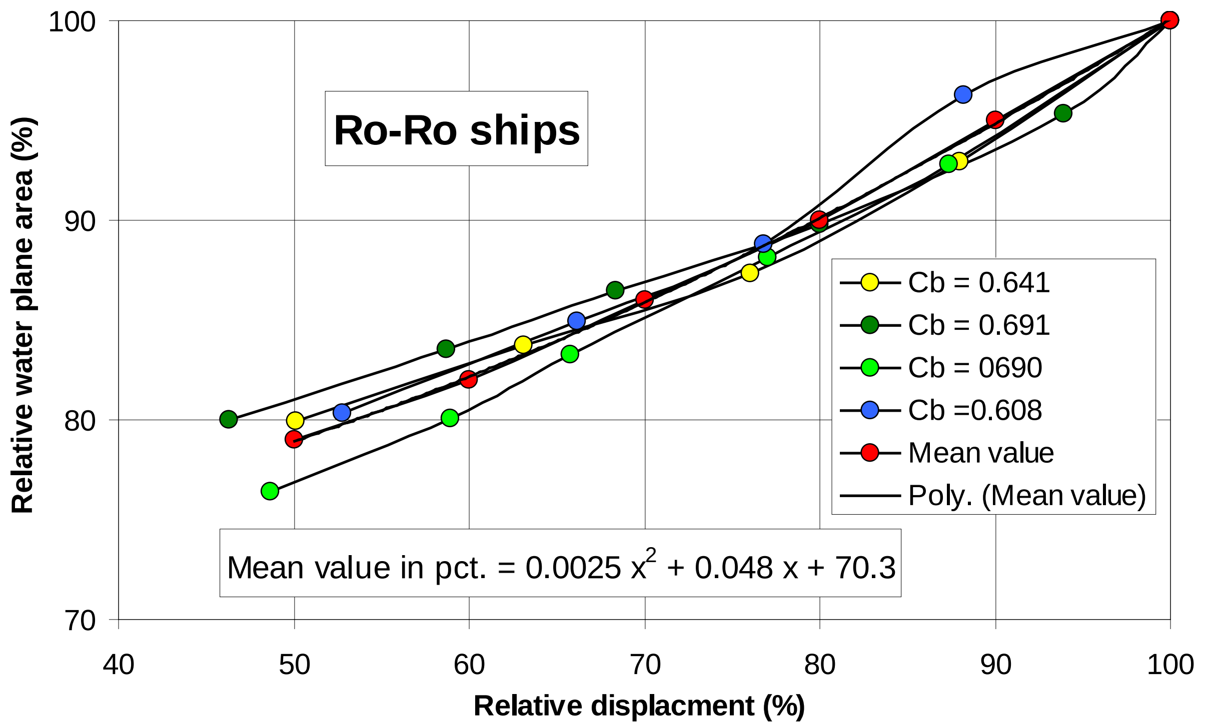

Fig. C4 Relationship between relative waterplane area coefficient and relative displacement for 4 Ro-Ro ships (identical with the ships in Fig. C3). DFDS data.

Appendix D – Service speed

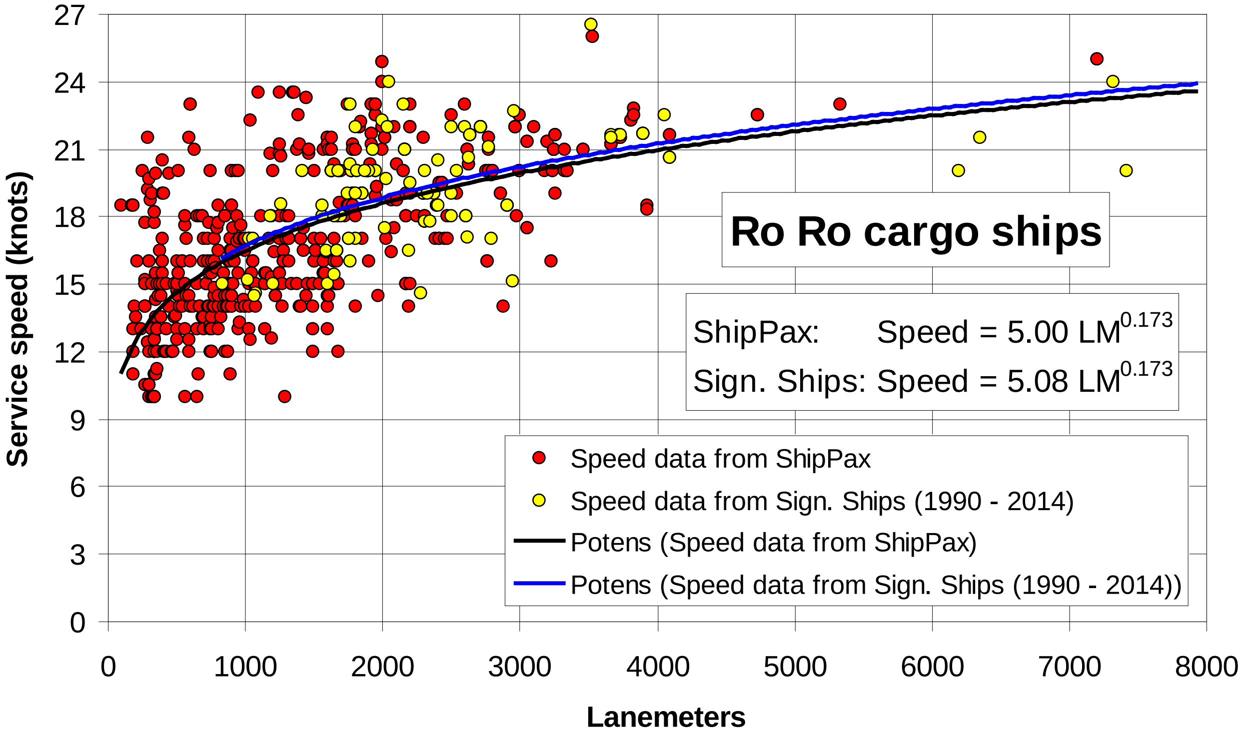

Fig. D1 Service speed for Ro-Ro cargo ships according to ShipPax database and Significant Ships (1990 – 2014)

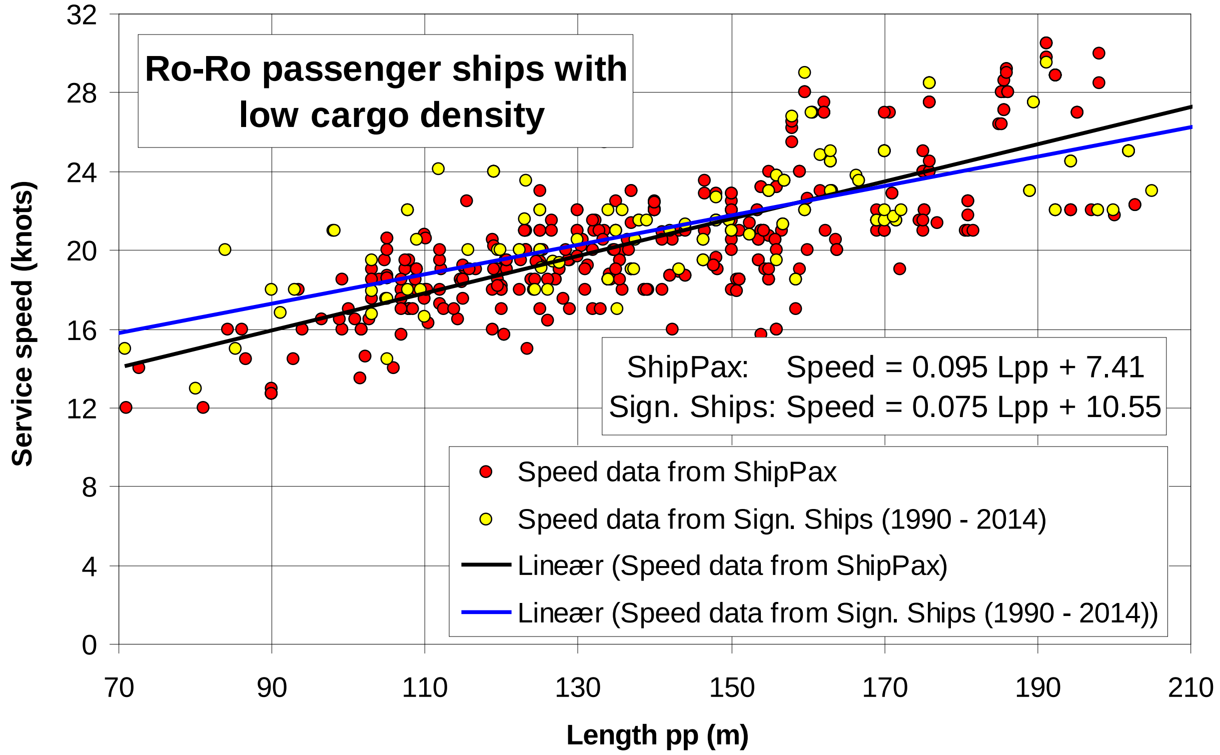

Fig. D2 Service speed for Ro-Ro passenger ships with low cargo density (ShipPax database and Sign. Ships (1990 – 2014)).

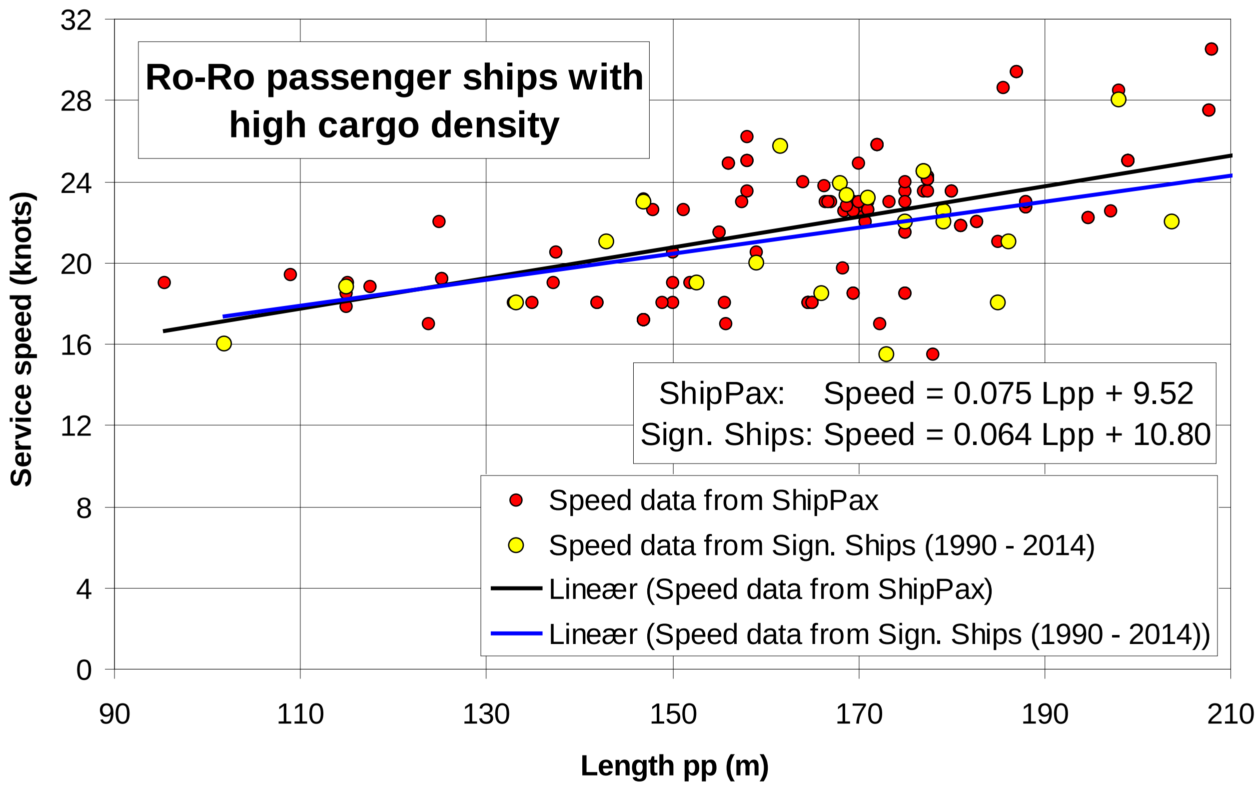

Fig. D4 Service speed for Ro-Ro passenger ships with high cargo density (ShipPax database and Sign. Ships (1990 – 2014)).

Appendix E - Propeller diameter

The propeller diameter shall be as large as possible to obtain the highest efficiency. But in order to avoid cavitation and air suction, the diameter is restricted by the draught. In this appendix expressions for the propeller diameter as function of the maximum draught are given and documented by relevant statistical data in Fig. D1 and D2 based on data from ShipPax data base and Significant Ships (1990 – 2014).

Single screw Ro-Ro ships (cargo and pass. ships): $D_{prop} = 0.56 \cdot \text{max. draught} + 1.07$

Twin screw Ro-Ro cargo ships: $D_{prop} = 0.71 \cdot \text{max. draught} - 0.26$

Twin screw Ro-Ro passenger ships: $D_{prop} = 0.85 \cdot \text{max. draught} - 0.69$

It is seen that the scatter of diameter to draught ratio is rather large (0.45 – 0.85) however with a majority of ships in the range between 0.65 and 0.75.

