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Permeability and operational draughts of passenger ships

03 February 2022

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The project has received funding from the European's Horizon 2020 research and innovation programme (Contract No.: 814753)

Agenda

- Operational Draughts
- Permeability
- Conclusion

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Operational draughts | Objectives

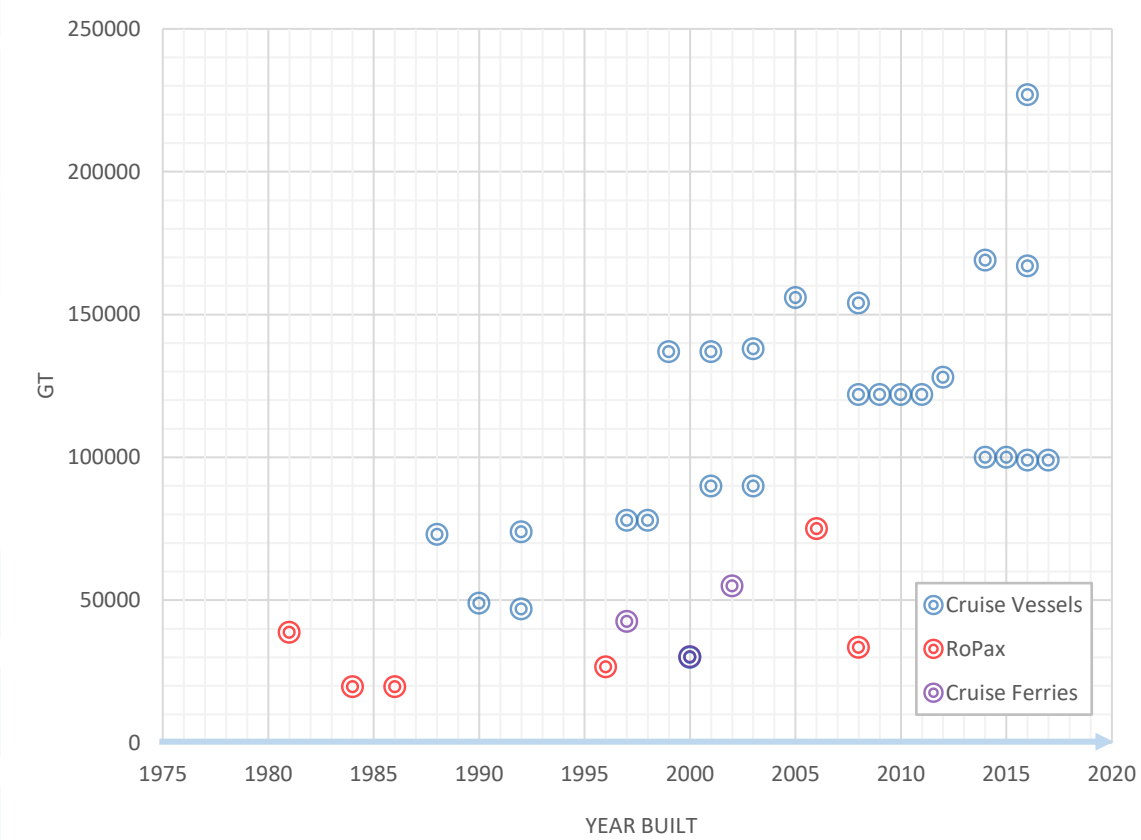
Analysis of on-board data:

- Analysis of ship operational loading condition histories
- Development of operational ship draught distributions and associated optimal calculation draughts and weighting factors.
- Development of ship draught distributions relative to SOLAS draught range and associated optimal calculation draughts and weighting factors.
- Assessment of impact of other factors on passenger vessel loading behaviour.

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Operational draughts | Sample ships



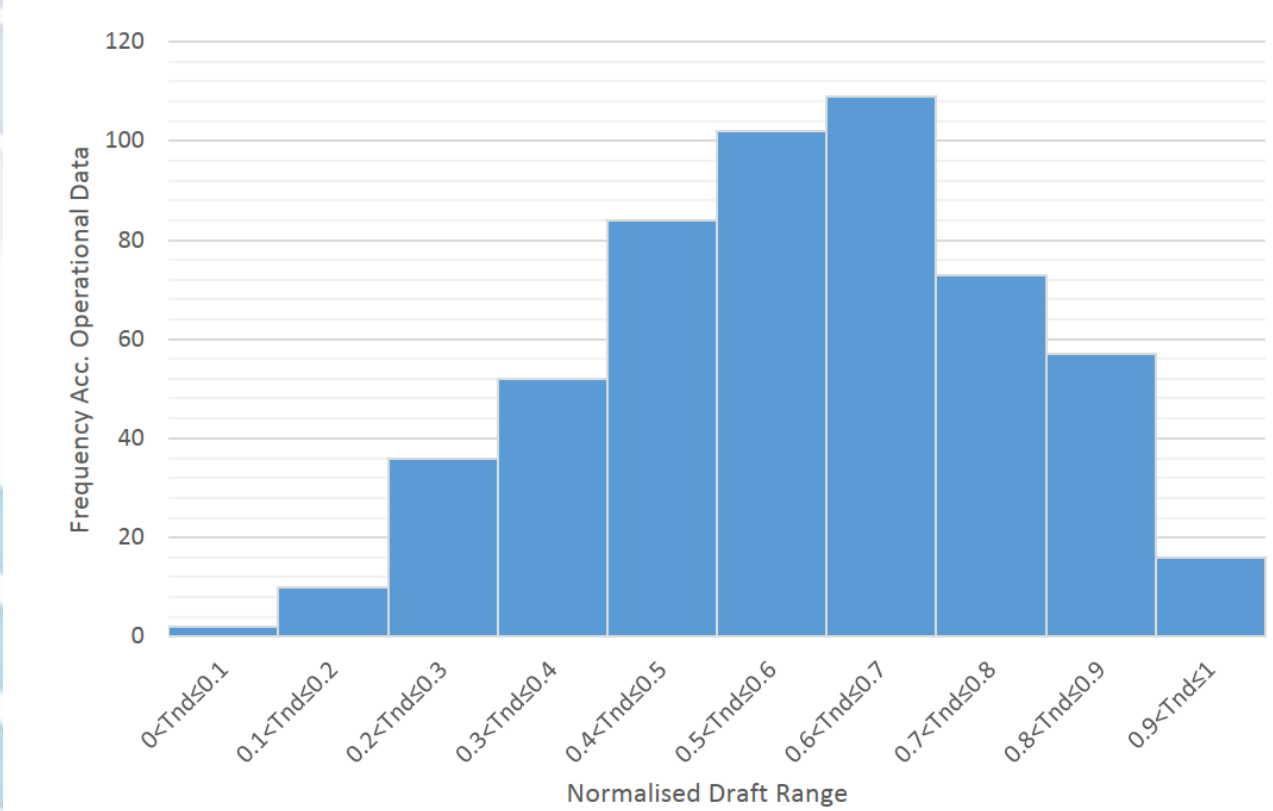
Sample Properties:

- 36 passenger vessels, comprising 27 cruise ships, 6 RoPax & 3 cruise ferries
- Vessel age ranging between 2 and 38 years old.
- Size ranging between 19,800 GT – 227,000 GT
- Loading condition histories ranging from 1-2 years of operational data.

