THE ECONOMICS OF A LONG TERM COATING

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SUMMARY

An important challenge during ship construction is the protection against corrosion of the ballast tanks. These tanks have many compartments, contain multiple structural elements and play a critical role in the seaworthiness. The majority of the ballast tanks are prepared and coated according to IMO Performance Standard for Protective Coating regulations (PSPC), using a light colored epoxy coating that, when maintenance is being performed by the crew, must remain in a "good" condition for 15 years. This method is set next to a protection system applied by a given owner who keeps its ships in an excellent condition for their complete lifetime using a long term coating. More attention is paid to the preparation and application of the coating and consequently it protects the ballast tanks for more than 25 years. These coating strategies are compared in an economic analysis, supplemented with a sensitivity analysis to evaluate the outcomes due to variable parameters. The results indicate that a long term coating only pays off for owners willing to keep the ballast tanks of their vessels in a good condition for the complete lifetime. The decisive factor is that a long term coating entails no recoating in dry dock. The latter results in less toxic components in the atmosphere.

1. INTRODUCTION

The corrosion rate on board of a merchant ship depends on many factors such as the ship's operational life, the quality of the steel, the methods of corrosion protection, the operation conditions, etc. The combination of all these factors may lead to substantial variation in the corrosion rate and thus differ considerable from case to case, calling for an increasing interest in building up phenomenological models for the probabilistic description of the corrosion, based on improved understanding of specific corrosion mechanisms (Lyuben, Ge & Ah Kuan, 2004).

Ship construction steel can only be protected in 2 ways: by making the steel cathodic, using sacrificial anodes or impressed current, and/or by applying a coating. Coating steel is by far the most practical way to protect it. The common protective coatings are paints, hot dip galvanizing, zinc or aluminum metal spray and any of the last three over coated with subsequently other layers of paints.

Several types of coatings have been developed providing long term protection by barrier mechanism (Thapar, 2013) (Popoola et al., 2014). Subsequent research has proven that oxygen and water, at a level sufficient to initiate the corrosion reaction, can indeed permeate through intact coatings. Current theories propose that water permeating through a coating to the steel surface can cause displacement of the coating from the steel allowing corrosion to occur. Low permeability and good 'wet adhesion' i.e. adhesion under immersion, are widely believed to be the single most important aspects of corrosion control by coatings (www.international-marine.com, 2014).

Within the context of this article only coated steel will be considered within ballast tanks. Today, ballast tanks are a critical area of weakness. The service life of many ships is not determined by the external battering of the ship's hull due to the waves but by the gradual internal corrosion of the ballast tanks (Thapar, 2013) (De Baere, 2011) (Lloyd's Register, 2006) (De Baere et al., 2013) (Sousa & Gorvatov, 2016).

The aim of this article is to economically assess the effect of the use of a long term coating. The latter implicates that the coating was well selected and applied in an appropriate manner; resulting in a good coating condition even after a life span of 25 years. On-site investigations identified a ship owner with a remarkable better coating performance when compared to the coating performance of an average ship (De Baere, Verstraelen, Willemen, Meskens & Potters, 2014).

Before determining the economic assessment of a long term coating, the corrosion rate and the corrosion wastage must be clearly identified as the economic assessment is based on the expected degradation of the ship's structure using actual corrosion rates. Additionally, a good coating condition is defined, as this is the target condition. This study is performed from an economic point of view; however, a long term coating is also beneficial for the environment. If less coating has to be applied there will be less toxic components and less volatile organic compounds will be expelled into the atmosphere. A ship with ballast tanks in a "good" condition is safer than a ship with her ballast tanks being classified "fair" or even "poor". 90% of ships failures can be attributed to corrosion (Melchers, 1999). Safer ships are better for crew, cargo and environment. Ships in better condition will last longer and so reduce the number of new ships to be built.

This paper will assess the economic impact of a long term coating compared to an average coating. In section

2, the assessment model is developed and presented. Section 3 presents the results, while section 4 concludes.

2. MATERIAL AND METHOD

2.1 INTRODUCTION

The objective is to compare the costs of two coating strategies that need to remain 'good' over a life span of 25 years. The first strategy (average coating) leads to an average coating performance and the second (long term coating) is a coating selected and applied so that it results in a longer service life. The approach is illustrated in Figure 1.