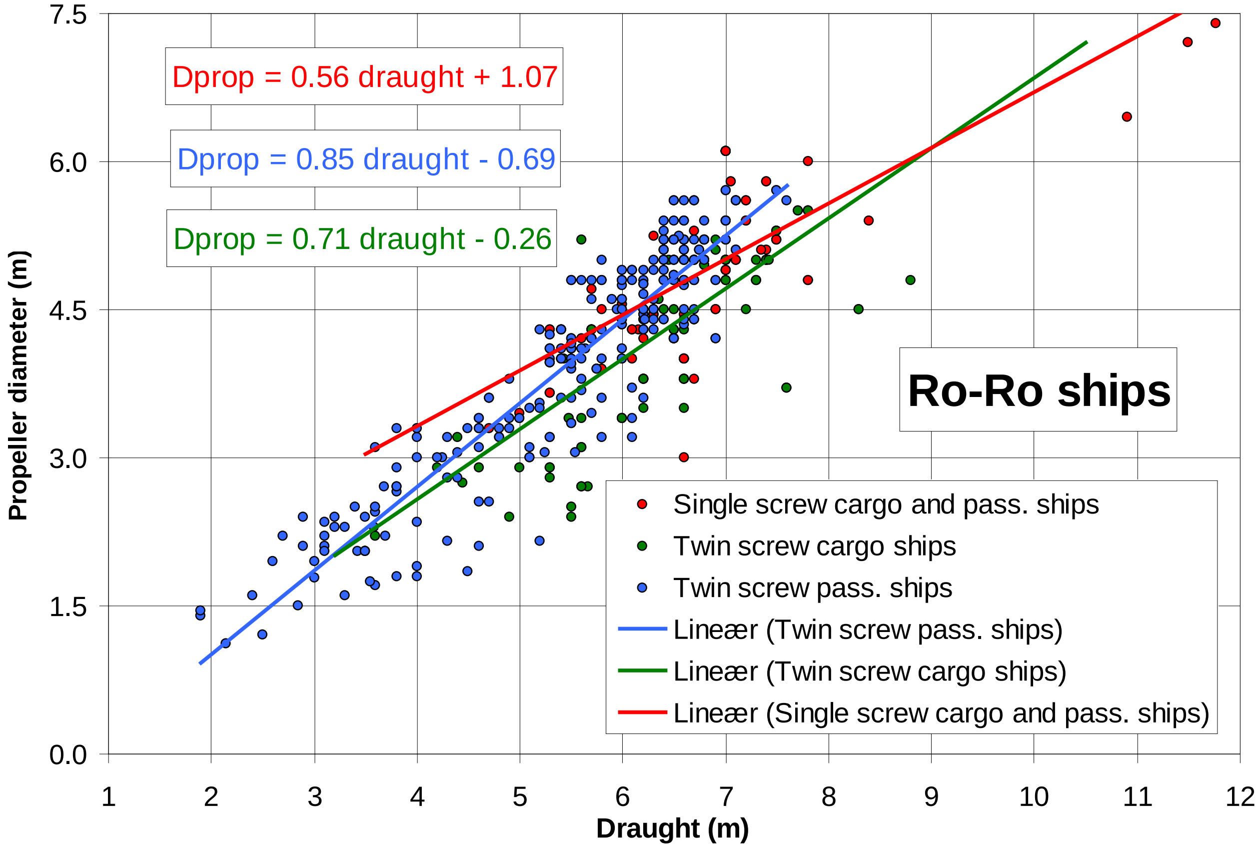

Fig. E1 Propeller diameter as function of maximum draught (ShipPax database and Significant Ships (1990 – 2014)).

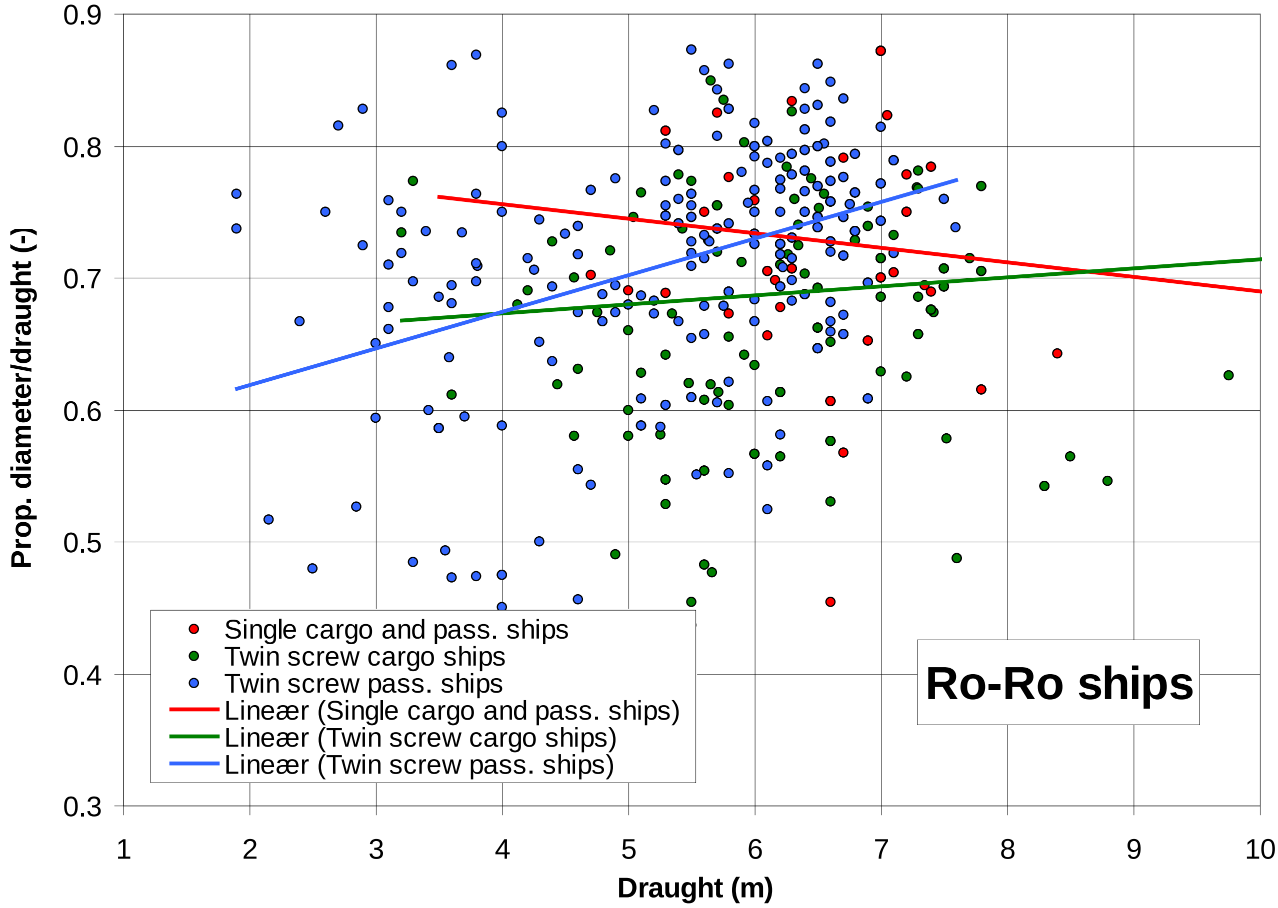

Fig. E2 Non dimensional propeller diameter (diameter/draught) as function of maximum draught. (ShipPax Database and Significant Ships (1990 – 2014)).

Appendix F – Main dimensions of Ro-Ro passenger ships

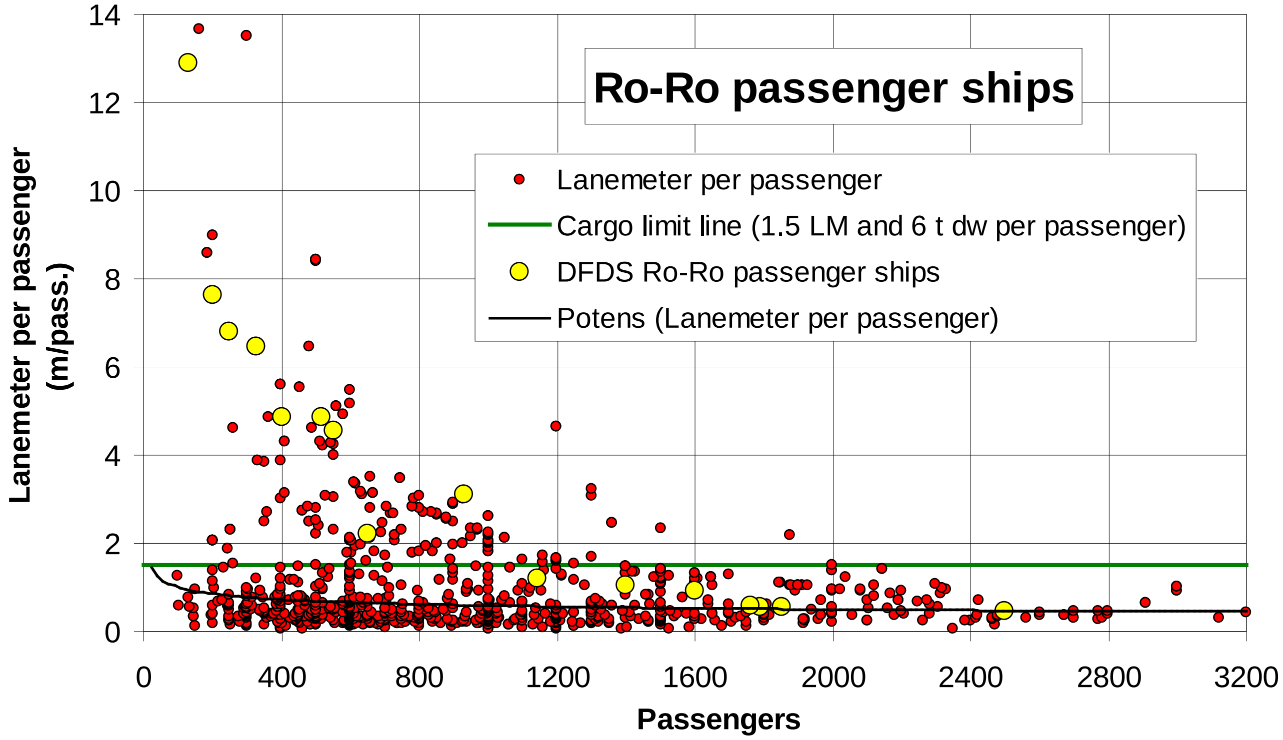

Fig. F1 Lane meter per passenger for Ro-Ro passenger ships
(ShipPax database, DFDS and Significant Ships (1990 – 2014)).

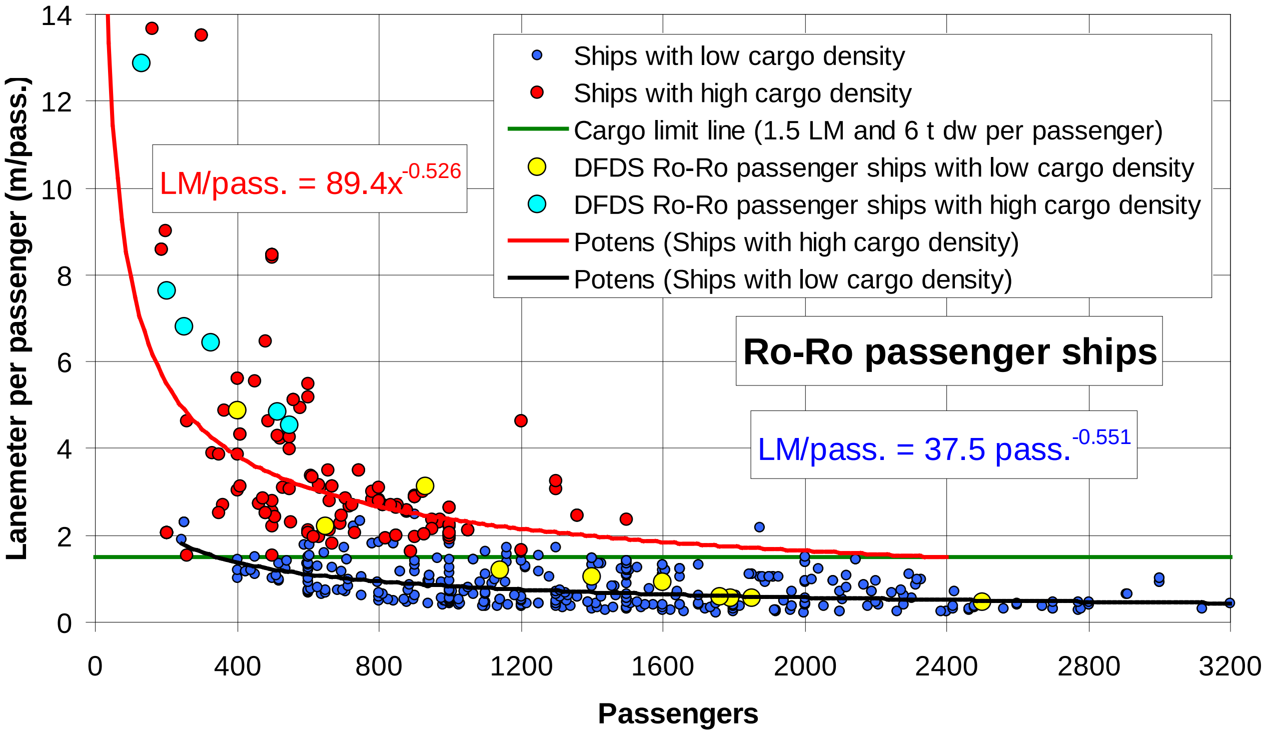

Fig. F2 Lane meter per passenger for Ro-Ro passenger ships
(ShipPax database, DFDS and Significant Ships (1990 – 2014)).