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Operational draughts | Approach



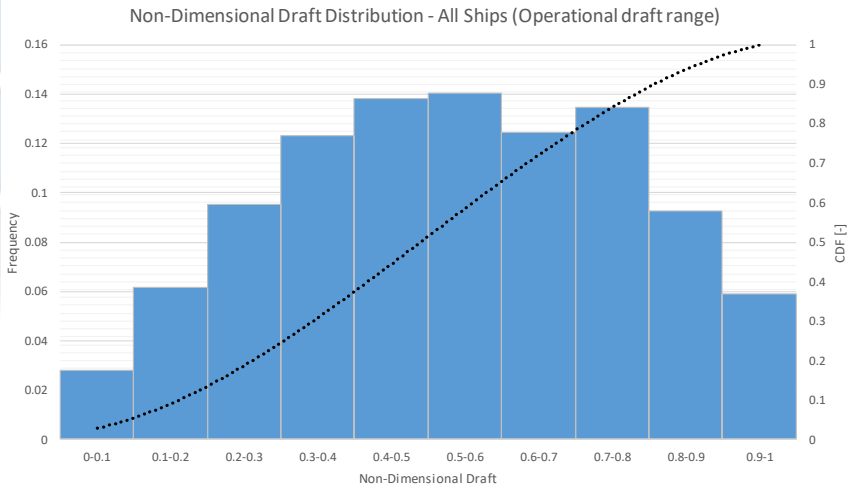
- Normalized draughts
- $T_{min} = 0$, $T_{max} = 1$
- T_{ND} = normalized draught

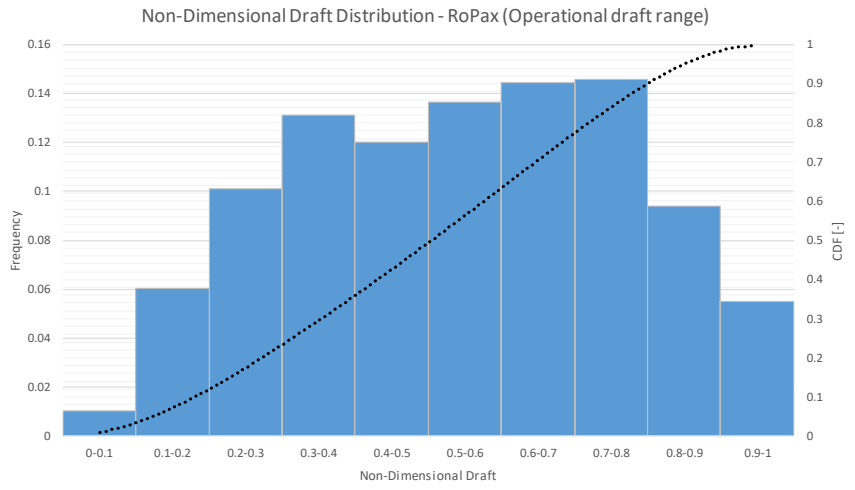
$$T_{ND} = \frac{\overline{T_i} - \min(\overline{T_i})}{\max(\overline{T_i}) - \min(\overline{T_i})}$$

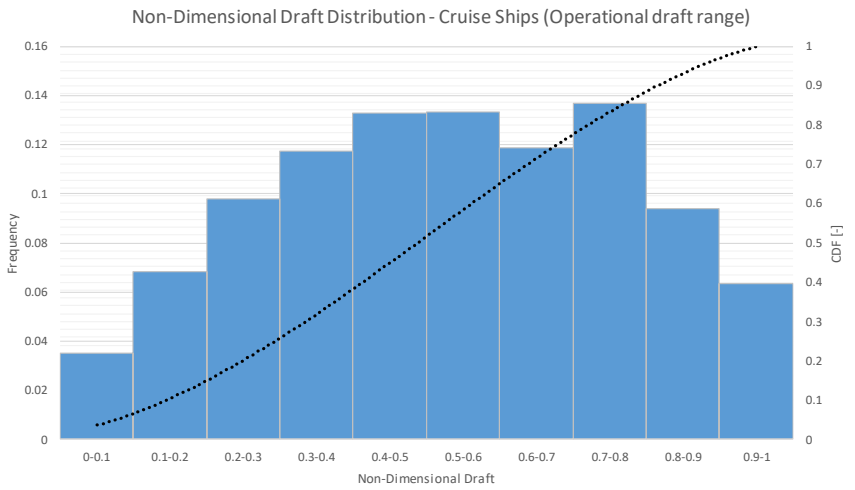
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Operational draughts | Distributions







All ship data

RoPax & Cruise ferry data

Cruise Vessel data

Key Observations:

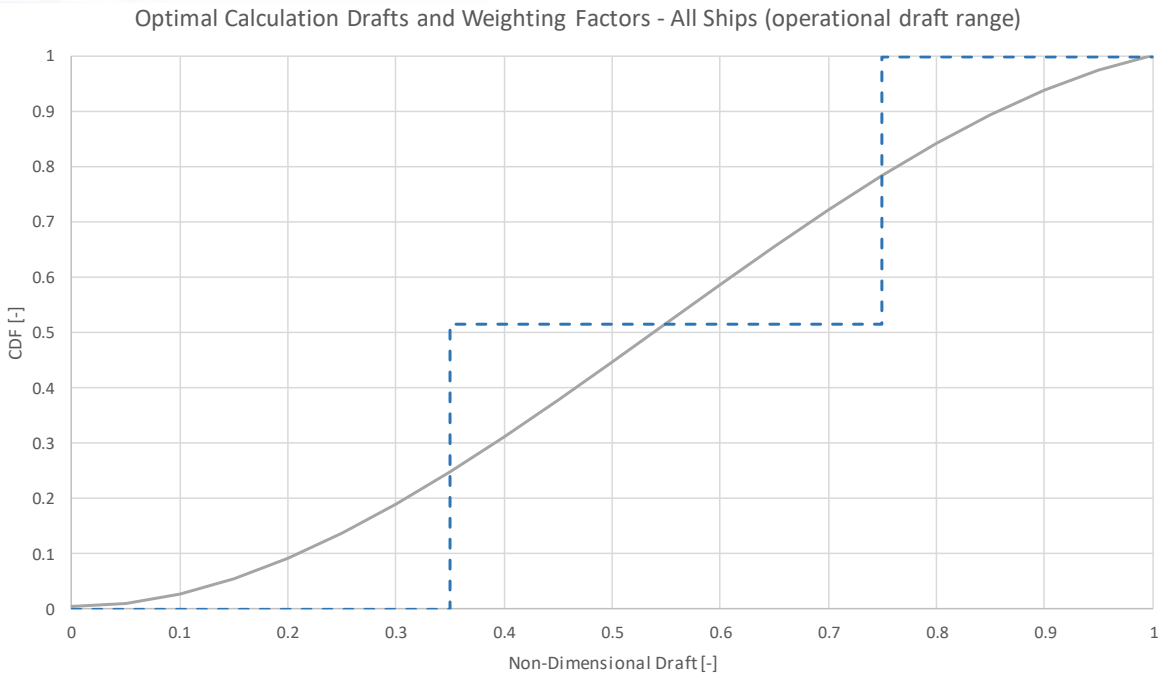
- The draught distributions indicate that passenger vessels operate fairly uniformly within the middle 60% of their operational draft range.
- In the majority of cases, the operational draught range was found to be narrower than that assumed by SOLAS.
- The distributions above, therefore, show minimal variation in draught within a range relatively speaking towards the upper portion of the assumed SOLAS draught range.

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Results WP2.2

Operational – Calculation Drafts and Weighting Factors (all ship data)



Parameters	Optimal Values	Practical Values
T_{ND1}	0.35	0.35
T_{ND2}	0.75	0.75
w_1	0.516	0.5
w_2	0.484	0.5
SSR	0.7316	0.736
Max Over	0.269	0.2687
Max Under	-0.268	-0.2680

Proposed Attained Index Formula:

$$A = \sum_{j=1}^{2} w_j \cdot A(T_j) \qquad (1)$$

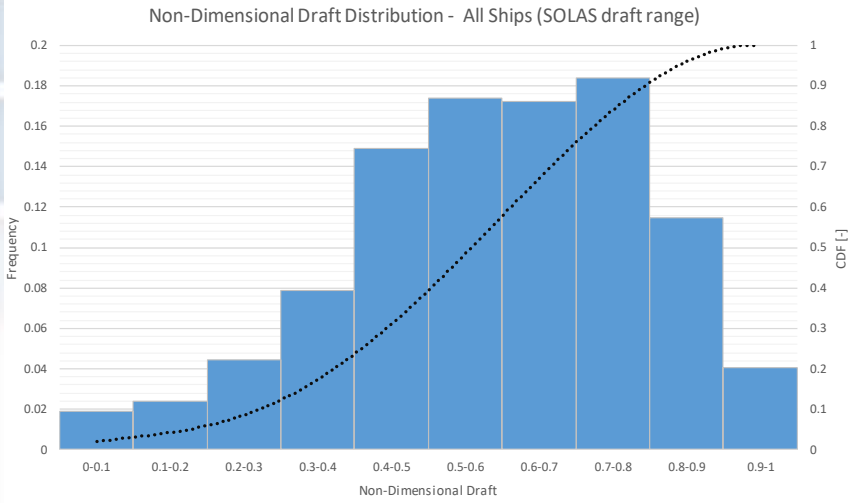
$$A = 0.5 \cdot A_{0.35} + 0.5 \cdot A_{0.75} \qquad (2)$$

