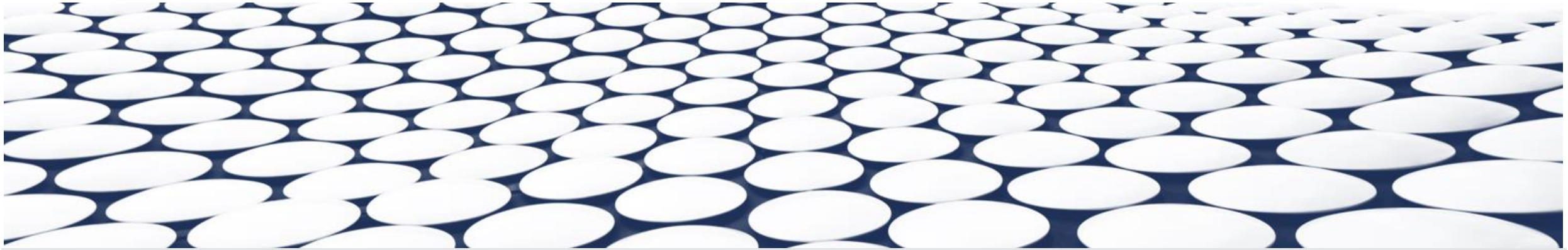
UNIVERSITY of STRATHCLYDE
MARITIME SAFETY
RESEARCH CENTRE

University of Strathclyde Engineering

ALTERNATIVE DESIGN APPROACH FOR SHIP SAFETY AND ENERGY EFFICIENCY BASED ON CRASHWORTHINESS ANALYSIS

HONGSEOK (ELVIS) BAE

배 홍 석



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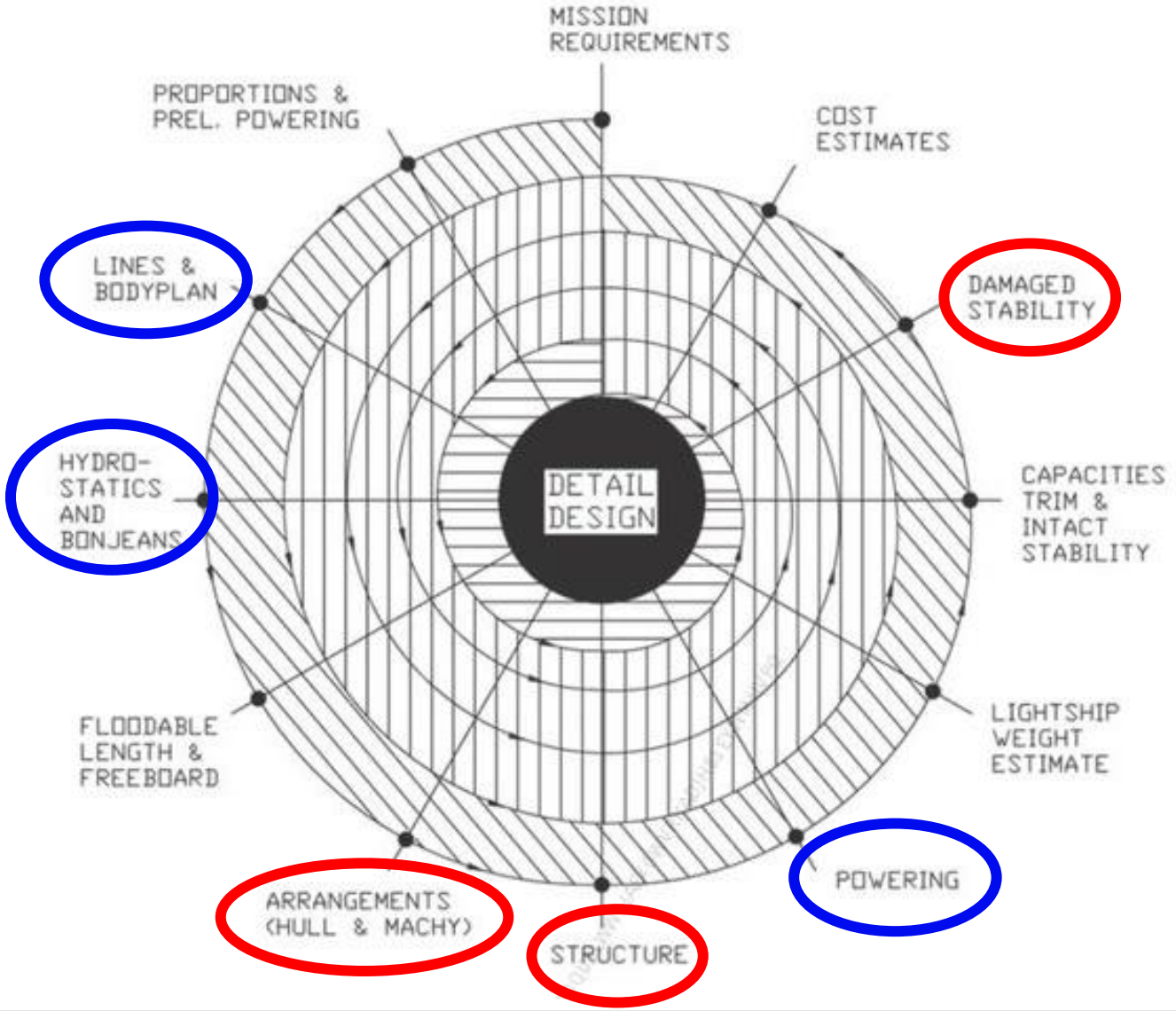
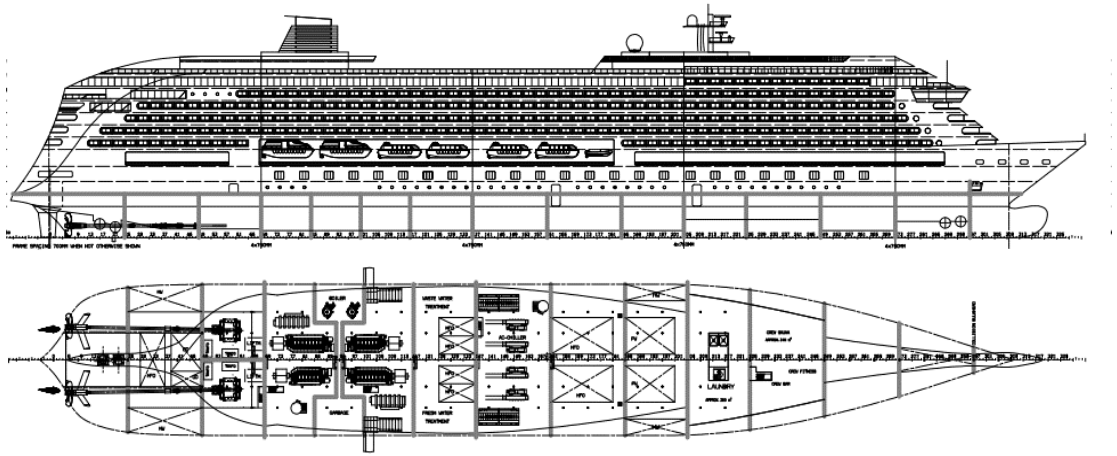
0. Technology Development Focus

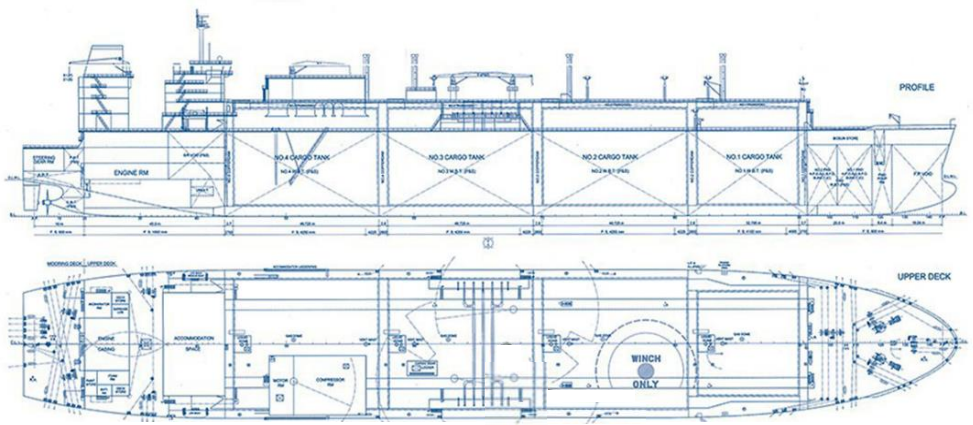


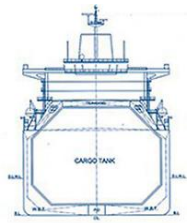
Currently,
- ✓ Fuel & Propulsion System
- ✓ Energy Saving Devices

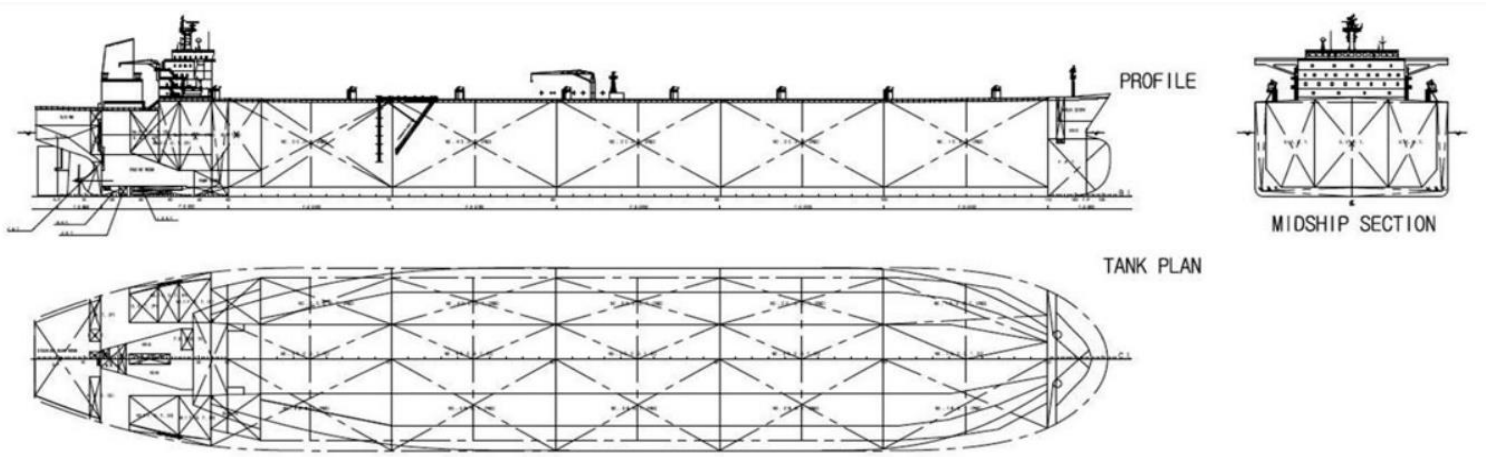
This Research,
Ship Arrangement
associated with Stability

0. Subdivisions due to Stability Requirements









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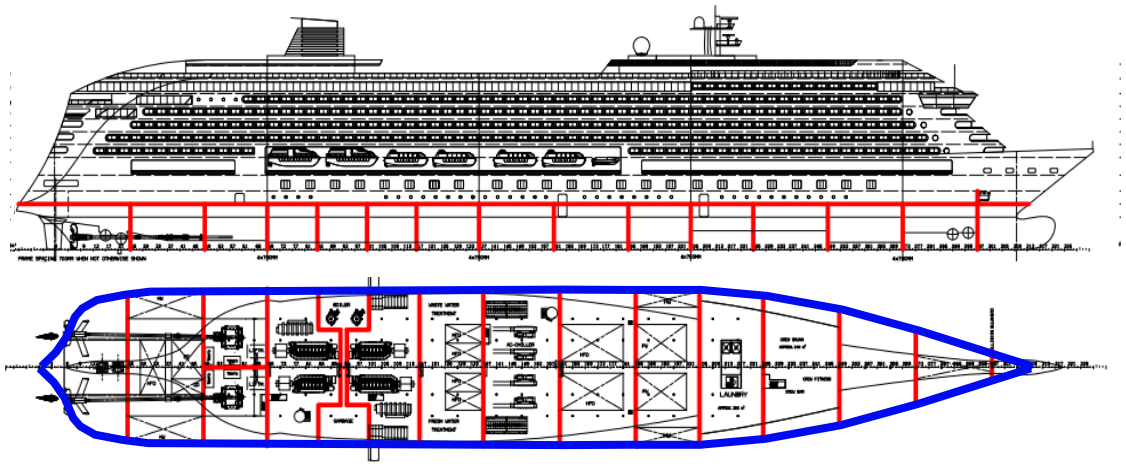

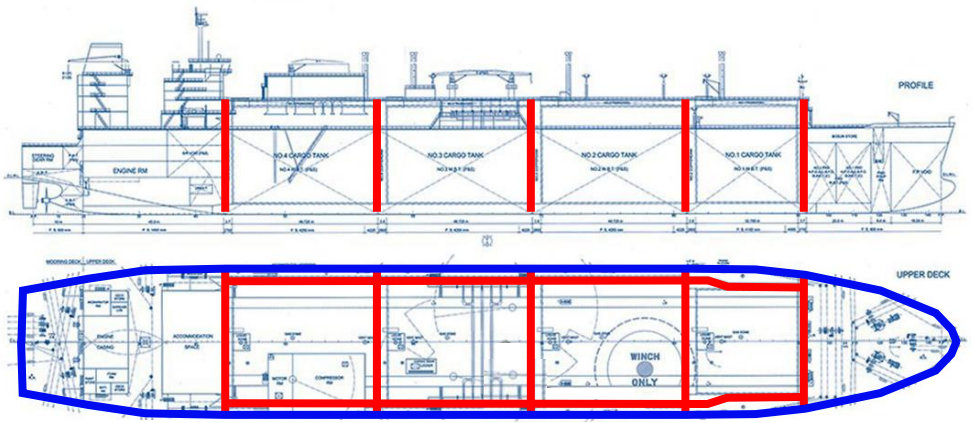

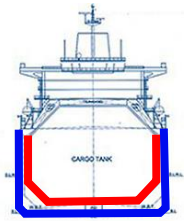

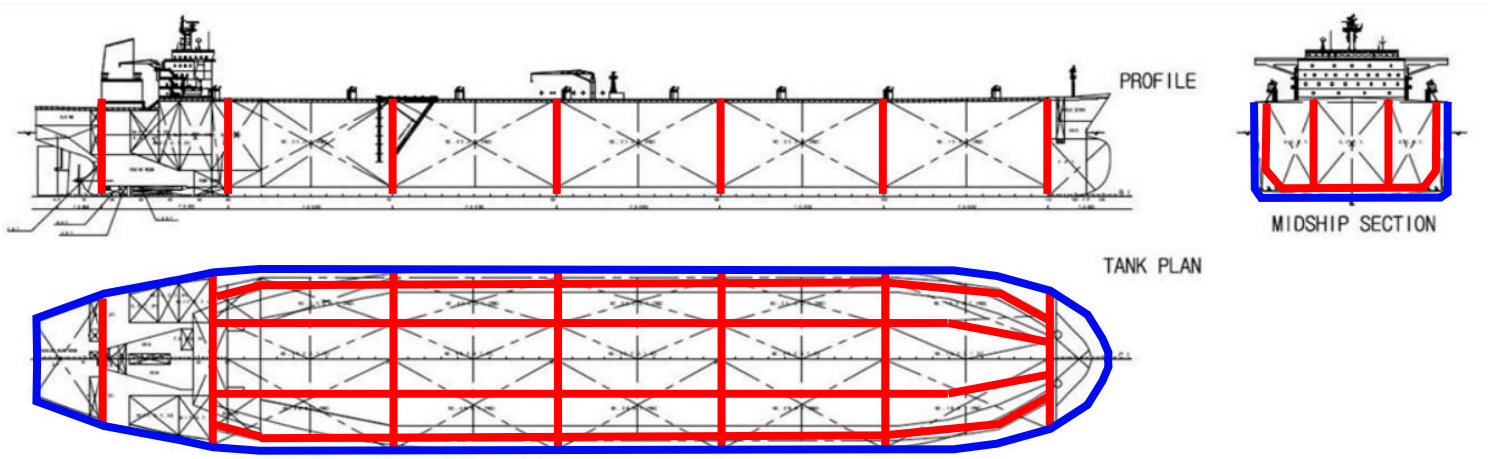

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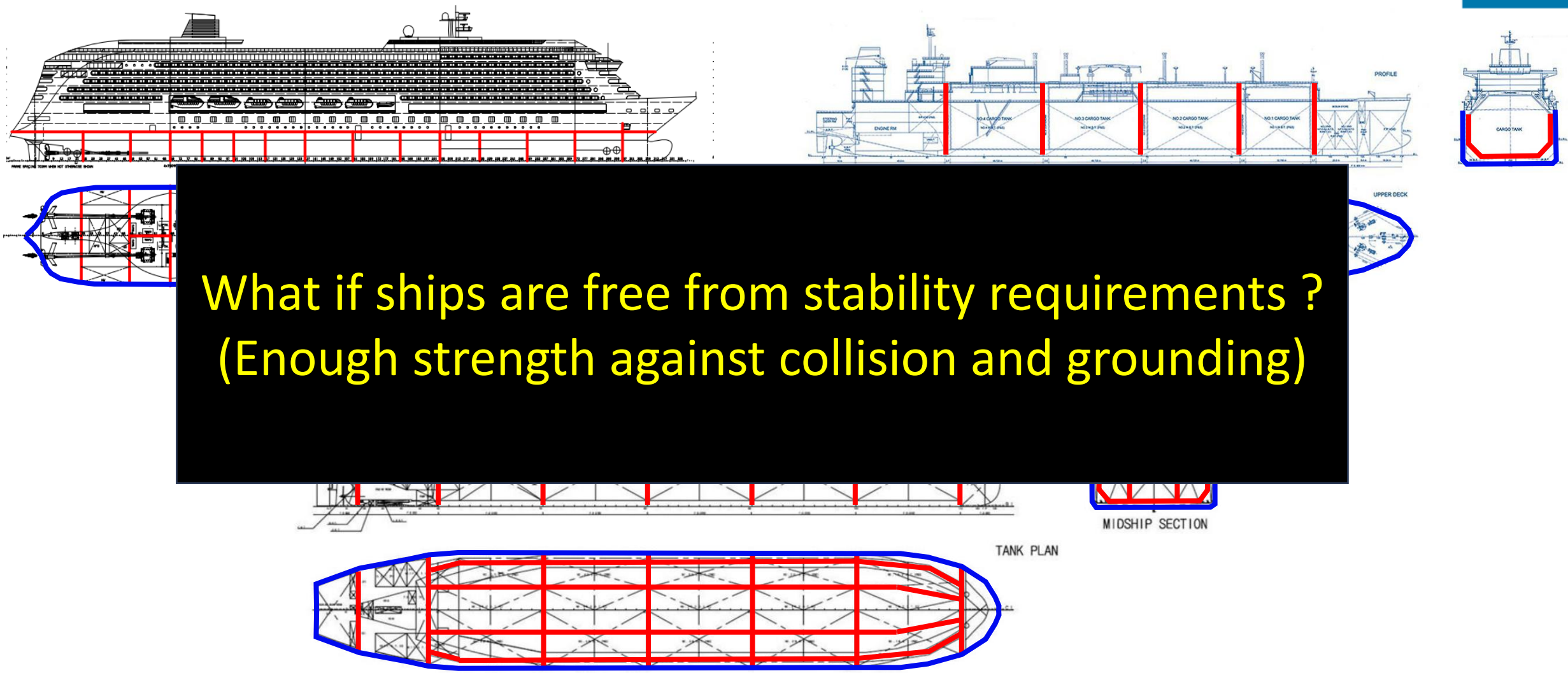
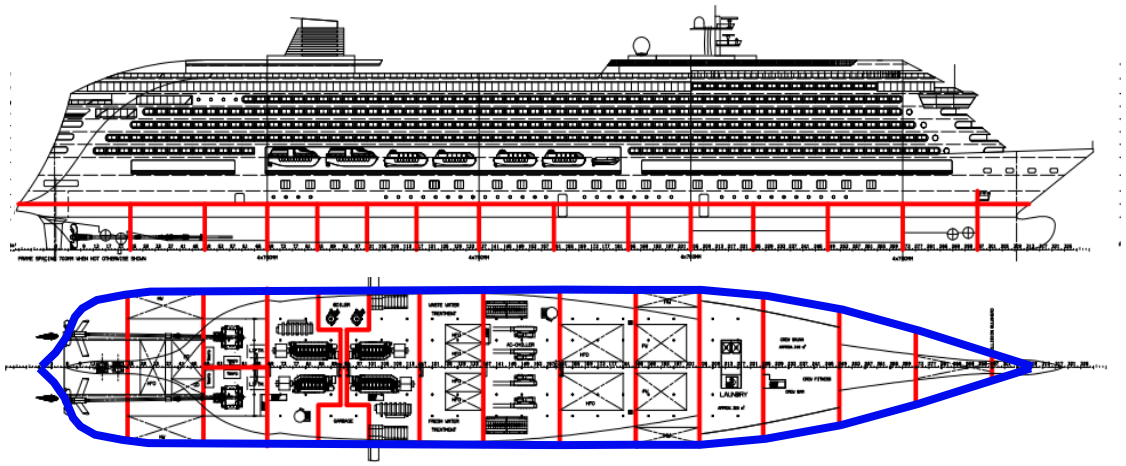
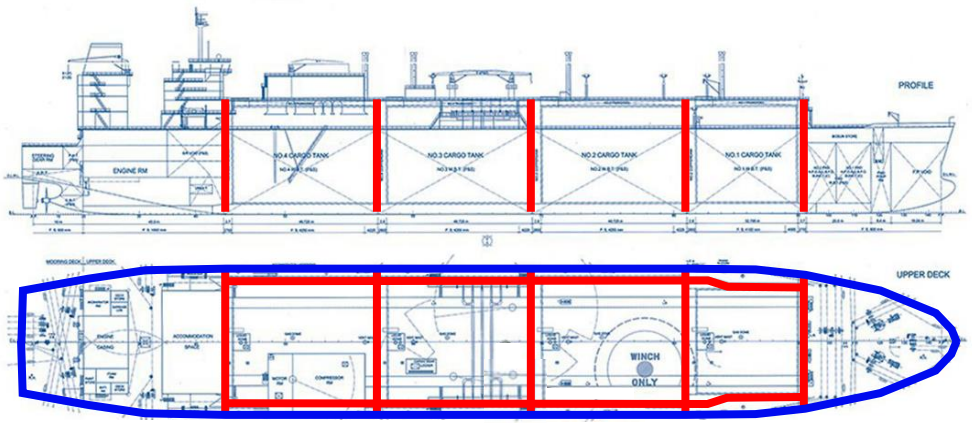
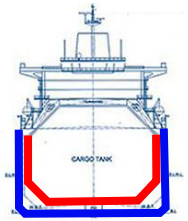


