LIFE CYCLE ASSESSMENT OF MARINE COATINGS APPLIED TO SHIP HULLS

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by

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Introduction

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Fouling → Roughness → Increase in Resistance → Increase in required Power and Fuel consumption

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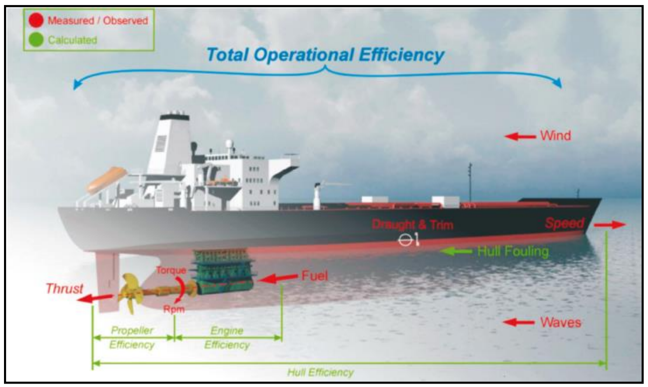
Increase in GHG Emissions

Negative Effects on Environment

To avoid fouling



Biocide accumulation and negative effects on non-target species

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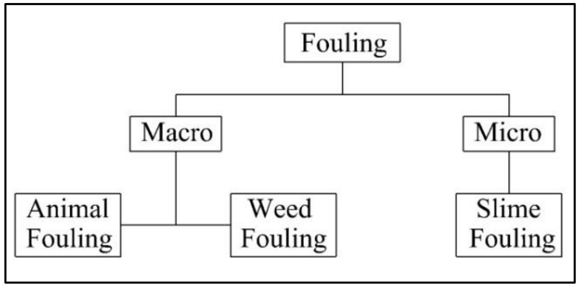
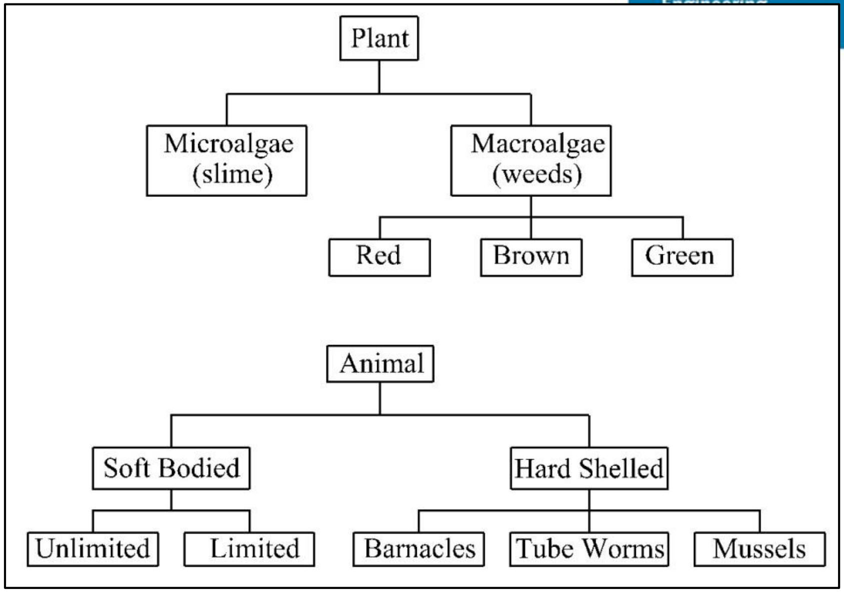
Biocidal antifouling coatings → Biocide releasing to environment

Marine coatings to prevent biofouling



Fouling organisms, adapted from Taylan (2010)



Classification of marine foulers, adapted from Atlar (2008)

"…the arsenic and sulfur have been well mixed with the Chian oil that you brought back on your last voyage, and the mixture evenly applied to the vessel's sides, that she may speed through the blue waters freely and without impediment.''

Aramaic papyrus

"All ships' bottoms were covered with a mixture of tallow and pitch in the hope of discouraging barnacles and teredos, and every few months a vessel had to be hove-down and graved on some convenient beach. This was done by careening her alternately on each side, cleaning off the marine growth, re-pitching the bottom and paying the seams."

Christopher Columbus

Marine coatings to prevent biofouling

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Historical development of antifouling strategies, adapted from Dafforn et al. (2011)

Timeline	**Major events**
1500-300 BC	Use of lead and copper sheets on wooden vessels
1800-1900s	Heavy metals (copper, arsenic, mercury) incorporated into coatings
1800s-present	Continued use of copper in AF coatings
1960s	Development of TBT conventional coatings
1974	Oyster farmers report abnormal shell growth
1977	First foul release AF patent
1980s	Development of TBT SPC coatings allowed control of biocide release rates
1980s	TBT linked to shell abnormalities in oysters (Crassostrea gigas) and imposex in dogwhelks (Nucella lapillus)
1987-90	TBT coatings prohibited on vessels <25 m in France, UK, USA, Canada, Australia, EU, NZ and Japan
1990s–present	Copper release rate restrictions introduced in Denmark and considered elsewhere e.g. California, USA
2000s	Research into environmentally friendly AF alternatives increases
2001	International Maritime Organization (IMO) adopts “AFS Convention” to eliminate TBT from AF coatings from vessels through: 2003 – prohibition of further application of TBT 2008 – prohibition of active TBT presence
2008	IMO “AFS Convention” comes into force