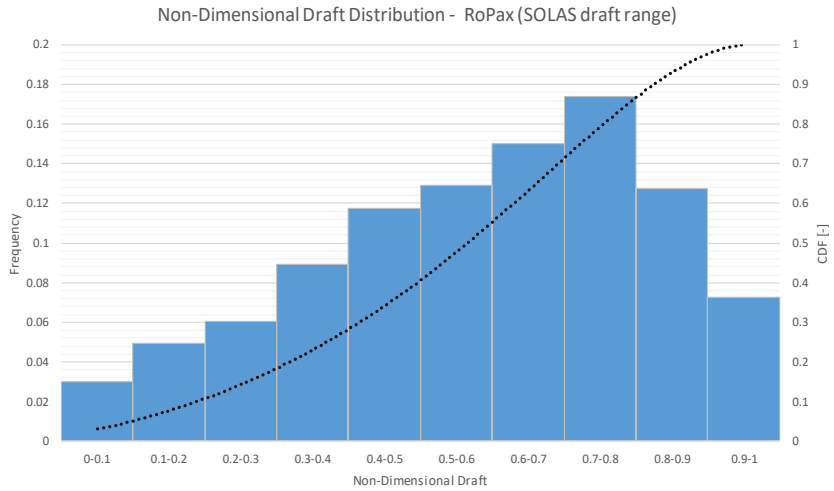
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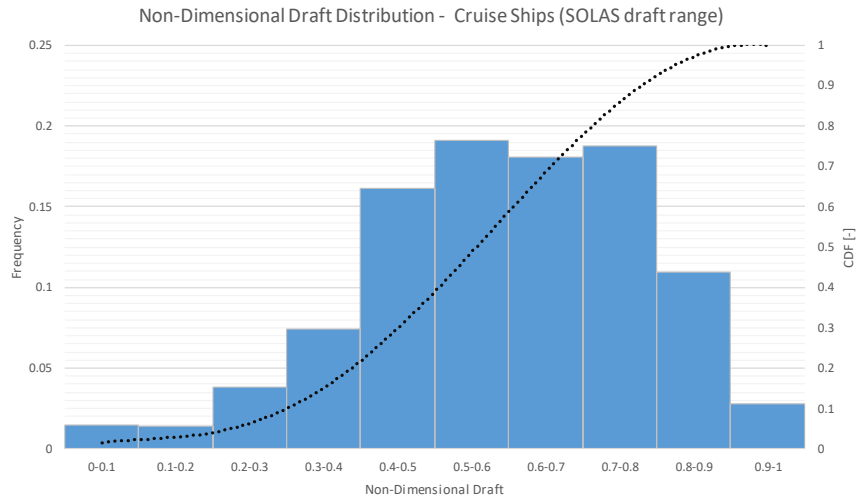
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Results WP2.2

Draft Distributions Relative to SOLAS







All ship data

RoPax & Cruise ferry data

Cruise Vessel data

Key Observations:

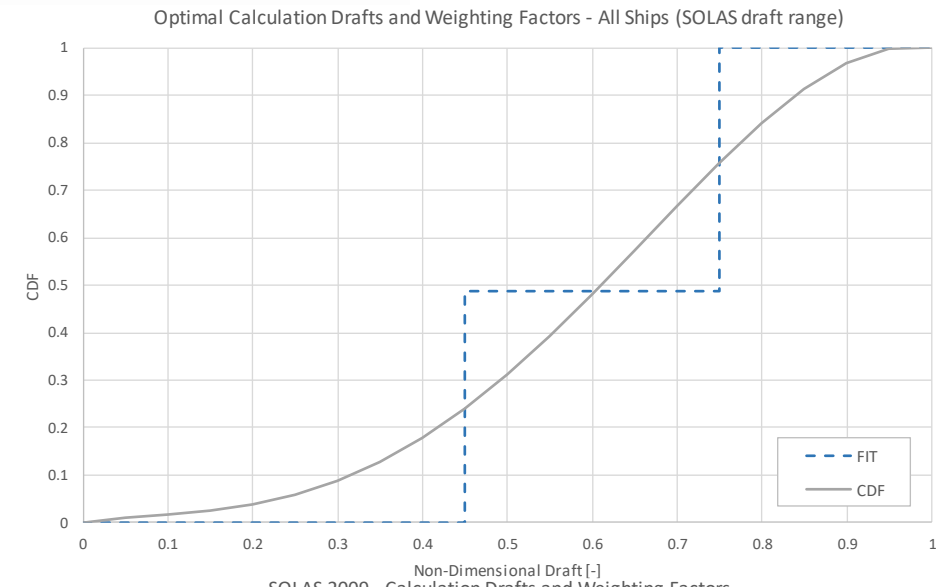
- In all cases, passenger vessels were found to operate predominantly within the upper region of their draft range.
- This tendency was, in general, more pronounced for cruise vessels, though RoPax operate at the upper extremity of their draft range more frequently. (Could stem from sample vessel age, avg. RoPax age = 24 years Vs. avg. cruise vessel age = 14 years)

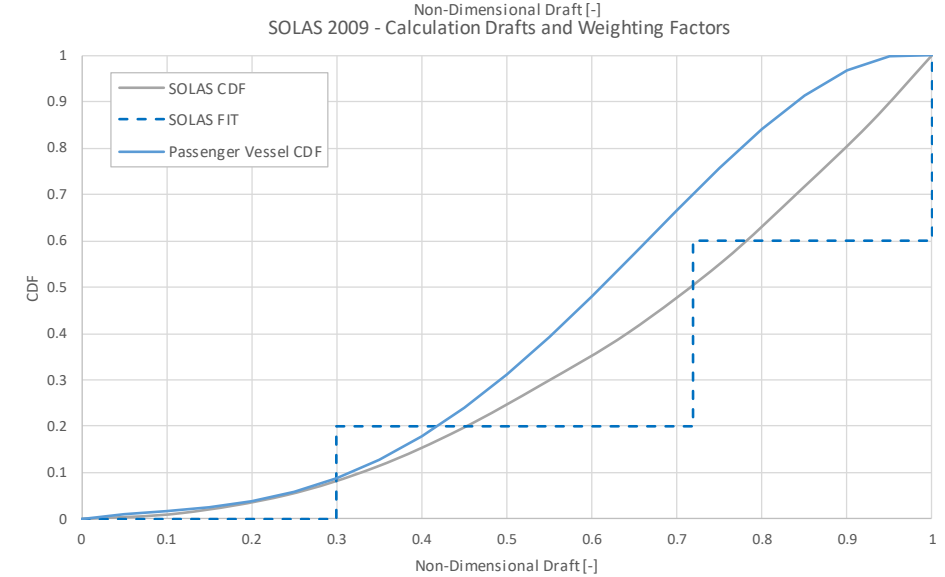
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Results WP2.2

SOLAS – Relative Calculation Drafts and Weighting Factors (all ship data)





Parameters	Optimal Values	Practical Values
T_{ND1}	0.45	0.45
T_{ND2}	0.75	0.75
w_1	0.486	0.5
w_2	0.514	0.5
SSR	0.6004	0.6025
Max Over	0.247	0.260
Max Under	-0.270	-0.256

Proposed Attained Index Formula:

$$A = \sum_{j=1}^{2} w_j \cdot A(T_j) \qquad (3)$$

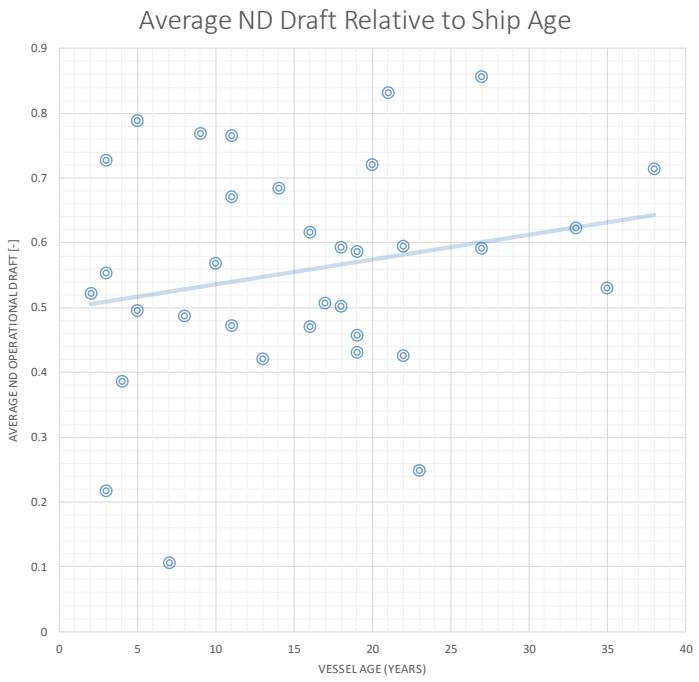
$$A = 0.5 \cdot A_{0.45} + 0.5 \cdot A_{0.75} \qquad (4)$$