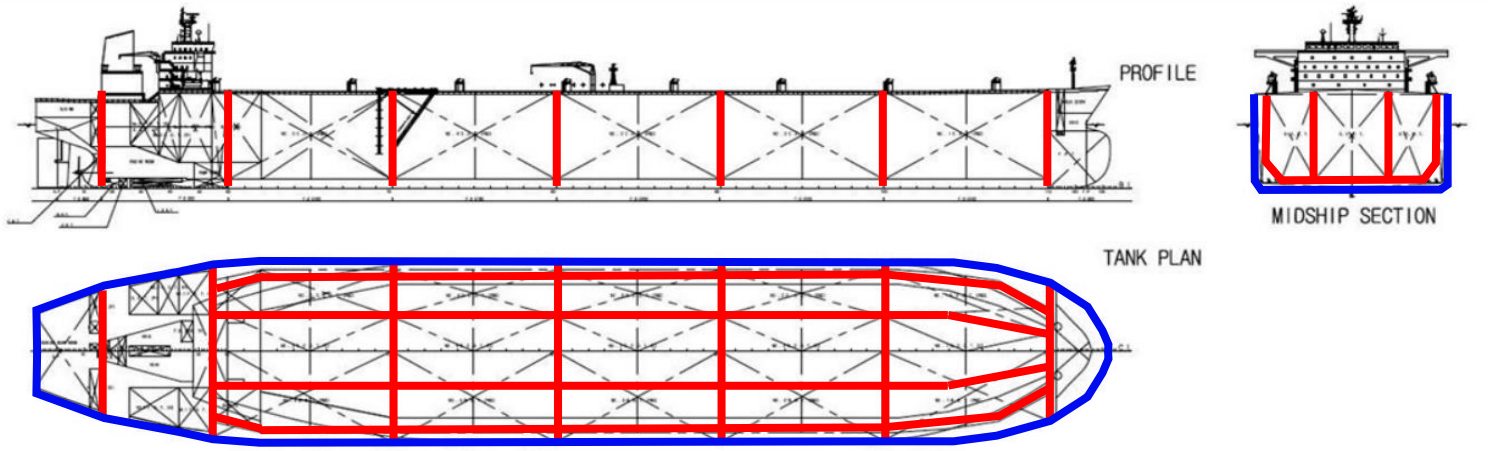
What if ships are free from stability requirements ?
(Enough strength against collision and grounding)

0. Subdivisions due to Stability Requirements









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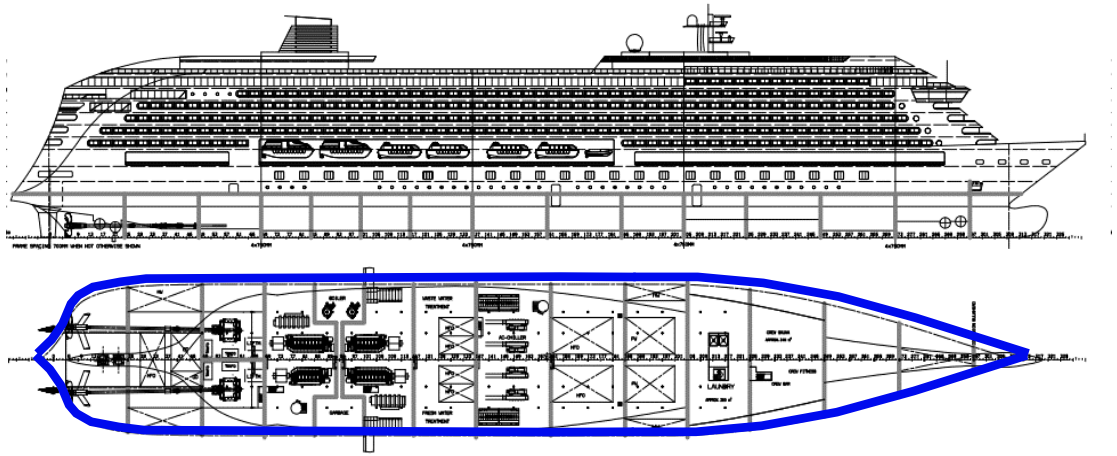
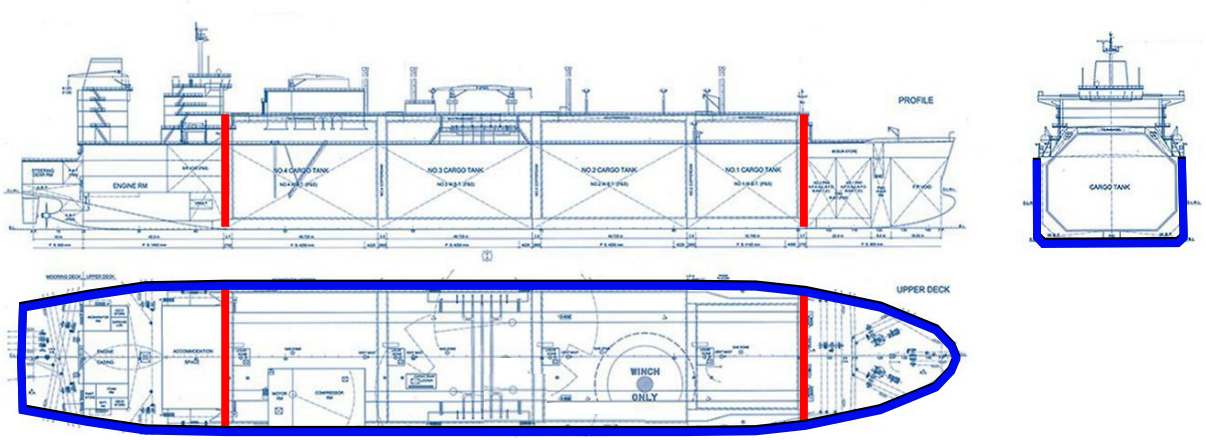
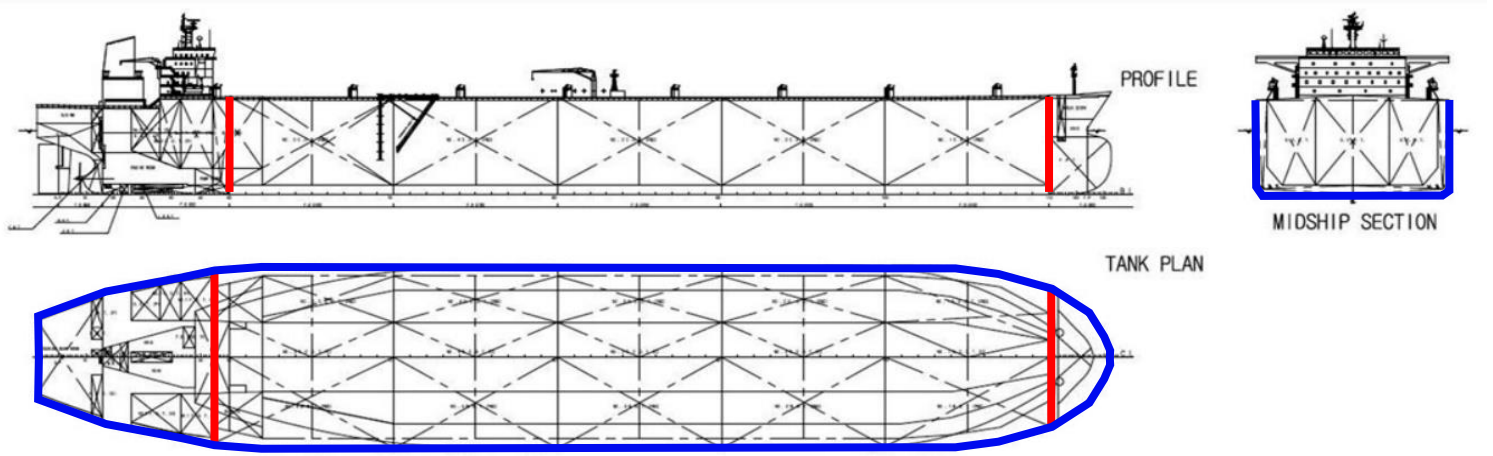
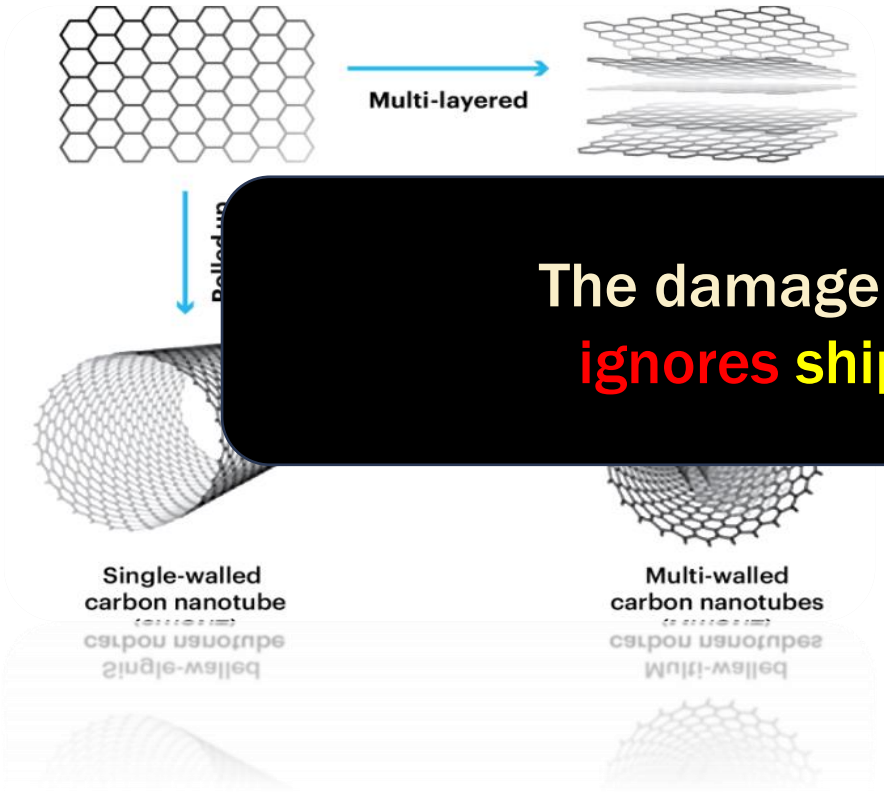






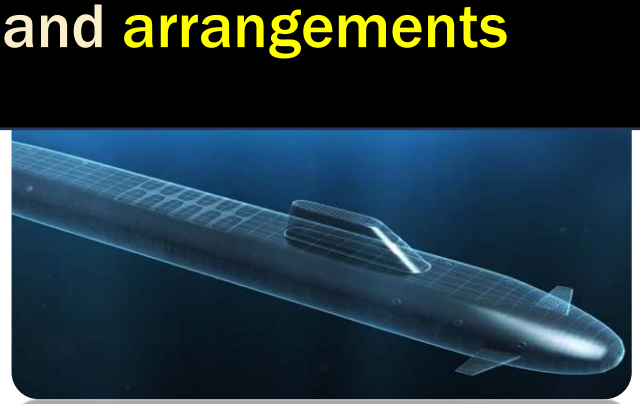
1. Problem

What about to apply advanced Material to ships?





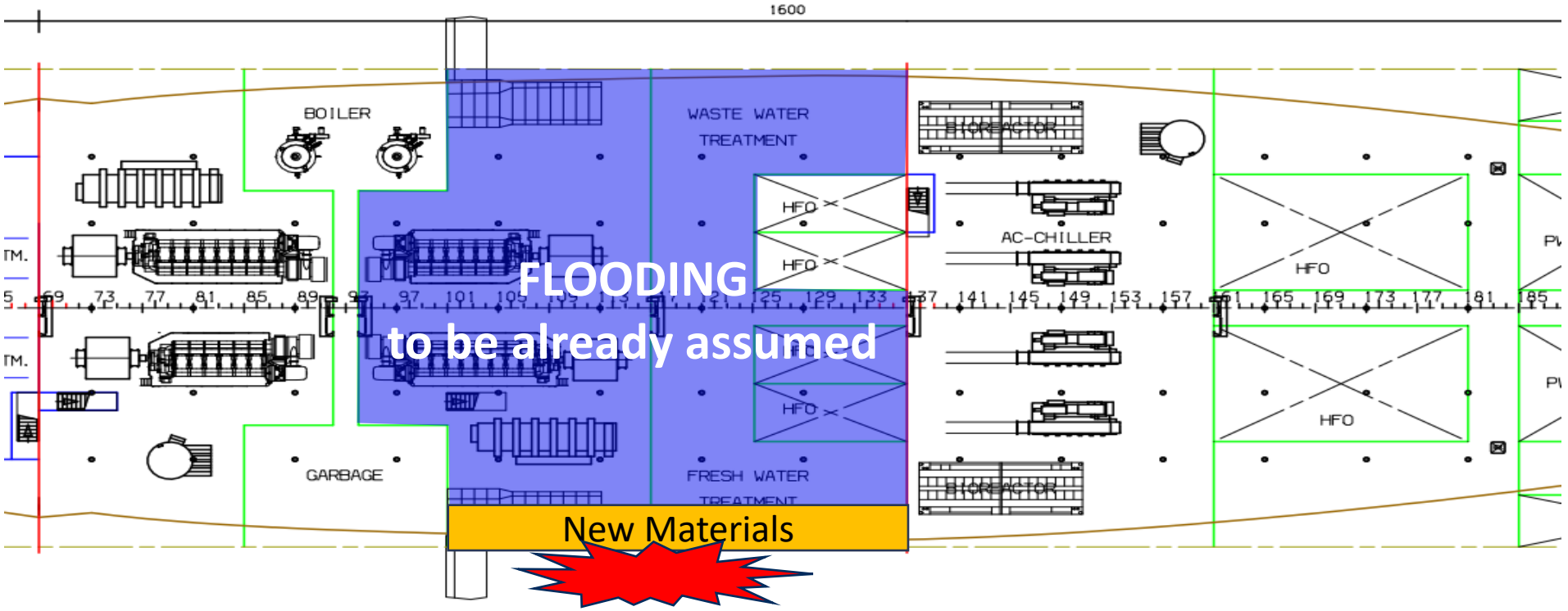




The damage stability framework adopted by SOLAS
ignores ship structural design and arrangements

1. Problem

The damage stability framework adopted by SOLAS
ignores ship structural design and arrangements

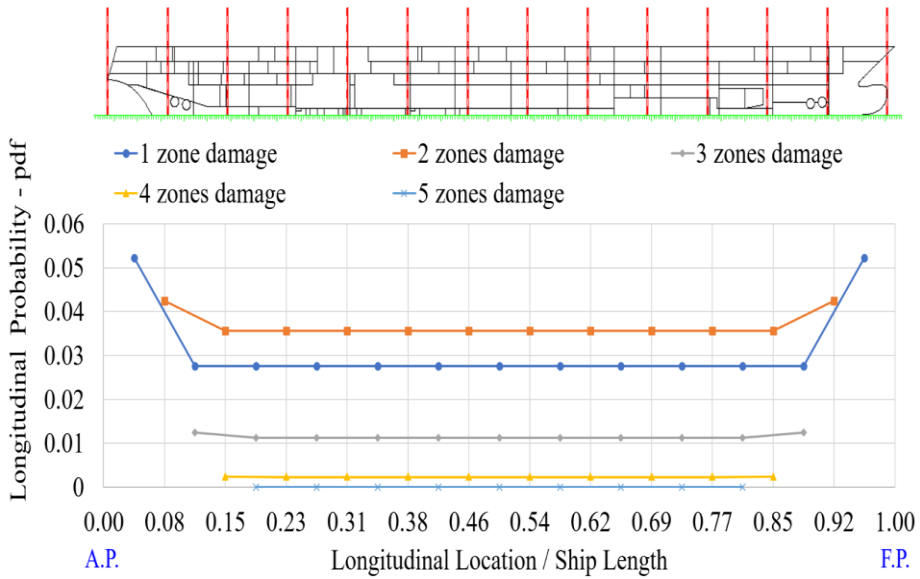


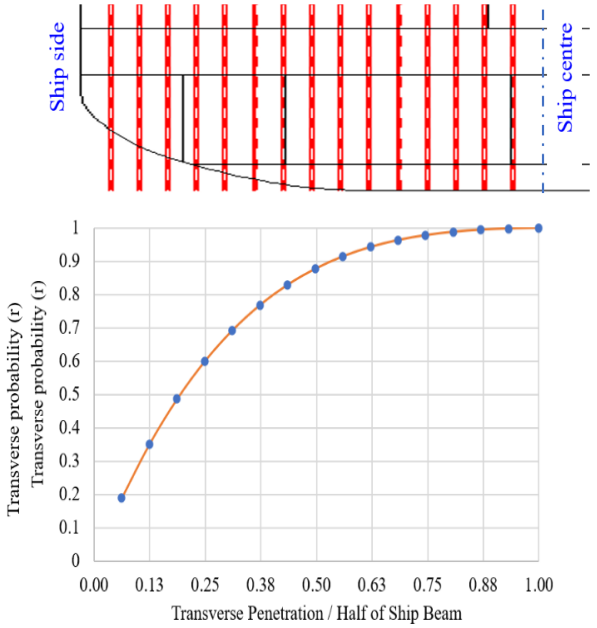
1. Problem

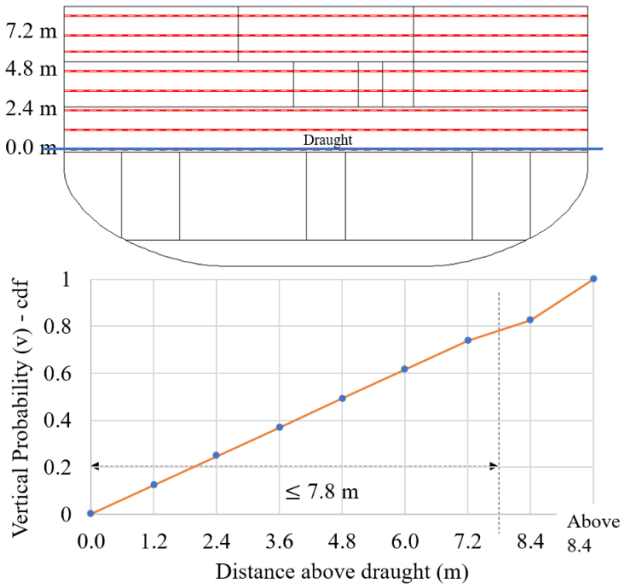
The current SOLAS Damage Stability Criteria : Attained Index ≥ Required Index

$$Attained\ Index = \sum Damage\ Probability\ (p\ factor) \times Survivability\ (s\ factor)$$

Damage Probability (p factor)

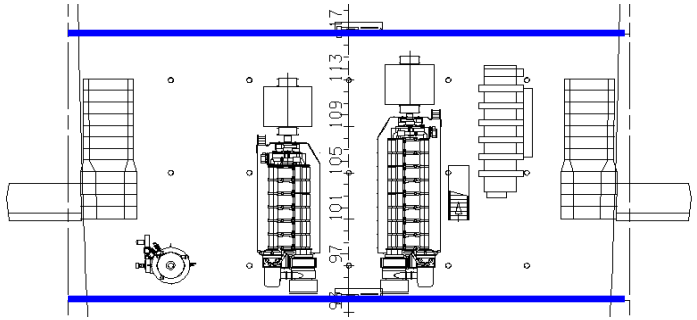




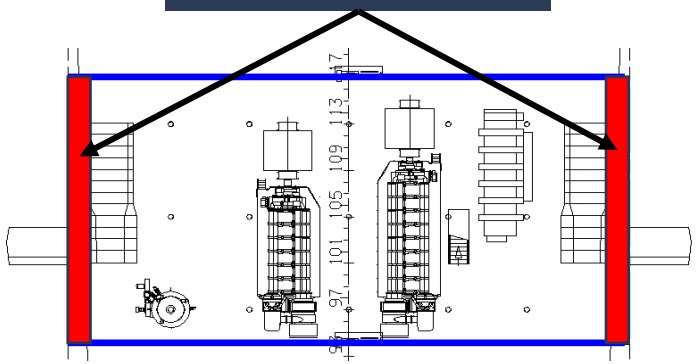


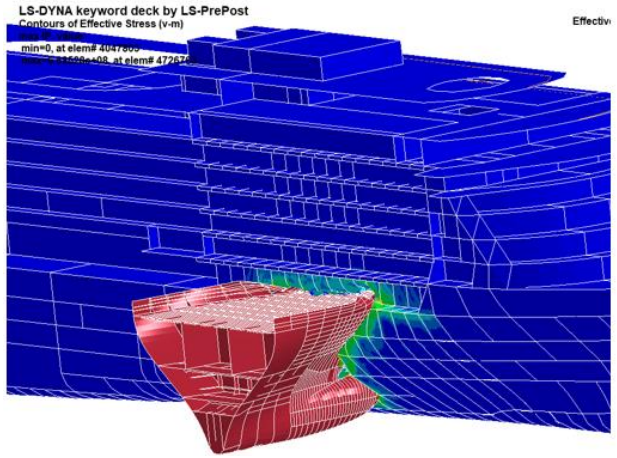
2. Concept

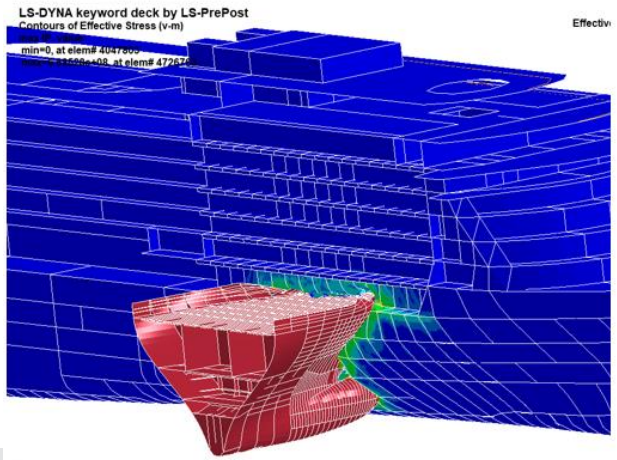
Aims to propose and develop a novel methodology of damage stability evaluation as QRA for new structural designs based on crashworthiness analysis.