First, a 'good' coating condition is defined as the strategies imply to keep the coating 'good' over a life span of 25 years. Subsequently the resulting coating degradation or corrosion wastage over time is defined for both strategies. In order to be able to express this evolution, a corrosion index (CI) was used. With this corrosion index, the coating degradation is translated into one figure only. From this we obtain the degradation over time visualised in regression curves.

The comparison itself will be an economic assessment. Ship owners will only be interested in the use of a long term coating, with a higher application cost than the average coating, if it becomes financially beneficial over time. Therefore, the economic assessment will compare the coating costs of two vessels of which the ballast tanks have different coating strategies. For a proper comparison, an identical coating condition after a certain life span is put forward, namely "good" for a life span of 25 years.

2.2 CORROSION WASTAGE

Building models of physico-chemical processes has many purposes. They are of help to an engineer in the industry as much as to a researcher in a laboratory. Models are a tool to predict what may happen in the future (Nešić, 2007).

Corrosion models can be subdivided in different categories ranging from very simple to complex, such as linear models (Southwell, Bultman & Hummer, 1979), trilinear and power models (Melchers, 1998), the model of Guedes Soares & Gorbaotov (Soares & Garbatov, 1997), the Qin & Cui's model (Qin & Cui, 2003) and finally the most complete, the Melchers' physically based model (Melchers, 2003) for steel immersed in seawater (Luque, Hamann & Straub, 2014).

All the models above take into account a phased evolution of the corrosion process. Lyuben, Spencer & Ge (2003) stated that when considering reasonable simplified assumptions, the corrosion process of coated steel proceeds in 3 phases. The first phase (0 - T_1) is when the protective coating is intact and there is no corrosion wastage of the structure. The second phase (T_1 - T_2) is a gradual acceleration of the corrosion. Implicating that every year more surface will corrode than the amount of surface that corroded the year before. In the final phase (> T_2) the corrosion rate reaches its maximum. At this moment the corrosion rate is constant over the ship's lifetime, implicating that every year a same amount of surface will corrode.