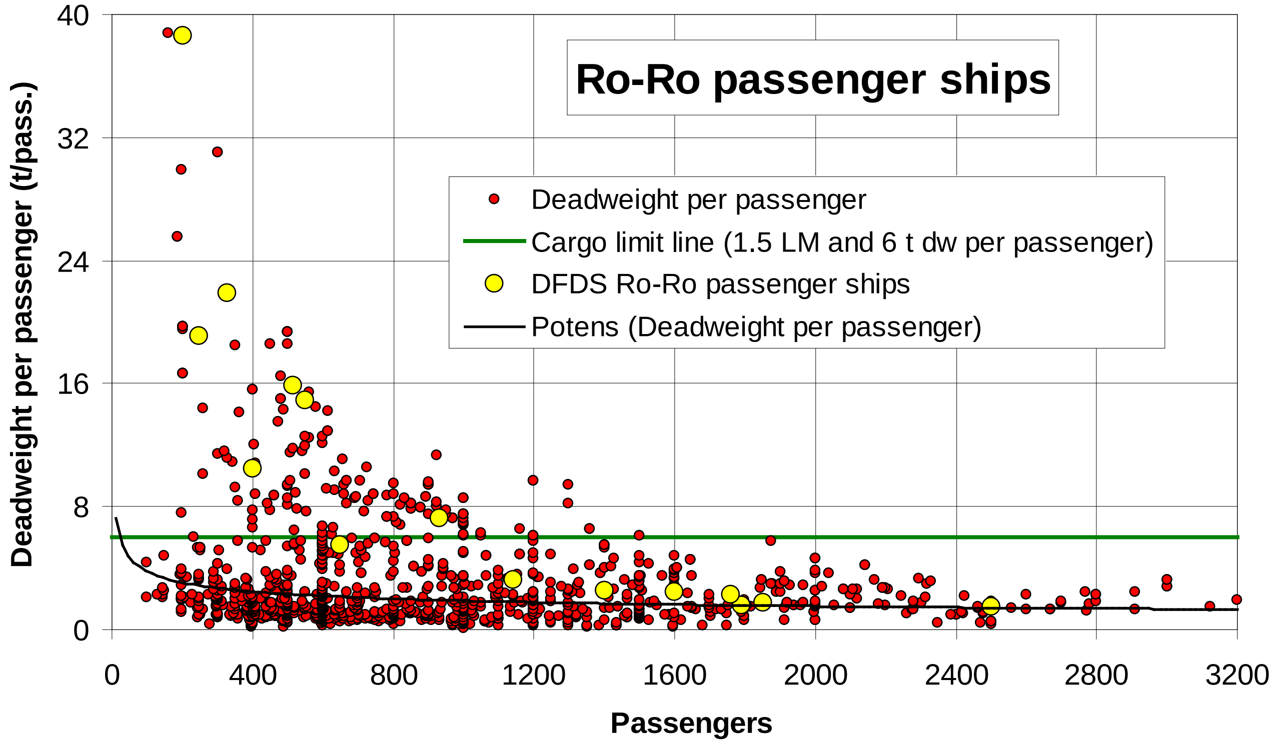

Fig. F3 Deadweight per passenger for Ro-Ro passenger ships (ShipPax database, DFDS and Significant Ships (1990 – 2014)).

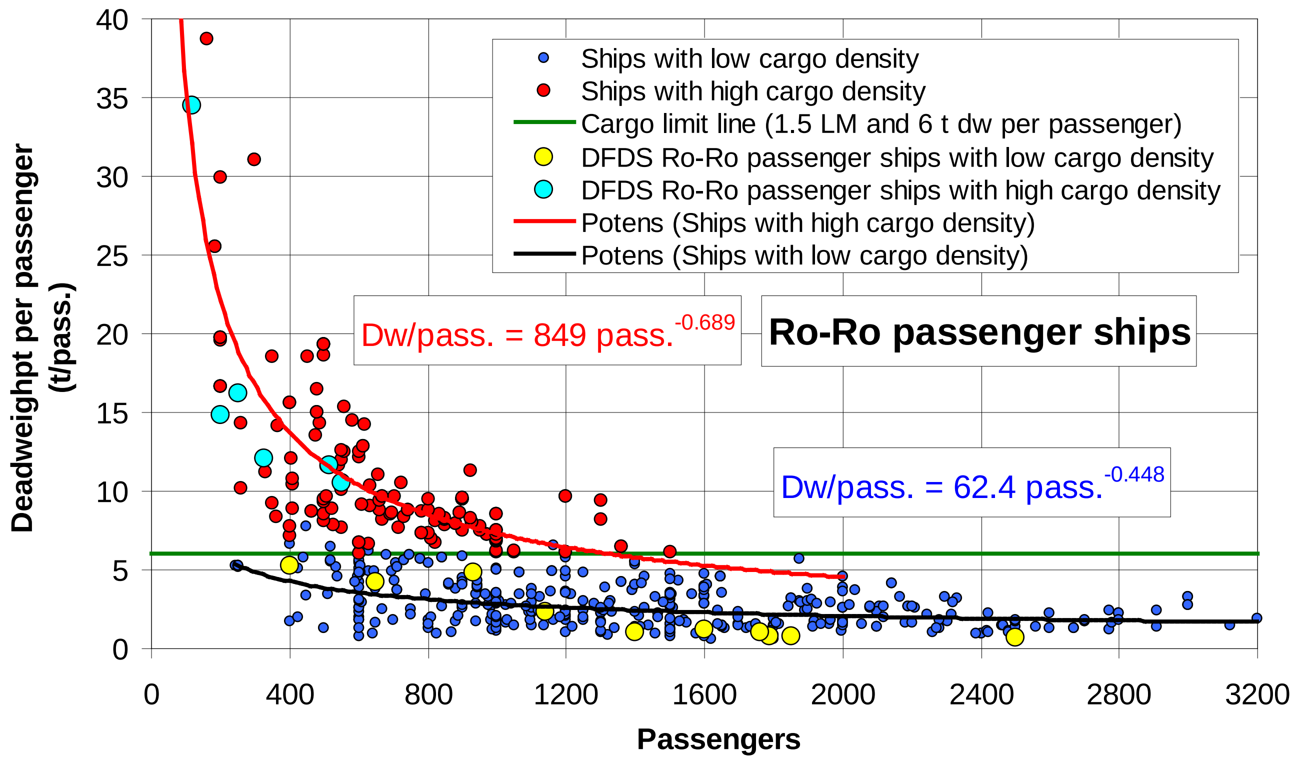

Fig. F4 Deadweight per passenger for Ro-Ro passenger ships (ShipPax database, DFDS and Significant Ships (1990 – 2014)).

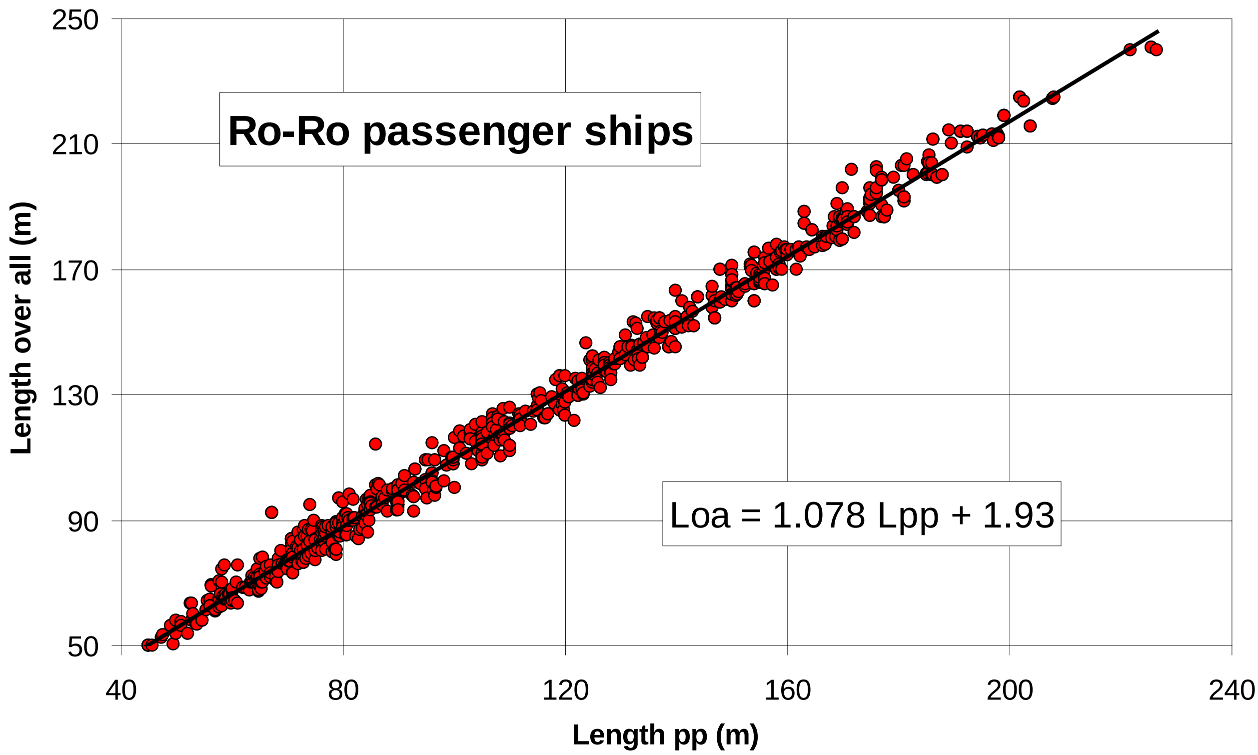

Fig. F5 Length overall as function of Lpp for Ro-Ro passenger ships (ShipPax database and Significant Ships (1990 – 2014)).

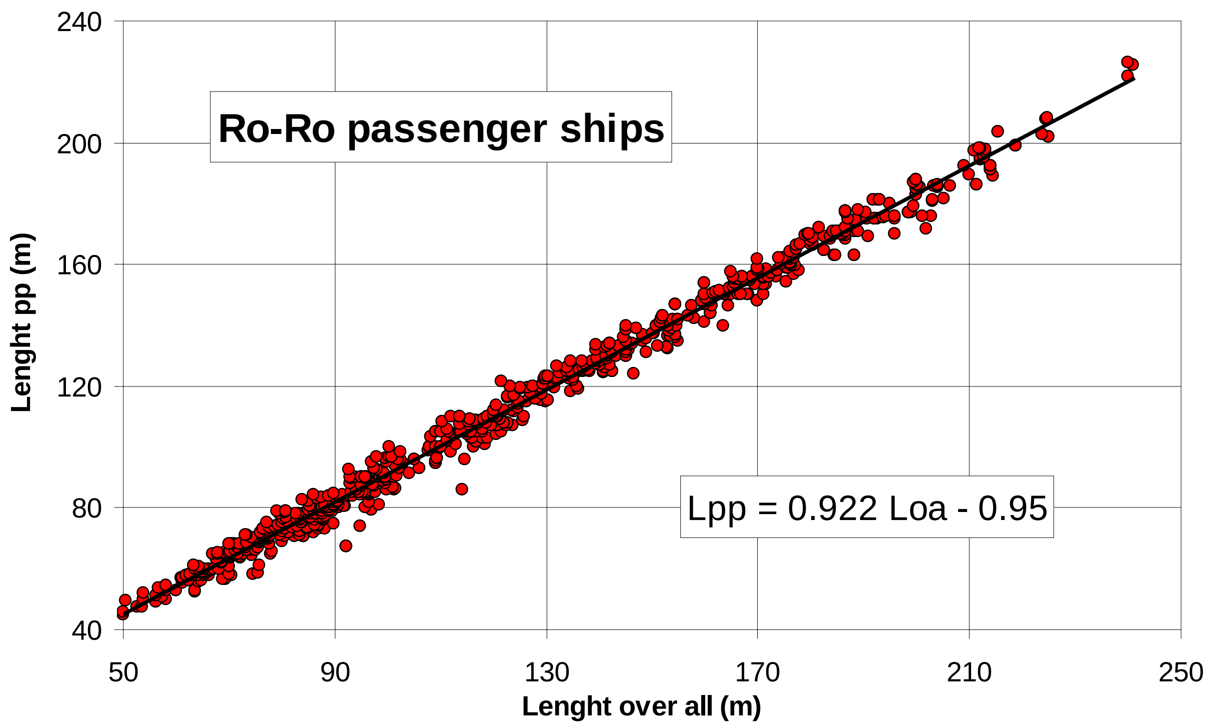

Fig. F6 Length pp as function of length over all for Ro-Ro passenger ships (ShipPax database and Significant Ships (1990 – 2014)).