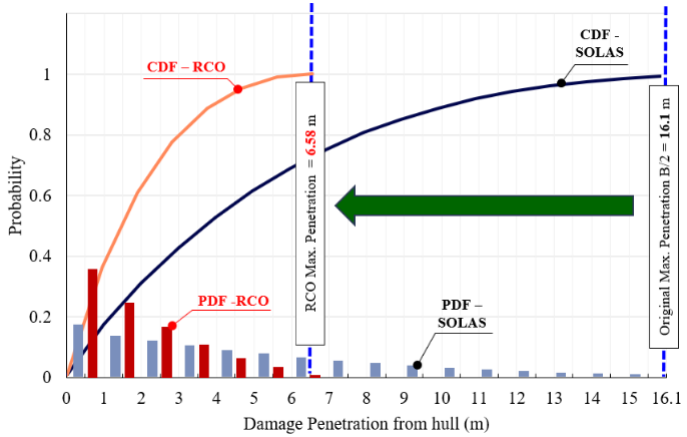


Alternative Designs



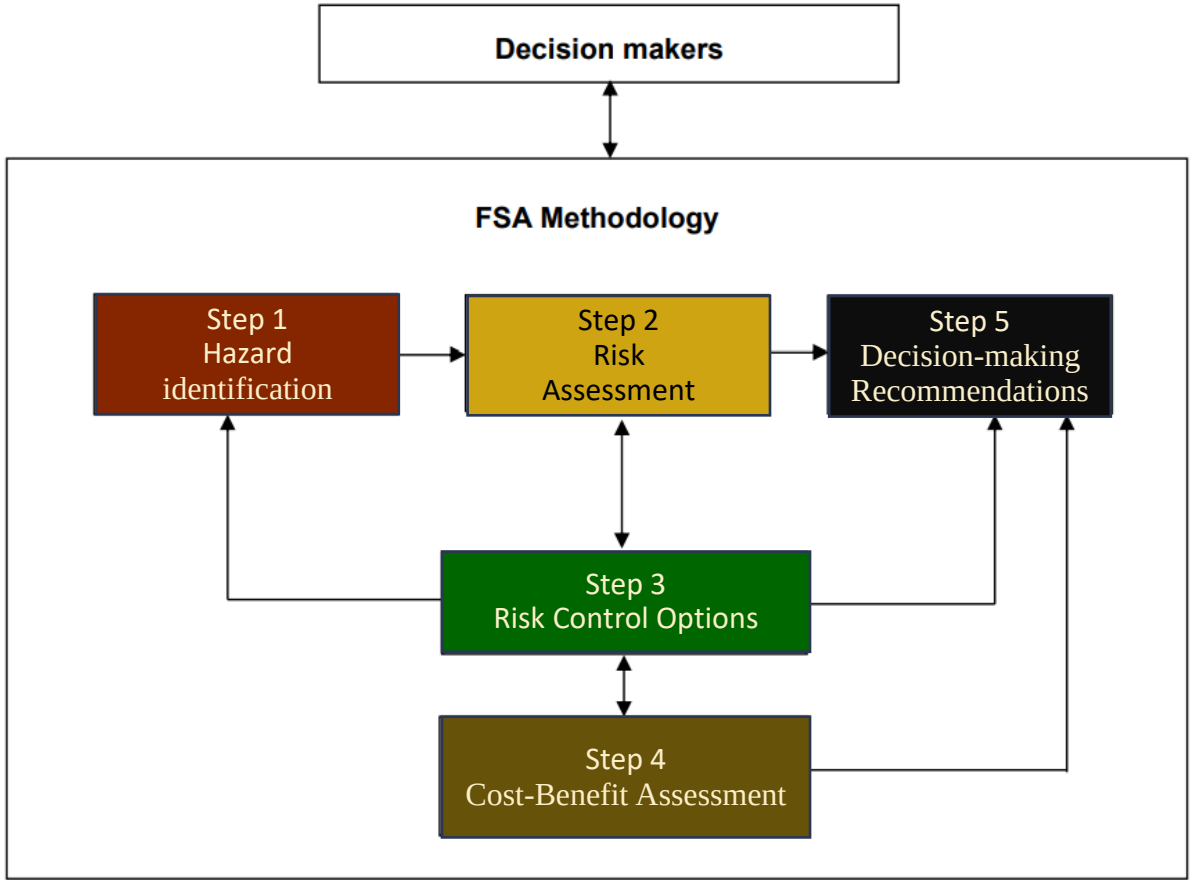




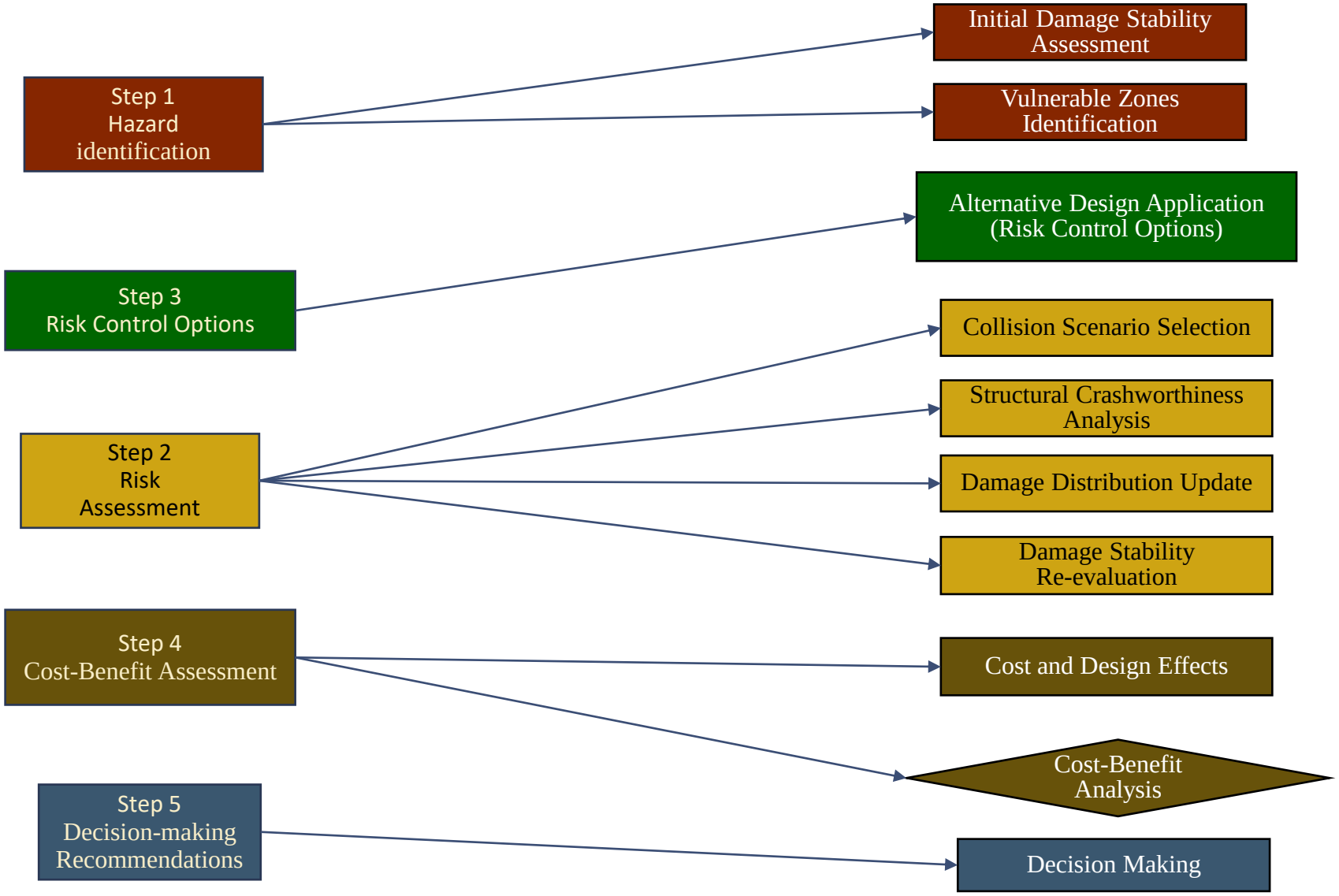


3 Methodology

Referring to Formal Safety Assessment (FSA) Procedure,
the proposed methodology focus on the ship in question using quantitative risk assessment with more detailed steps.



3. Methodology



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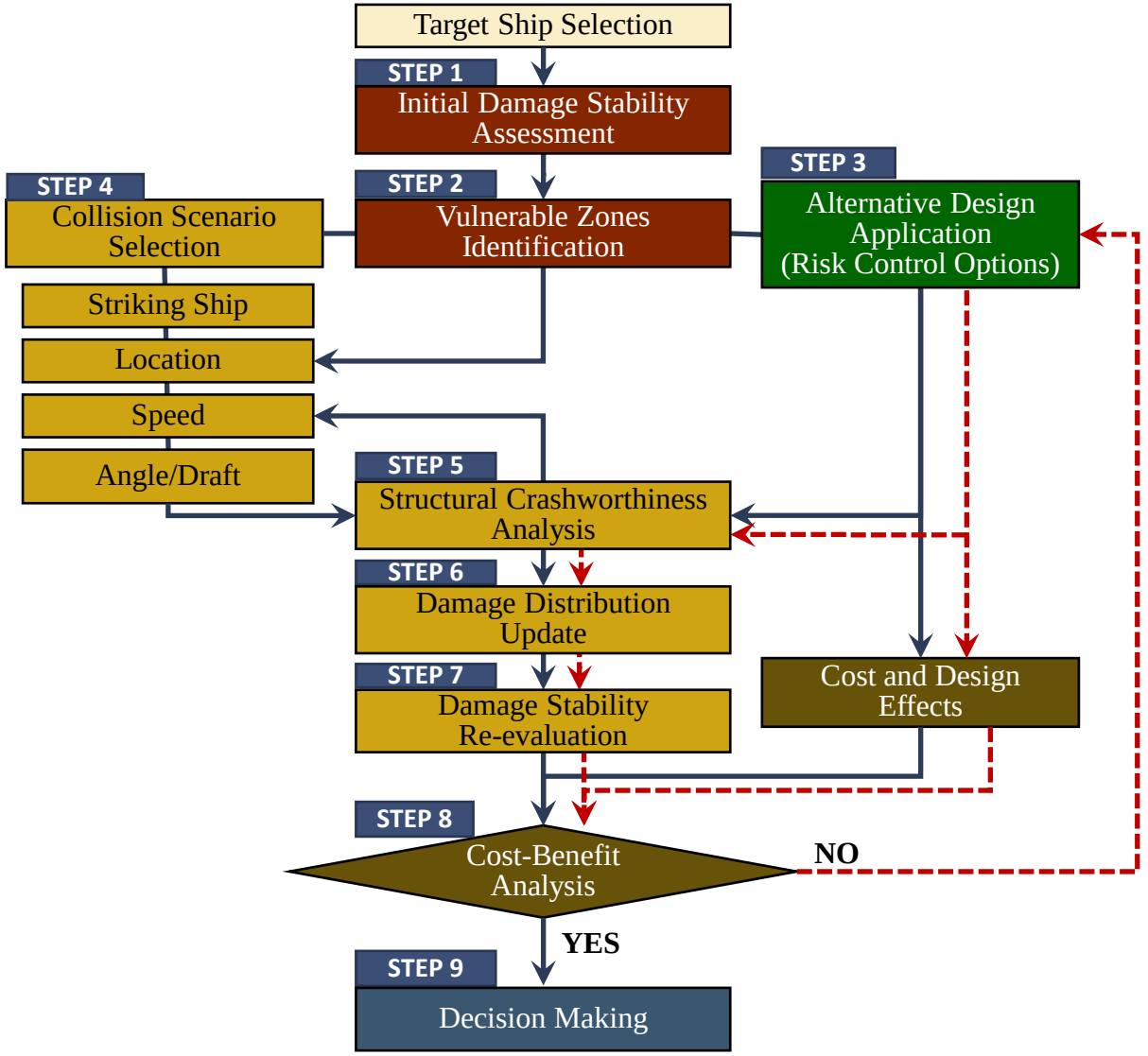

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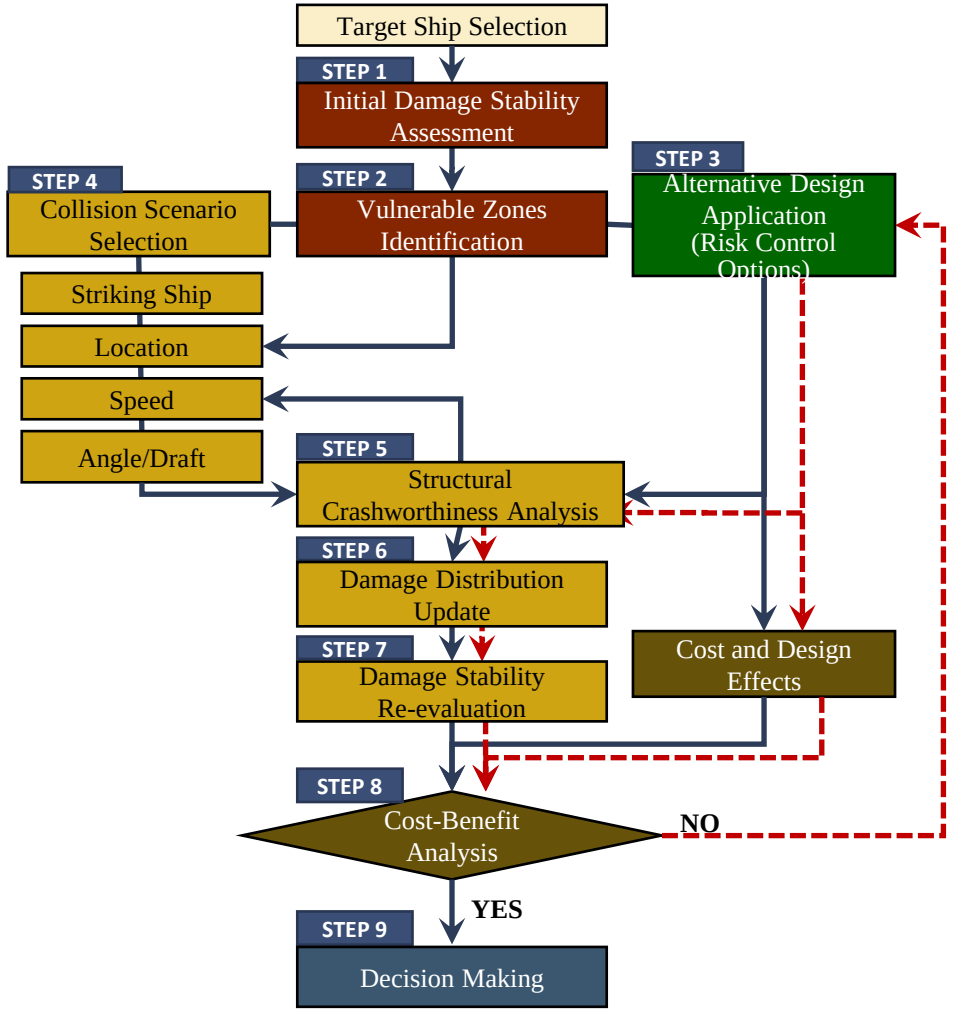

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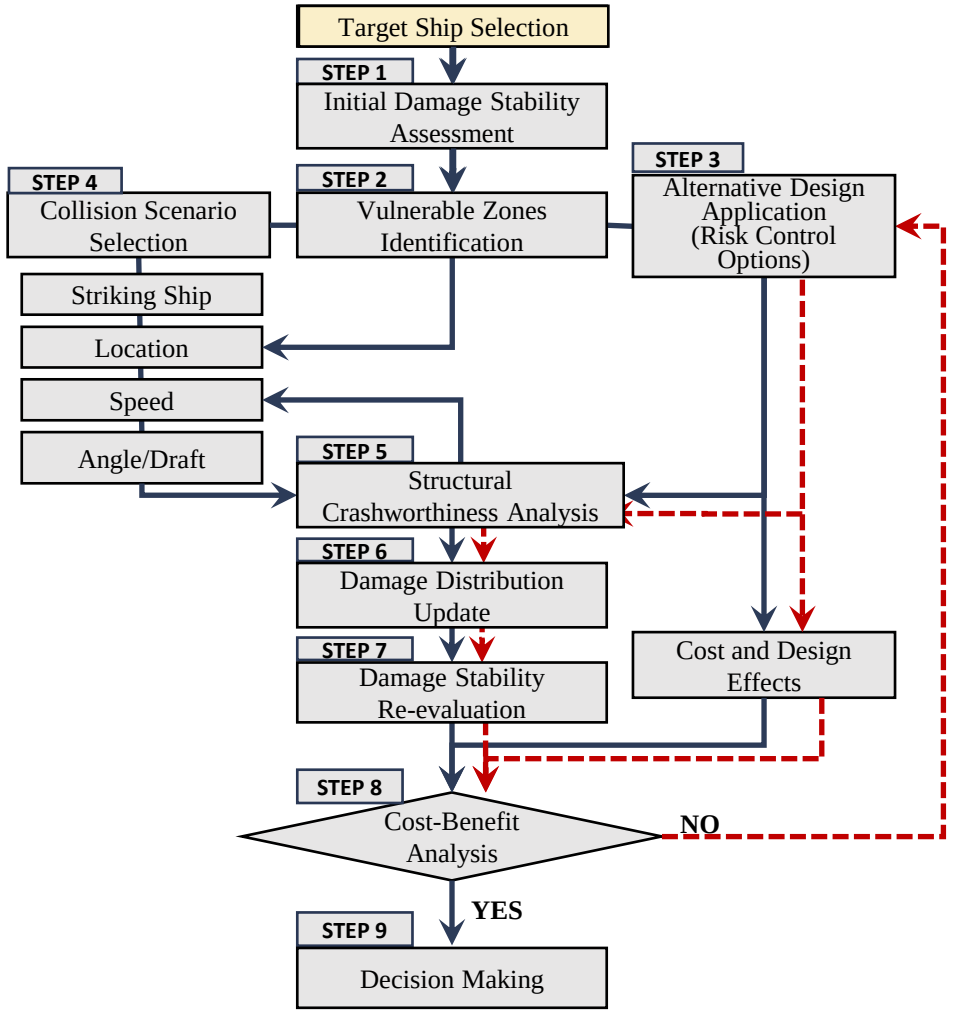
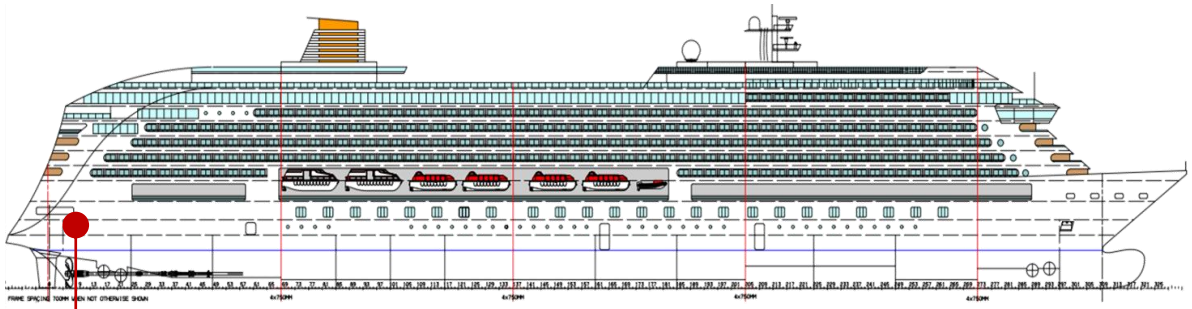
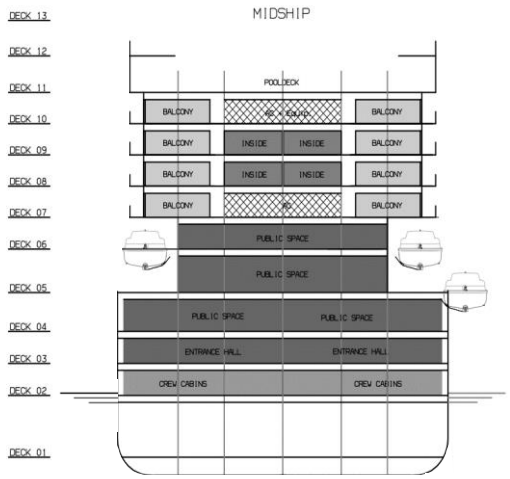


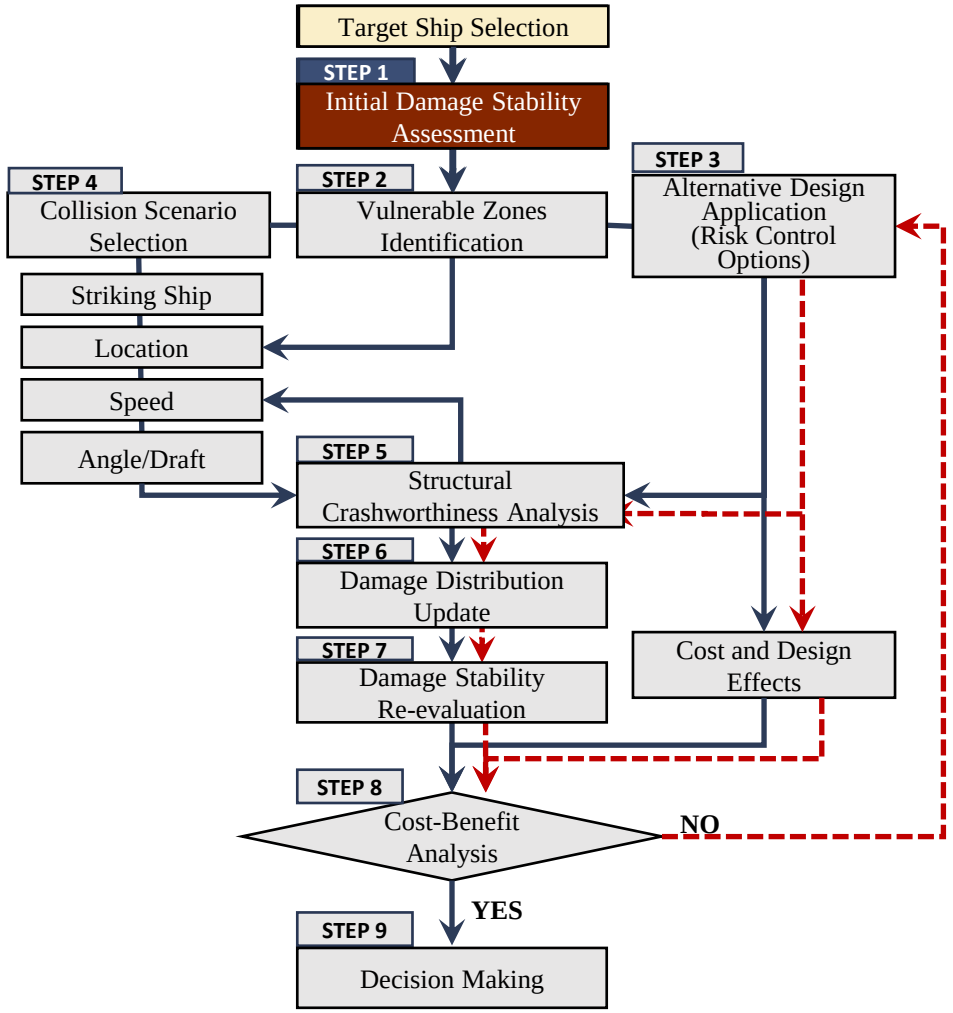


Struck Ship

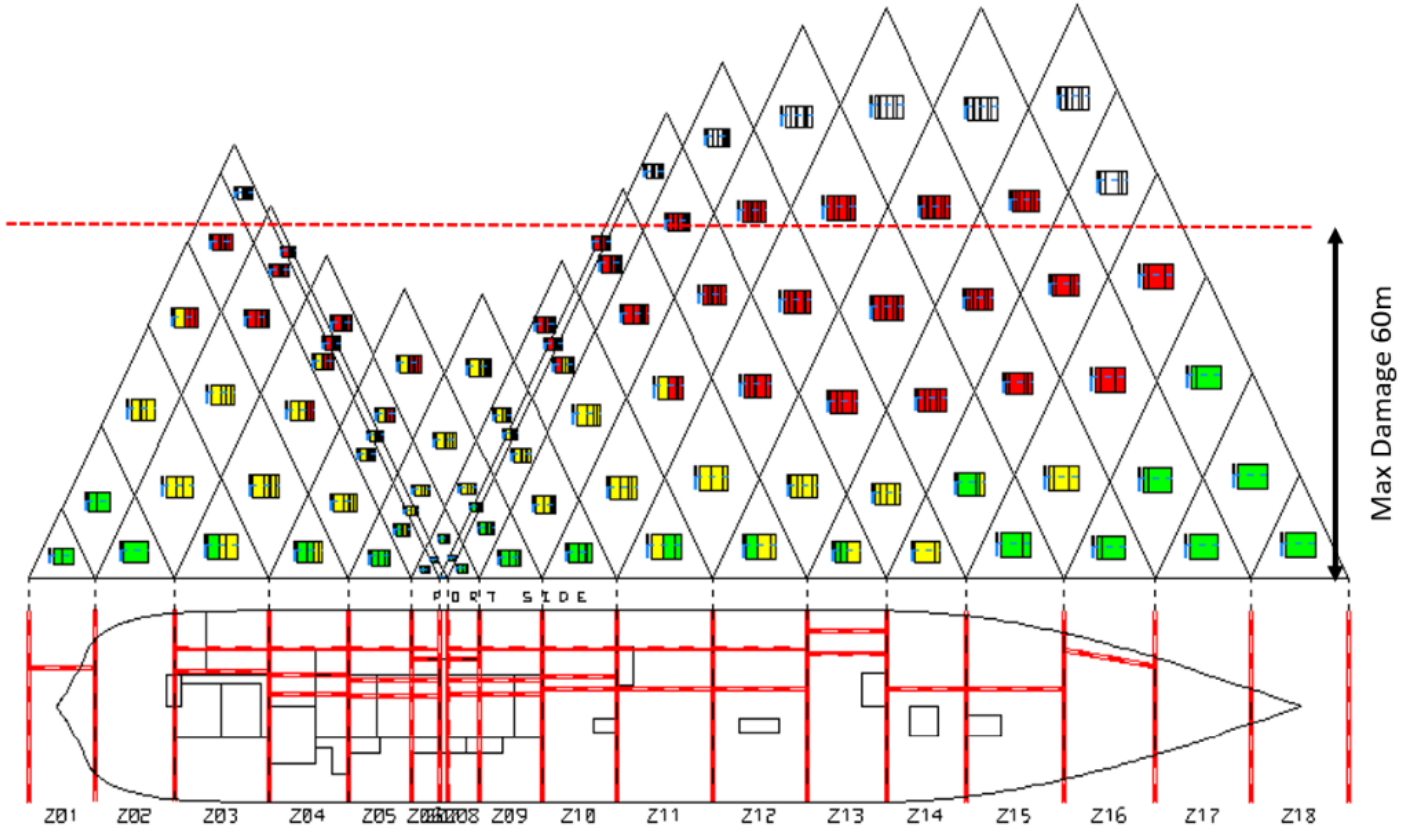
- 63,000GT Cruise Ship
- L/B/T : 216.8 / 32.2 / 7.2 m
- Displacement : 35,367 tonne
- Persons on board : 2,400