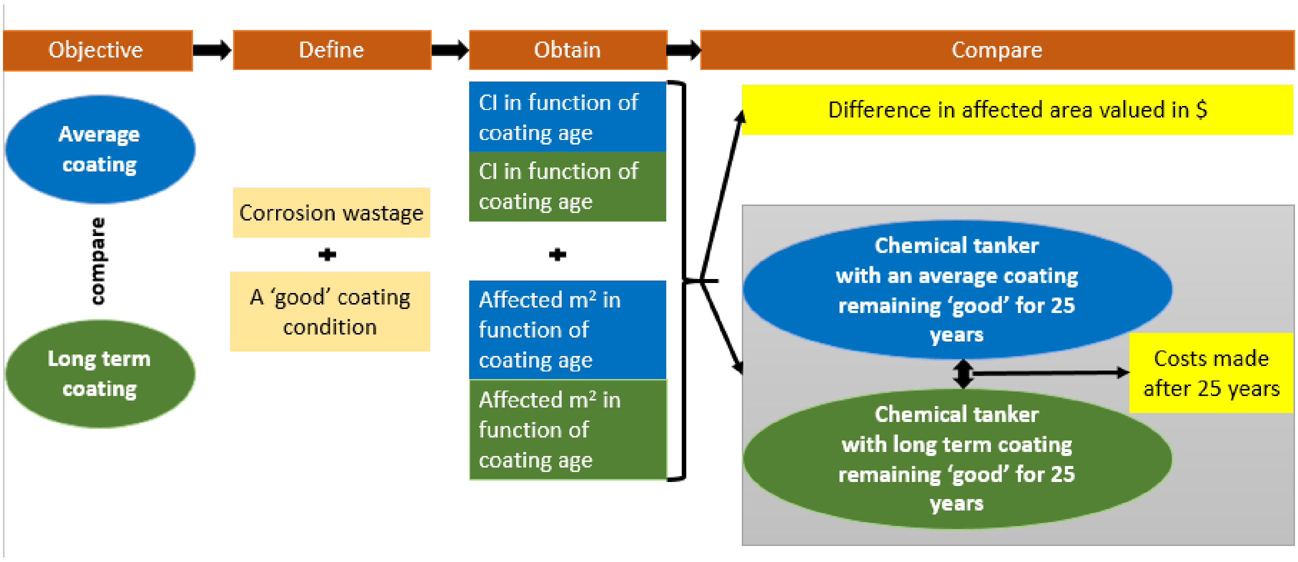

Figure 1: Schematic overview of the methodology used

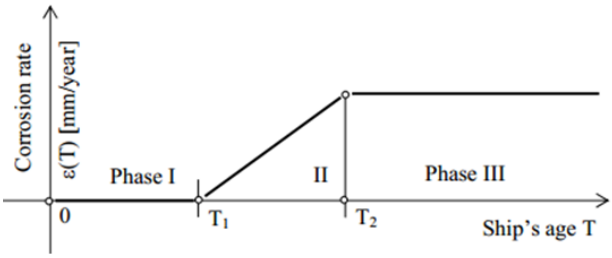

Figure 2: Corrosion rate versus ship's age, 3 distinctive phases. Phase I: no corrosion wastage, phase 2: gradual acceleration of corrosion, phase III constant corrosion rate (Lyuben et al., 2003)

The corrosion wastage or total corroded surface at any time, equals then the area under the curve of Figure 2.

$$\delta(T) = \int_0^T \varepsilon(T)\,dT$$

(Lyuben et al., 2003)

with: δ(T) = corrosion wastage at any time in mm

ε(T) = corrosion rate in mm/year

Corrosion is inevitably present on board of a ship and the amount of corrosion depends on the coating age. Limiting the corrosion wastage will extend the lifespan of a vessel.

The Performance Standard for Protective Coating (PSPC), adopted by the International Maritime Organization (IMO) Resolution MSC.215 (82), became mandatory on 1 July 2008 for dedicated seawater ballast tanks on all types of ships of not less than 500 gross tonnage and for double-side skin spaces arranged in bulk carriers of 150 m in length and upwards. The $PSPC_{15}$ standard set out a target useful coating life of 15 years, over which the coating is intended to remain in "good" condition from initial coating application.

The Tanker Structure Co-Operative Forum's (TSCF) guidelines for ballast tank coating systems and surface preparation is the conclusion of a study, based on experiences of coating lives and cross referencing these with the various application standards used. The design life specifications are designated as $TSCF_{10}$, $TSCF_{15}$ and $TSCF_{25}$. Following these specifications, it is intended to provide coating systems with life expectancies of not less than 10, 15 and 25 years respectively. Here the life of the coating is considered effective until the coating degrades, by normal wear and tear, to a "poor" condition as defined by IACS in the Enhanced Survey Program (ESP) (Shell, 2000).

In practice, comparing the difference between the 15 year system specification and a 25 year system specification is mainly surface preparation & edge grinding, more attention to application conditions with an increase in dry film thickness from 320 to 350µm and three full spray coats (+ three stripe coats) instead of two.

Table 1 stipulates the main differences between $PSPC_{15}$ and $TSCF_{25}$. For a complete overview please consult IMO resolution MSC.215 (82) and the TSCF guidelines for ballast tank coating systems and surface preparation (Shell, 2000).

Ballast tanks of 162 randomly chosen ships, including 21 ships owned by a company (further on designated as "X") with an excellent reputation in ballast tank performance, were investigated between 2007 and 2015 according to the protocol presented in Verstraelen et al., (2009) and De Baere et al., (2014). Except for the series of ships owned by company X, no selection criteria whatsoever were taken into account and the ships were visited as the opportunity arose. Owner "X" is able to obtain this good performance by using more demanding standards than $PSPC_{15}$. $TSCF_{25}$ is catalogued under more demanding standards.

The corrosion wastage of the water ballast tanks on board of the 162 ships has been assessed. The corrosion wastage was expressed as a corrosion index (CI) which was weighed based on ascertained local breakdown on edges and welds. The corrosion on the edges was used as a quantifier for the later defined distributive keys (Verstraelen et al., 2009).

Establishing the CI, every tank was divided into a maximum of three levels. For each level (1 [top], 2 [middle], or 3 [bottom]), the percentage breakdown of the coating was visually inspected and compared with a list of reference images. The reference images and values are based upon internationally used standards. (ABS, 2007), (IMO, 2009), (IACS, 2015).