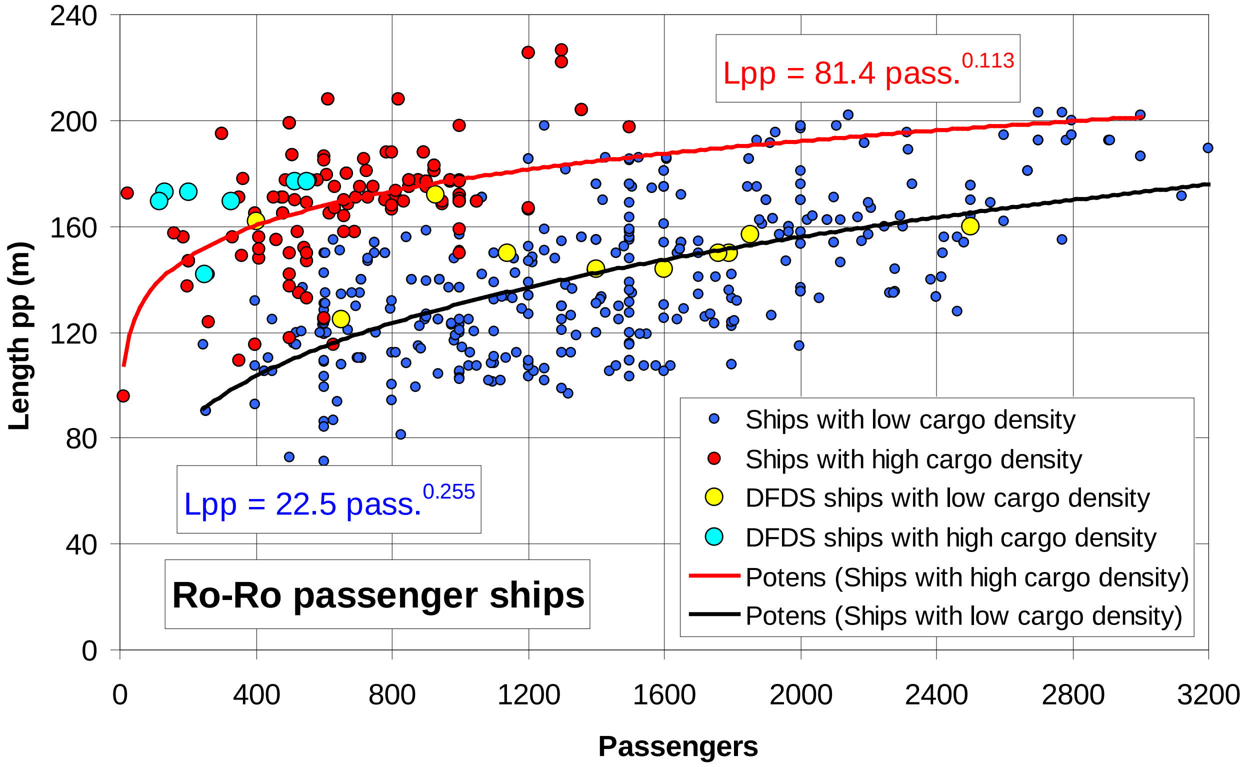

Fig. F7 Length as function of passengers for Ro-Ro passenger ships.
(ShipPax database, DFDS and Significant Ships (1990 – 2014))

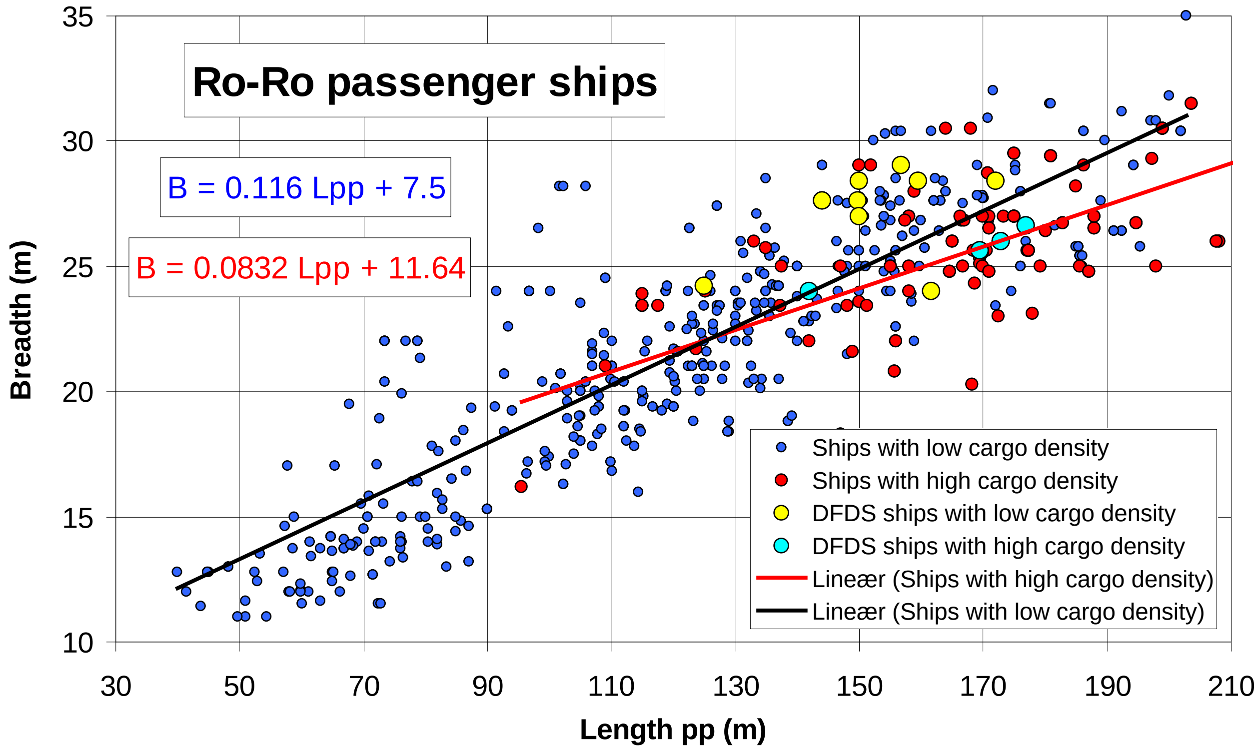

Fig. F8 Breadth as function of length pp for Ro-Ro passenger ships
(ShipPax database, DFDS and Significant Ships (1990 – 2014)).

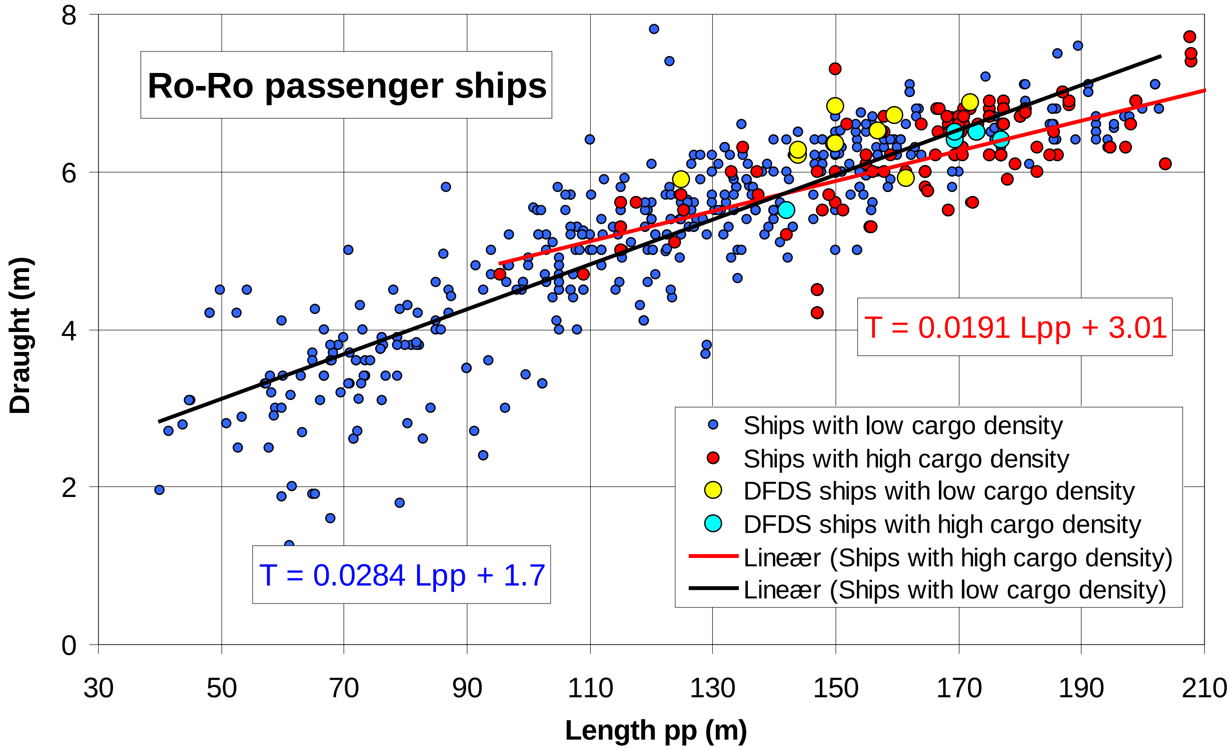

Fig. F9 Draught as function of length pp for Ro-Ro passenger ships (ShipPax database, DFDS and Significant Ships (1990 – 2014)).

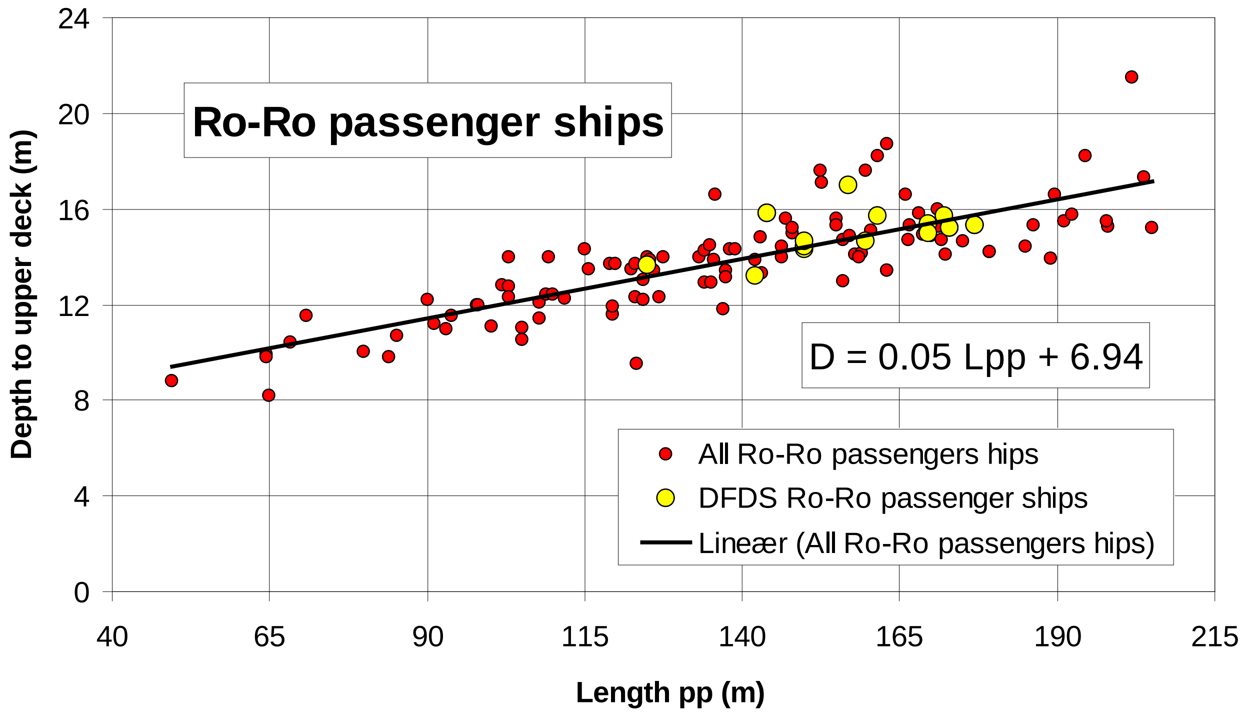

Fig. F10 Depth to upper deck as function of Lpp for Ro-Ro passenger ships (DFDS and Significant Ships (1990 – 2014)).

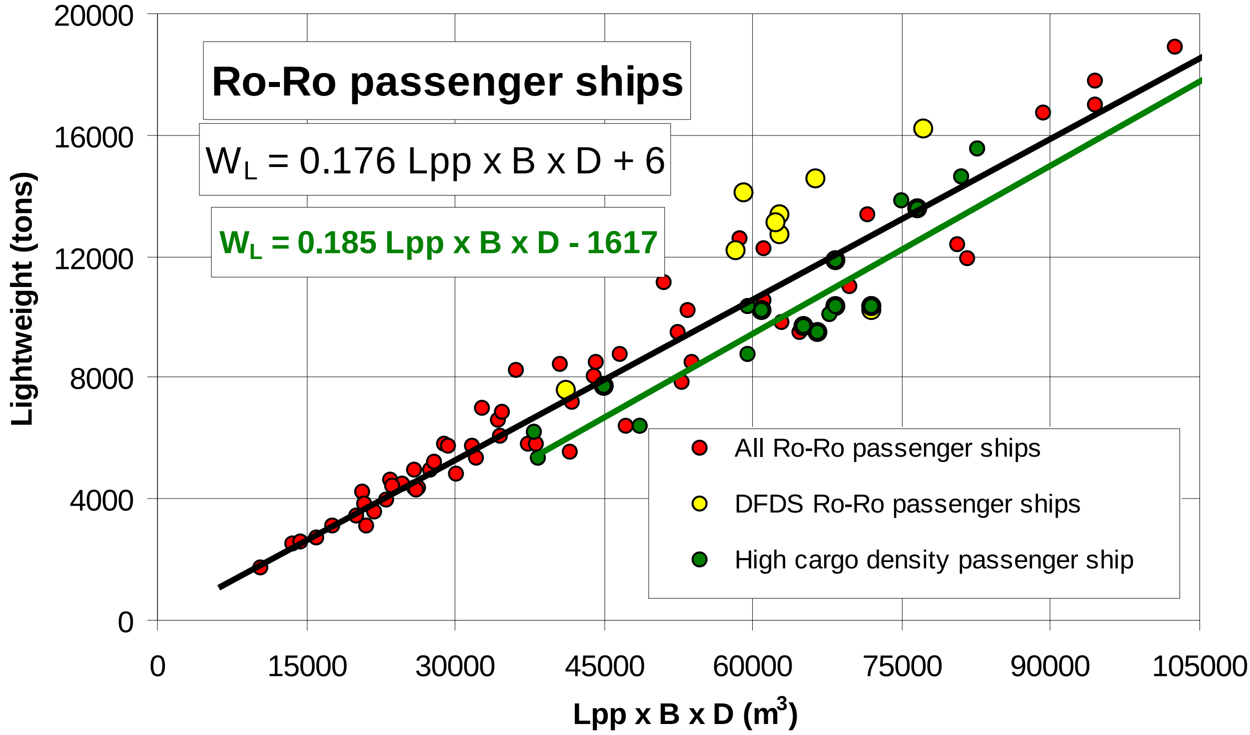

Fig. F11 Lightship weight as function of Lpp · B · D for Ro-Ro passenger ships. DFDS and Significant Ships (1990 – 2014) and Hans Otto Kristensen archive