EU FP7 FOUL-X-SPEL Project

SEVENTH FRAMEWORK PROGRAMME

FOUL-X-SPEL

University of Strathclyde Engineering

"Environmentally Friendly Antifouling Technology to Optimise the Energy Efficiency of Ships" (FOUL-X-SPEL). "The basic idea concerns the modification of usual hulls by providing a new antifouling coating, by fixing bioactive molecules, which can provide biocide activity, in order to avoid leaching and to promote a long-term effect of surface protection"

Partners

- Instituto Superior Tecnico
- Estaleiros Navais De Peniche, S.A.
- Hempel A/S
- Fundacion Tekniker
- University of Strathclyde
- Instituto De Soldadura E Qualidade
- Carnival Plc
- Lloyd's Register EMEA
- University of Southampton
- National Technical University of Athens

FOUL X SPEL

EU FP7 FOUL-X-SPEL Project

10%

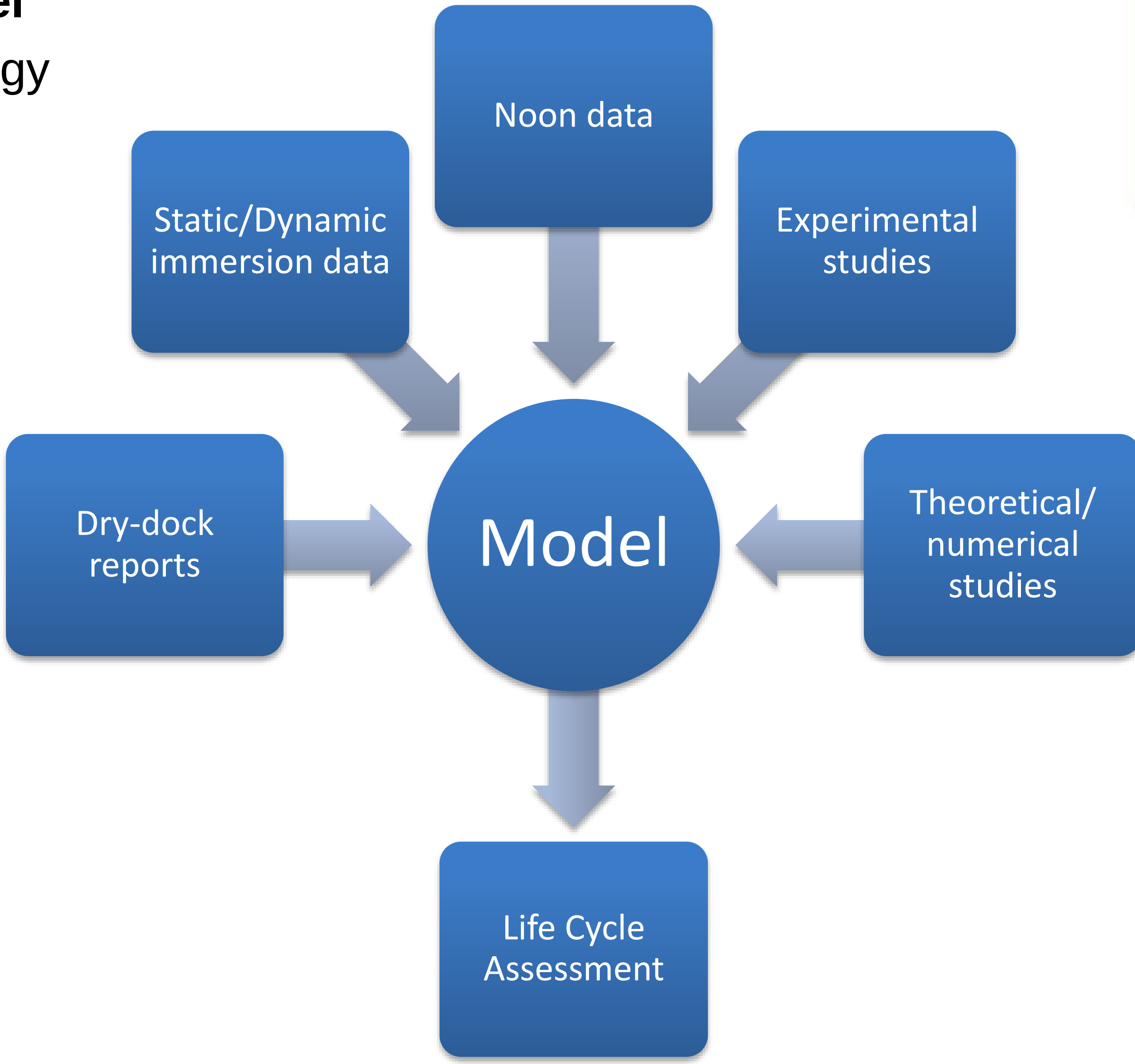
7%

Marine Coatings → Literature → Turbulent boundary layer / skin friction of **lab-scale plates**

"How might the roughness of coatings and biofouling be related to full-scale ship resistance and powering?"