Three separate values were noted for each level:
1. The percentage of corrosion on the flat surfaces (%)
2. The percentage of corrosion on edges and welds (%)
3. The percentage of the quantity of rust scale (%)

The percentages of corrosion on the flat surfaces, edges, and welds and the quantity of rust scale were each translated into a single figure or CI (Verstraelen et al., 2009) as follows:

1. The area of rust scale was included in the breakdown of coating on the flat surfaces and named "breakdown of coating or area rusted".
2. The percentages of "breakdown of coating or area rusted" (CP) and "local breakdown of coating or rust on edge or weld lines" (CE) were weighted using the following distributive keys based on the percentage of edge corrosion:
   - If CE < 20% then CI = (0.85 ×CP) + (0.15 ×CE)
   - If 20% ≤ CE ≤ 40% then CI = (0.725 ×CP) + (0.275 ×CE)
   - If CE > 40% then CI = (0.60 ×CP) + (0.40 ×CE)

Table 1: Differences $PSPC_{15}$ & $TSCF_{25}$ (TSCF, 2000)
* Most important difference between $TSCF_{25}$ & $PSPC_{15}$

	PSPC15	**TSCF25**
Primary surface Preparation:		
Blasting and profile	Sa 2 ½, 30-75 micron	Sa 2 ½, 30-75 micron
Blasting abrasive	No guidance	Some guidance
Soluble salt limit	50 mg/m	30 mg/m
Pre-construction primer:	Pre-qualified shop primer	Ethyl-zinc-silicate
Block holding primer:	No guidance	Not acceptable
Secondary surface preparation:		
Steel condition	Preparation grade P2, Three pass edge grinding.	Preparation grade P2, edge grinding to radius
Block joints*	Sa2.5	St3
Salt limit for secondary S.P.	50 mg/m	30 mg/m
Surface treatment	Sa 2 ½ on damaged preconstruction primer and welds, Sa2 on intact pre-construction primer removing 70% of primer.	Sa 2 ½ for full area
After erection	Butts St3 or better or Sa 2 ½ where practicable	Butts and damages Sa 2 ½
Profile requirements	30-75 micron or as per coating requirement	As per coating requirement
Dust	“1” for dust sizes class “3”, “4” or “5”	“1”
Salts after blasting / grinding	50 mg/m	30 mg/m
Bellmouths	No guidance	Extra protection for the area under the bellmouth by reinforced coating or increased thickness
Painting Requirements:		
Minimum surface temp.	R.H.<85% & surface temp min 3° above dew point, only specified during coating, not while curing.	R.H. max. 60% Minimum +10°C, at all times.
Thickness requirement	320 mic dft minimum	350 mic dft minimum
Coating type	Light colour epoxy	Light colour epoxy
Number of coats	Minimum two full stripe coats followed by two full spray coats	Minimum three full stripe coats followed by three full spray coats.

Following the in-situ observations an average coating and a long term coating is identified by regressing the corrosion index (CI) on the coating age (in years). The impact of the regression curves is analysed by comparing the average CI (or affected area) for the general average coating, to the average CI (or affected area) for the coating of company X (long term coating) at any moment in time. The difference between the two coatings (average versus long term) is valued. This is referred to as the depreciation or the avoided costs of a long term coating.

For the translation of the CI into an affected area, a coated ballast tank area of 90,000m (representing a chemical tanker with a summer deadweight of 37,000MT, a length over all of 170m and a breadth of 32m) is considered.

The value of the avoided costs is defined as the investment at any given moment in time equal to the cost necessary to recoat the extra corroded area of our traditional coating compared to the long term coating. The recoating cost is set at 60 USD/m after consulting the pricelist of some major dry-docks, the principles brought forward in “Guide to ship repair estimates” (Butler, 2000), coating producers and experienced coating inspectors. The costs of staging, sandblasting, removal of grit, tank conditioning, coating application, removal of staging, time charter equivalent is taken into account as well as the cost for renting the dock.

2.3 COATING CONDITION

Ship owners are not only pushed by international legislation (IMO, 2009) but also by commercial needs in preserving a good reputation, to keep the ballast tanks of their vessels in a “good” condition to avoid extra inspections and costs.