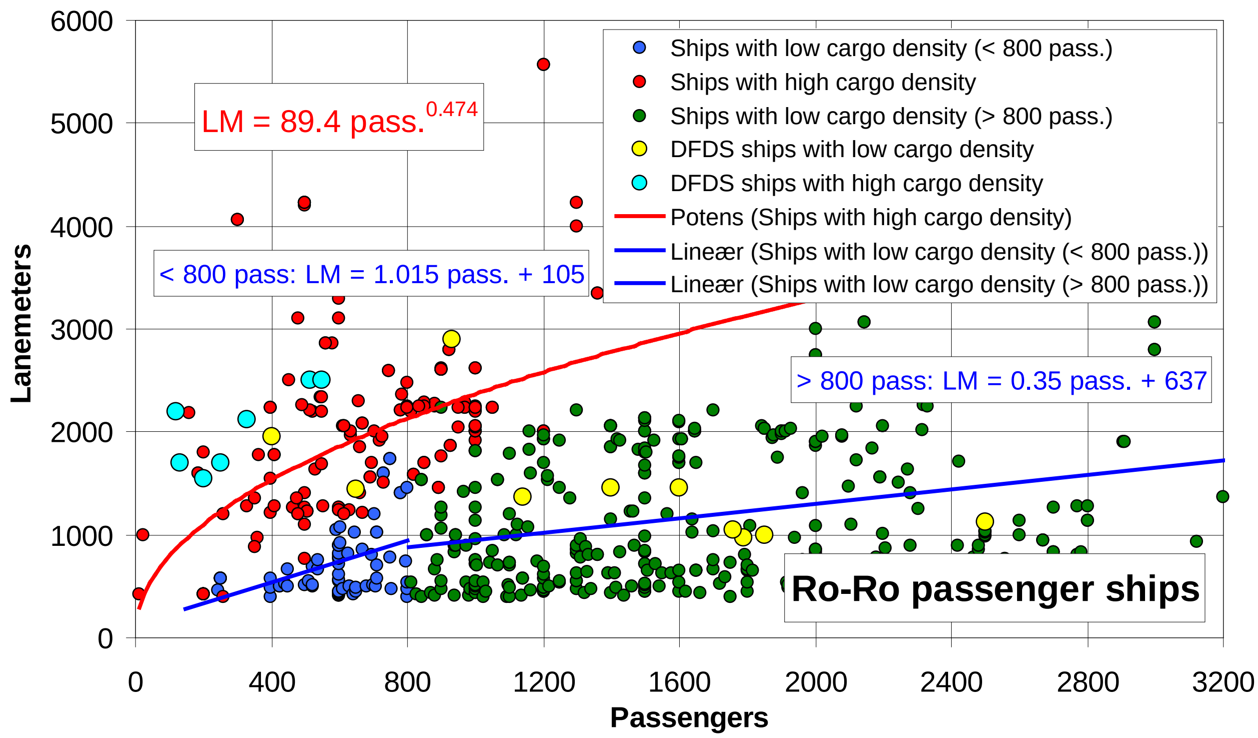

Fig. F12 Length of lanes as function of number of passengers for Ro-Ro passenger ships (ShipPax database, DFDS and Significant Ships (1990 – 2014)).

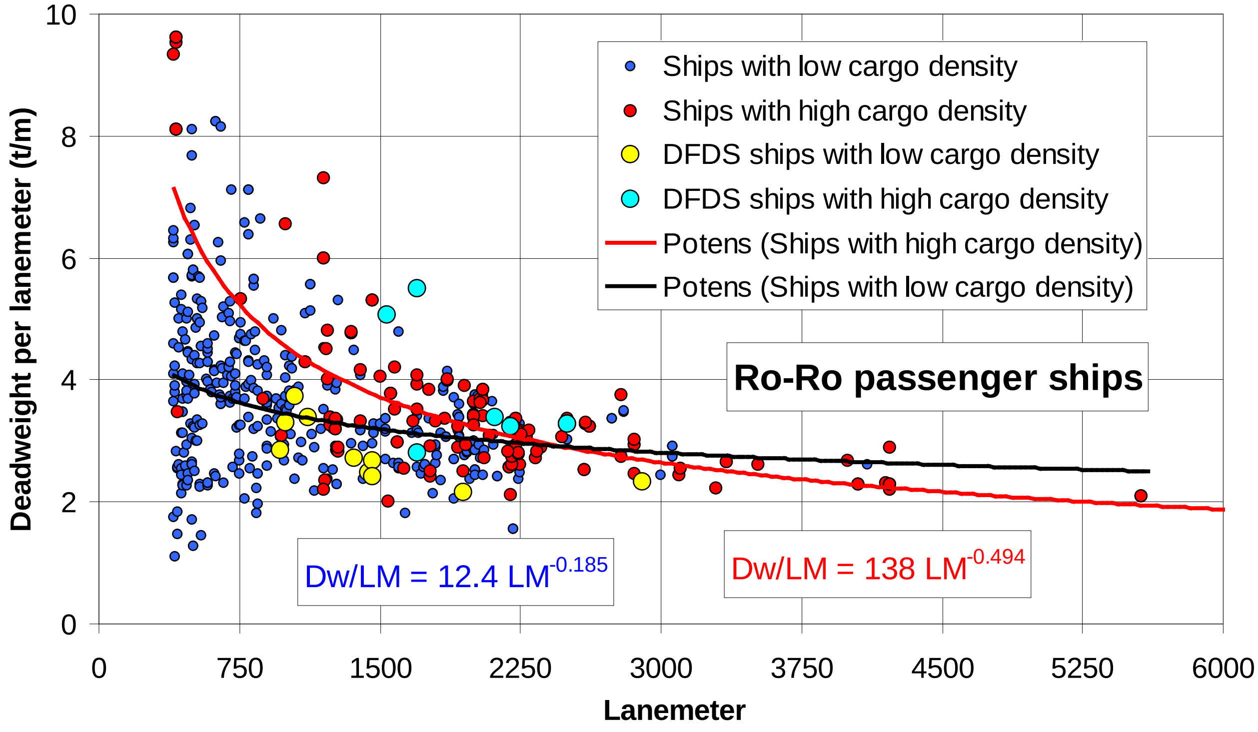

Fig. F13 Deadweight per lane meter as function of lanemeters for Ro-Ro passenger ships (ShipPax database, DFDS and Significant Ships (1990 – 2014)).

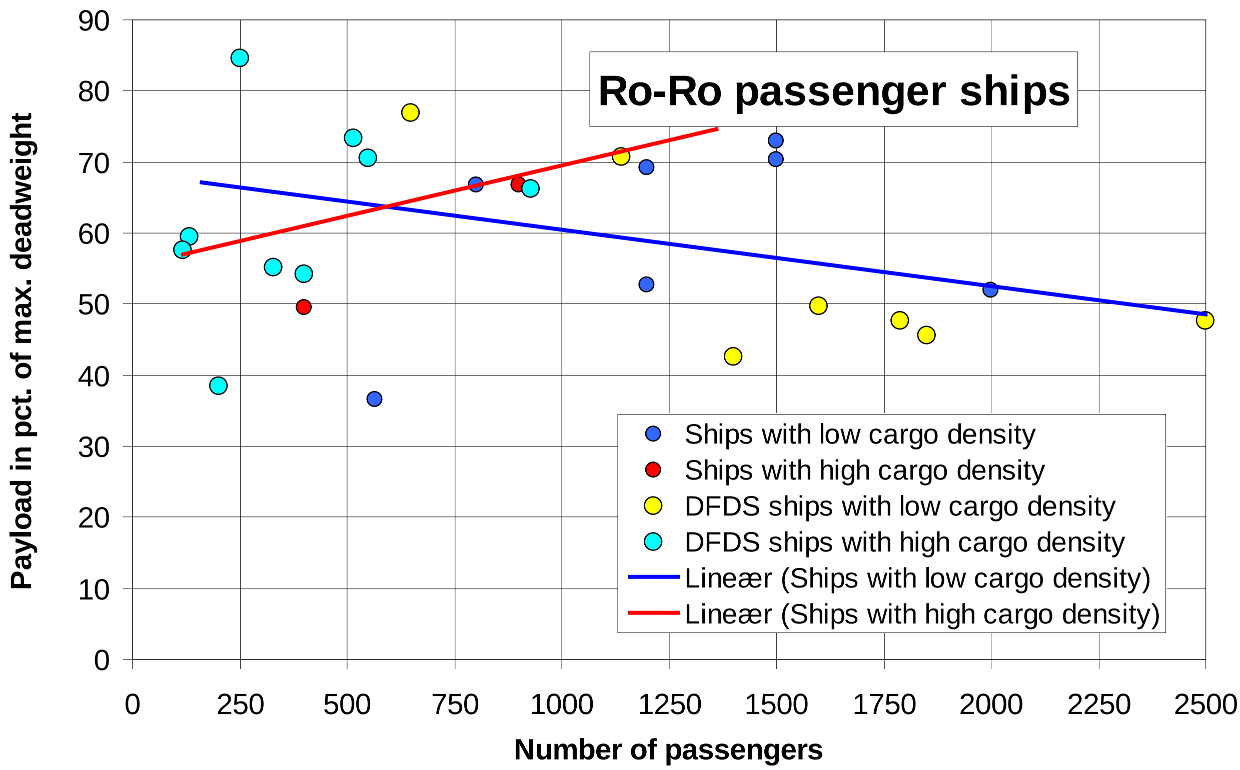

Fig. F14 Maximum payload in per cent of maximum deadweight for Ro-Ro passenger ships (DFDS, Significant Ships (1990 – 2014) and Hans Otto Kristensen archive).

Table F1 Ro-Ro passenger ships with low cargo density

Passengers	Lpp	B	D	T	Lpp/B	B/T	Lpp/T	Lpp/D	C_B	Lpp/Displ.vol.$^{1/3}$
-	m	m	m	m	-	-	-	-	-	-
100	72.81	15.95	10.58	3.77	4.57	4.23	19.32	6.88	0.699	5.02
200	86.89	17.58	11.28	4.17	4.94	4.22	20.85	7.70	0.672	5.35
300	96.35	18.68	11.76	4.44	5.16	4.21	21.72	8.19	0.663	5.53
400	103.68	19.53	12.12	4.64	5.31	4.20	22.32	8.55	0.660	5.64
600	114.98	20.84	12.69	4.97	5.52	4.20	23.16	9.06	0.660	5.79
800	123.73	21.85	13.13	5.21	5.66	4.19	23.73	9.43	0.661	5.88
1000	130.97	22.69	13.49	5.42	5.77	4.19	24.17	9.71	0.641	6.02
1200	137.21	23.42	13.80	5.60	5.86	4.18	24.52	9.94	0.626	6.12
1450	143.99	24.20	14.14	5.79	5.95	4.18	24.87	10.18	0.613	6.23
1700	149.95	24.89	14.44	5.96	6.02	4.18	25.17	10.39	0.603	6.31
2000	156.30	25.63	14.75	6.14	6.10	4.18	25.46	10.59	0.595	6.39
2300	161.97	26.29	15.04	6.30	6.16	4.17	25.71	10.77	0.588	6.46
2600	167.11	26.88	15.30	6.45	6.22	4.17	25.92	10.93	0.582	6.52
2900	171.83	27.43	15.53	6.58	6.26	4.17	26.11	11.06	0.578	6.56
3200	176.20	27.94	15.75	6.70	6.31	4.17	26.28	11.19	0.575	6.61

Table F2 Ro-Ro passenger ships with high cargo density

Passengers	Lpp	B	D	T	Lpp/B	B/T	Lpp/T	Lpp/D	C_B	Lpp/Displ.vol.$^{1/3}$
-	m	m	m	m	-	-	-	-	-	-
100	136.97	23.04	13.79	5.63	5.95	4.09	24.35	9.93	0.576	6.31
200	148.13	23.96	14.35	5.84	6.18	4.10	25.37	10.33	0.593	6.42
300	155.07	24.54	14.69	5.97	6.32	4.11	25.97	10.55	0.602	6.48
400	160.20	24.97	14.95	6.07	6.42	4.11	26.39	10.72	0.608	6.53
600	167.71	25.59	15.33	6.21	6.55	4.12	26.99	10.94	0.616	6.60
800	173.25	26.05	15.60	6.32	6.65	4.12	27.42	11.10	0.621	6.65
1000	177.67	26.42	15.82	6.40	6.72	4.13	27.75	11.23	0.625	6.68
1200	181.37	26.73	16.01	6.47	6.79	4.13	28.01	11.33	0.628	6.71
1450	185.29	27.06	16.20	6.55	6.85	4.13	28.29	11.43	0.631	6.75
1700	188.65	27.34	16.37	6.61	6.90	4.13	28.53	11.52	0.634	6.77
2000	192.15	27.63	16.55	6.68	6.96	4.14	28.76	11.61	0.636	6.80
2300	195.21	27.88	16.70	6.74	7.00	4.14	28.97	11.69	0.639	6.82
2600	197.93	28.11	16.84	6.79	7.04	4.14	29.15	11.76	0.641	6.84
2900	200.39	28.31	16.96	6.84	7.08	4.14	29.31	11.82	0.642	6.86
3200	202.63	28.50	17.07	6.88	7.11	4.14	29.45	11.87	0.644	6.88