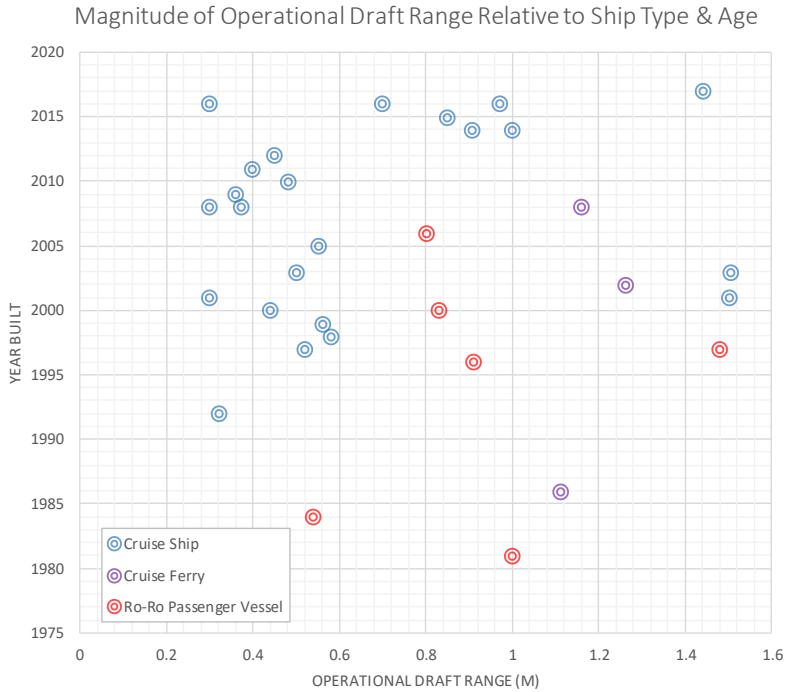
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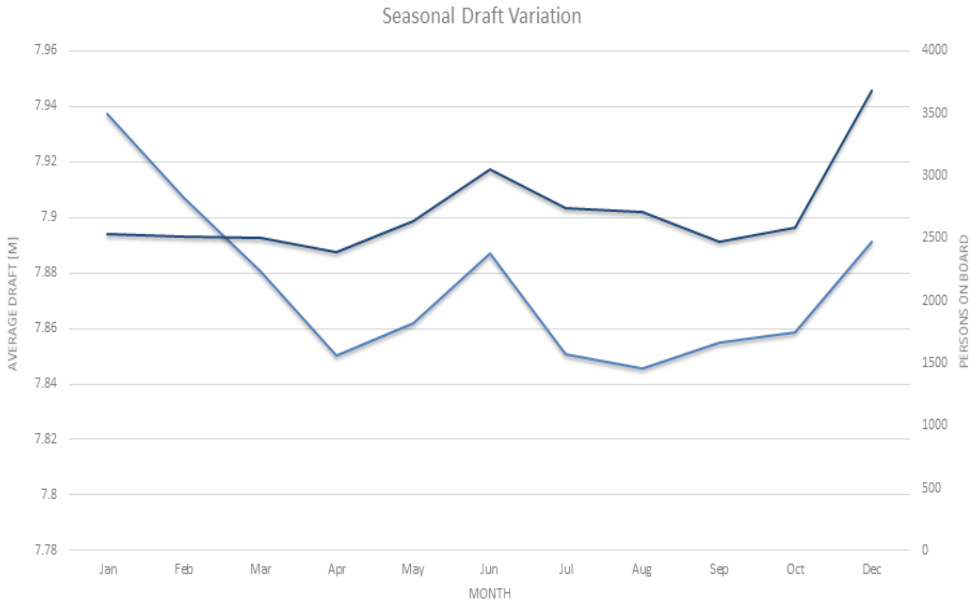
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Results WP2.2

Influence of other factors on loading behaviour







- In general, avg. operational draft increases with ship age, though this is not true for all vessels (significant scatter)
- The magnitude of the operational draft range was found to be independent from vessel age.
- Seasonal draft variations were found in some cases quite pronounced (0.1m-0.15m) with passenger numbers varying by as much as 2000 persons. Raising interesting questions with regards to the determination of damage stability risk i.e. less people at risk, lower passenger induced heeling arms, less people to be evacuated, higher crew/passenger ratio…

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Results WP2.2

Conclusions & Recommendations

Based on the findings of this study, the following conclusions can be drawn:

- The results have shown that passenger vessels, in general, operate within a much narrower draft range than that presently assumed within SOLAS.
- It was found that the calculation drafts currently considered within SOLAS are not optimal with regards to the operation of passenger vessels. Instead, two calculation drafts should be considered at intermediate locations within the vessel draft range, as passenger vessels were found to rarely operate at the extremities of their draft range.
- The resultant optimal non-dimensional calculation draft values for vessels in operation and thus relative to the operational draft range, were found to be 0.35-0.45.
- With regards to vessels within the design stage, the optimal non-dimensional calculation drafts were found to be 0.45-0.75 relative to the currently assumed SOLAS draft range.
- In both cases, the optimal weighting factors to be applied to the calculation drafts was identified as a common weighting factor of 0.5.

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WP 2.3 Permeability

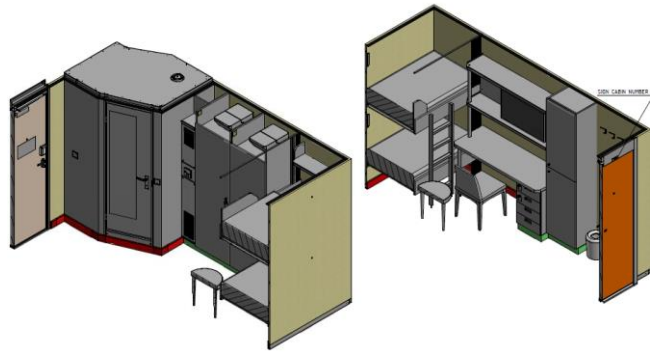
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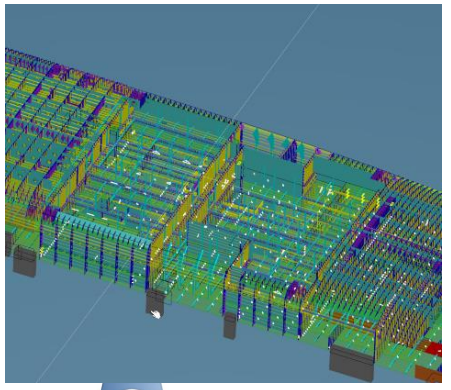
Engine rooms and Cabin areas

Analyzing done for existing ships

Machinery spaces SOLAS	0.85	Cabin area SOLAS	0.95
Main Engine room #1	0.92	Cabin area #1	0.93
Main Engine room #2	0.916	Cabin area #2	0.894
Main Engine room #3	0.91	Cabin area #3	0.924
Aux. Engine room #1	0.91		
Aux. Engine room #2	0.933		
Mean value	0.918	Mean value	0.916