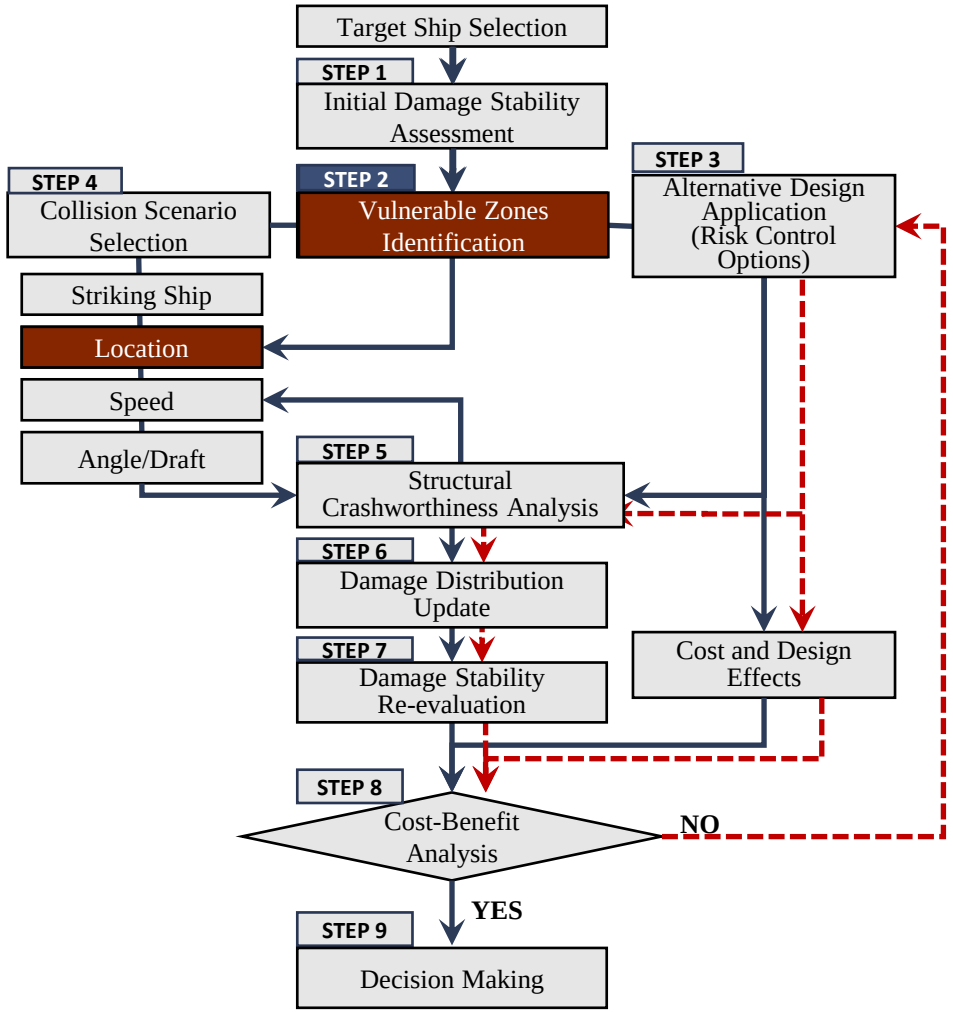
3. Methodology : STEP 1



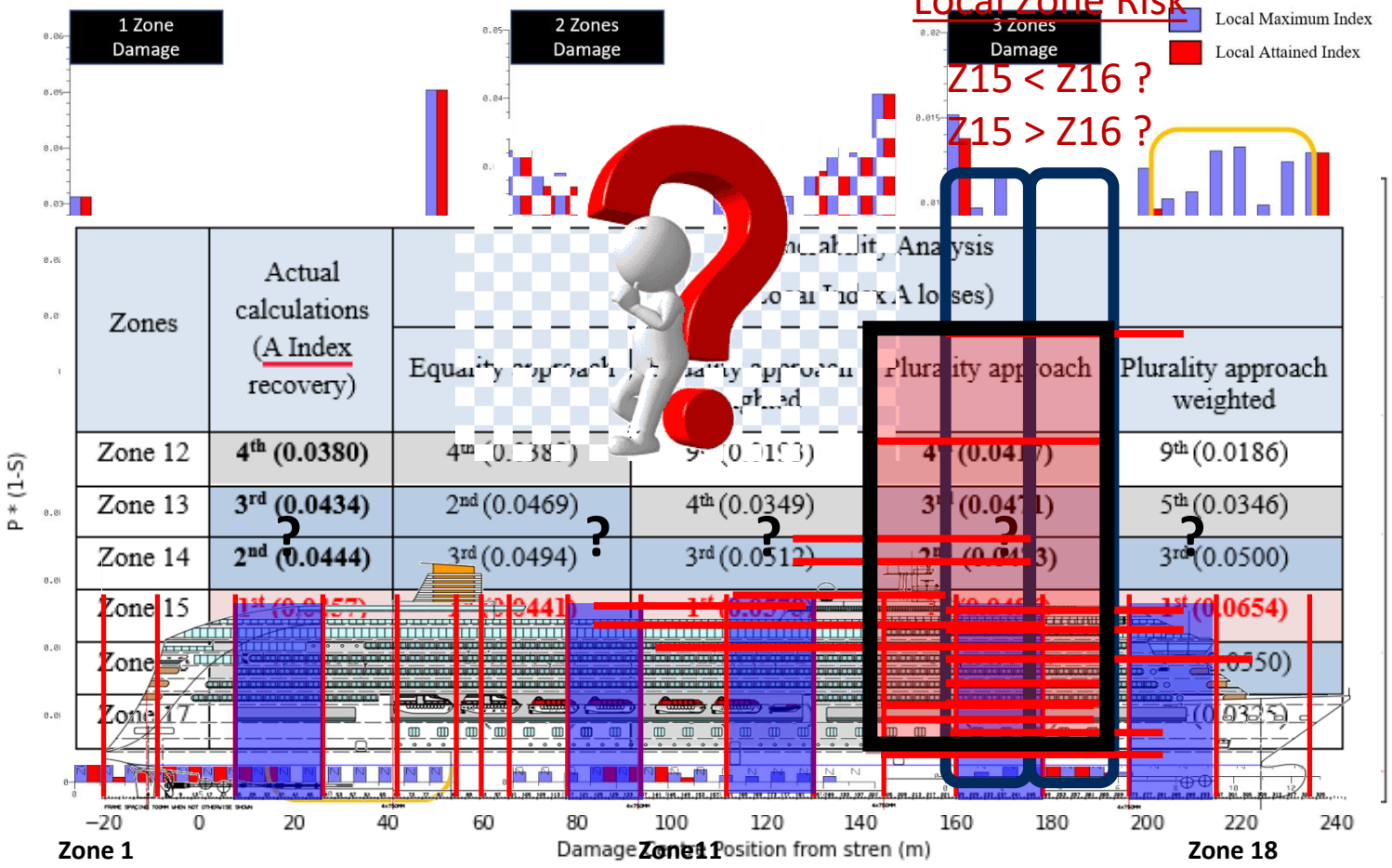
Initial Damage Stability Calculation based on the current SOLAS2020 for a target vessel for the current risk status