A “good” coating condition is put forward by various institutions. IACS states that the recommended short, medium and long term maintenance (e.g. 5, 10 and 15 years’ target lifetime respectively) is to either maintain or to restore “good” coating conditions (IACS, 2015). IMO PSPC

MSC.215 (82) states: "*This standard is based on specifications and requirements which intend to provide a target useful coating life of 15 years, which is considered to be the time period, from initial application, over which the coating system is intended to remain in "good" condition.*" Cargo owners reject ships because the coating in the ballast tanks does not meet IACS "good" requirements as interpreted by the class surveyor, even if the structure is entirely sound (Eliasson, 2003).

A coating is defined "good" when noticing spot rusting on less than 3% of the area under consideration without visible failure (breakdown) of the coating. Rusting edges or welds should be less than 20% of edges or weld lines in the area under consideration. This definition results from the IMO standard which is illustrated in Table 2.

Table 2 is not explicit and consequently open for discussion. Firstly, it is not clear if the three ratings/conditions have to be considered separately or in combination. Secondly, a straightforward definition of "the area under consideration" is missing. According IMO's Maritime Safety Committee, MSC.1/Circ.1330, 4.2, 11 June 2009, "areas under consideration" are areas small enough to be readily examined and evaluated by the surveyor. However, the areas subdivided should not be so small as to be structurally insignificant or too numerous to practically report on.

This unstable definition gives a class surveyor a lot of room for personal interpretation. At the same time this encumbers him with a big responsibility, seeing the consequence of ranking tanks as "fair" or "poor" instead of "good" has huge financial and practical implications. Coming into the "fair" region entails that the inspection program of the ballast tanks becomes more stringent, which can be understood from Table 3. The inspection regime will change from the dry-dock periods to a yearly regime.

Translating the IMO guideline coating conditions scale into the CI, the boundaries of the fair regions were taken as follows:

Minimum Fair condition: CP 3% + CE 20% thus CI = 8%
Maximum Fair condition: CP 20% + CE 50% thus CI = 32%

This results in Table 4.

Table 2: IMO guidelines "GOOD", "FAIR" and "POOR" coating conditions (IMO, 2009)

	GOOD (3)	FAIR	POOR
Breakdown of coating or area rusted (1)	< 3%	3 – 20%	> 20%
Area of hard rust scale (1)	-	< 10%	≥ 10%
Local breakdown of coating or rust on edges or weld line (2)	< 20%	20 – 50 %	> 50%

Notes:
1 *% is the percentage calculated on basis of the area under consideration or of the "critical structural area"*
2 *% is the percentage calculated on basis of edges or weld lines in the area under consideration or of the "critical structural area"*
3 *spot rusting, i.e. rusting in spot without visible failure of coating*

Table 3: Surveys prescribed according to IACS Rec. 87. S: special survey, I: intermediate survey, A: annual survey (IACS, 2015)

Coating condition	Surveys (Internal inspection)															
GOOD	S			I		S			I		S			I		S
FAIR or POOR	S	A	A	I	A	S	A	A	I	A	S	A	A	I	A	S
Vessel age	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Table 4: CI % translated into the IMO guideline coating conditions scale. CI is corrosion index

	GOOD	FAIR	POOR
CI	< 8%	8 – 32%	> 32%

2.4 ECONOMIC ANALYSIS

The economic analysis compares the coating costs made to have two ships in a "good" coating condition during the lifespan of 25 years when each use a different strategy, namely the average coating performance and a more demanding standard in accordance with a long term coating strategy (i.e. $TSCF_{25}$).

The consequences of sailing with a ship with ballast tanks in an IACS "fair" condition are significant. Time and money consuming coating surveys come at a yearly interval instead of once every 5 years. Freight will be lost since certain cargoes will not be loaded because the ship did not pass vetting inspections even if the structure is entirely sound (Eliasson, 2003). Safety and environment are compromised.

Cost and benefits (avoided costs) of the long term coating are analysed over the life span of a vessel when compared to the average coating.

As basic premises, the model ship selected for this study is a chemical tanker with a summer deadweight of 37,000MT, a length over all of 170m, a breadth of 32m and 90,000m of coated ballast tank. The same ballast tank surface is being considered as formerly used to define the depreciation between the regression curves.

The first cost to be taken into consideration is the initial application cost of the coating upon newbuilding of the vessel. Consulting owner "X", coating producers and experienced coating inspectors, the initial coating costs are rated as follows:

- average coating = "standard" coating ($PSPC_{15}$ was considered) 40 USD/m
- long term coating = "excellent" coating (following the input of company X, $TSCF_{25}$ was considered) at 50 USD/m .