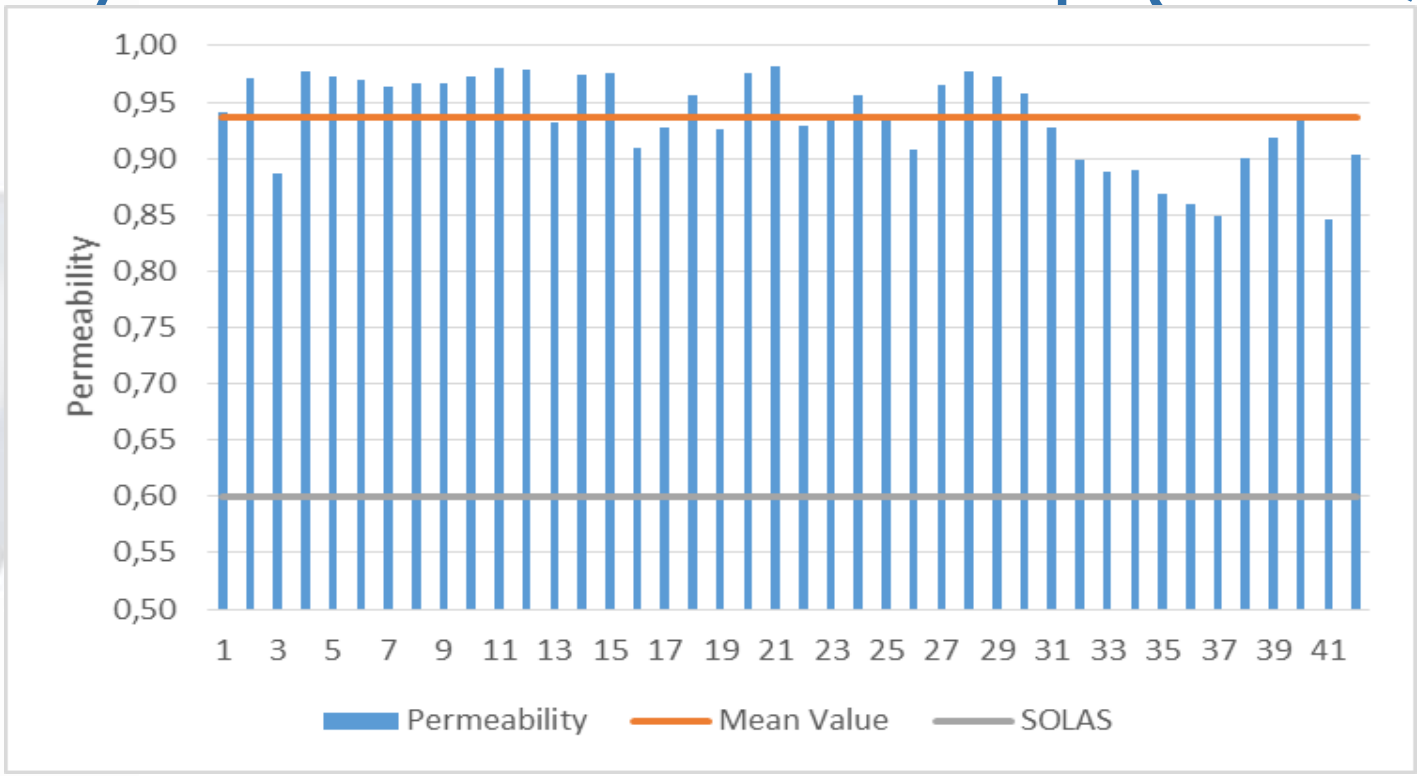
Proposal for a recommendation: all permeability set to 0.9

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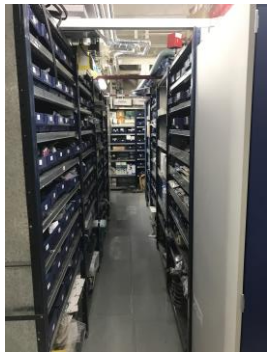
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Stores

Analyzed done for 42 stores on 2 ships (1 cruise, 1 ropax)









Proposal for a recommendation: all permeability set to 0.9

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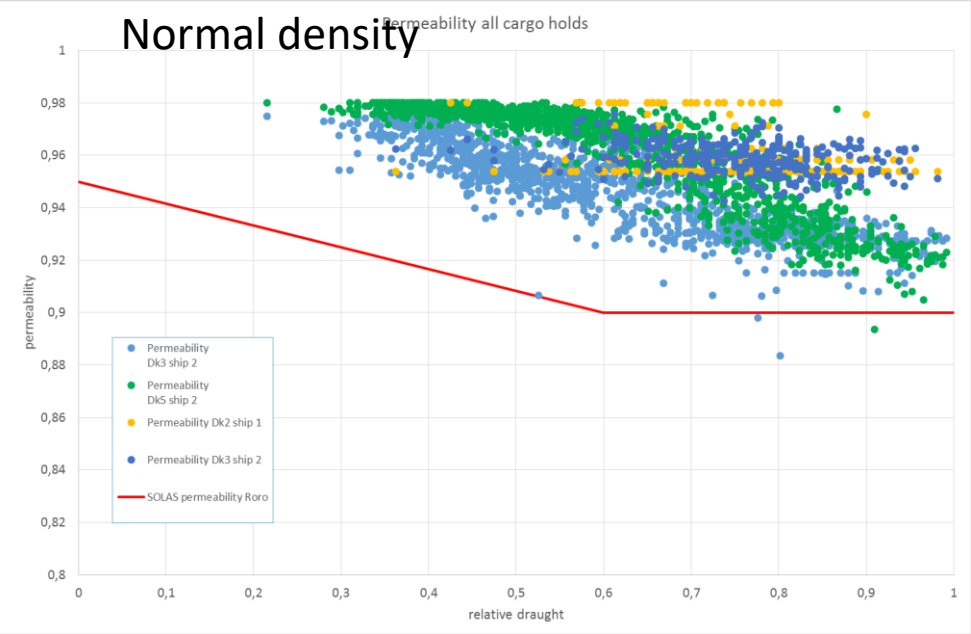
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Cargo holds

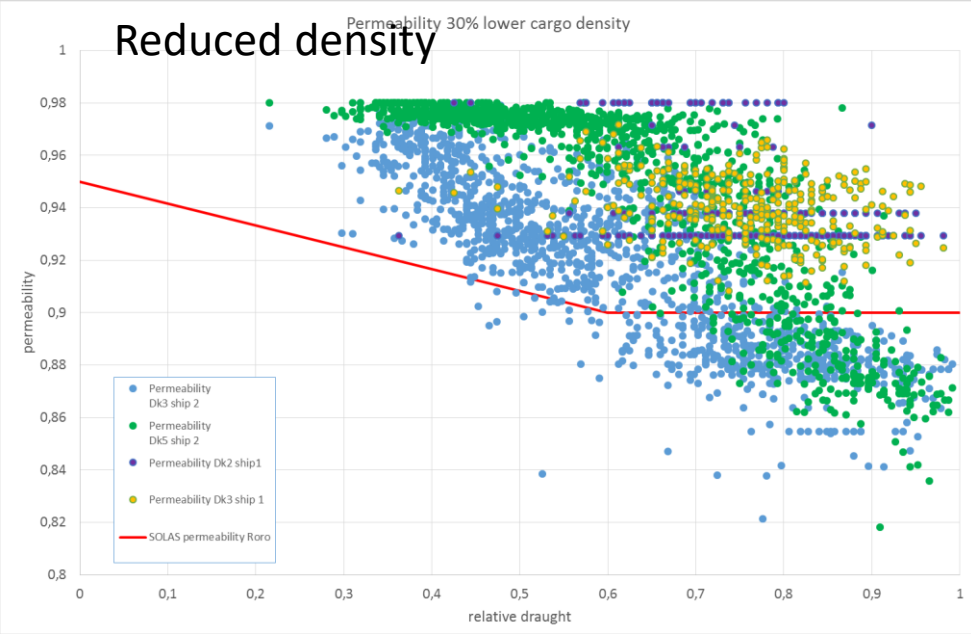
3 ships analyzed for one year on daily basis for different hold