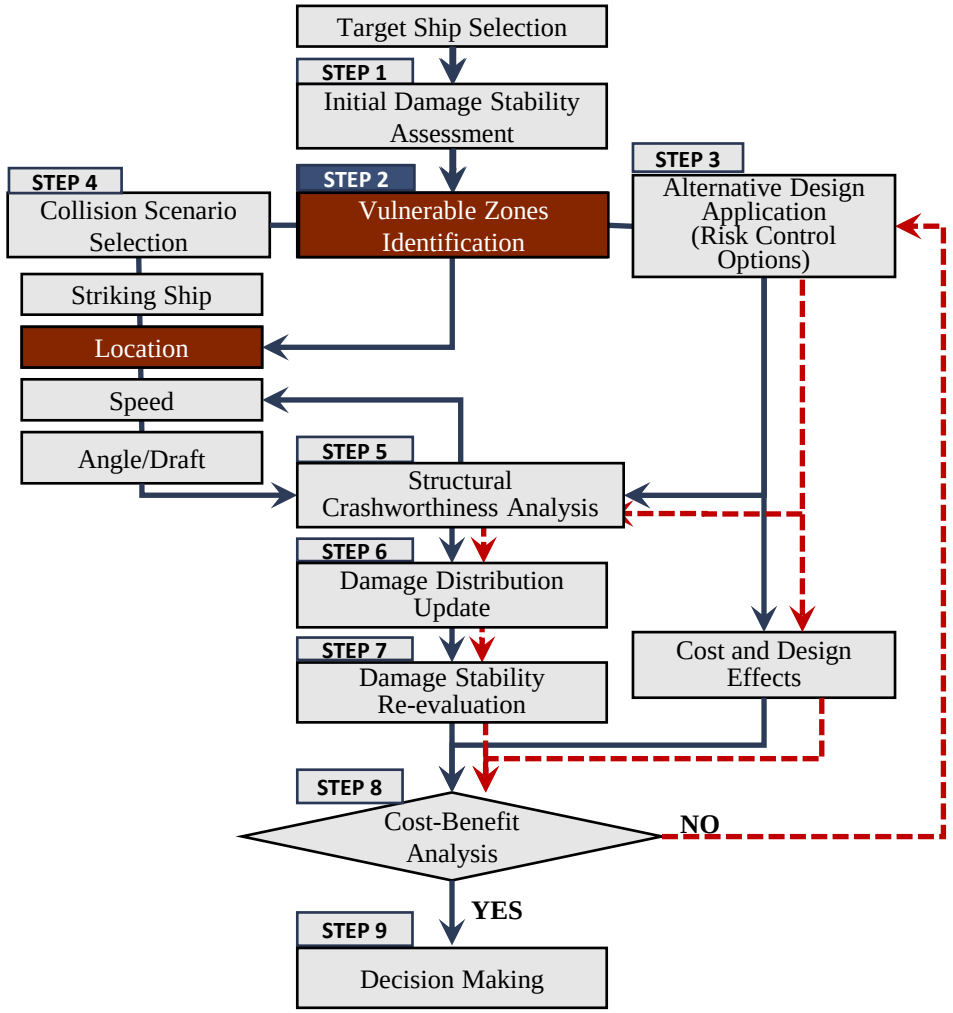
3. Methodology : STEP 2

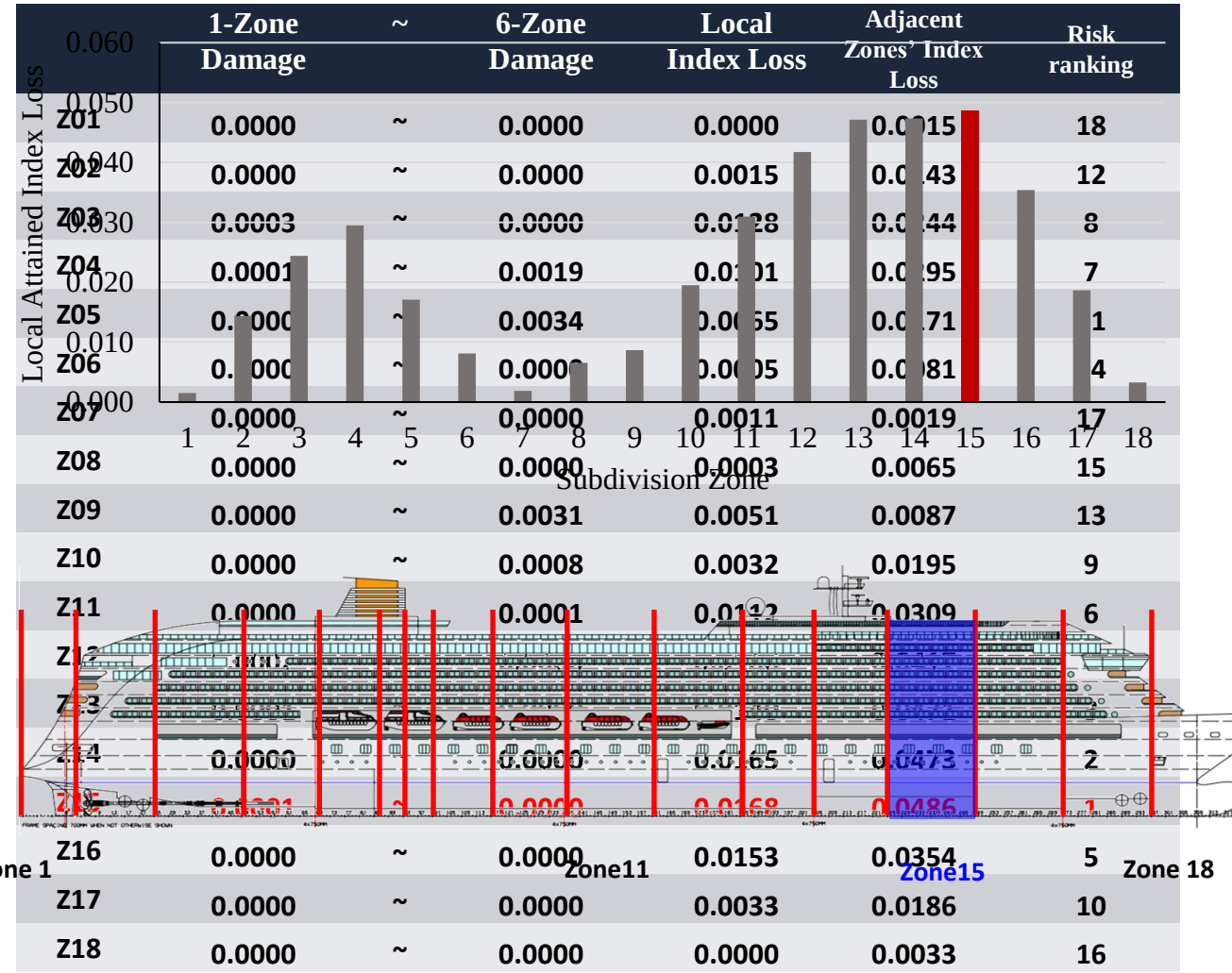


Vulnerability Analysis for the determination of target areas

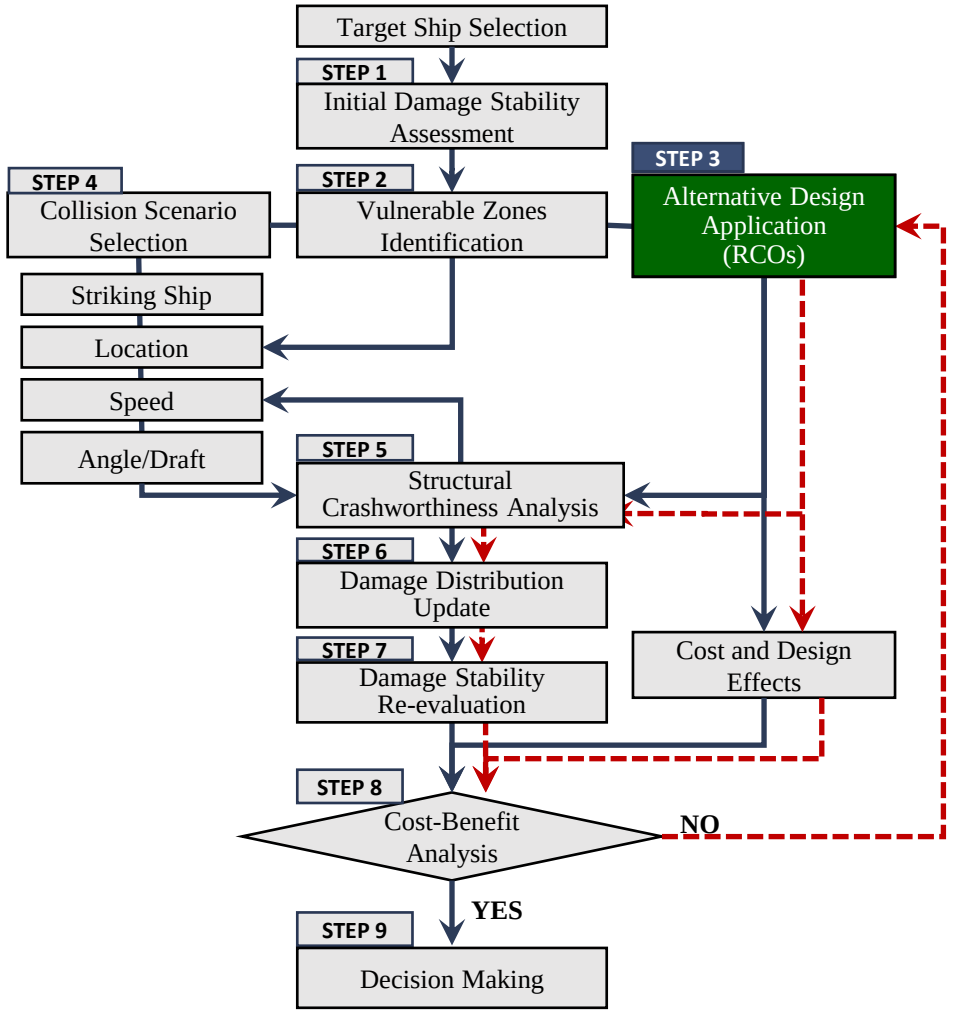


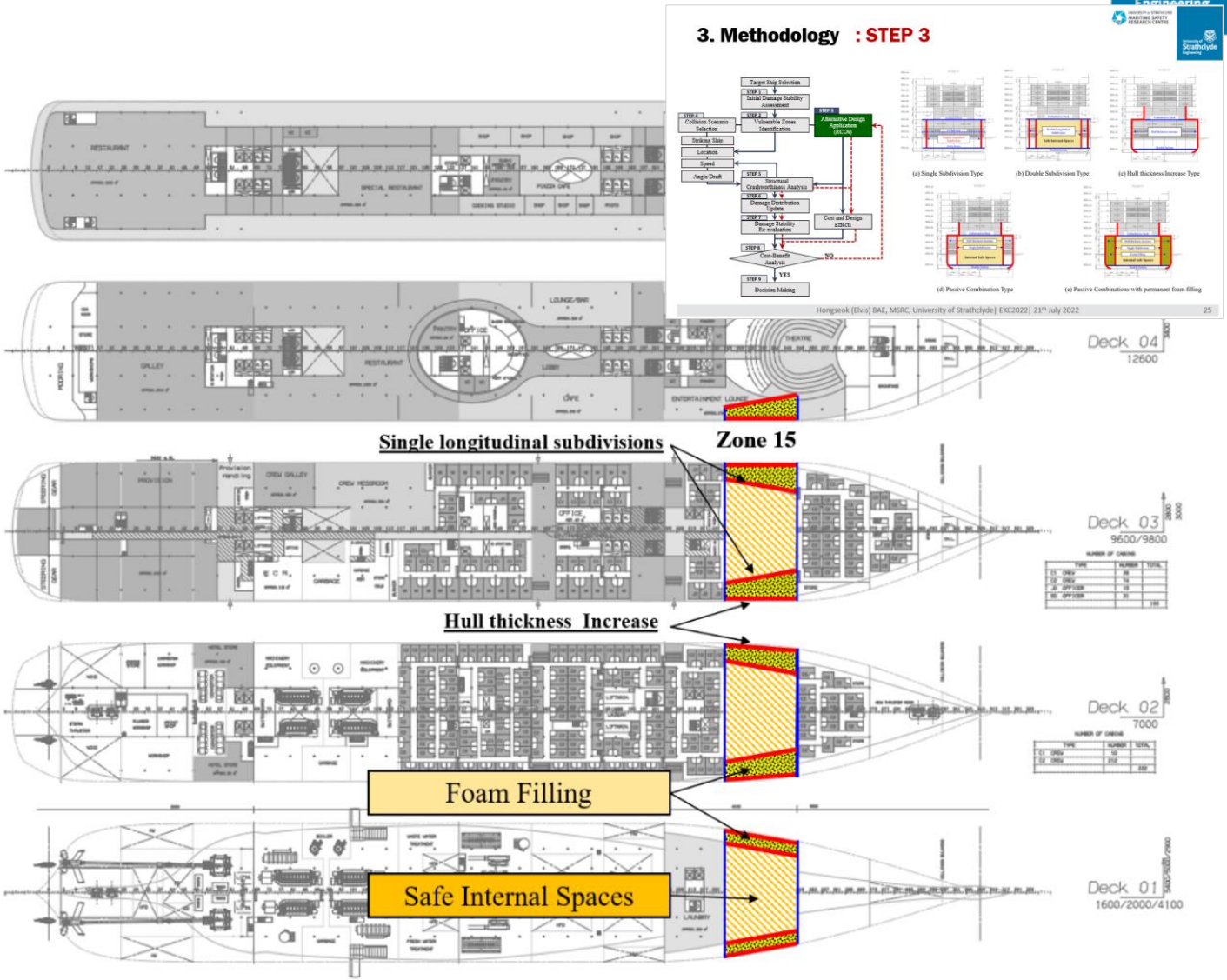
3. Methodology : STEP 2



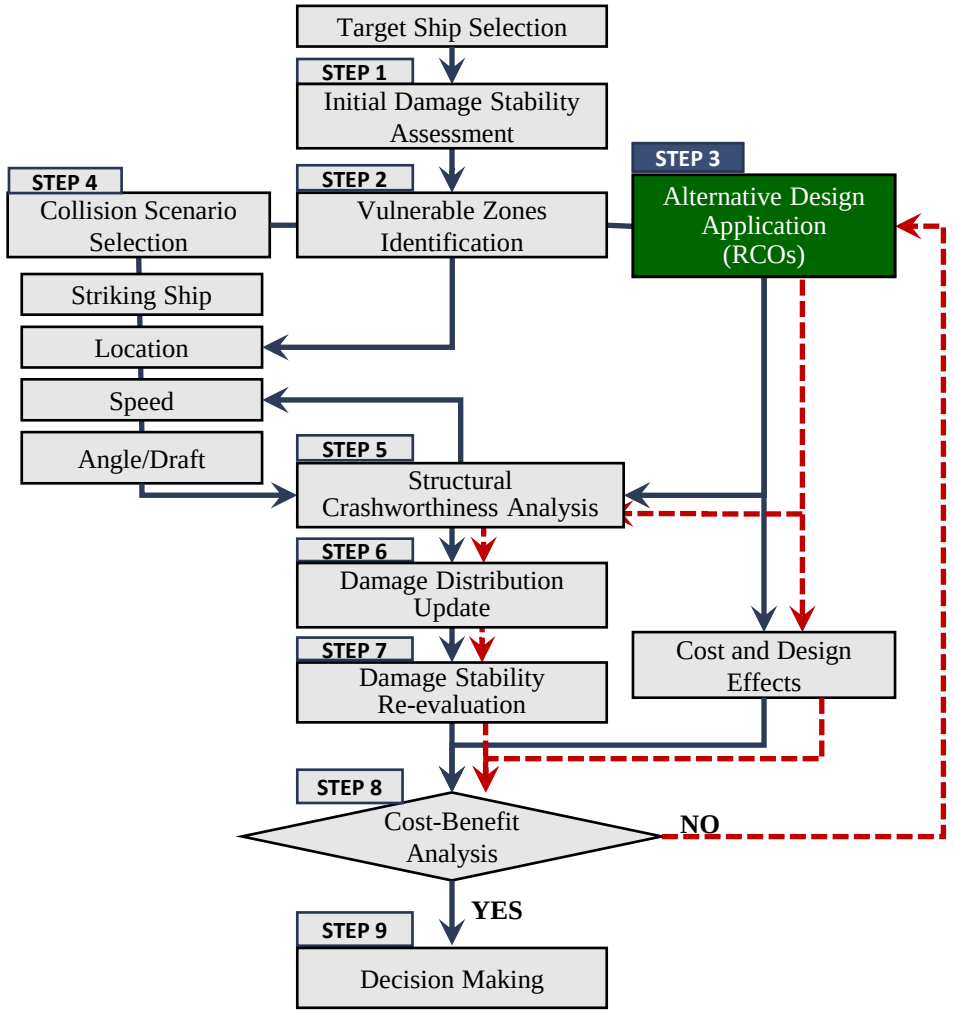


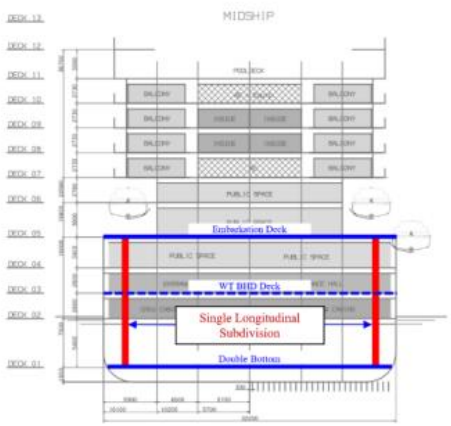
3. Methodology : STEP 3



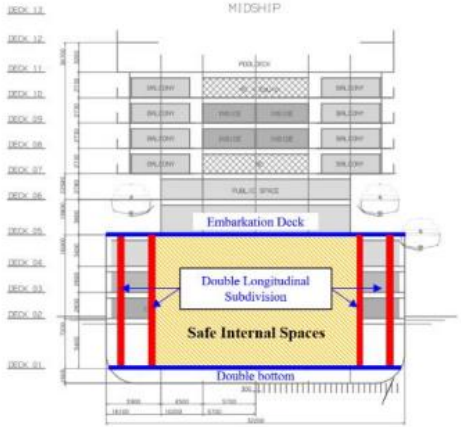


3. Methodology : STEP 3

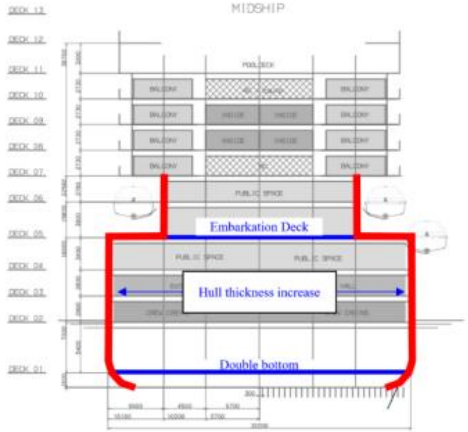




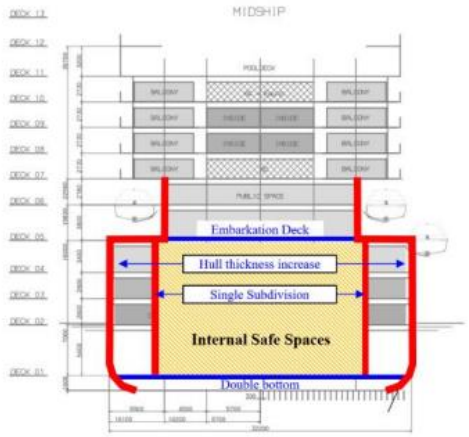
(a) Single Subdivision Type



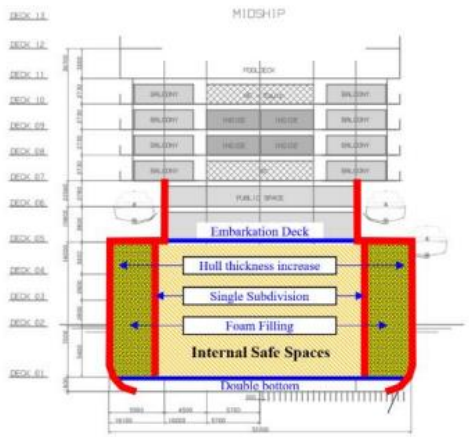
(b) Double Subdivision Type



(c) Hull thickness Increase Type



(d) Passive Combination Type



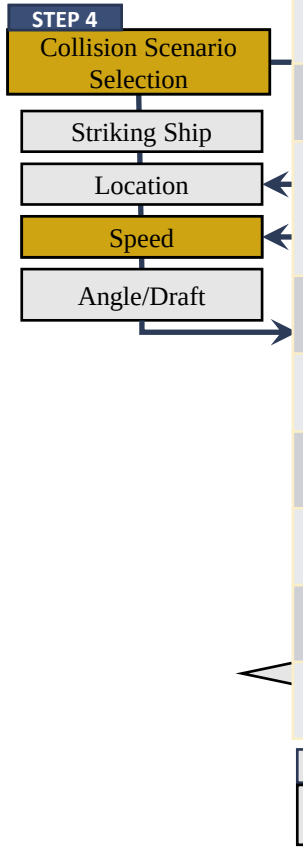
(e) Passive Combinations with permanent foam filling

3. Methodology : STEP 4

For large scale ship collision simulations,

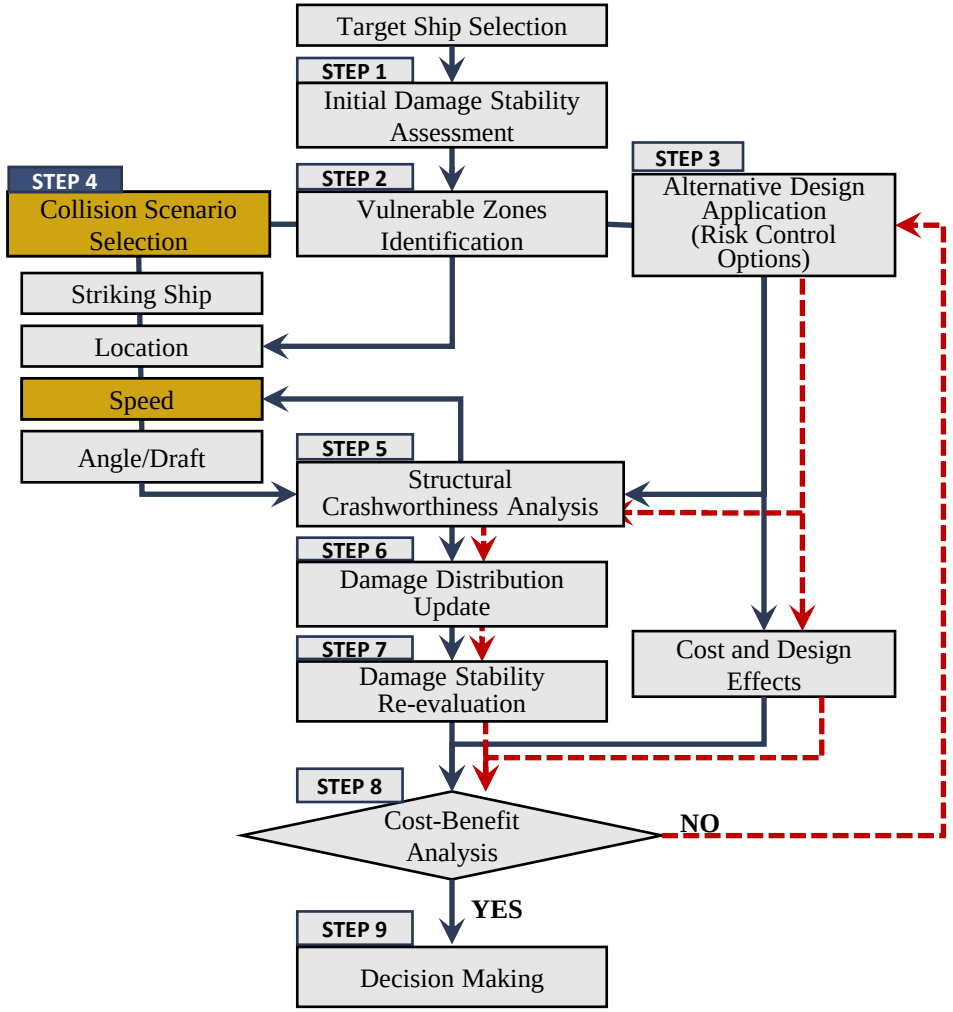
Relative Collision speed resulting in B/2 penetration from pre-

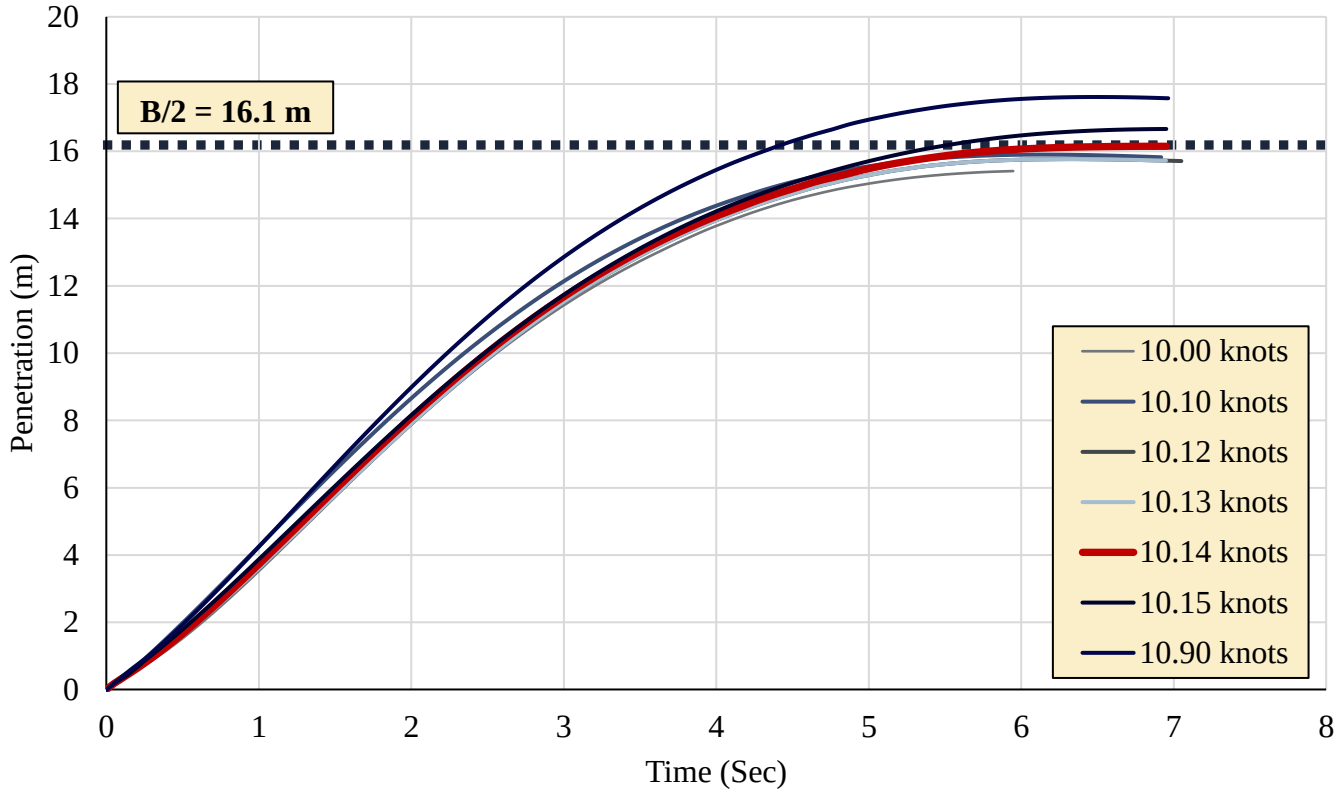
Author	Collision Speed	Struck ship	Striking ship
Zhang et al. (2004)	**10 m/s (19.44 knots)**	90m cargo ship	tanker bow shape
Zheng et al. (2007)	**7, 14 and 18 knots**	Aframax tanker	Aframax tanker
Ehlers et al. (2008)	**10 m/s (19.44 knots)**	Crashworthy structure	Bow shape indenter
Ehlers et al. (2009)	**10 m/s (19.44 knots)**	180m tanker	Cone-shaped bulbous bow
Schreuder et al. (2011)	**2 ~ 10 knots**	179m RoPax	179m RoPax
Hogström/Ringsberg (2012)	**5 and 7 knots**	179m RoPax	179m RoPax
Kõrgesaar et al. (2014)	**10 m/s (19.44 knots)**	310m LNG carrier	
Paik et al. (2017)	**a max. 6.024 knots**	VLCC tanker	Various vessel type
Kim et al. (2021)	**0.5 ~ 9.0 knots**	9,000 TEU container	9,000 TEU container
Kim et al. (2022)	**5 and 10 knots**	65K GT Cruiseship	35K GT Ro-Pax



- **Kinetic energy with 19.44 knots is 15 times larger than 5 knots**
- **Consequences of those simulations are completely different.**

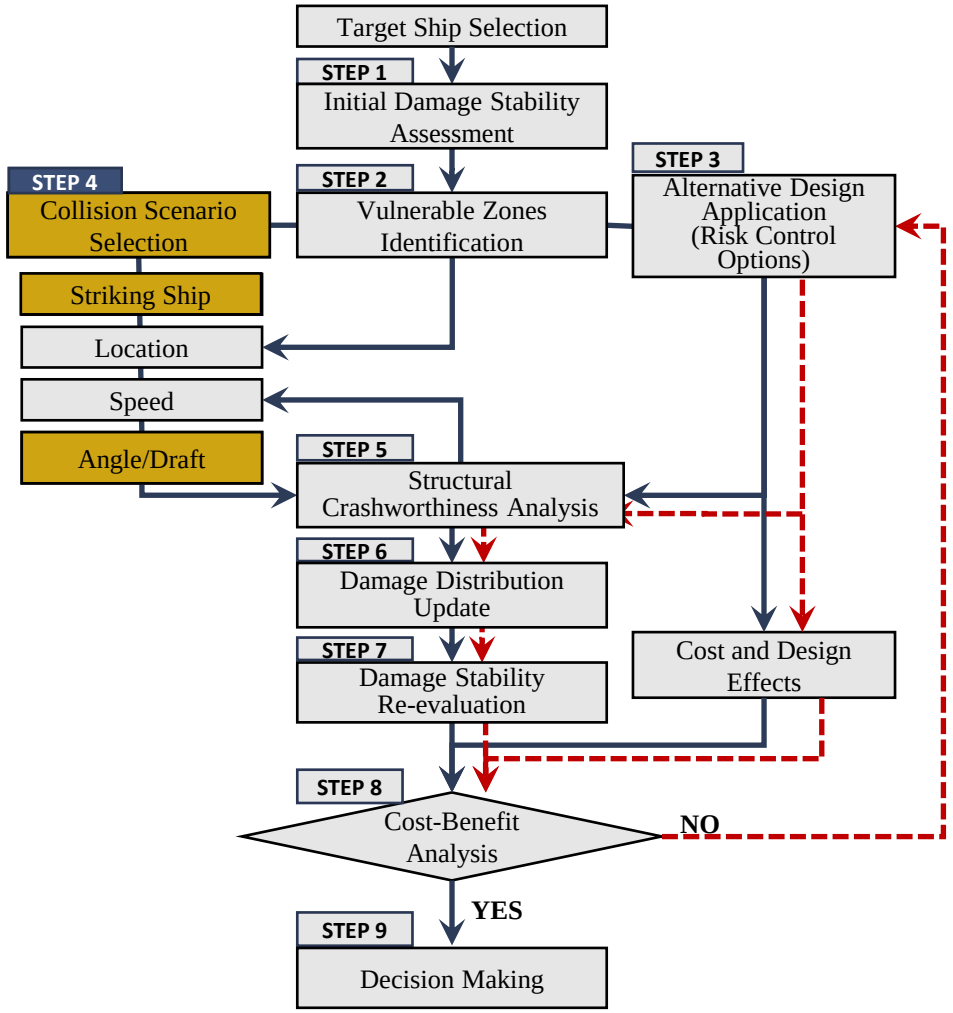
3. Methodology : STEP 4



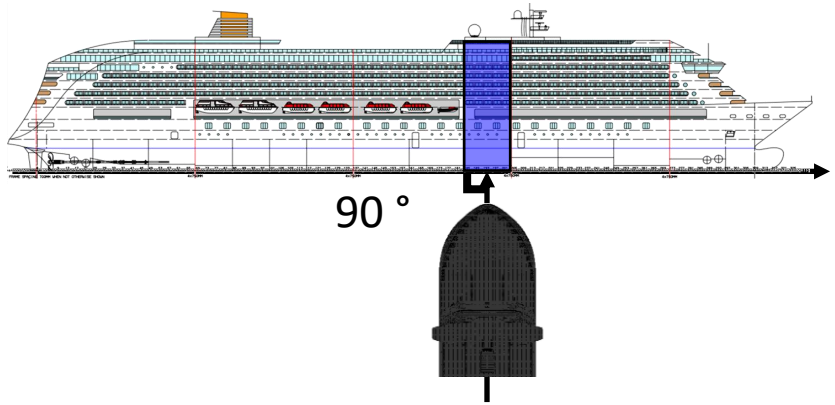


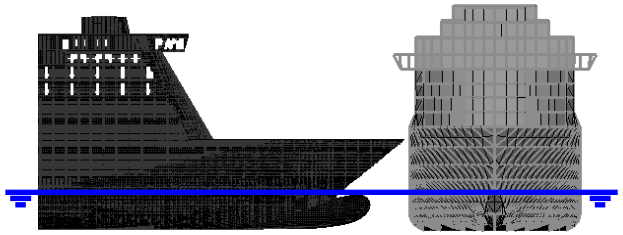
→ **Relative Collision speed : 10.14 knots**

3. Methodology : STEP 4



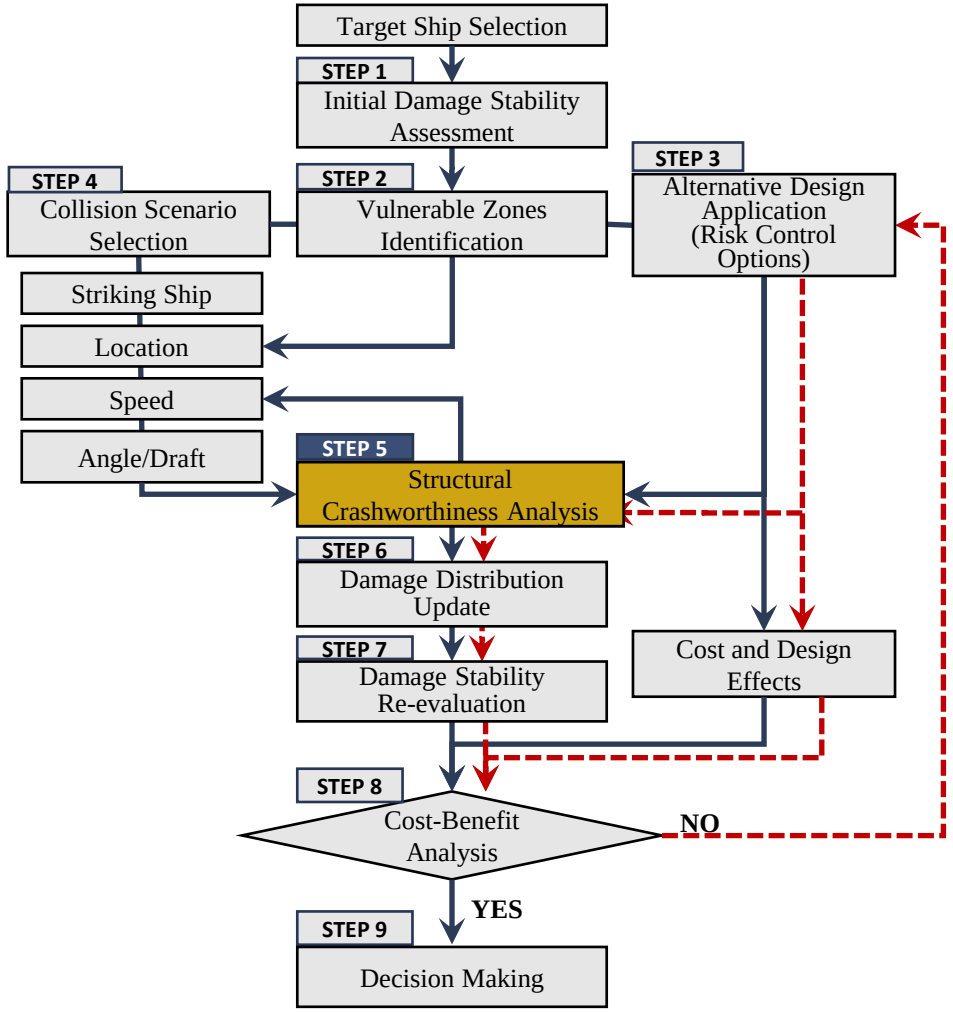
1. **Striking ship** to be selected based on the target ship operational area and to be discussed with the Administration
2. Collision angle and draft to be assumed as **90 degrees collision at a design draft** for conservative results