This leads to an initial average coating cost equal to 3,600,000 USD and the long term coating cost comes down to 4,500,000 USD.

Each coating system has a lifespan. The end of the "good" coating condition and thus the start of the "fair" coating condition is considered within this study as the end of the coating's service life. Consequently, in case a ship enters the "fair" condition prior to the age of 25, recoating in dry dock will be taken into account. The value of recoating is again set at 60 USD/m^2 (similar to part 2.2).

Finally ballast tank maintenance must be considered. The most unidentified factor is the "on-board" coating maintenance cost effected within the ballast tanks. The guidelines for maintenance and repair of protective coatings states that "*Maintenance means minor coating restoration work regularly performed by a ship's crew using normal shipboard means and tools to maintain "good" or "fair" coating conditions. Maintenance delays or slows down the coating deterioration and effects short term steel protection.*" (IMO, 2009). Consequently, with onboard maintenance one can try to maintain its IACS classification "good" or "fair", but it will not upgrade your classification to a higher level. The fact that onboard maintenance may only be a very short term barrier to slow down coating deterioration is supported by ABS stating that "*Ship operators traditionally carry out maintenance of coatings while at sea by the crew. Studies have shown that this type of maintenance has limited efficacy. This has been attributed to a variety of practical reasons including dirty surfaces, non-performance of coatings, inability to provide even coatings and others. These reasons ignore the critical performance issue: the structure is in working mode (in stress cycles and corresponding deflections) and as such the coating cannot perform as it cannot properly cure due to the disturbances introduced by the vessel's motions"* (Contraros, 2003).

The quotes stress even more the importance of a good coating application in order to obtain an excellent coating performance. Written confirmations of relevant ship-owners suggest that on average shipboard coating maintenance in ballast tanks is minimal to non-existent. Our own observations of 162 ballast tanks surveys revealed very sporadic touch-ups and thus maintenance is not taken into consideration for the traditional coating.

On the contrary, company "X" puts maintenance as a top priority, sailing with crews far in excess of the minimum manning. This in order to keep the ship in showroom condition and thus passing vetting inspections with flying colors. This excellent coating performance can partly be attributed to an intensive on board maintenance program. By maintenance we mean touch-up of local damages, regular de-mudding, rinsing with fresh water and cleaning of the anodes if present. Traces of coating touch-ups were regularly observed. We assume that on board the "X" ship ballast tank coating maintenance is standard routine. Following discussions with former "X" employees, observations on board and own deductions using the International Labor Organization (ILO) salary wages, we concluded that on average 25,000 USD per year is a realistic cost for the on board ballast tanks coating maintenance for the long term coating strategy.

Within this study the inflation % is based on the Long Term U.S. Inflation since 1913 (McMahon, consulted 02/2015). The discount % is based on the average Weighted Average Cost of Capital (WACC) of some important shipping companies as shown in Table 5.

The economic assessment concludes a sensitivity analysis as some uncertainties were noticed. Discussion with tanker companies indicated that the ILO salary wages are not always representing the actual salaries. Literature study revealed a variety in figures as to the recoating/refurbishing cost in dry dock. These uncertainties were consequently incorporated in the model.

Table 5: WACC of some major shipping companies

	WACC	Year	Source
Teekay Cooperation	7.8%	2012	11th Annual German Ship Finance Forum
Golar LNG	8.9%	2012	11th Annual German Ship Finance Forum
Seaspan	6.7%	2012	11th Annual German Ship Finance Forum
Euronav	7.4%	2012	Annual report Euronav 2012
CMB	9.4%	2013	Annual report 2013
AP Moller Maersk	9.0%	2013	Credit Suisse
Overview	8.0%	2011	Audi Capital The shipping Industry – Navigate with the flow
Average	8.2%		

3. RESULTS

3.1 AVERAGE AND LONG TERM COATING PERFORMANCE

Figure 3 shows the CI as a function of the time after coating application of the surveyed ballast tanks. Only 157 ships, for which the date of application of the coating is known, were taken into consideration.