Sensitivity study with 30% reduced density

Normal density



Reduced density



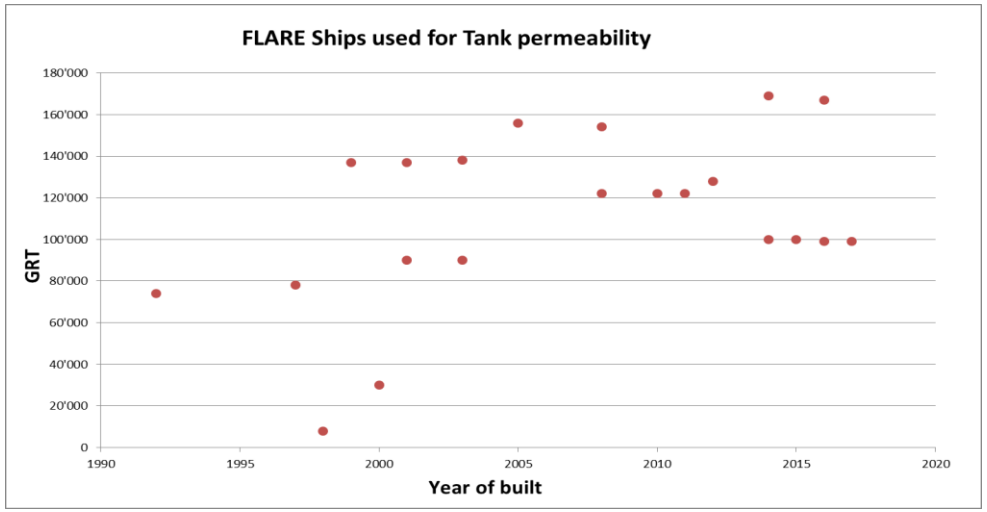
SOLAS default values confirmed

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Tanks: Collected data

Ship n.	Max Draft	Min Draft	Year	GT	Operating Area	Note on tanks loading
1	9.2	7.7	2001	137000	Caribbean and US East Coast	Used
2	8.6	8.12	2010	122000	Caribbean, Europe and South America	Used
~~3~~	~~8,60~~	~~8.24~~	~~2009~~	~~122000~~	~~Caribbean~~	~~Displacement N/A and draughts out of range~~
4	9.00	8.45	2005	156000	Caribbean	Used
~~5~~	~~9.3~~	~~8.33~~	~~2016~~	~~227000~~	~~Caribbean~~	~~PW not available~~
6	9.024	8.65	2008	154000	Caribean and Europe	Used
7	5.95	5.51	2000	30000	Asia, Europe and Caribbean	Used
8	9.1	8.6	2003	138000	Asia and Caribbean	Used
9	7.85	7.53	1992	74000	Caribbean	Used
10	8.3	7.3	2014	100000	Caribbean, Europe, Middle East and Asia	Used
11	8.25	7.4	2015	100000	Europe middle East	Used
12	8.25	7.95	2016	99000	Middle East, europe and Ceribbean	Used
13	8.26	6.82	2017	99000	Caribbean and Europe	Used
~~14~~	~~7.3~~	~~6.11~~	~~1990~~	~~49000~~	~~Caribbean~~	~~Displacement and Draughts not available~~
15	8.8	8.1	2016	167000	Asia and Alaska	Used
16	8.8	7.892	2014	169000	Asia	Used
~~17~~	-	-	~~2000~~	~~30000~~	~~Caribbean, Europe and Middle East~~	~~Draught range not available~~
18	8.6	8.3	2001	90000	Alaska and Australia	Used
19	8.6	8.152	2012	128000	Caribbean and Europe	Used
20	7.9	7.38	1997	78000	Caribbean and Europe	Used
21	8.6	8.201	2011	122000	Caribbean and Europe	Used
22	8.6	8.3	2008	122000	Asia and Alaska	Used
23	8.596	7.091	2003	90000	Caribbean, East Coast and Europe	Used
~~24~~	~~7.8~~	~~7.712~~	~~1988~~	~~73000~~	~~Europe and South america~~	~~Displacement and Draughts not available~~
25	7.9	7.32	1998	7800	europe and US	Used
26	9.1	8.54	1999	137000	Asia	Used
~~27~~	-	-	~~1992~~	~~47000~~	~~Europe~~	~~Draught range not available~~



N.21 cruise ships over 27 have been used

N.6 ships have been excluded due to missing data (e.g. draughts and/or main tanks capacity for PW, MIS, WB, FO or GW)

Number of Loading Conditions used: 11359

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Calculation of the actual global tanks permeability

The tanks permeability for each recorded loading condition was calculated by assuming that the liquid loaded within the damaged tanks is totally replaced by sea water.

Therefore the actual global tanks permeability is obtained from the following equation:

$$\sum_{i=1}^{n}(\rho \cdot c_i - m_i) = \rho \cdot tperm \cdot \sum_{i=1}^{n} c_i$$

$$tperm = 1 - \frac{\sum_{i=1}^{n} m_i}{\rho \cdot \sum_{i=1}^{n} c_i}$$

- i : index for the i-th tank;
- ρ : sea water density (1.025 t/m^3);
- c_i : capacity of the i-th tank [m^3];
- m_i : mass of liquid within the i-th tank [t];
- $tperm$: actual global tanks permeability.

Normalized draught

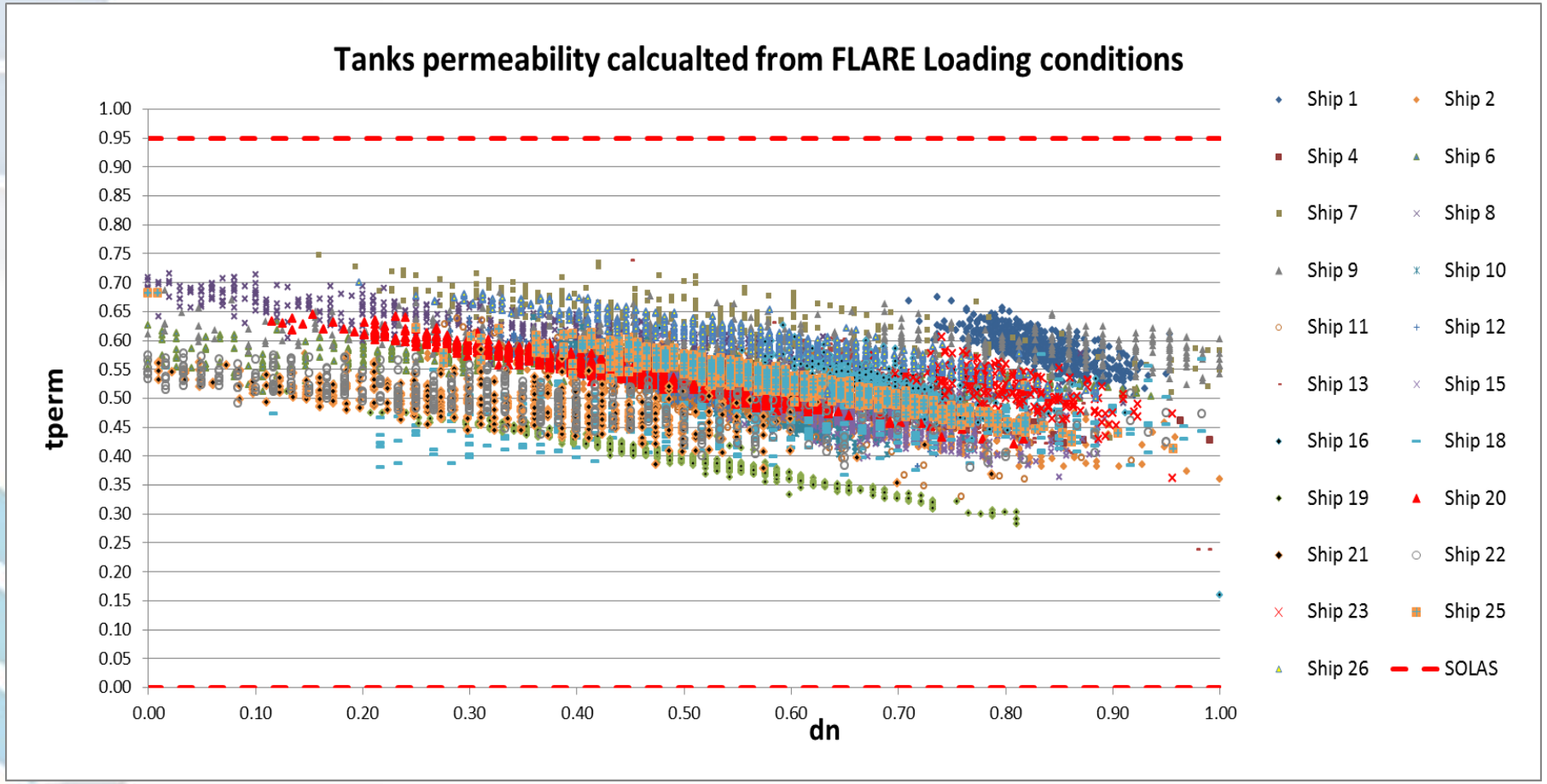
$$dn = \frac{T_m - T_l}{T_S - T_l}$$

- T_m : draught at mid-ship perpendicular [m].
- T_s : maximum draught [m] (corresponding to deepest subdivision draught for ships built under SOLAS 2009);
- T_l : minimum draught [m] (corresponding to light service draught for ships built under SOLAS 2009);

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Calculation of the actual global tanks permeability



FLARE data confirmed that SOLAS permeability for tanks is not realistic and very conservative