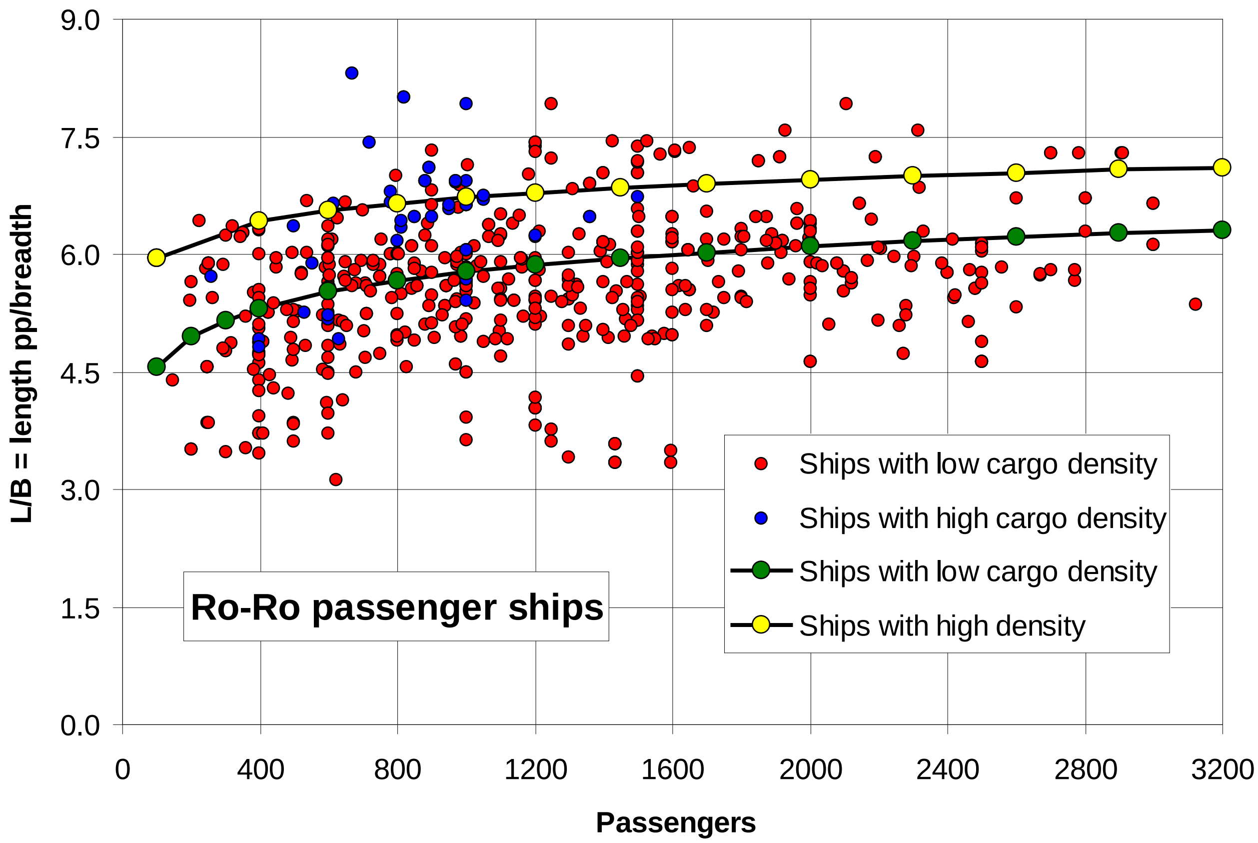

Fig. F15 Length-breadth ratio as function of passenger capacity for Ro-Ro passenger ships (ShipPax database).

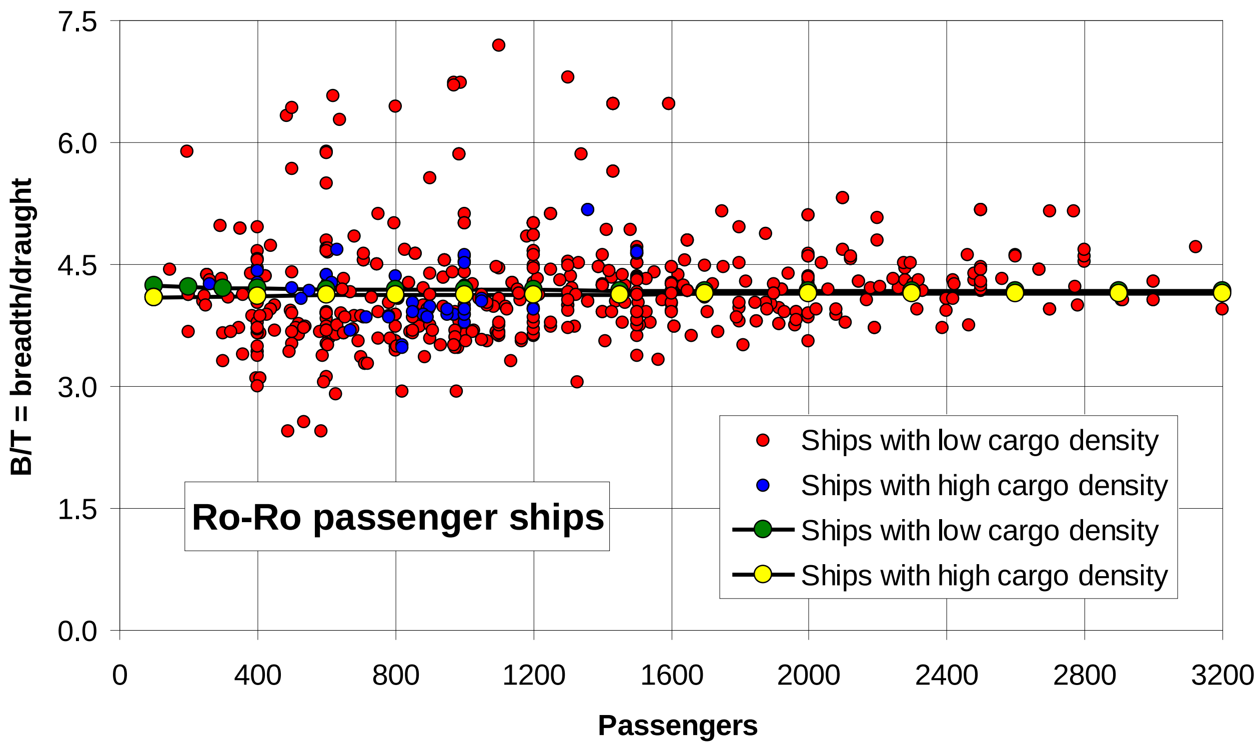

Fig. F16 Breadth-draught ratio as function of passenger capacity for Ro-Ro passenger ships (ShipPax database).

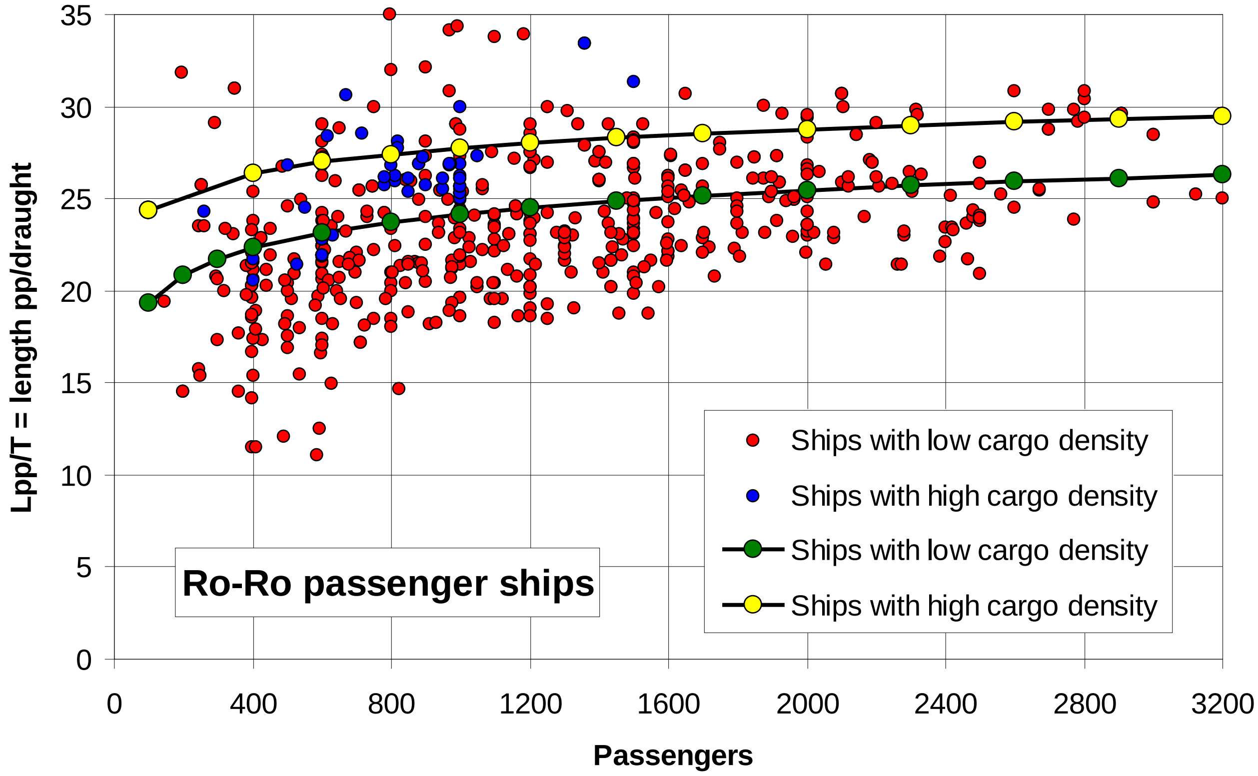

Fig. F17 Length-draught ratio as function of passenger capacity for Ro-Ro passenger ships (ShipPax database).

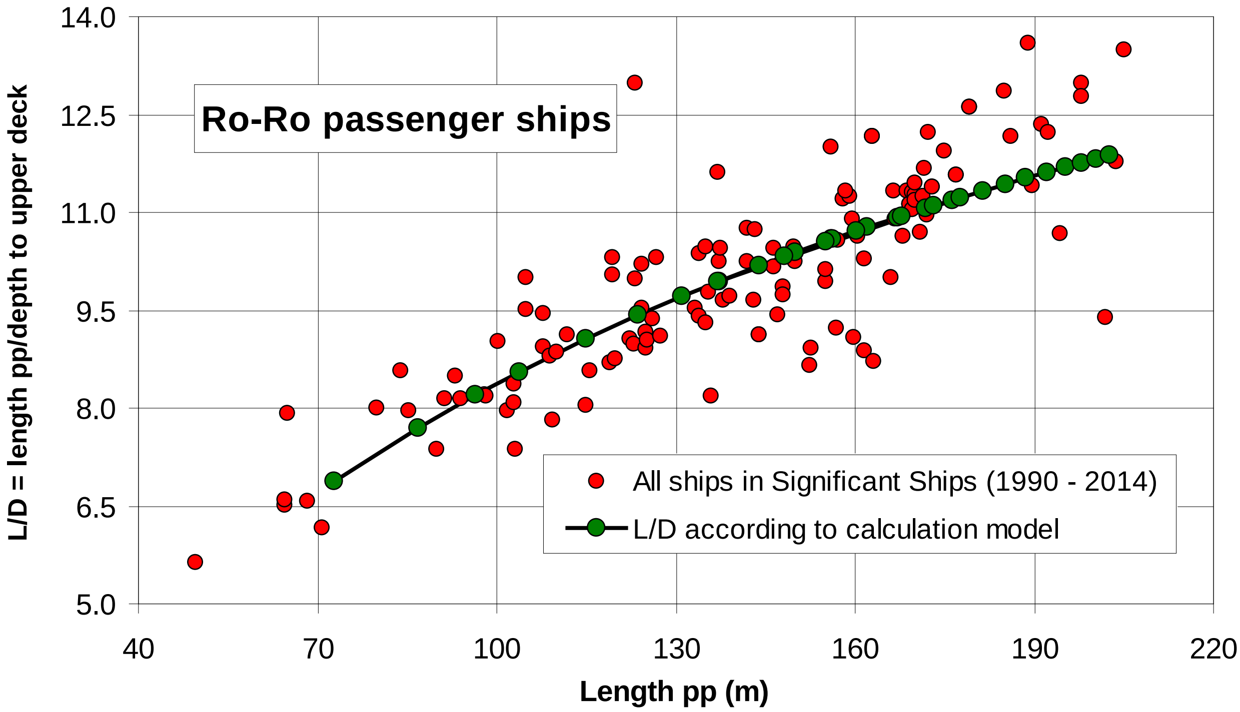

Fig. F18 Length-depth ratio as function of length pp for Ro-Ro passenger ships. (DFDS and Significant Ships (1990 – 2014))