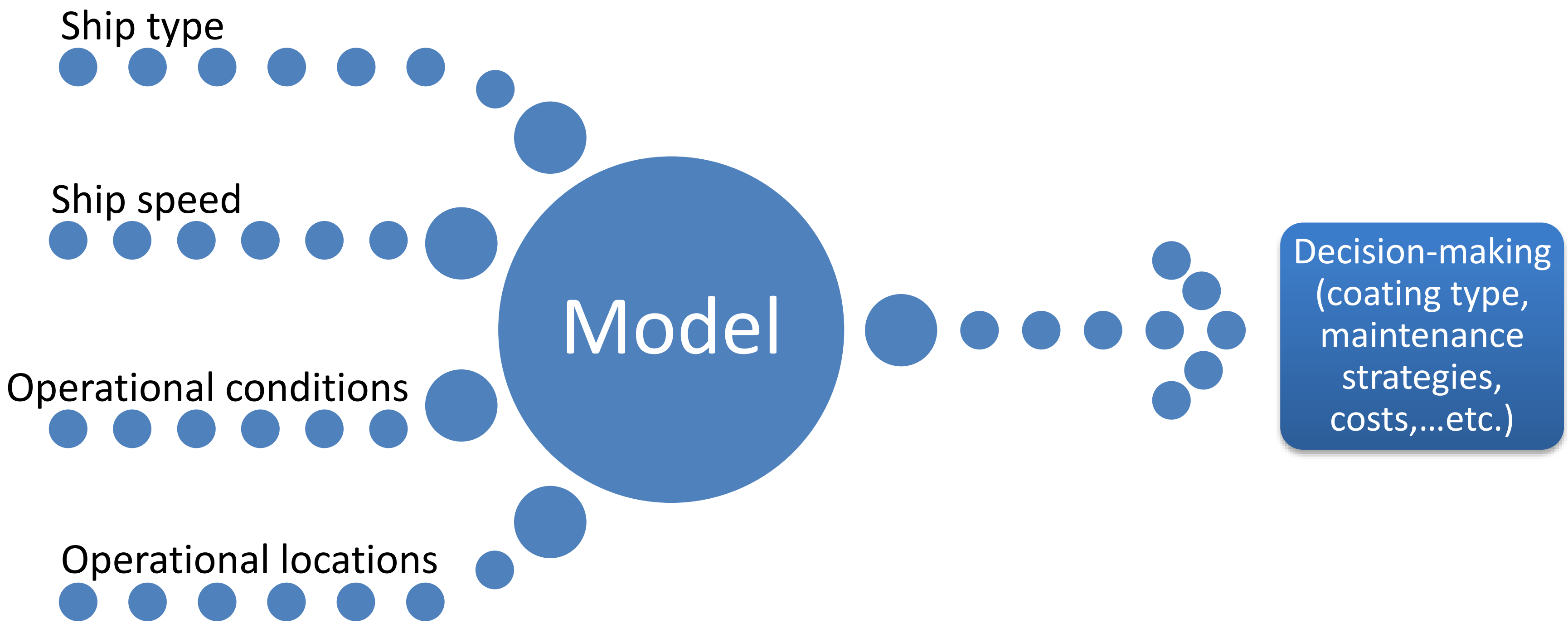
LCA Model

Methodology



LCA Model

User Input



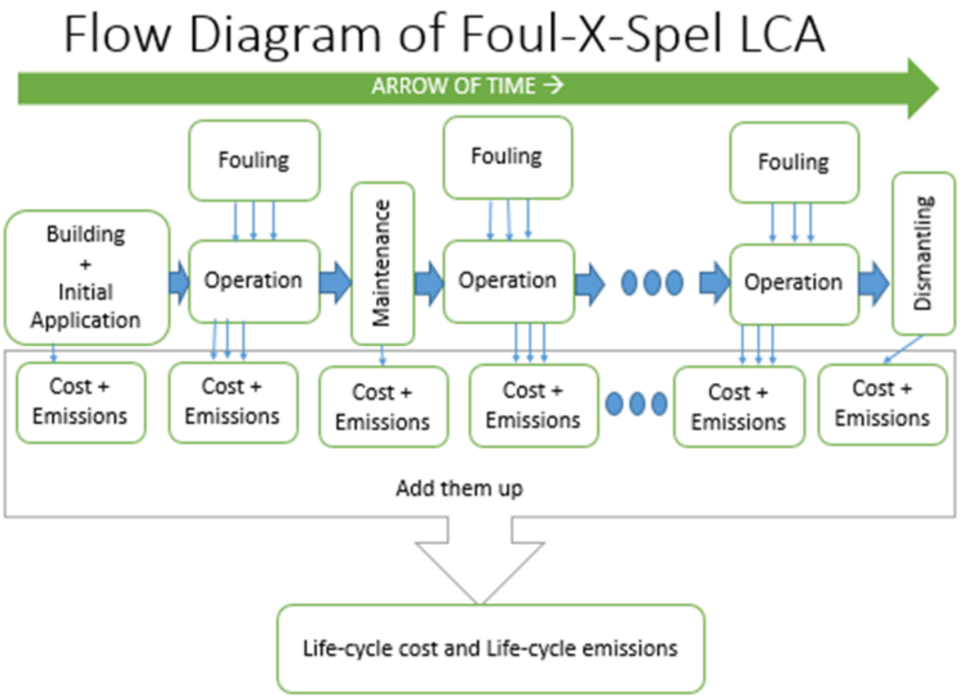
LCA Model

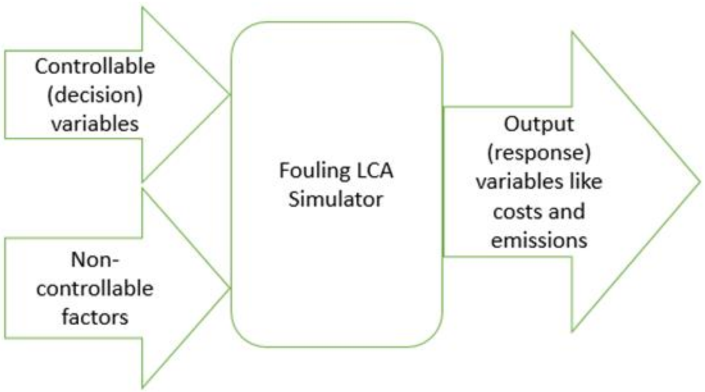
Stages

Major stages of LCA of an AF coating.

Stage	Activities
1. Production of AF coatings	Activities related to the extraction and acquisition of natural resources, including mining non-renewable material required to produce the different system components and transporting this materials to processing facilities.
2. Application	Application of antifouling coatings on ship hulls.
3. Operation of ships with AF coatings	Extra fuel is consumed due to the effects of antifouling coatings/fouling
4. Maintenance of ships (Hull cleaning and recoating)	System maintenance activities (dry-dock and in water hull cleaning).
5. End-of-Life	Dismantling of a ship

LCA Model





1. A representation of voyages and anchorages of the ship in question. The representation should describe the time and location of the ship over its lifetime.
2. Model of temperature-dependent and time-dependent growth of fouling.
3. Model of variation of sea-temperature with location.
4. Model of the costs and effects of hull maintenance activities.
5. Model of fuel-consumption behaviour of the ship.

Coating Application

Production stage of antifouling

Production and marketing of the paint					
Item	**Emission**	**Energy**	**Selling rate**	**Size of unit application area**	**Density**
Anticorrosive					
Tiecoat					
Antifouling					

Application of antifouling to a new building ship

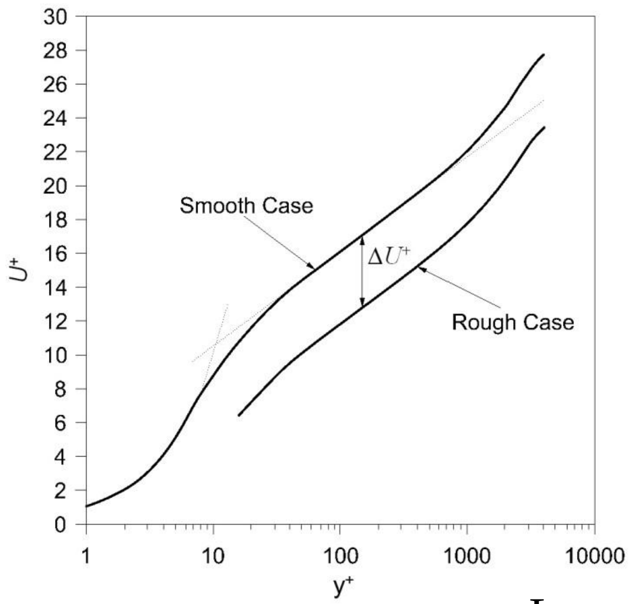
Application in New Building				