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Linear Regression

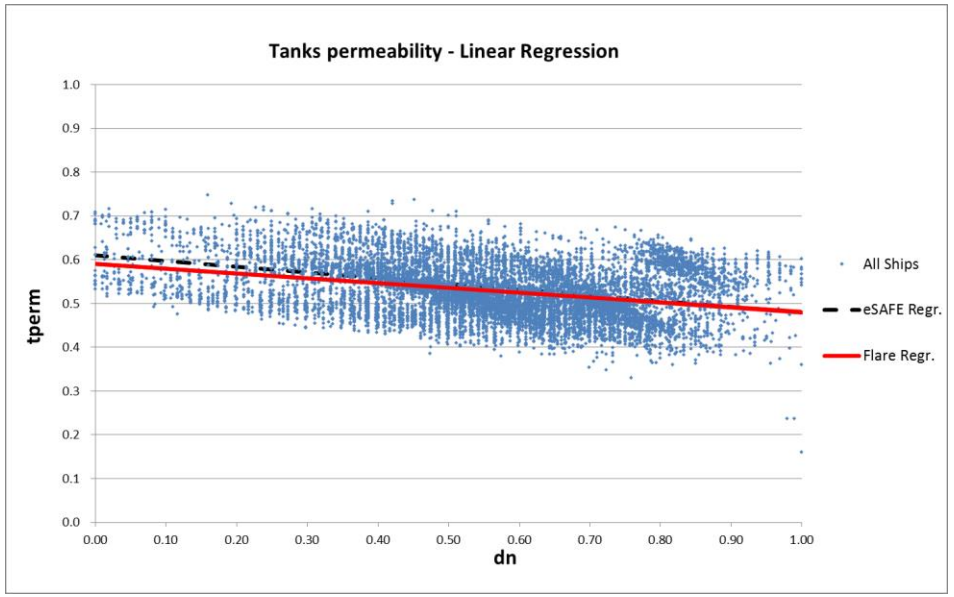
Global Tanks permeability (Heling tanks excluded)

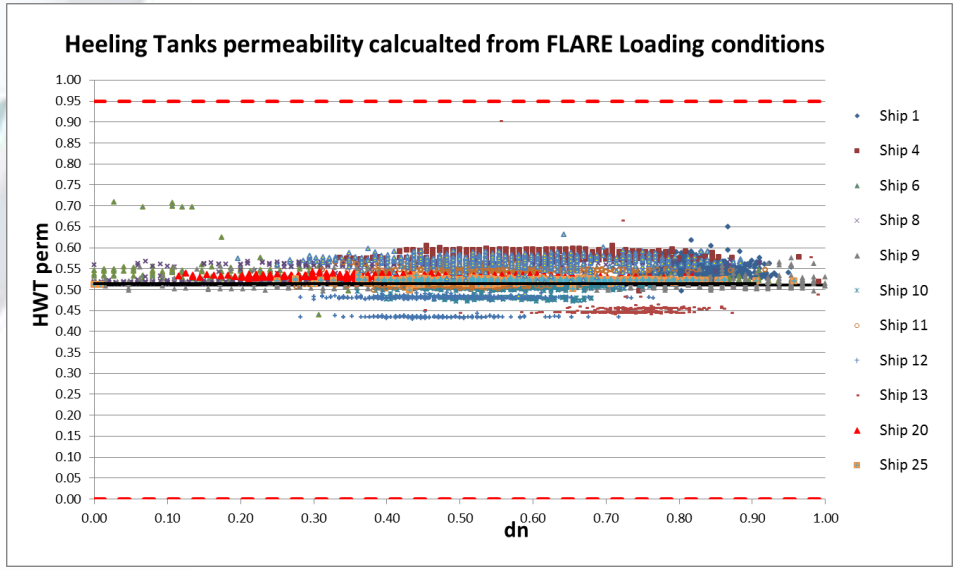
eSAFE formula:

$$Tperm = 0.61 - 0.13\,\frac{T - T_{min}}{T_{max} - T_{min}}$$

FLARE formula:

$$\boldsymbol{Tperm = 0.59 - 0.11\,\frac{T - T_{min}}{T_{max} - T_{min}}}$$





Heeling Tanks permeability 0.51

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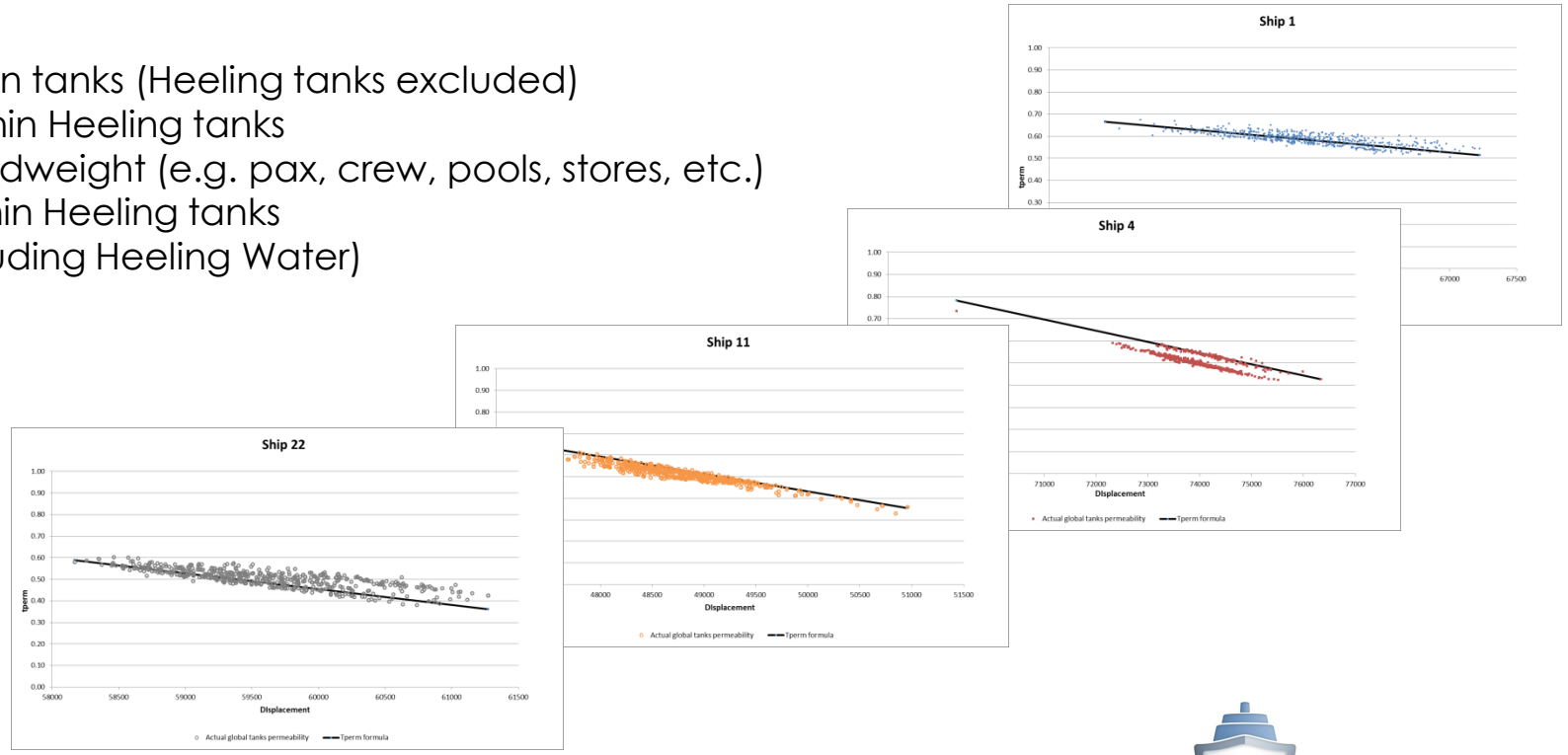
Tank permeability based on mathematical approach

$$Disp = LWT + T_{DWT} + HWM + O_{DWT}$$

$$Tperm = 1 - \frac{0.96 \times Disp - LWT - 0.5 \times HCap}{\rho \times TCap}$$

Where:

$Disp$ = Intact Displacement
LWT = Lightship weight
T_{DWT} = mass of liquid loaded within tanks (Heeling tanks excluded)
HWM = mass of water loaded within Heeling tanks
O_{DWT} = remaining part of the Deadweight (e.g. pax, crew, pools, stores, etc.)
$HCap$ = mass of water loaded within Heeling tanks
$TCap$ = Total tanks capacity (excluding Heeling Water)
ρ = sea water density $1.025\ ^{t}/_{m^3}$