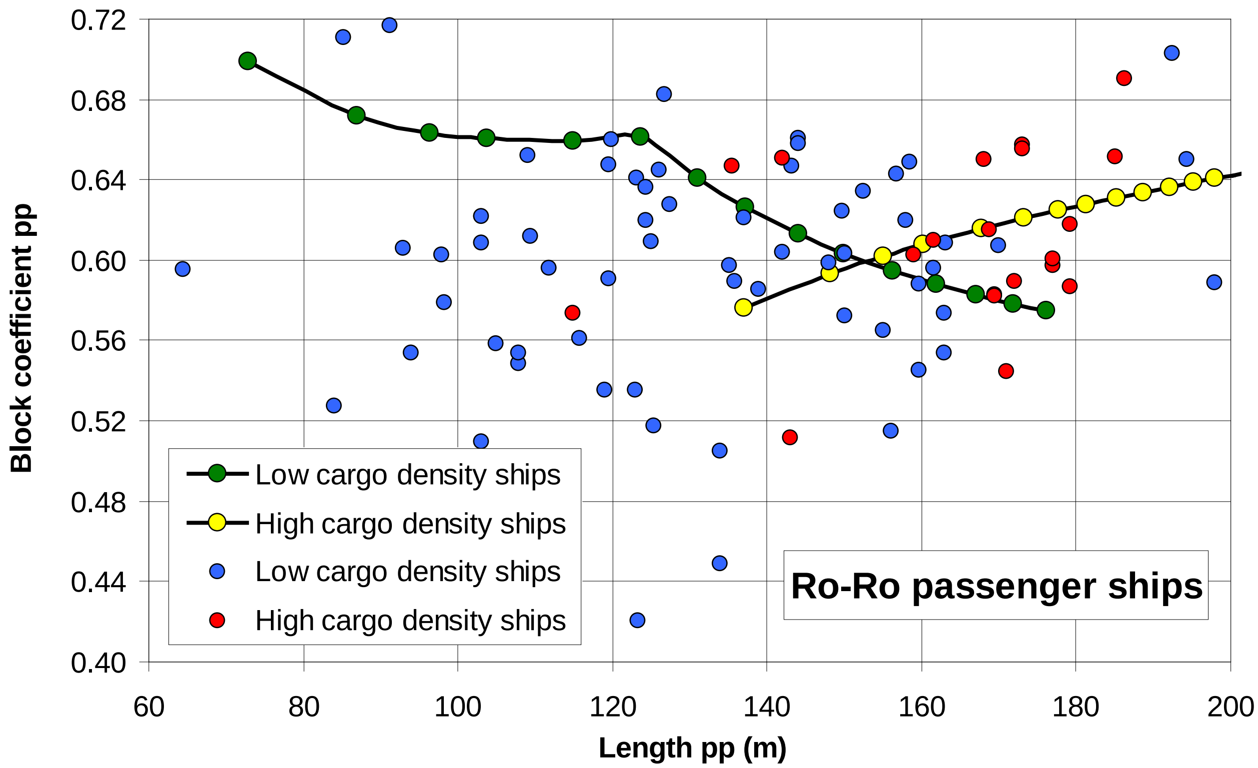

Fig. F19 Block coefficient as function of Lpp for Ro-Ro passenger ships.
(DFDS, Significant Ships (1990 – 2014) and Hans Otto Kristensen archive)

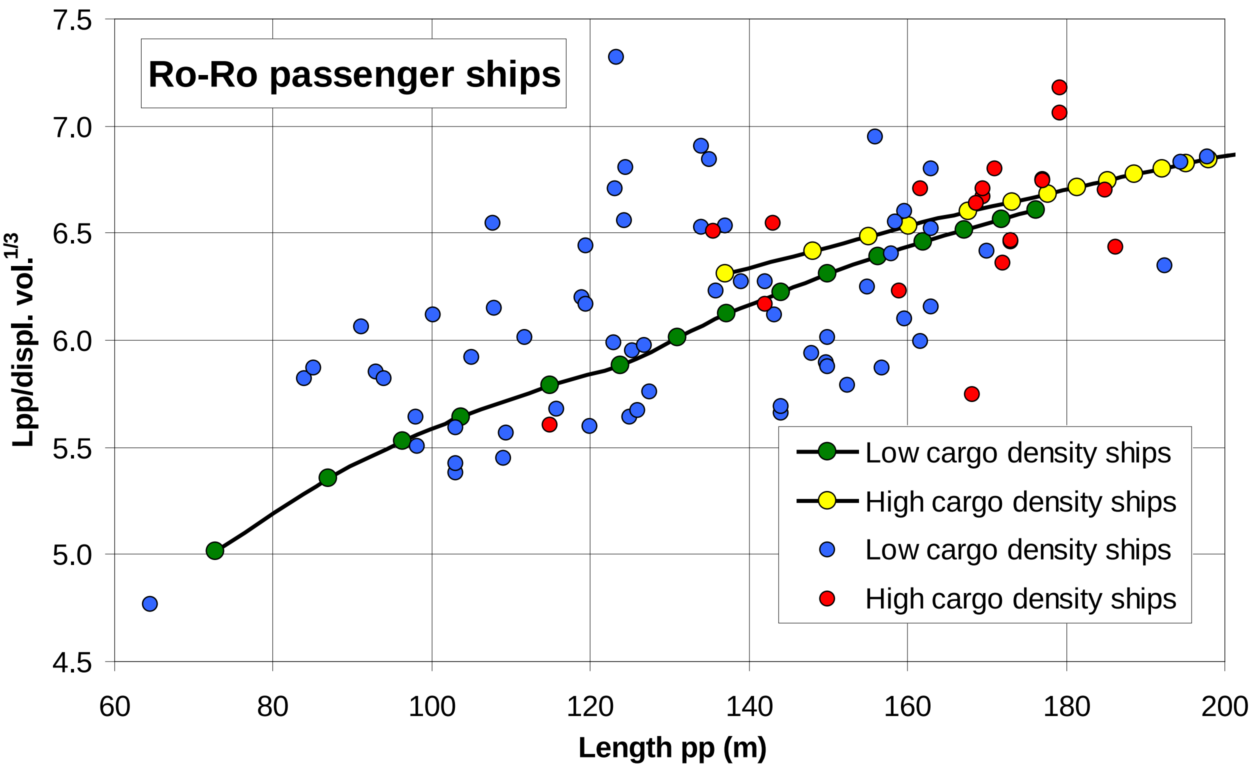

Fig. F20 Length-displacement ratio as function of Lpp for Ro-Ro passenger ships.
(DFDS, Significant Ships (1990 – 2014) and Hans Otto Kristensen archive)

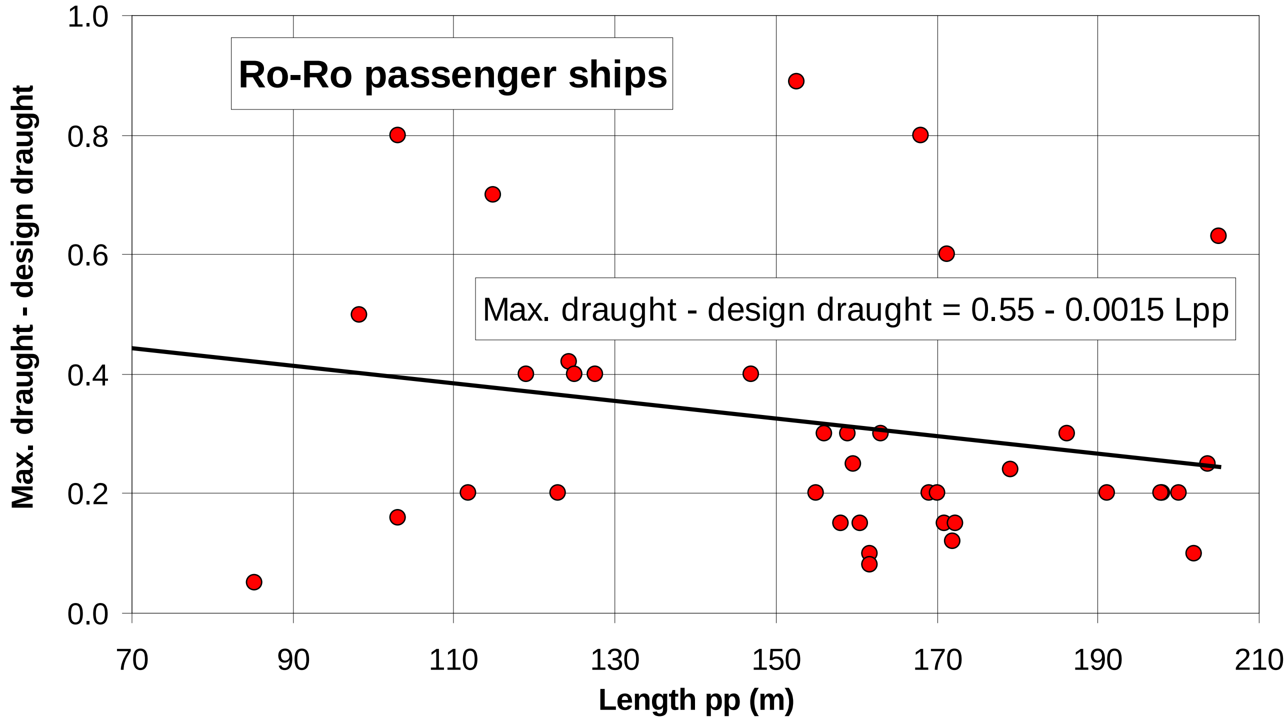

Fig. F21 Difference between maximum draught and design draught as function of Lpp for Ro-Ro passenger ships. Significant Ships (1990 – 2014).

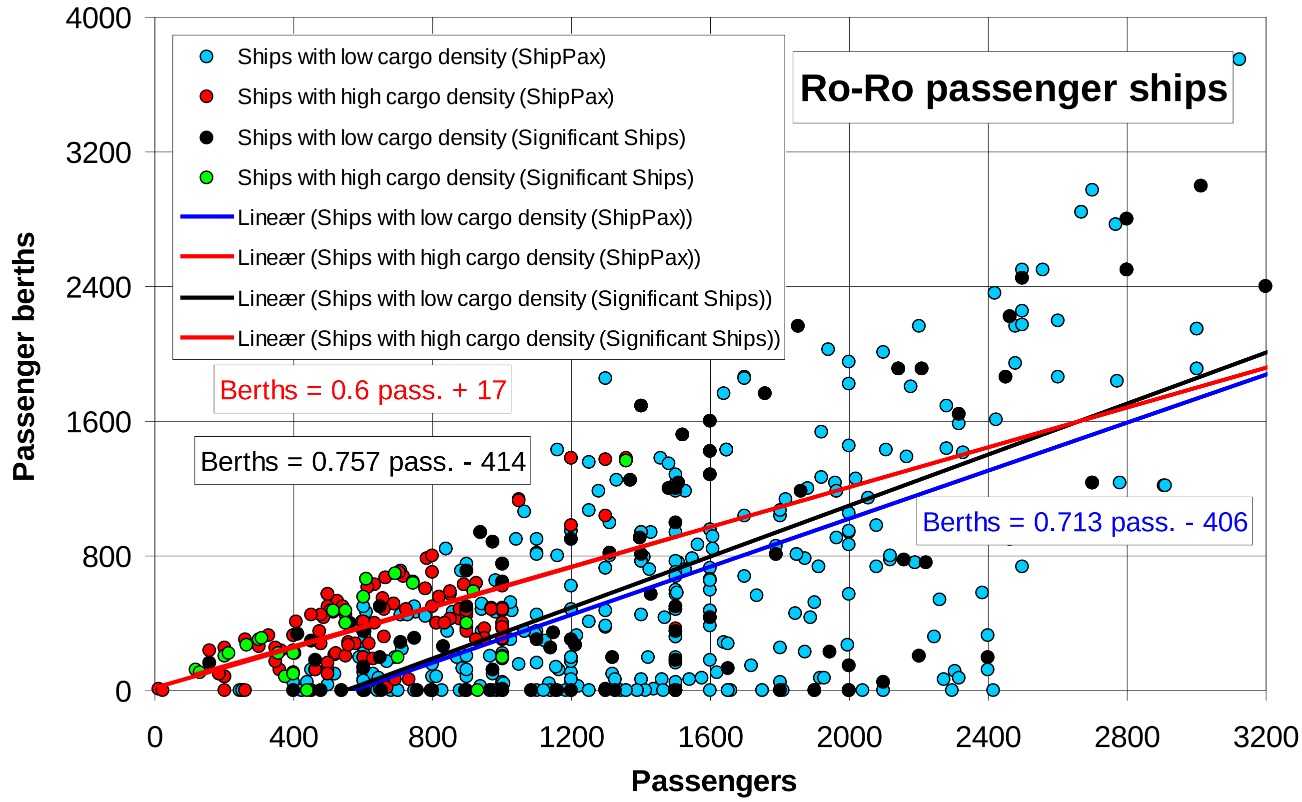

Fig. F22 Number of berths as function of passenger capacity for Ro-Ro passenger ships (ShipPax database, DFDS and Significant Ships (1990 – 2014)).