Item	**How many coats**	**Cost**	**Emission**	**Energy**
Hull surface preparation & Painting				
Full Grit Blasting to Sa2.5	N/A			
Full coat anticorrosive				
Full coat tiecoat				
Full coat antifouling				

Application of antifouling to a ship in Dry-dock

Dry-dock				
Item	**How many coats**	**Cost**	**Emission**	**Energy**
Hull surface preparation & Painting				
High pressure fresh water washing	N/A			
Wash down after first coat	N/A			
Ph0 cleaning and washing	N/A			
Sa1 Spot Blasting	N/A			
Sa2 Spot Blasting	N/A			
Touch up coat anticorrosive				
Touch up coat Tiecoat				
Touch up coat antifouling				
Full coat antifouling				
Topside masking	N/A			
Hose connection for maindeck and cooling water overboards	N/A			
Blanking all overboard	N/A			

Fuel Consumption Model

Roughness Effect on Flow



ΔU^{+} ⟶ Roughness function

$$\Delta U^{+} = U^{+}_{smooth} - U^{+}_{rough}$$

$$\frac{U}{U_\tau} = f\left(\frac{yU_\tau}{\nu}, \frac{kU_\tau}{\nu}\right)$$

$U^{+} = f(y^{+})$ ⟵ used to be — Law of the wall for inner layer — becomes ⟶ $U^{+} = f\left(y^{+}, k^{+}\right)$

$U^{+} = \frac{1}{\kappa}\ln y^{+} + B$ ⟵ used to be — Logarithmic velocity profile — becomes ⟶ $U^{+} = \frac{1}{\kappa}\ln(y^{+}) + B - \Delta U^{+}(k^{+})$

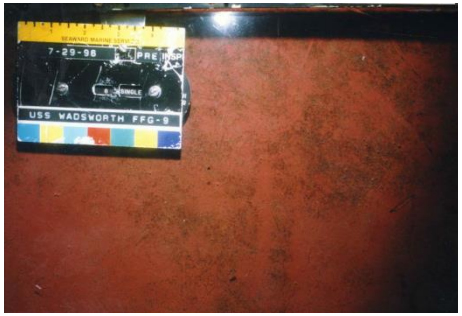
Fuel Consumption Model

Table I. A range of representative coating and fouling conditions. The Naval Ships' Technical Manual (NSTM) rating is a fouling index used by the US Navy based on Naval Ships' Technical Manual (2002). The values of equivalent sand roughness height (k_s) and average coating roughness (Rt_{50}) are based on the measurements of Schultz (2004).