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Standard deviation

Description	Formula	STANDARD DEVIATION from real permeability calculated for FLARE Loading conditions (abt 11000 loading cases)
SOLAS Permeability	**0 or 0.95** whichever results in the more severe requirement	**0.42**
FLARE Linear Regression	$Tperm = 0.59 - 0.11 \frac{T - T_{min}}{T_{max} - T_{min}}$	**0.06**
FLARE Mathematical Formula	$Tperm = 1 - \frac{0.96 \times Disp - LWT - 0.5 \times HCap}{\rho \times TCap}$	**0.04**

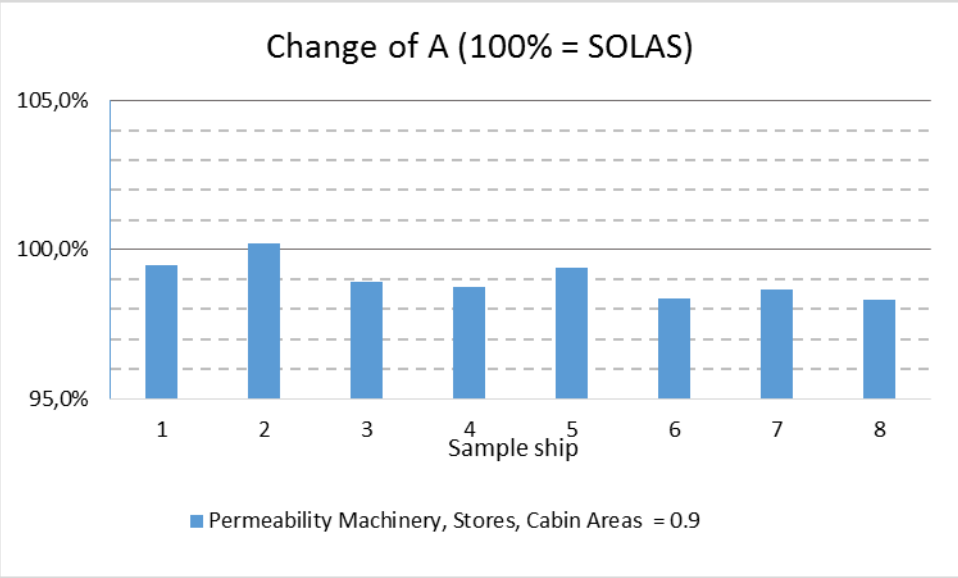
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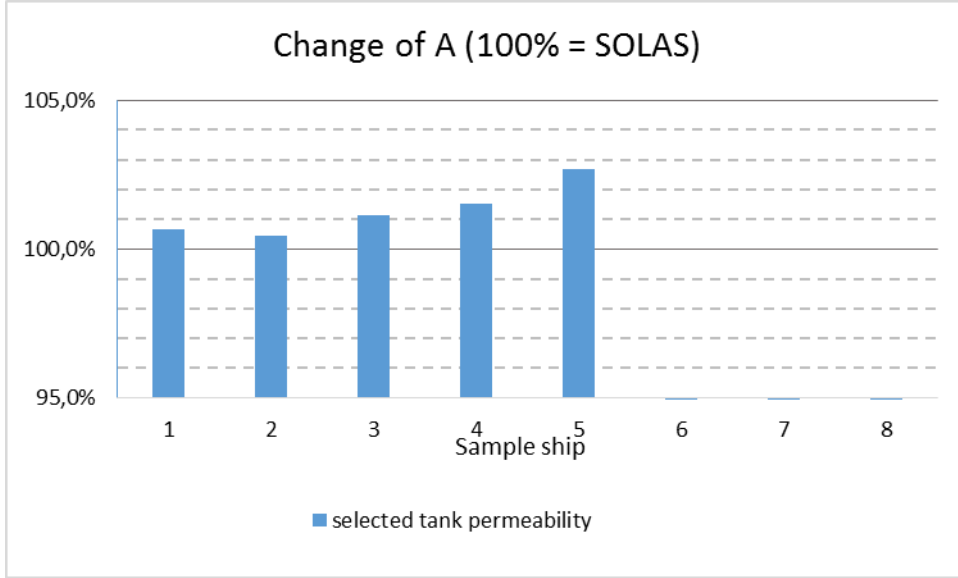
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Impact of permeability on attained index A

8 sample ships (5 cruise, 3 ropax)

Attained index A calculated for new permeability



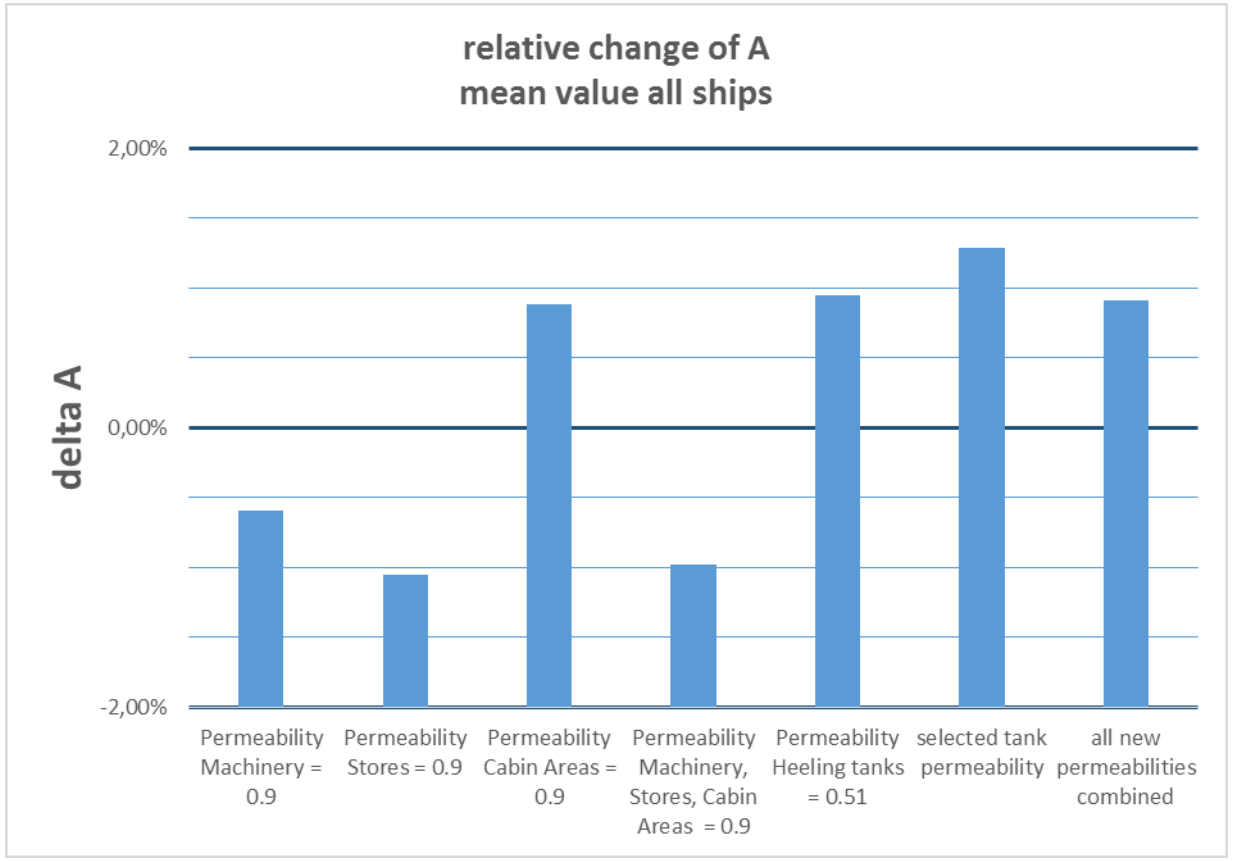


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Impact of permeability on attained index A

All new values for permeability applied show only slight impact



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Conclusion and recommendation

All new values for permeability applied show only slight impact

The variation of A is for the different applications very small and within a range ±1%.

It can be concluded that the application of the new proposed permeability for machinery spaces, stores, cabins and heeling tanks should be used for all passenger ships.

The application of the new variable permeability for tanks can be considered as reasonable as well and should be used in the future for cruise ships and pure passenger ships without cargo.

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Thank you

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