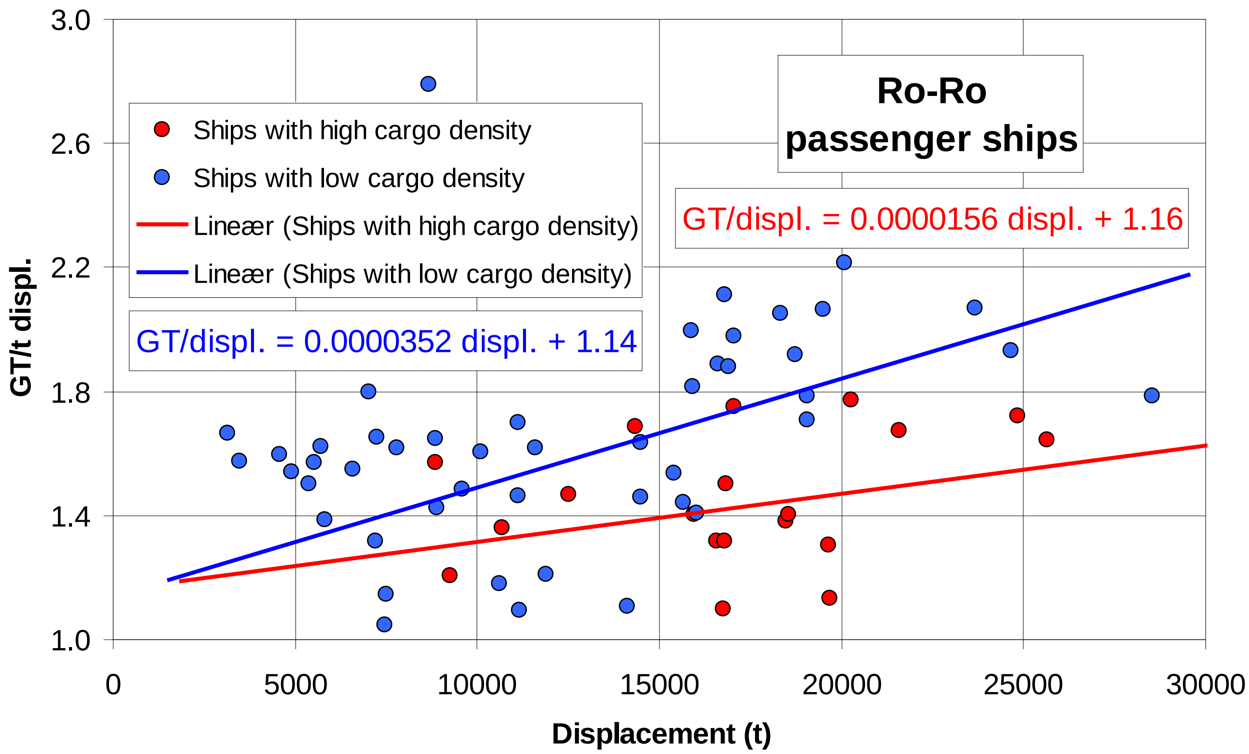

Fig. F23 Gross tonnage per ton displacement as function of displacement for Ro-Ro passenger ships. (Significant Ships (1990 – 2014), DFDS and Hans Otto Kristensen archive).

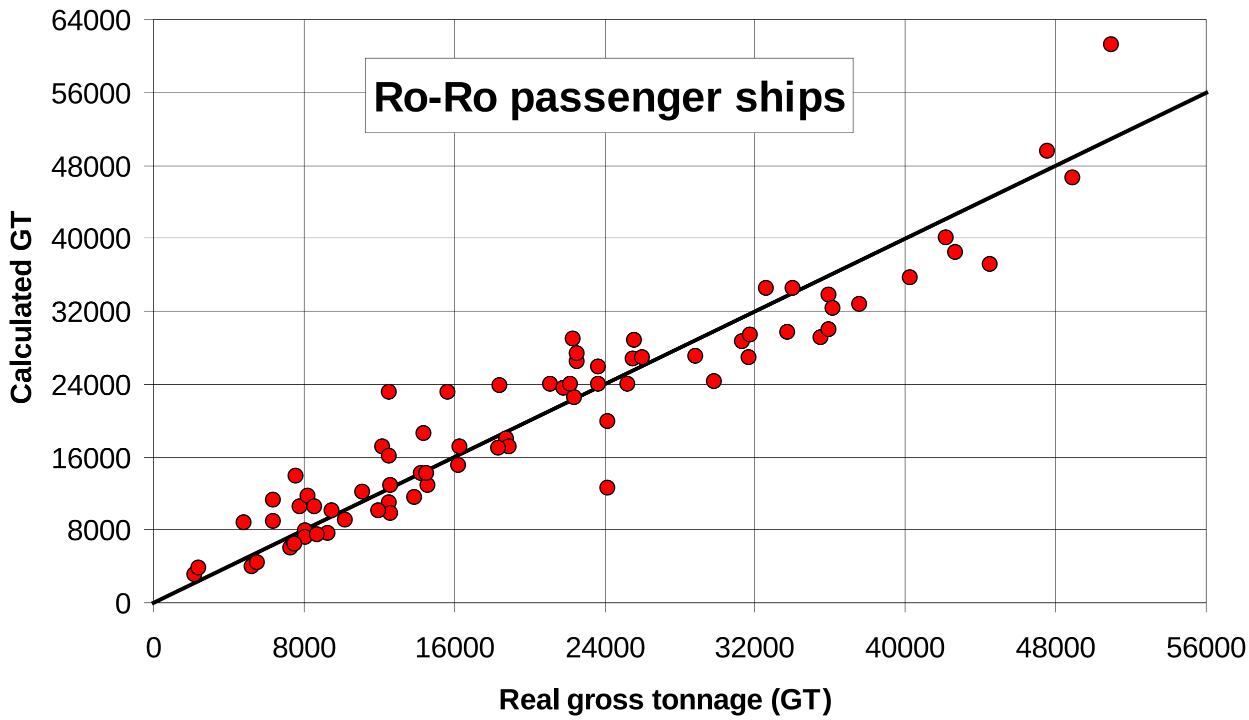

Fig. F24 The real gross tonnage compared with the calculated gross tonnage for Ro-Ro passenger ships. (Significant Ships (1990 – 2014), DFDS and Hans Otto Kristensen archive).

Appendix G – Photos of the DFDS fleet - Ro-Ro cargo ships

Anglia Seaways **IMO No. 9186649**

Botnia Seaways **IMO No. 9192129**

Ark Futura **IMO No. 9129598**

Finlandia Seaways **IMO No. 9198721**

Petunia Seaways IMO No. 9259501

Primula Seaways IMO No. 9259513

Begonia Seaways   IMO No. 9262089

Selandia Seaways   IMO No. 9157284

Hafnia Seaways   IMO No. 9357602

Britannia Seaways IMO No. 9153032

Suecia Seaways IMO No. 9153020

Ark Dania **IMO No. 9129598**

Fionia Seaways **IMO No. 9395343**

Appendix H – Photos of the DFDS fleet
Ro-Ro passenger ships with low cargo density

Pearl Seaways IMO No. 8701674

Princess Seaways **IMO No. 8502391**

Crown Seaways **IMO No. 8917613**

King Seaways **IMO No. 8502406**

Princess Anastasia **IMO No. 8414582**

Princess Maria **IMO No. 7911532**

Calais Seaways **IMO No. 8908466**

Cote Dalabatre **IMO No. 9320128**

Ro-Ro passenger ships with high cargo density

Patria Seaways IMO No. 8917390

Vilnius Seaways IMO No. 8311900

Kaunas Seaways **IMO No. 8311924**

Athena Seaways **IMO No. 9350680**

Liverpool Seaway **IMO No. 9136034**

Regina Seaways **IMO No. 9458535**

Optima Seaways **IMO No. 9188427**

Malo Seaways **IMO No. 9215505**

Dover Seaways **IMO No. 9318345**

Appendix I – Rules and regulations for trucks

TRANSPORT XXL RULES AND REGULATIONS OF ABNORMAL TRANSPORTS IN EUROPE

··· HOME / EU DIRECTIVE / VEHICLE WEIGHTS ···

EU DIRECTIVE

- Dimensions
- Vehicle weights
- Axle loads

DOES MY TRANSPORT REQUIRE A SPECIAL PERMIT?

APPLICATION

- Denmark
- Germany
- Great Britain
- Finland
- France
- Netherlands
- Norway
- Spain
- Sweden

MAXIMUM AUTHORISED VEHICLE WEIGHTS

Vehicles with 2 axles	
Motor vehicle	18 tonnes
Trailer	18 tonnes
Vehicles with 3 axles	
Motor vehicle	• 25 tonnes or • 26 tonnes, where the driving axle is fitted with twin tyres and air suspension or suspension recognised as being equivalent within the Community or where each driving axle is fitted with twin tyres and the maximum weight of each axle does not exceed 9.5 tonnes.
Trailer	24 tonnes
Vehicles with 4 axles	
Motor vehicle with two steering axles	32 tonnes, where the driving axle is fitted with twin tyres and air sus-pension or suspension recognised as being equivalent within the Community or where each driving axle is fitted with twin tyres and the maximum weight of each axle does not exceed 9.5 tonnes.
Truck with semi-trailer	• 36 tonnes if the distance between the axles of the semi-trailer is 1.3 or greater but not more than 1.8 metres • 36 tonnes if the distance between the axles of the semi-trailer is greater than 1.8 metres or • 38 tonnes if the distance between the axles of the semi-trailer is greater than 1.8 metres and the maxi- mum authorised weight of the motor vehicle (18 tonnes) and the maximum authorised weight of the tandem axle of the semi-trailer (20 tonnes) are re-spected and the driving axle is fitted with twin tyres and air suspension or suspension recognised as be-ing equivalent within the Community.
Truck with ordinary trailer	36 tonnes
Vehicles with 5 or more axles	
Truck with ordinary trailer	40 tonnes
Truck with semi-trailer	• 40 tonnes or • 44 tonnes, for a three-axle motor vehicle with two or three-axle semi-trailer carrying a 40-foot ISO container as a combined transport operation.
Additional requirements	
1. 2.	

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Appendix J - Calculation example from CEN standard 16258

Example for combined passenger and freight transport: ferry lines

G.1 Description of the example

This example serves as an illustration of the impact of the two allocation methods specified in Annex B on one real ferry transport system.

The areas in the example are based on 100 % accessible area capacity according to valid general arrangement plan (GA-plan). The transport statistics used are one year real data i.e. this example presents an example of annual average allocation values. The values per entity used are the default values presented in Annex B, Table B1.

Table G.1 — Data for this example

	Annual activity data			Value per entity			
Entity	**Quantity**	**Mass (t)**	**Area (m²)**	**Mass (kg)**	**Area (m²)**	**Length (m)**	**Width (m)**
Pax deck area					7 550		
Vehicles deck area					5 770		
Passenger and luggage	478 500	47 850		100			
Passenger car	90 000	135 000	1 674 000	1 500	18,6	6	3,1
Bus	1 000	15 000	37 200	15 000	37,2	12	3,1
Caravan (small)	500	500	4 650	1 000	9,3	3	3,1
Caravan (medium)	500	1 000	9 300	2 000	18,6	6	3,1
Caravan (large)	500	1 250	15 500	2 500	31,0	10	3,1
Mobile home	-	-	-	3 500	24,8	8	3,1
Motorcycle	1 000	200	4 650	200	4,7	1,5	3,1
Unaccompanied trailer							
Empty trailer				8 000	43,4	14	3,1
Average load per trailer				19 000			
Total	4 000	108 000	173 600	27 000	43,4	14	3,1
Accompanied trailer							
Empty trailer				16 000	52,7	17	3,1
Average load per trailer				19 000			
Total	34 000	1 190 000	1 791 800	35 000	52,7	17	3,1

G.2 Results and comparison of the two allocation methods

In the mass allocation method, the weight of vehicles (including their loads for freight) and weight of passengers are based on annual activity data and values per entity presented in Table G.1. Table G.2 gives the corresponding results.

Table G.2 — Results with use of Mass allocation method

Mass allocation method	mass	%
Freight	1 298 000	87 %
Passengers	200 800	13 %
Total	1 498 800	100 %

In the area allocation method the relation between areas used by freight and passenger serves as the allocation ratio. Whole passenger deck area is allocated to passengers. Vehicle deck area is allocated according to the ratio between freight vehicles and passenger vehicles according to activity data and values per entity presented in Table G1. Table G.3 gives the corresponding results.

Table G.3 — Results with use of Area allocation method

Area allocation method	area	%
Freight	3 056	23 %
Passengers	10 264	77 %
Total	13 320	100 %

In conclusion, by using one allocation method or the other for the same combined passenger and cargo ferry, the distribution of energy consumption and GHG emissions gives completely different results. Hence, if the emission and energy data includes ferry vessel operation and the receiver of the data wishes to compare results, particular attention should be paid to the consistency in allocation methodology. As stated in Annex B.1, the ferry allocation method shall be consistent over time and per ferry line unless the ship is converted or allocated to a different line. Information about the allocation method used for a particular transport service will be available to the receiver of the data, and can be found in the supporting information which accompanies the declaration of results (see 10.3.2).

Appendix K – Extract from Res. MEPC A245(66) – Annex 5

Part 8

.3 For ro-ro cargo and ro-ro passenger ships f_{jRoRo} is calculated as follows:

$$f_{jRoRo} = \frac{1}{F_{n_L}^{\alpha} \cdot \left(\frac{L_{pp}}{B_s}\right)^{\beta} \cdot \left(\frac{B_s}{d_s}\right)^{\gamma} \cdot \left(\frac{L_{pp}}{\nabla^{1/3}}\right)^{\delta}} \quad ; \quad \text{If } f_{jRoRo} > 1 \text{ then } f_j = 1$$

where the Froude number, F_{n_L}, is defined as:

$$F_{n_L} = \frac{0.5144 \cdot V_{ref}}{\sqrt{L_{pp} \cdot g}}$$

and the exponents α, β, γ and δ are defined as follows:

Ship type	Exponent:			
	α	β	γ	δ
Ro-ro cargo ship	2.00	0.50	0.75	1.00
Ro-ro passenger ship	2.50	0.75	0.75	1.00

Part 12

.3 For ro-ro passenger ships having a DWT/GT-ratio of less than 0.25, the following cubic capacity correction factor, f_{cRoPax}, should apply:

$$f_{cRoPax} = \left(\frac{\left(DWT/_{GT}\right)}{0.25}\right)^{-0.8}$$

Where DWT is the Capacity and GT is the gross tonnage in accordance with the International Convention of Tonnage Measurement of Ships 1969, annex I, regulation 3.