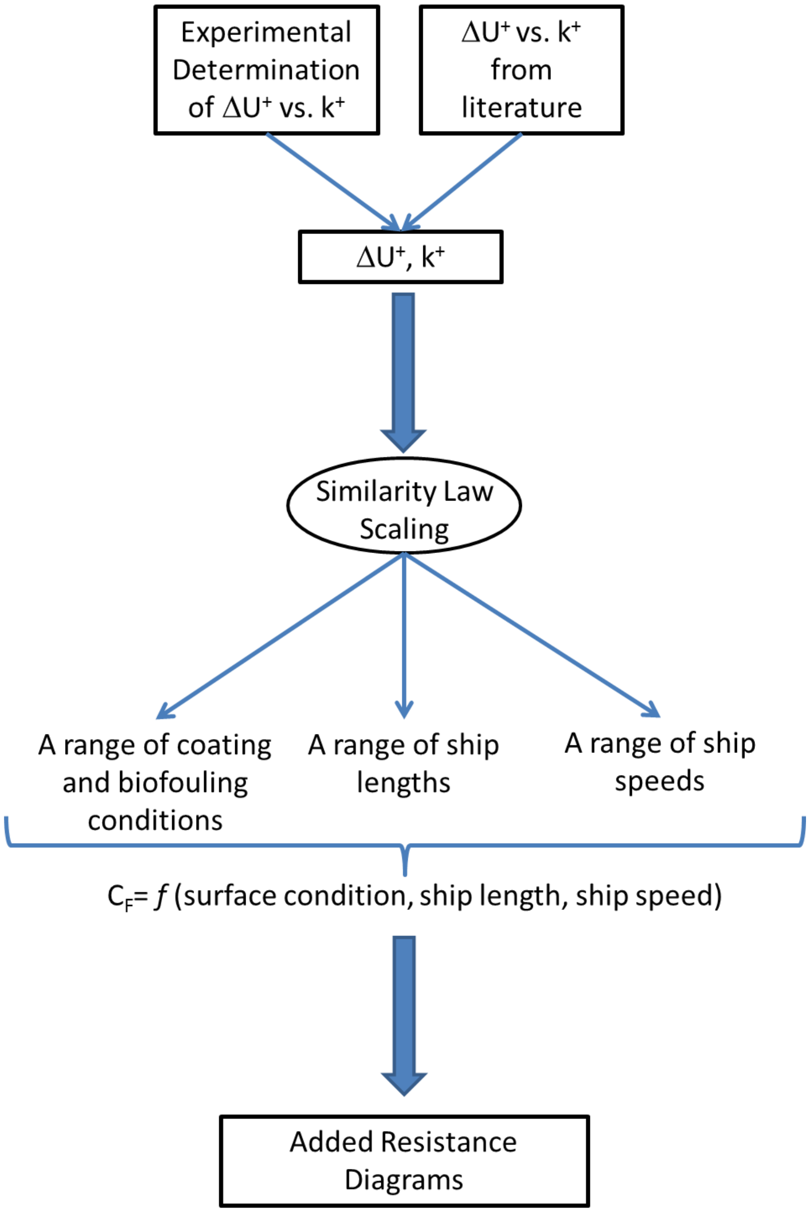
Description of condition	NSTM rating*	k_s (μm)	Rt_{50} (μm)
Hydraulically smooth surface	0	0	0
Typical as applied AF coating	0	30	150
Deteriorated coating or light slime	10–20	100	300
Heavy slime	30	300	600
Small calcareous fouling or weed	40–60	1000	1000
Medium calcareous fouling	70–80	3000	3000
Heavy calcareous fouling	90–100	10,000	10,000

*NSTM (2002).

(Schultz, 2007)