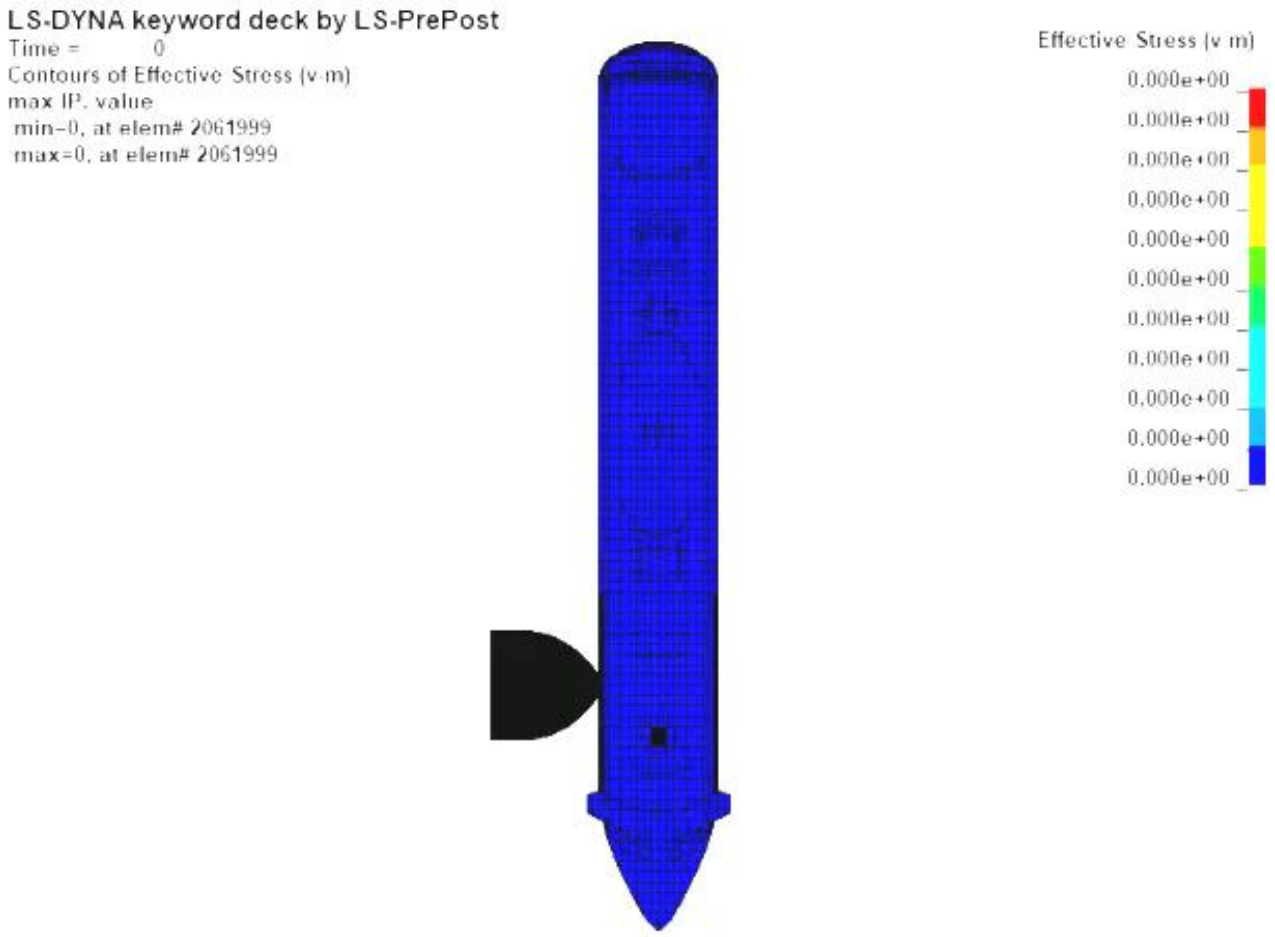


Design Draft

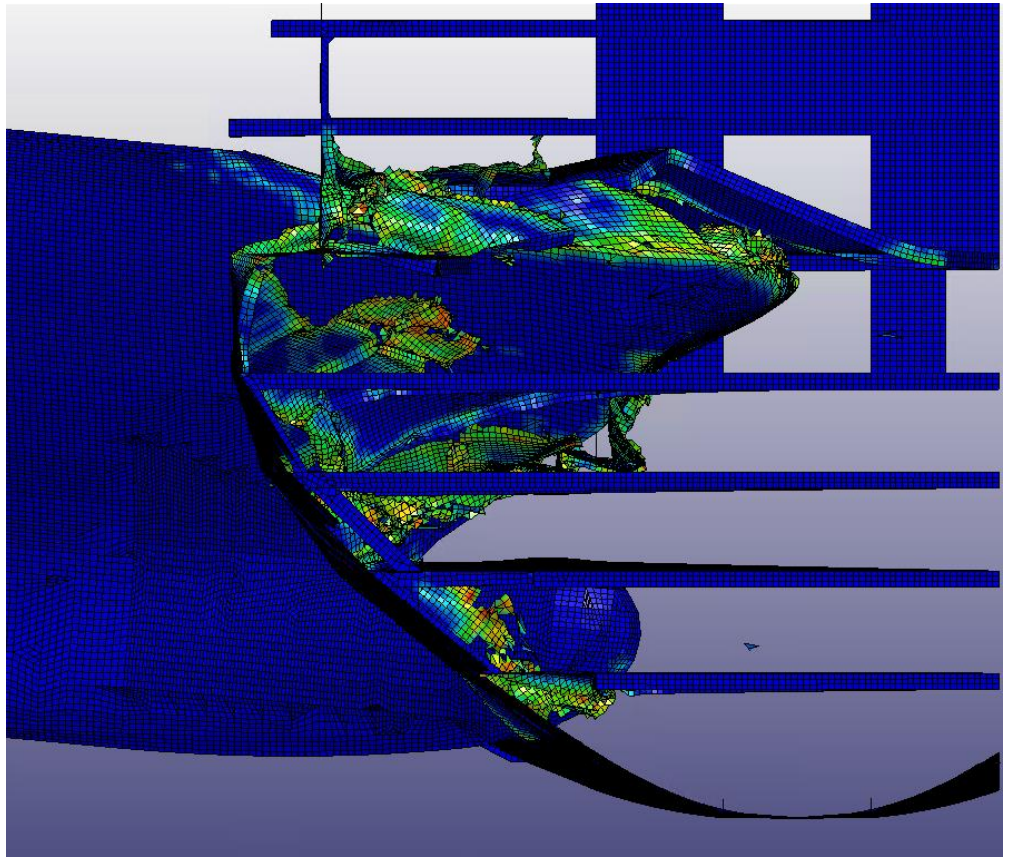
3. Methodology : STEP 5

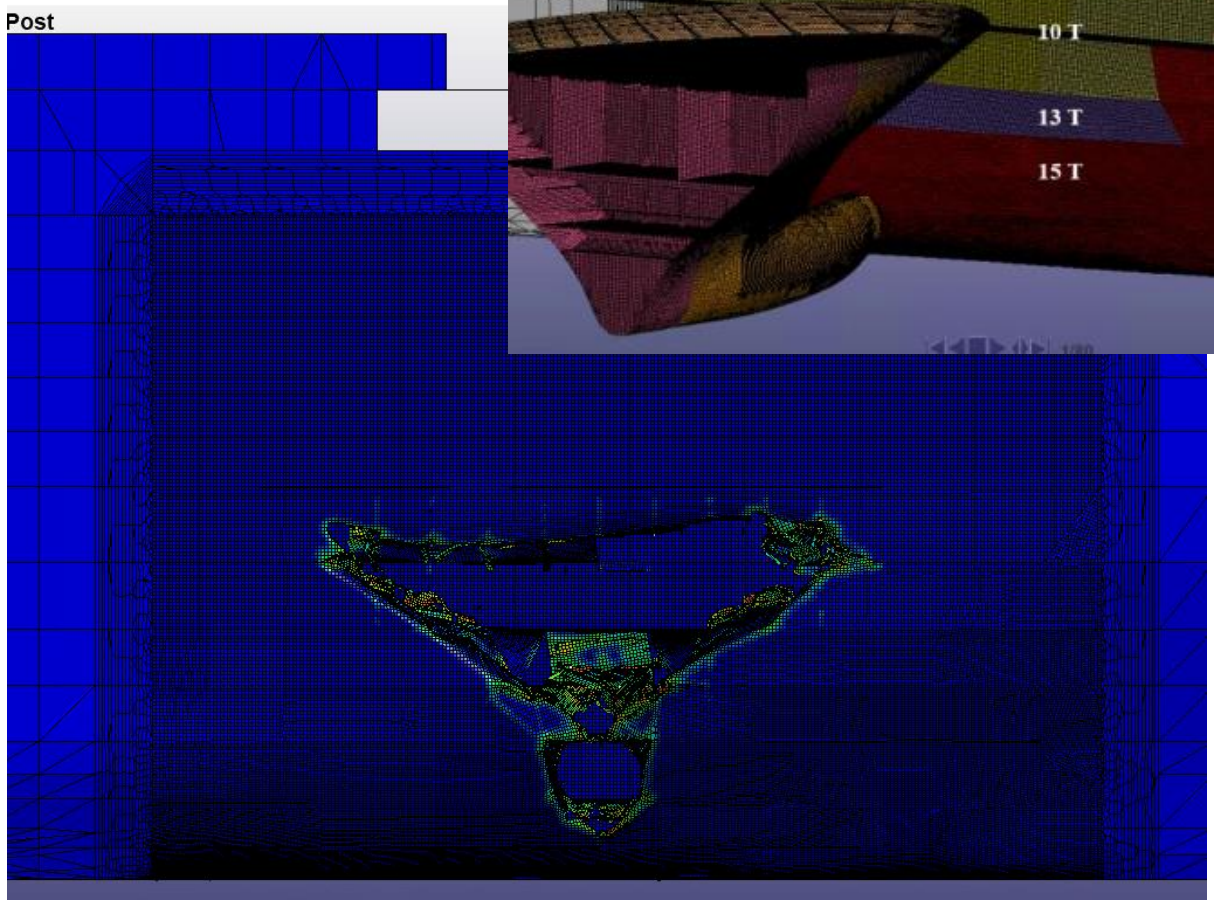


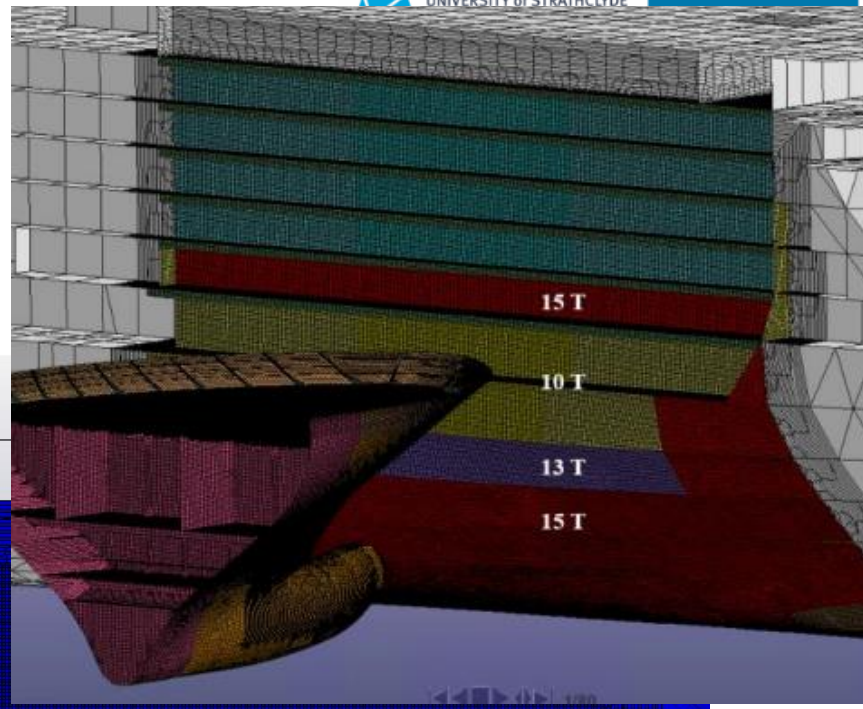
Crash simulations to be carried out using NFEAM



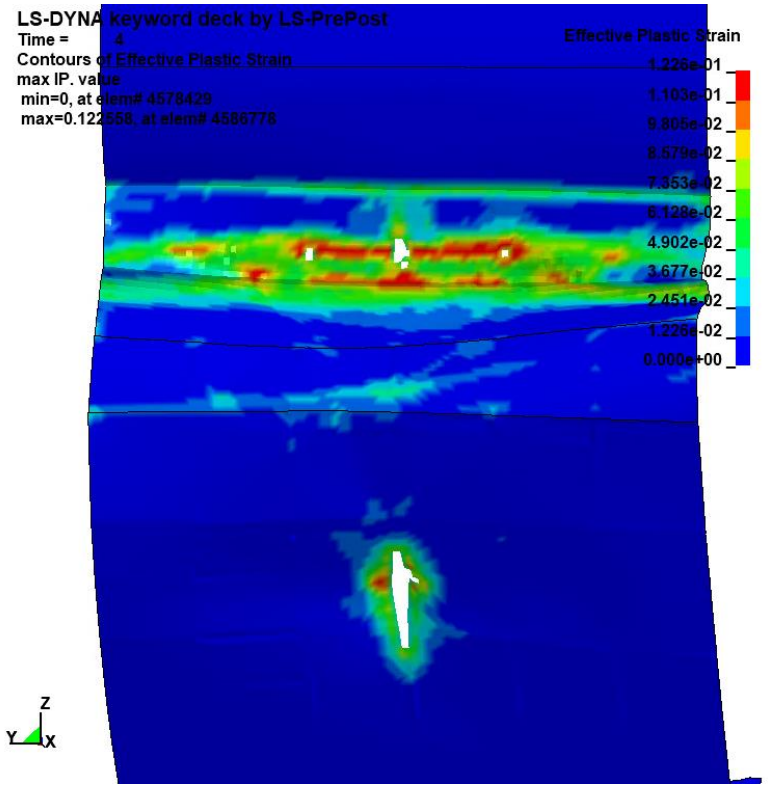
3. Methodology : STEP 5







3. Methodology : STEP 5



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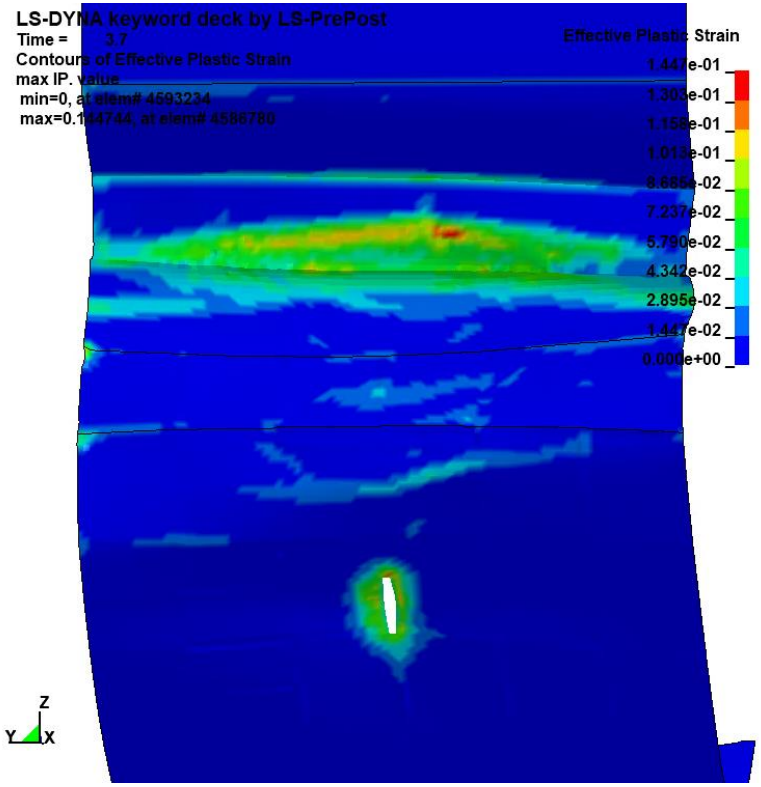

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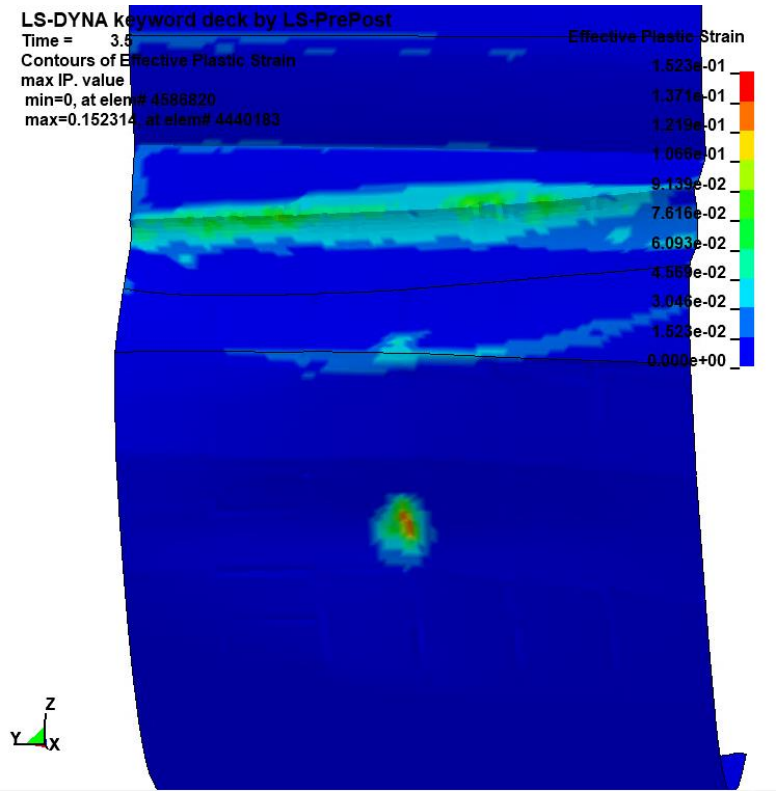
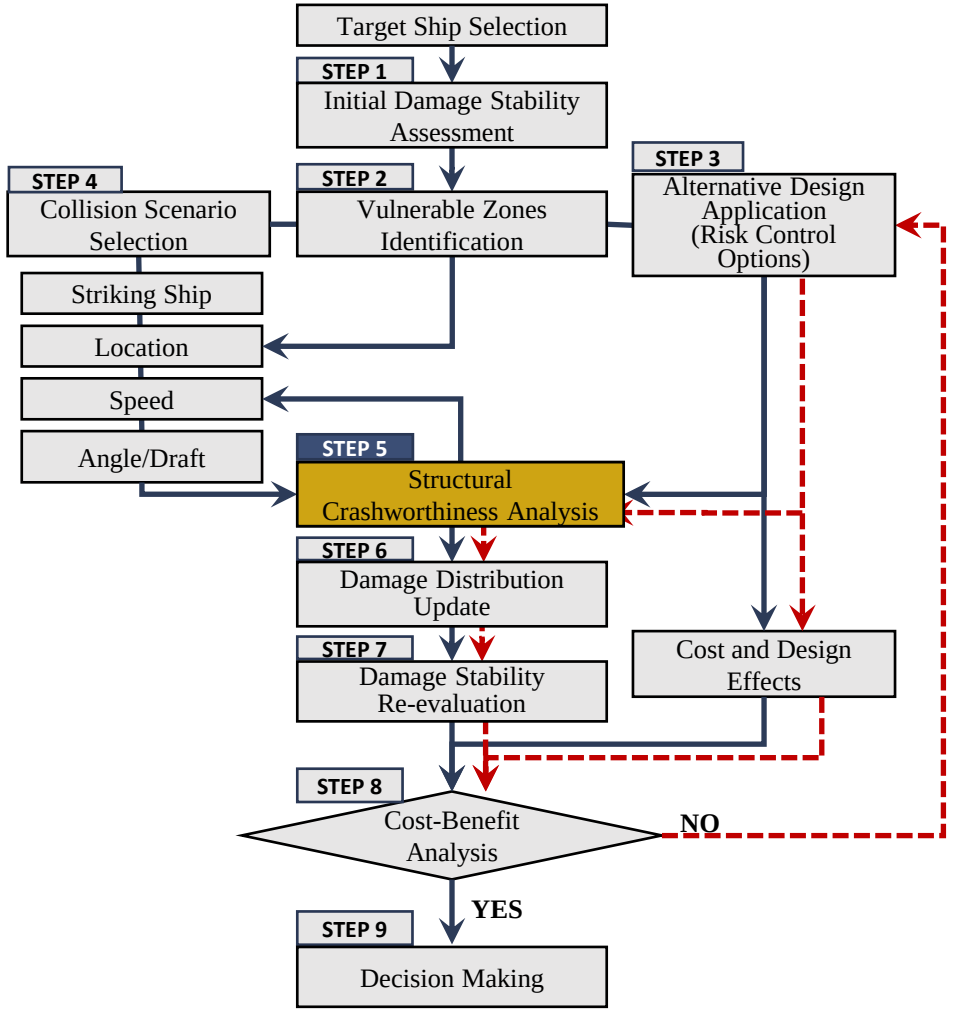
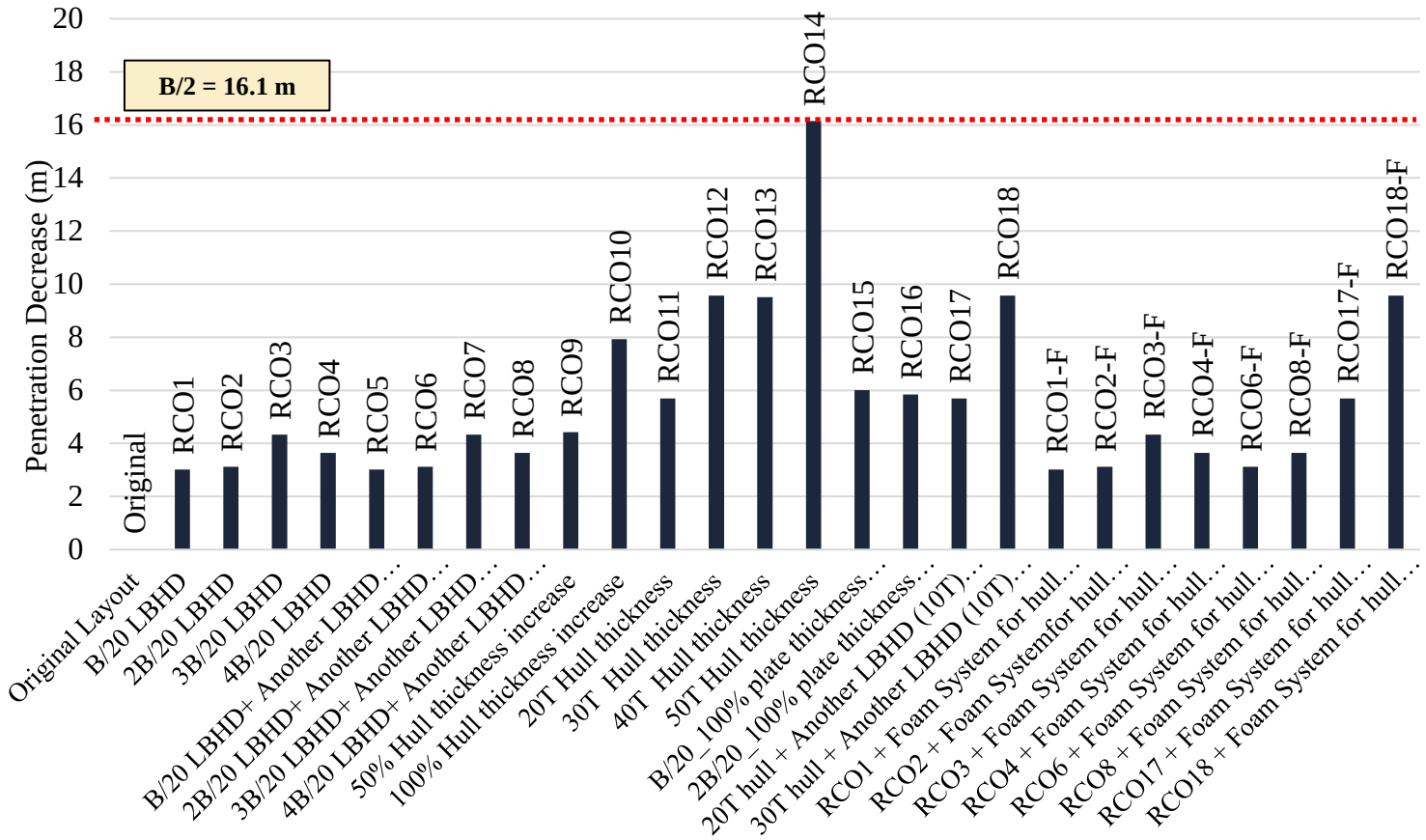