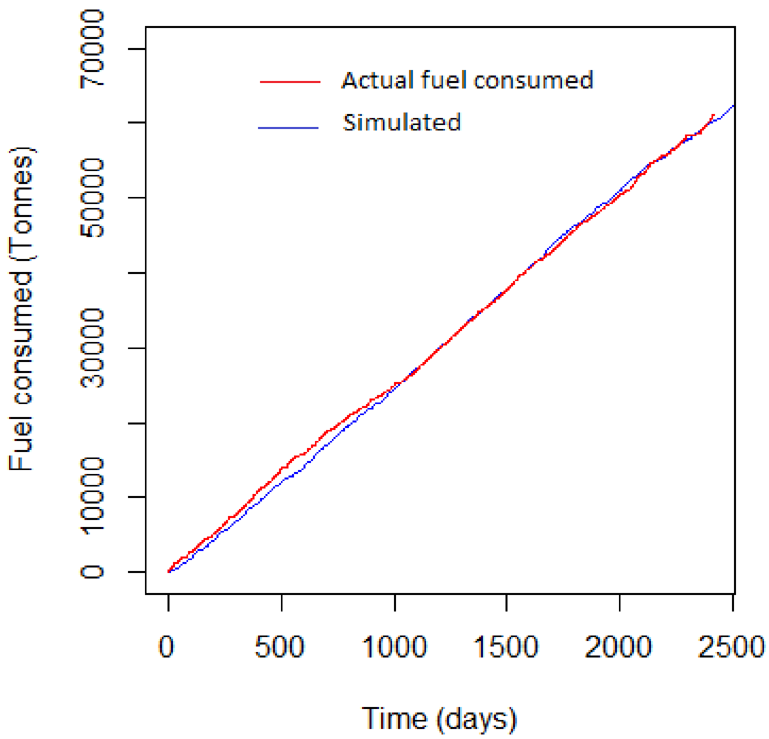
Fuel Consumption Model



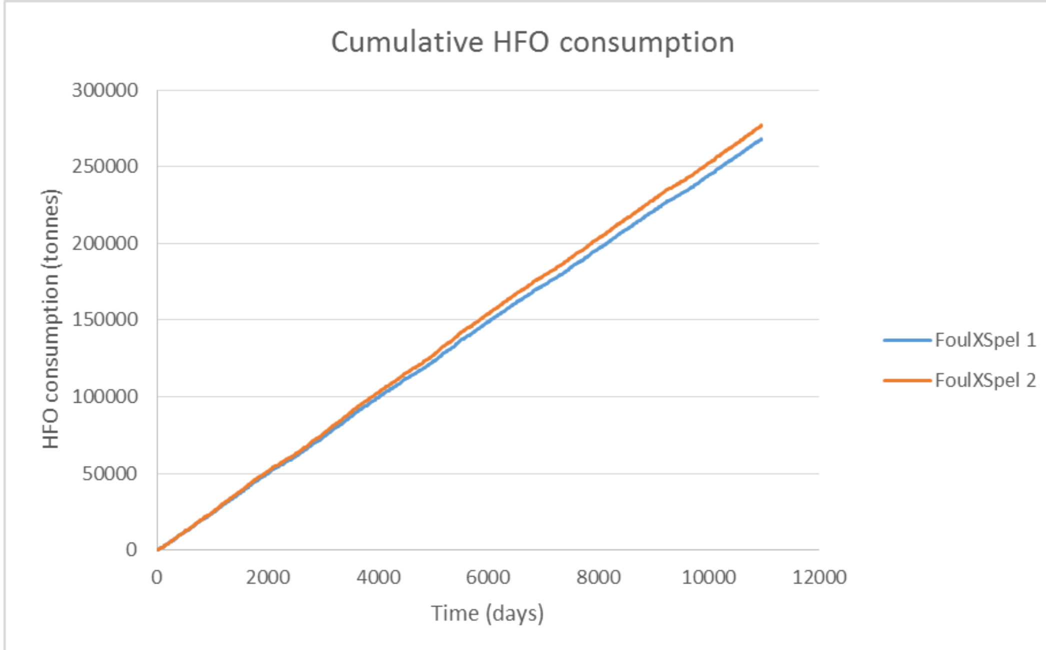
Case Study

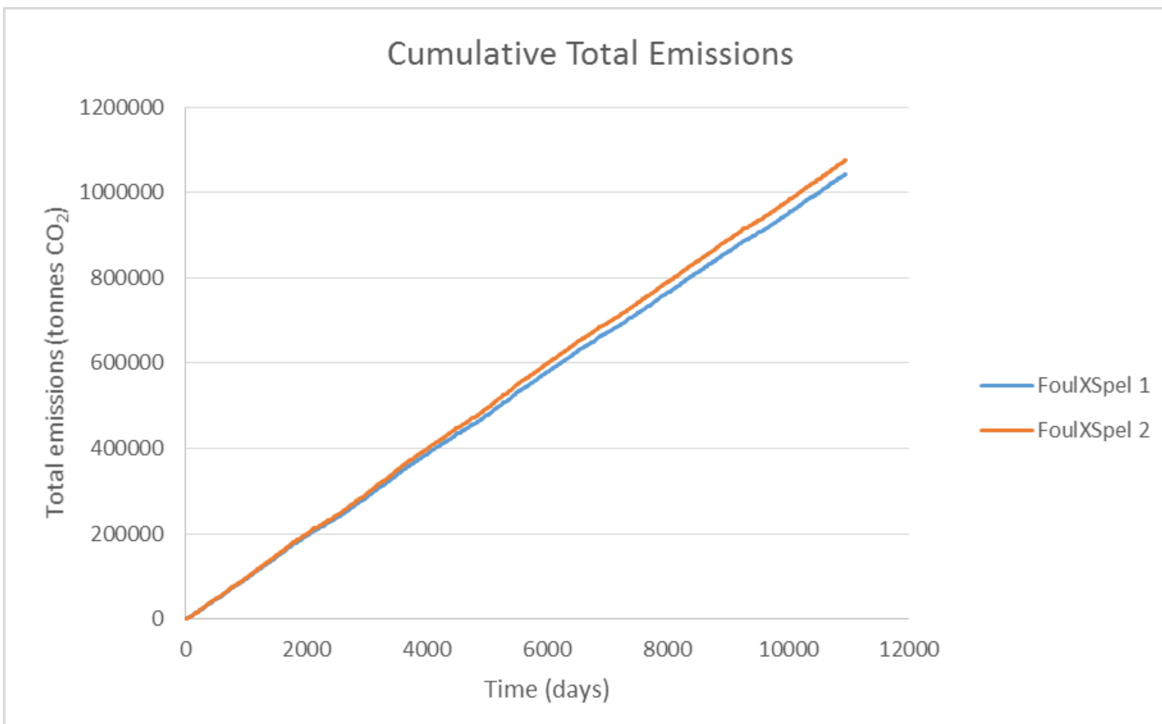
An existing tanker (~115000 DWT)

- a fouling release coating (FoulXSpel 1) and
- a tin free self-polishing antifouling paint (FoulXSpel 2).

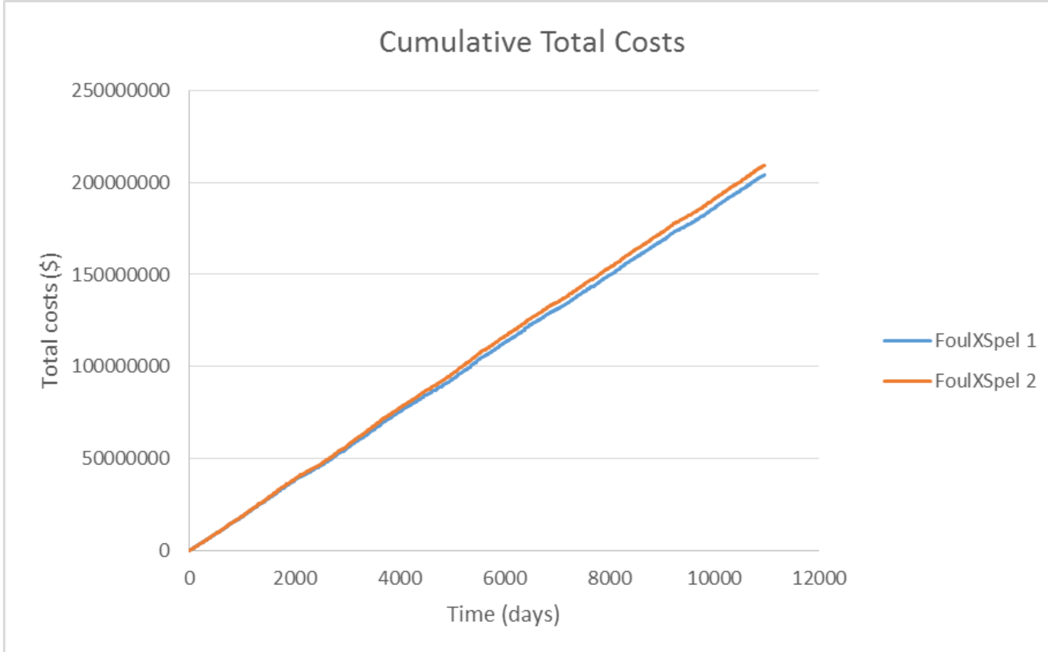


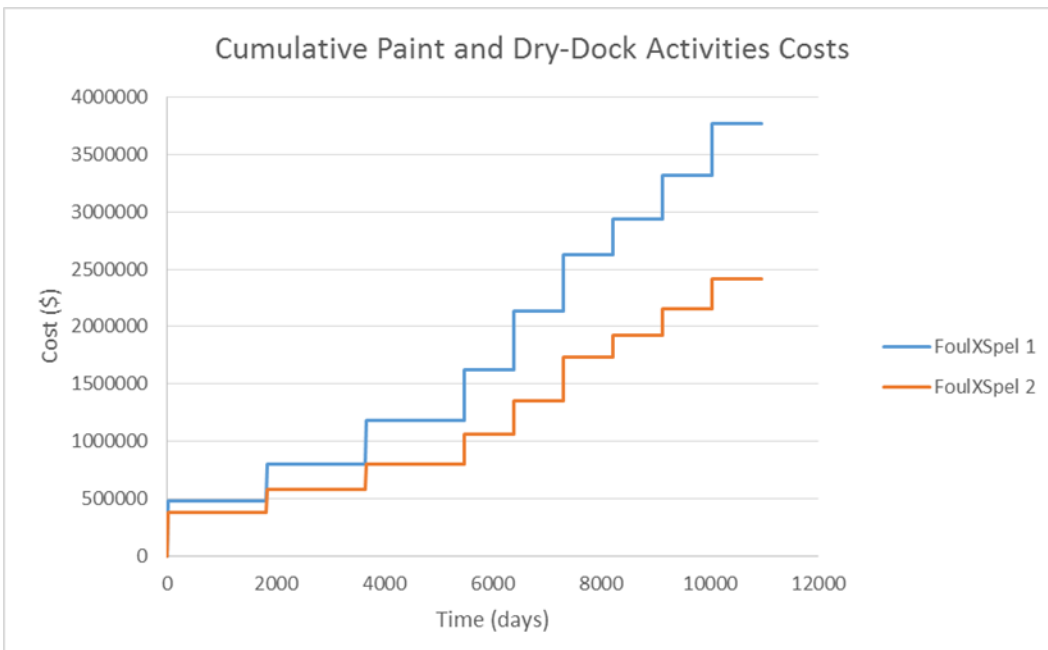
Case Study


Cumulative HFO consumption
HFO consumption (tonnes)
300000
250000
200000
150000
100000
50000
0
0
2000
4000
6000
8000
10000
12000
Time (days)
FoulXSpel 1
FoulXSpel 2