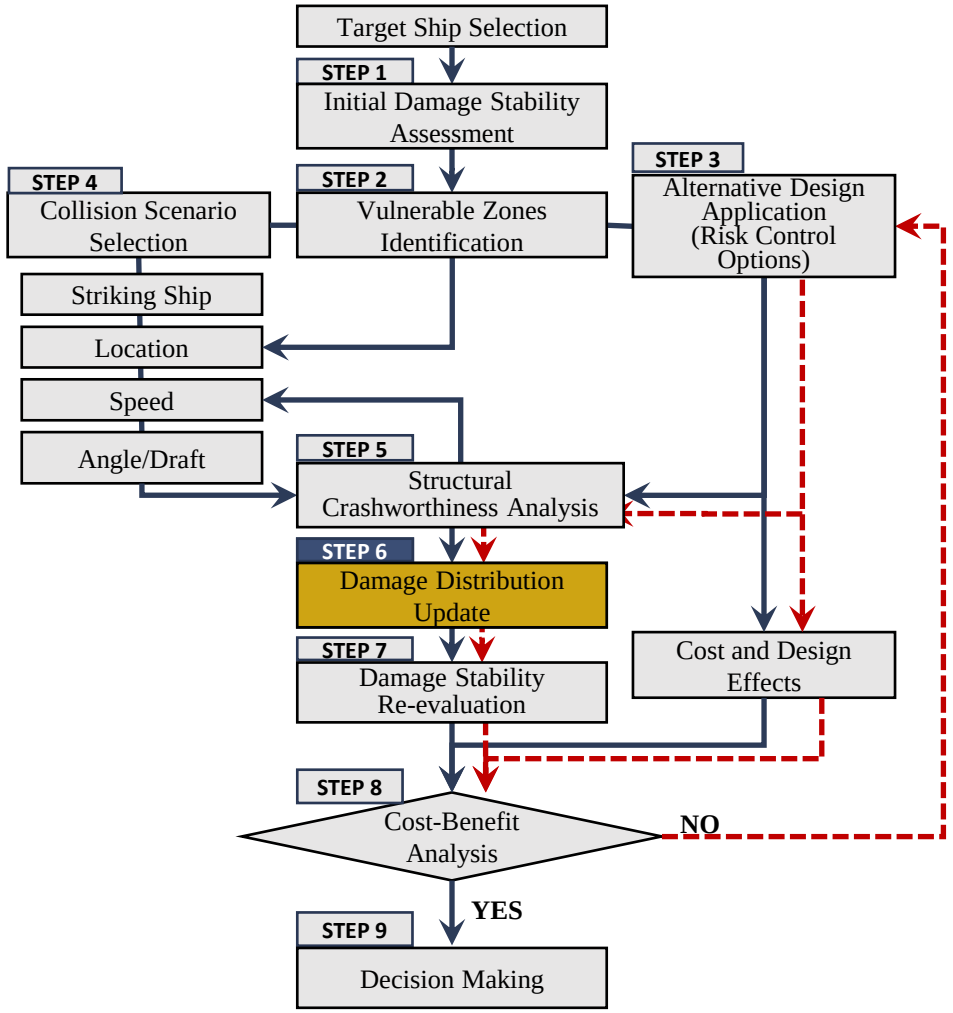
50T

3. Methodology : STEP 6

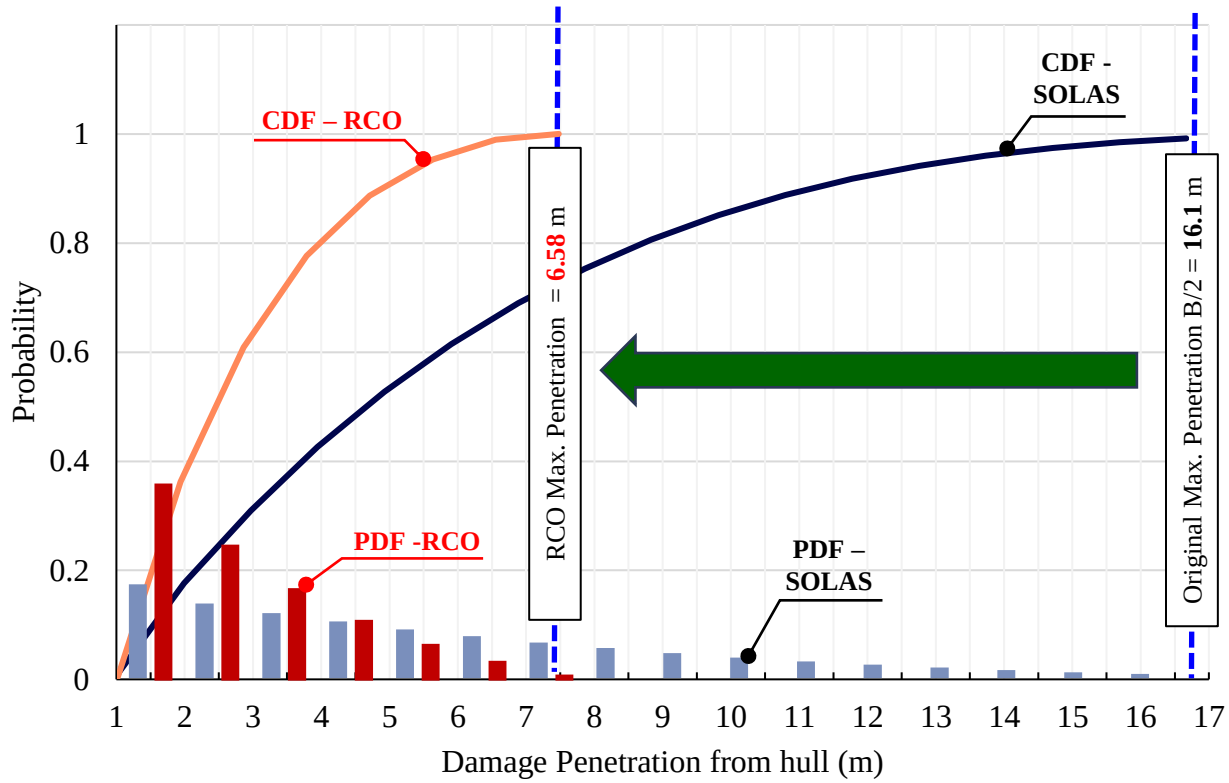




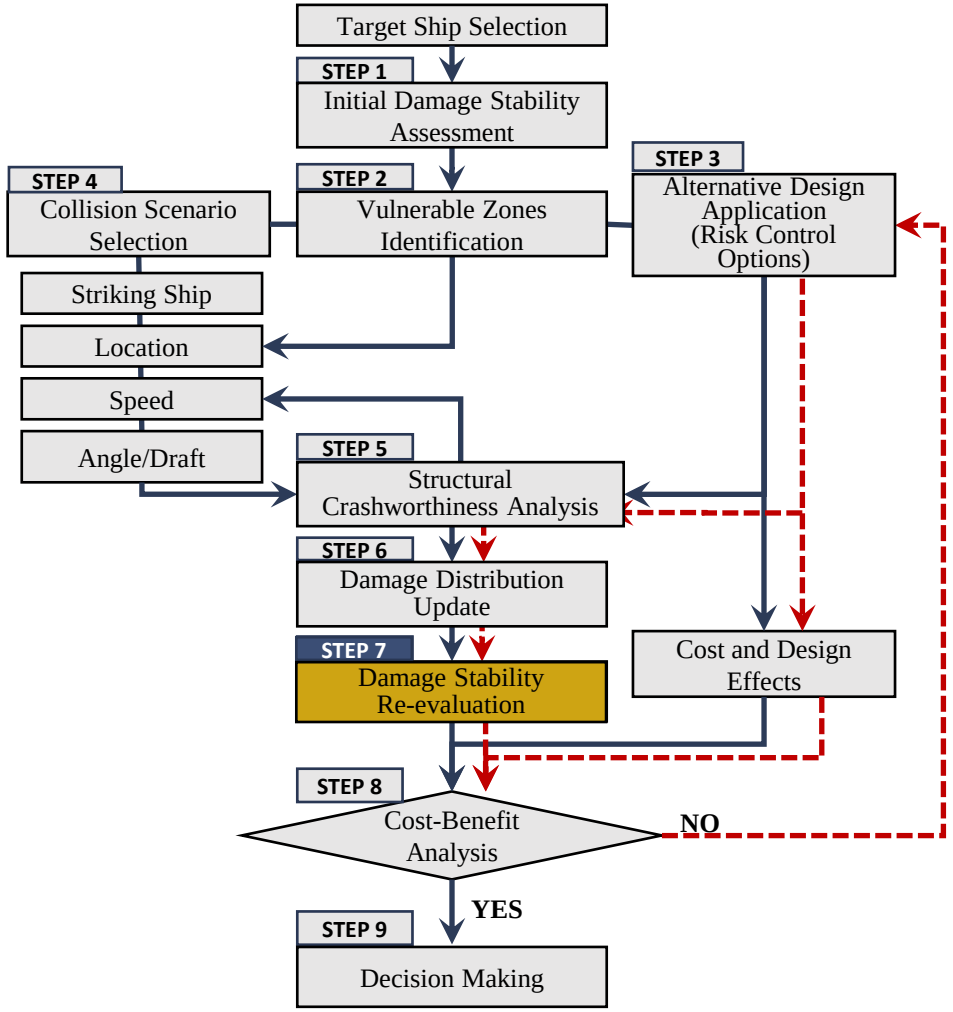
3. Methodology : STEP 6



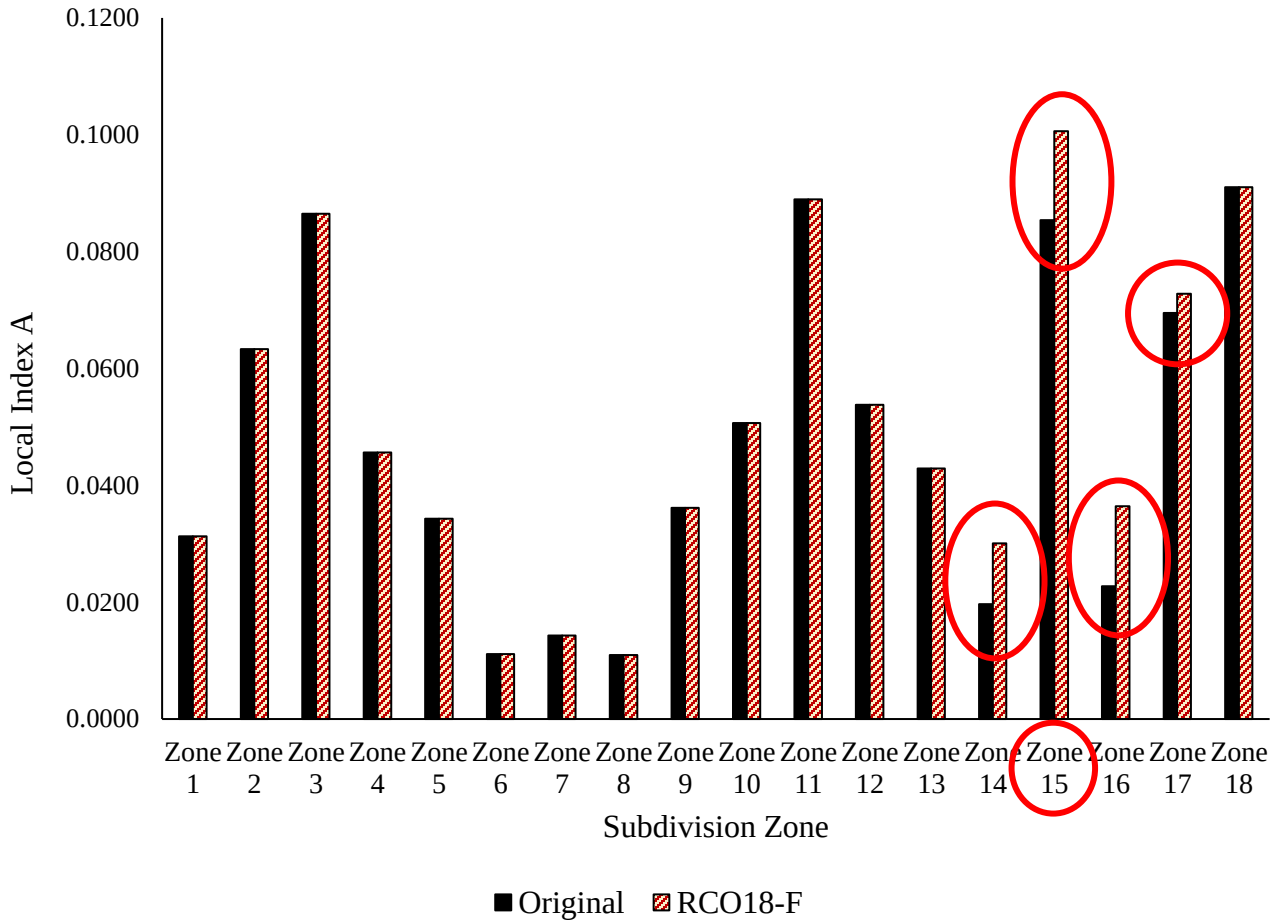
Based on actual penetration from simulation results, the transverse damage distribution (p-factor) to be updated.



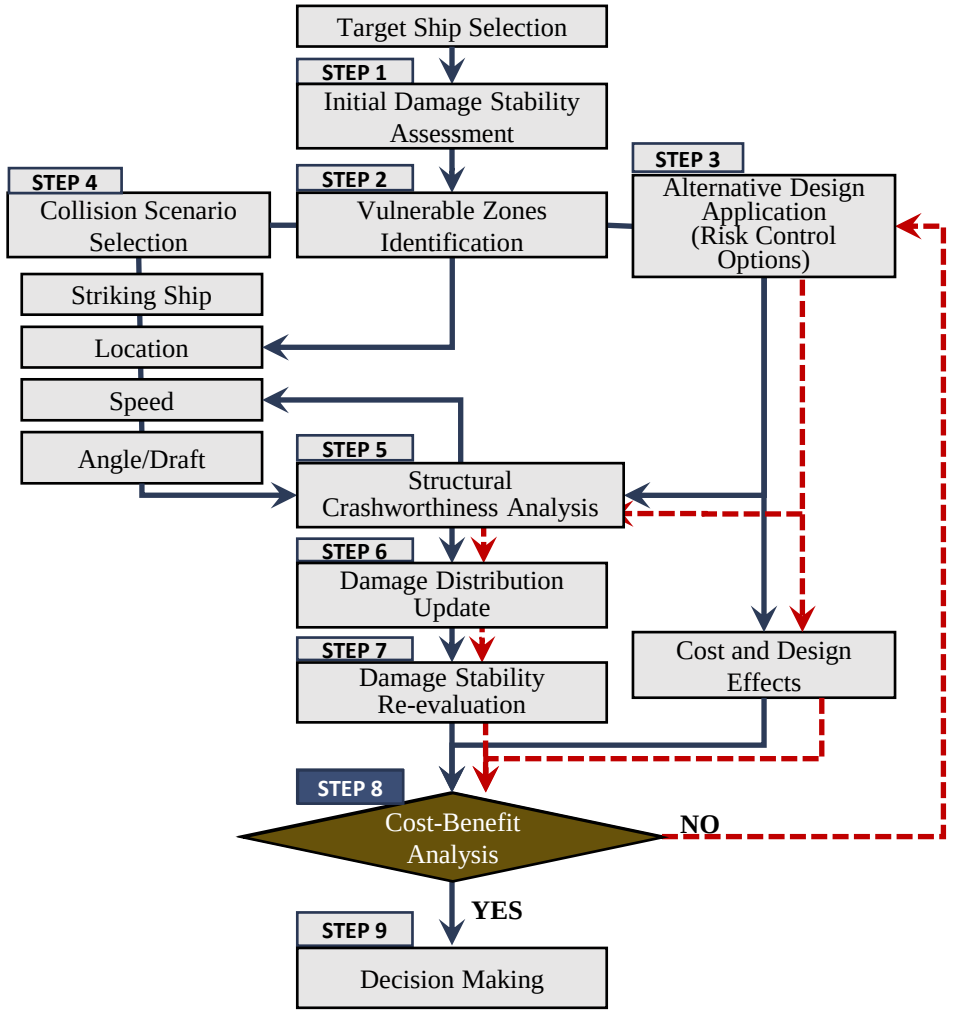
3. Methodology : STEP 7



Damage stability with RCOs to be re-evaluated



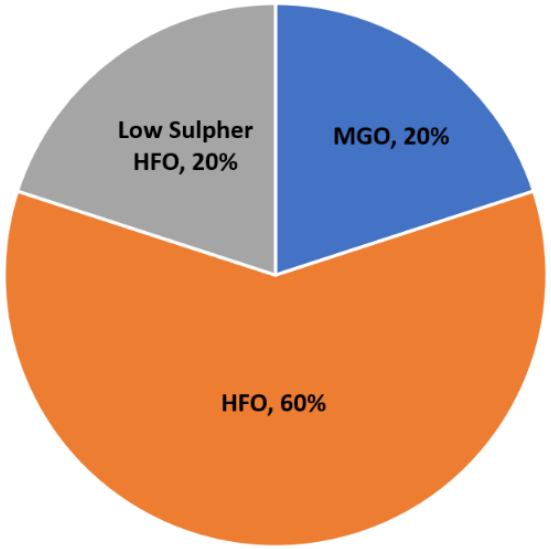
3. Methodology : STEP 8



Cost-Benefit Analysis to be conducted for each RCO in terms of **GCAF (Gross Cost of Averting a Fatality)** = ΔCost / Δ Risk

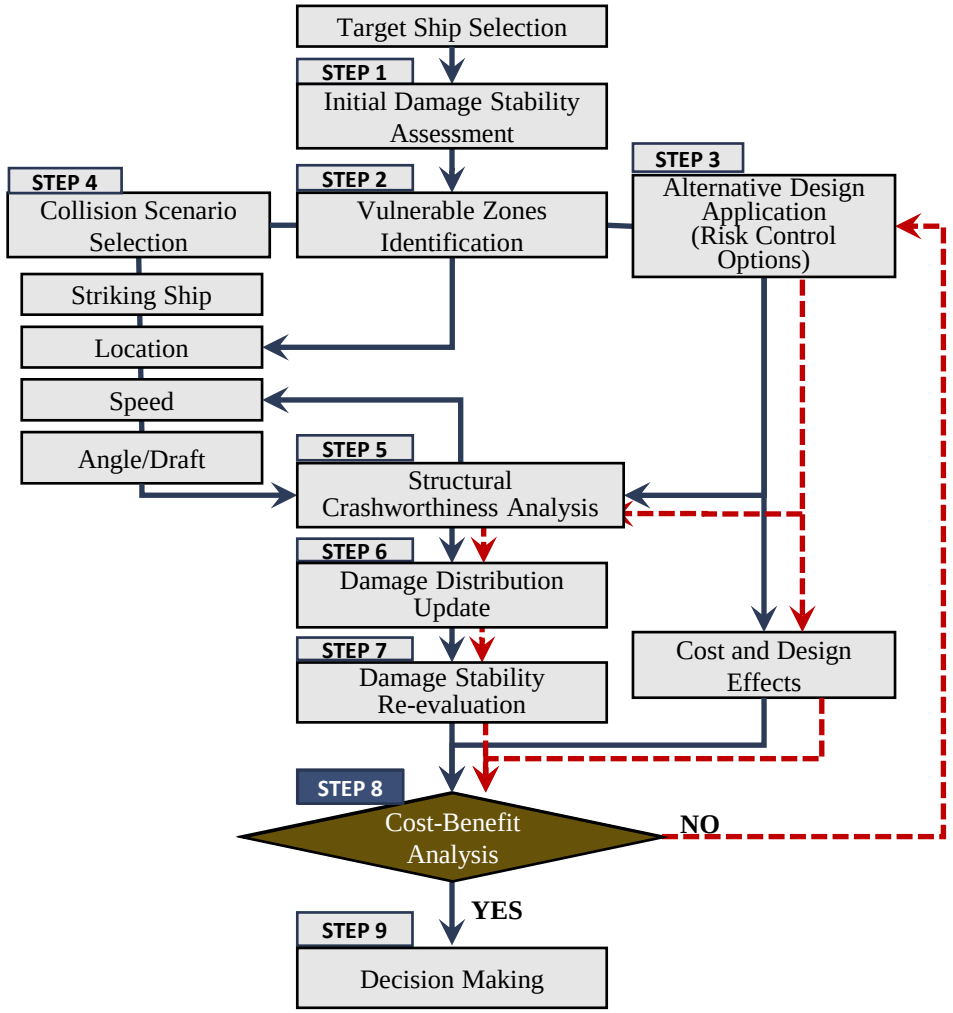
Cost of RCO

1. Material and Labour (Based on Weight)
2. Additional equipment (i.e. WTD)
3. Operating cost (Fuel oil) increase for ship lifetime (Based on WSA)



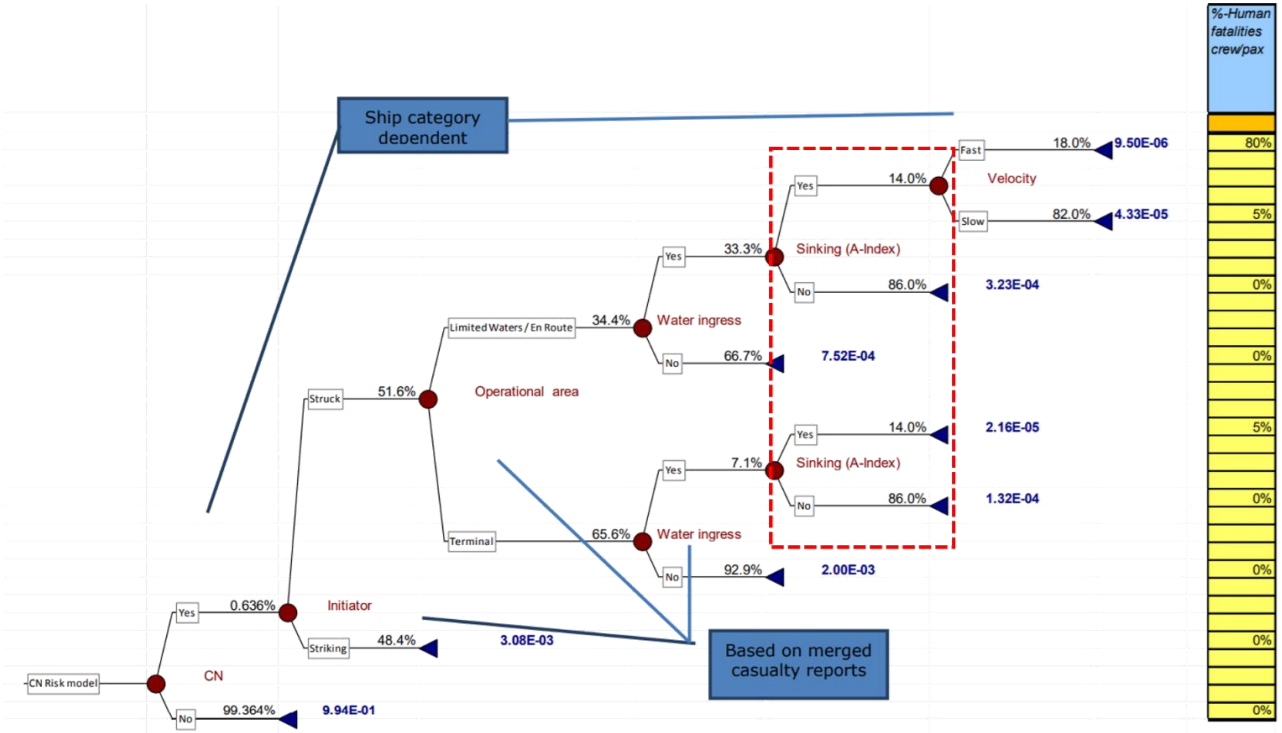
Distribution of fuel types (EMSAIII, 2013-2016)