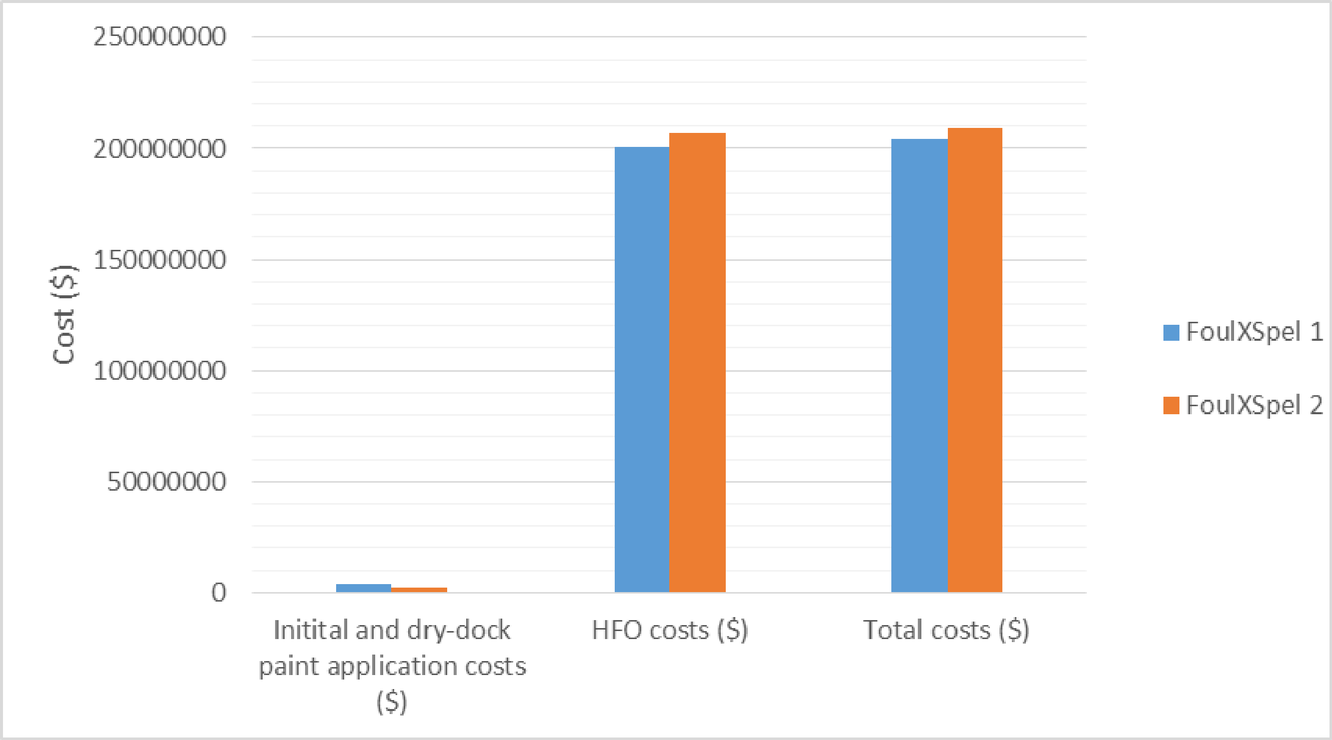

Cumulative Total Emissions
Total emissions (tonnes CO_2)
1200000
1000000
800000
600000
400000
200000
0
0
2000
4000
6000
8000
10000
12000
Time (days)
FoulXSpel 1
FoulXSpel 2

Case Study


Cumulative Total Costs
250000000
200000000
150000000
100000000
50000000
0
Total costs ($)
0
2000
4000
6000
8000
10000
12000
Time (days)
FoulXSpel 1
FoulXSpel 2


Cumulative Paint and Dry-Dock Activities Costs
4000000
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
Cost ($)
0
2000
4000
6000
8000
10000
12000
Time (days)
FoulXSpel 1
FoulXSpel 2

Case Study



250000000
200000000
150000000
100000000
50000000
0
Cost ($)
Initital and dry-dock paint application costs ($)
HFO costs ($)
Total costs ($)
FoulXSpel 1
FoulXSpel 2

Overall (30 years)

The use of Silicone-based paint;

- 2.5% saving in cost
- 3.17% saving in HFO
- 3% saving in emissions

Conclusions

- A new Life Cycle Costs and Environmental Impact Assessment model was developed for the assessment of marine coatings applied to ship hulls. For this reason, a new methodology is also proposed within the model.

- Initial application and periodic renewal of a coating system may incur higher capital costs than others, but the benefits might outweigh the costs once the costs are amortised over the entire life-cycle. The real impact of a coating can only be assessed through LCA of the coating systems in question.

- This model can be used as a decision making tool which determines the suitable coating type for particular types of ships.

- It may also be used to decide the best maintenance and/or hull cleaning activities and/or intervals.

- Techno-economic feasibility study of a new coating can be carried out using this LCA model.

Acknowledgement

The authors gratefully acknowledge that the research presented in this paper was partially generated as part of the EU funded FP7 project FOUL-X-SPEL (Environmentally Friendly Antifouling Technology to Optimise the Energy Efficiency of Ships, Project number 285552, FP7-SST-2011-RTD-1).

The authors would like to thank Prof. Michael P. Schultz for kindly providing his data.

Q&A

Thank you for your attention

Beards on faces
NOT on boats!!!

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