3. Methodology : STEP 8

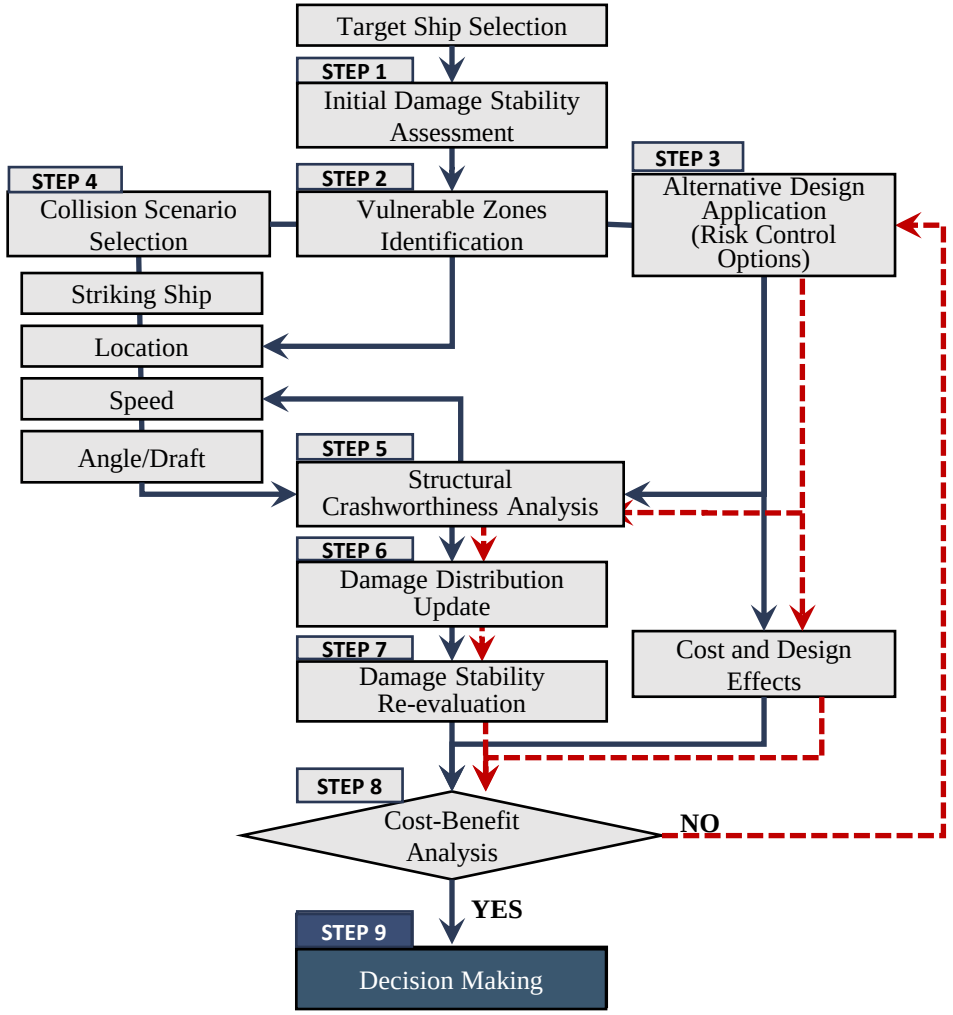


Risk of RCOs

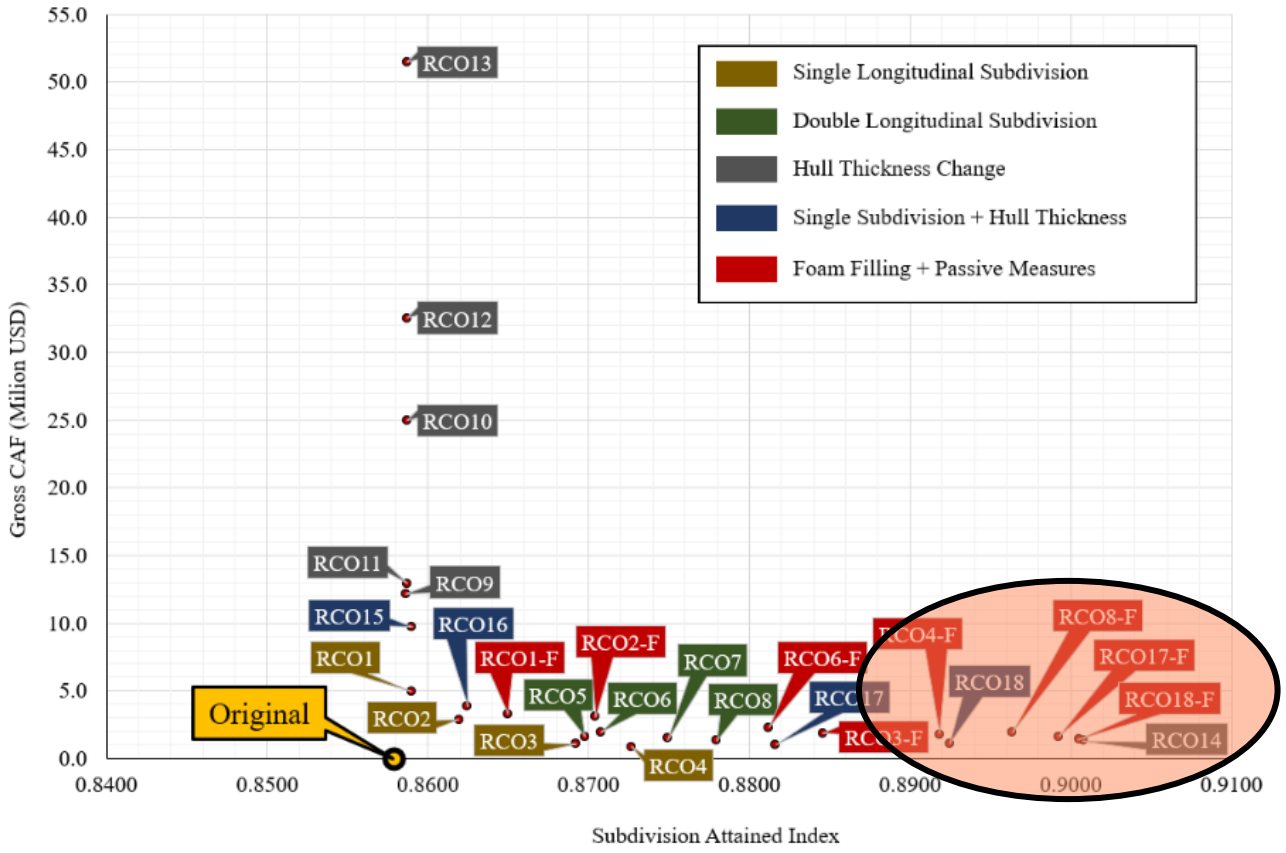
1. Potential Loss of Life (PLL)
2. EMSAIII project definition to be adopted
3. EMSAIII collision and ground risk models
4. Attained Indexes for the original and each RCO to be applied



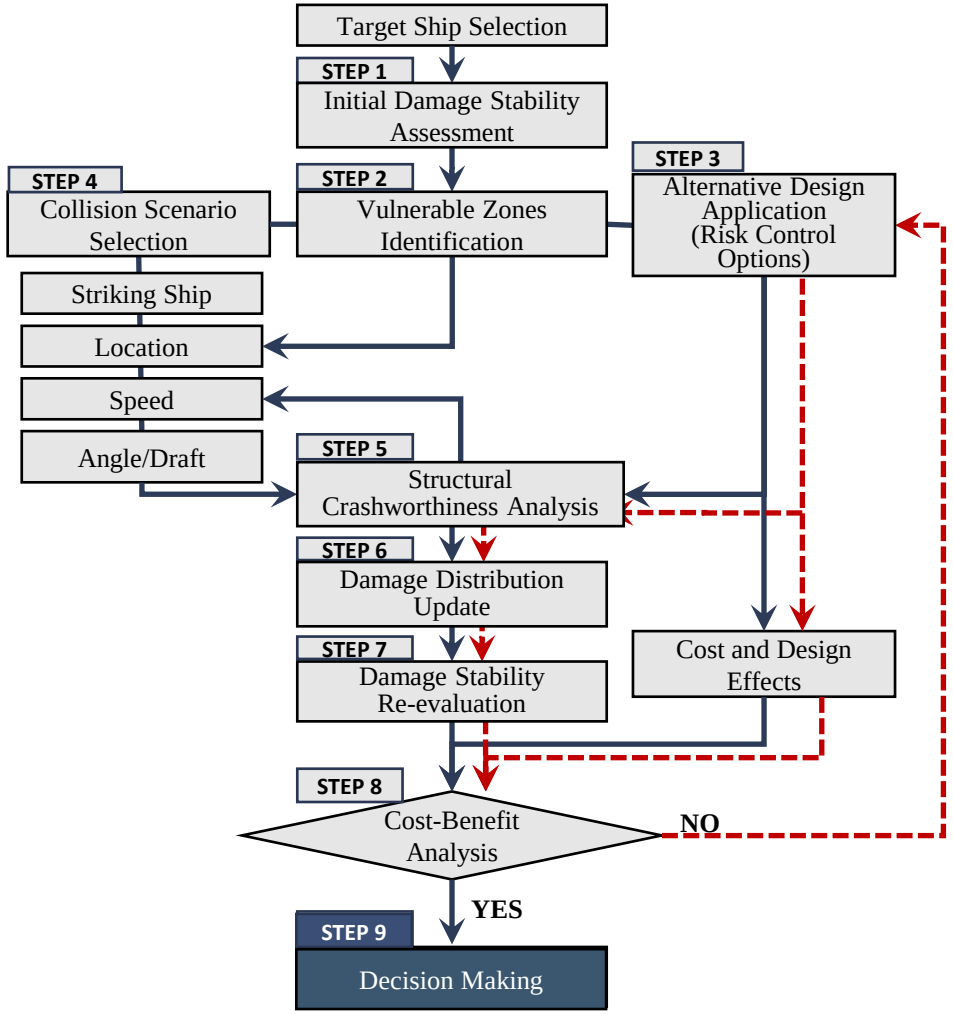
3. Methodology : STEP 9



Final decision making to be made with optimum RCOs for alternative design approval and implementations.



3. Methodology : STEP 9



Optimum RCOs

1. RCO 14 : 50T Hull
2. RCO 18 : 30T Hull + LBHD
3. RCO 18-F : 30T Hull + LBHD + Foam

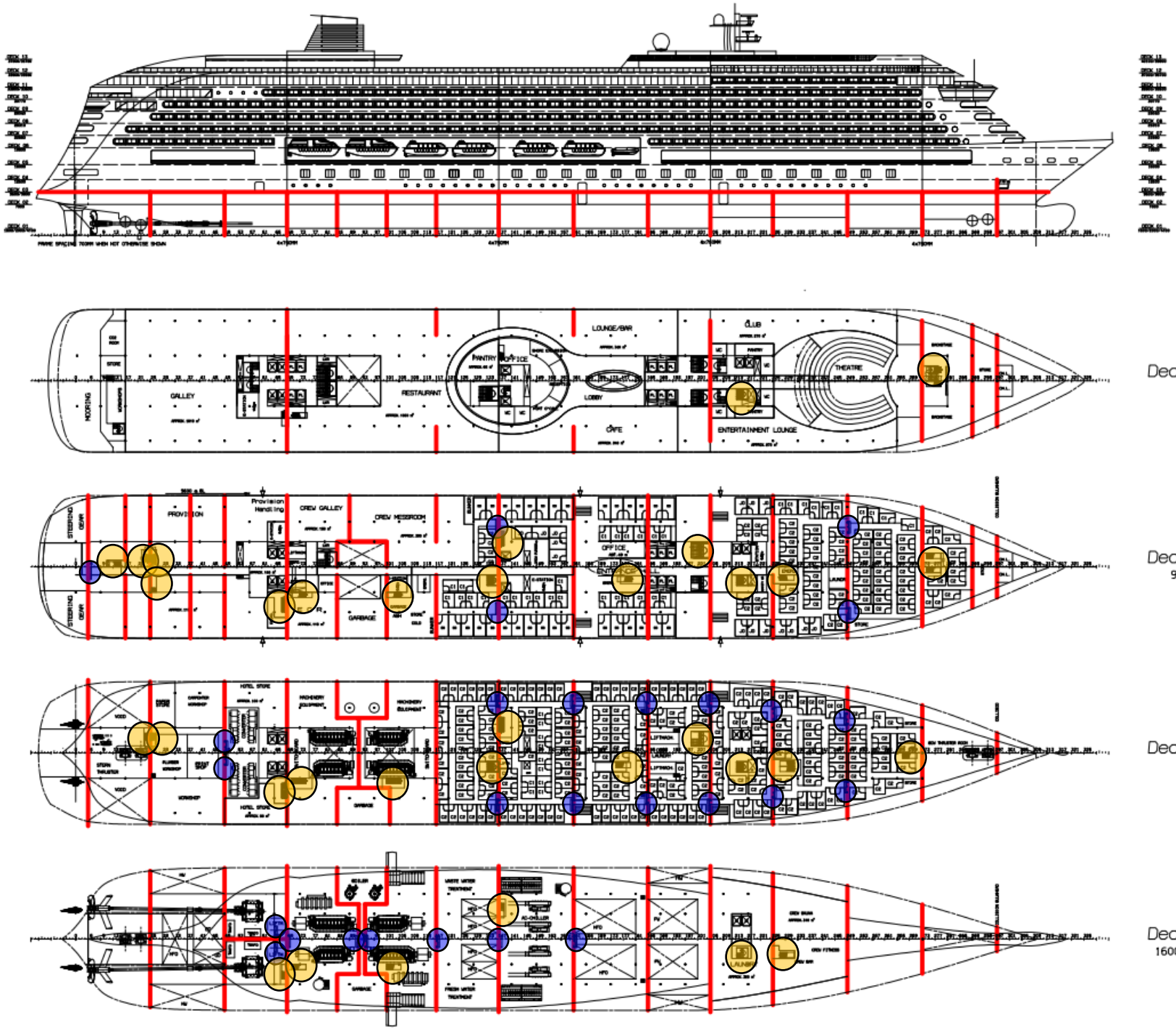
	Weight (Ton)	A-Index	Cost (Mil$)	GCAF
ORIGINAL	-	0.8579	-	-
RCO14	279.98	0.9008	2.74	1.32
RCO18	161.55	0.8925	1.84	1.00
RCO18-F	196.62	0.9005	2.90	1.40

4. Conclusion

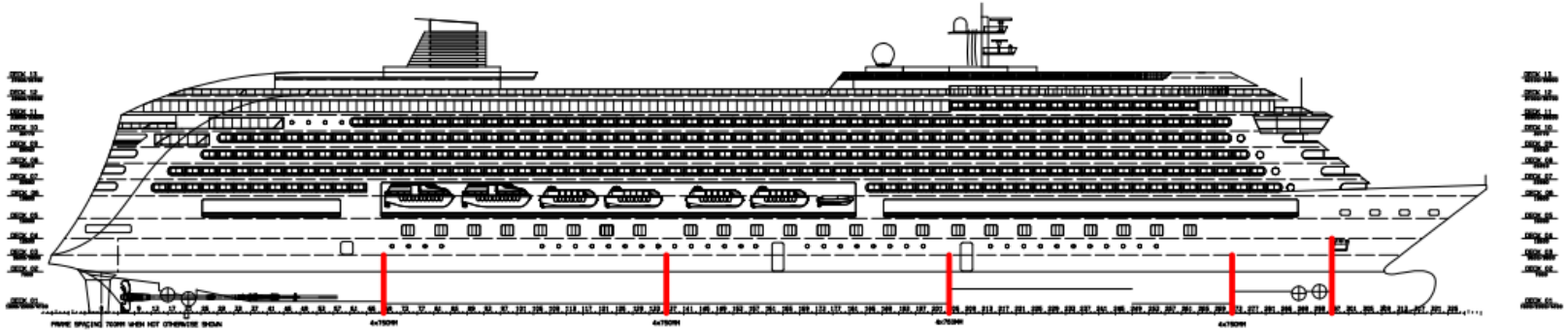
This research to be motivated by the following problems with the current SOLAS framework:

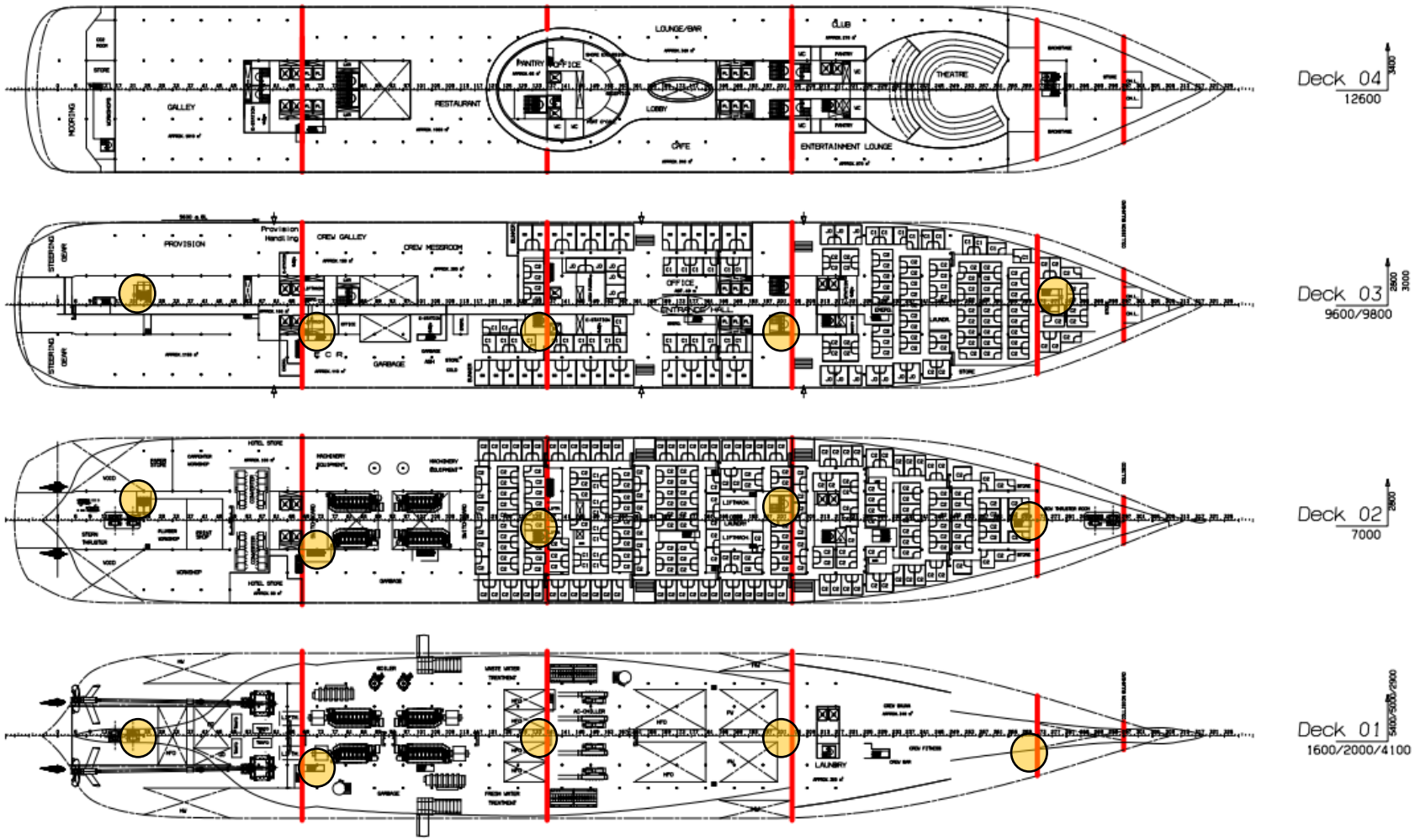
1. ship structural design in damage stability to be ignored
2. damage probability to be already predefined, so not to be changed

The proposed methodology enable crashworthy arrangement to be evaluated though QRA platform. It has been successfully demonstrated and verified from the case study.



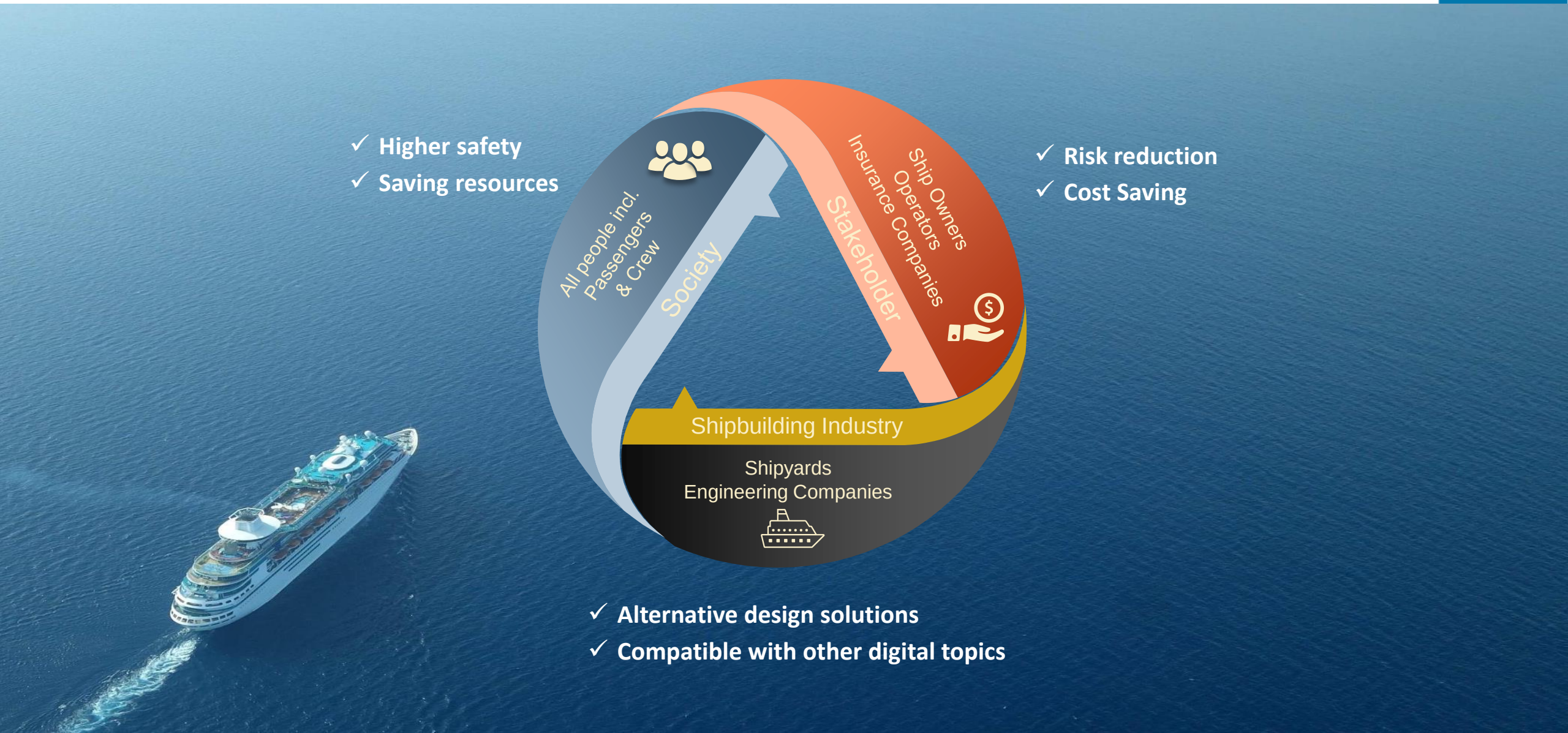
- WT Trans. BHD
- Watertight Doors
- Escape Access
- Pipe/Duct/Cable
- HVAC
- Fire Insulations





- No WT Trans. BHD
- No Watertight Doors
- Less Escape Access
- Less Pipe/Duct/Cable
- Less HVAC
- Less Fire Insulations

5. Research Benefits



Thank you!

(Elvis) BAE

Relevant Publications

BAE, H., VASSALOS, D. & BOULOUGOURIS, E. 2020. Methodology in Risk-based Crashworthiness to improve ship Survivability in a seaway. *ICSOS2020 : International Conference on Ships and Offshore Structures.* Online, Glasgow, UK.

BAE, H., VASSALOS, D., PATERSON, D., MUJEEB-AHMED, M. & BOULOUGOURIS, E. 2021. The Effectiveness of Crashworthiness as a Damage Stability Risk Control Option. *Conference: 1st International Conference on the Stability and Safety of Ships and Ocean Vehicles (STAB&S 2021).* Glasgow, UK.

LE SOURNE, H., PINEAU, J., KIM, S., CONTI, F., KAYDIHAN, L., BAE, H., VASSALOS, D., KUJALA, P. & HIRDARIS, S. A comparison of crashworthiness methods for the assessment of ship damage extents. 1st International Conference on the Stability and Safety of Ships and Ocean Vehicles, 2021.

KIM, S. J., TAIMURI, G., KUJALA, P., CONTI, F., LE SOURNE, H., PINEAU, J.-P., LOOTEN, T., BAE, H., MUJEEB-AHMED, M. & VASSALOS, D. 2022. Comparison of numerical approaches for structural response analysis of passenger ships in collisions and groundings. *Marine Structures,* 81**,** 103125.

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