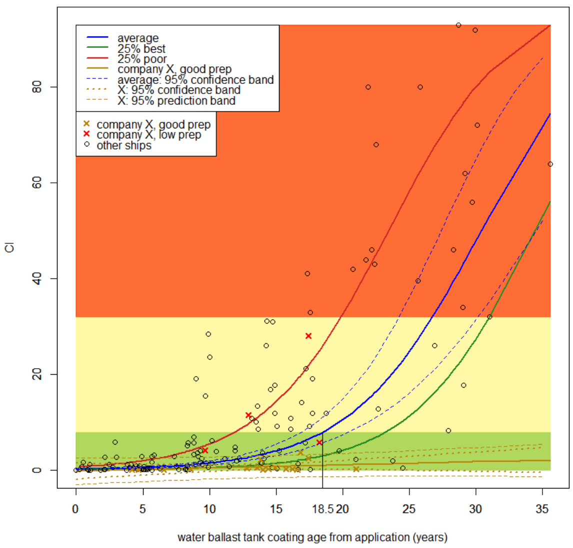

Figure 3: Corrosion % as a function of time after coating application. Blue, red and green using a logistic model. Yellow using a linear model. Blue curve gives average trend line for all 157 vessels (including those of company "X"), green curve shows the 25% best performing vessels and red line the 25% poorest performing vessels. The yellow and red x indicate ships owned by company "X"; the yellow curve is the (extrapolated) linear model for vessels with a long term coating. Definition of "good" using the CI and a visualizing the performance of long term coating within the "good" definition. The dotted lines give the 95% prediction band.

Inspecting the logistic corrosion wastage evolution of the average coating from our database (blue line in Figure 3), we notice that the coating starts to degrade slightly after 5 to 6 years, thus outlining the position T_1. The first 5 to 6 years the coating will age and might show minor rust, but no significant increase in the corrosion rate is identified. After T_1 a clear increase in corrosion rate is detected and around the age of 26 years this increase stabilizes, becomes constant, indicated by the linear continuation of the blue curve. This shows a clear similarity with the trend of the corrosion rate versus the ship's age as suggested in Figure 2. The parameters of the logistic models are statistically significant at the 95% level.

The average of the 25% poorest performing coatings is illustrated by the red line in Figure 3. In this case there is no significant phase 1 (period of intact coating condition). Using the assumption of a negligible CI below 0.5% and using the logistic trend, a CI below 0.5% is never obtained. The transition between phase II and phase III (phase III being the linear growth) occurs at the age of about 20 years.

The green line represents the average of the 25% best performing coatings. Here, the end of phase I can be set around 10 years after coating application; more specifically it is calculated to be 10.1 years when we assume a negligible CI below 0.5%. Phase III is reached after around 30 years.

Following the inspections performed on the 157 ships/coatings, 21 ships of a distinct ship owner "X" with a long term coating strategy could be identified, visualised by the yellow and red crosses in Figure 3. Company "X" has an outstanding reputation when it comes to the selection and application of coatings. The effect of his approach is obvious, seeing the position of the yellow crosses as indicated in Figure 3. The yellow crosses are clearly indicating a performance as good as or even better than the overall 25% best performing vessels from the database. The four red crosses are also vessels owned by "X". As these were either bought second hand or the stringent coating selection and application conditions could not be met, they deviate from the other vessels from the "X" fleet. Seeing that the coating for these off-cases was not controlled by company "X", these cannot be considered in this investigation to validate the importance of a good coating selection and application.

In order to be able to define the corrosion wastage and rate of the long term coating, a linear regression was used based on the observations of company "X". As the CI of those vessels hardly increases over time, a logistic model cannot describe the trend for vessels with a long term coating. The linear model for company "X" shows a slight increase of CI over time, at a rate of 0.07% per year.

For company "X", data on older ships are scarce: only one vessel has a coating aged more than 20 years (21 years). Hence all predictions for the long term coating after 25 years are based on an extrapolation of the regression curve. For this reason the 95% prediction band for the linear regression of company "X" was included on Figure 3 (dashed yellow line). This prediction band stays entirely below a CI of 8, even after 35 years. If we adopt the linear model, we may assume that vessels with a long term coating will remain in "good" condition for more than 25 years.

Comparing the linear regression line for company "X" with the logistic model for all vessels, we notice that the long term coating strategy promises an important reduction of the corrosion rate. This means that the coating is more sustainable and thus more resistant to corrosion. A long term coating can consequently be defined as a well selected coating applied with care and according to high standards. As this definition of a long term coating is established based on in-situ expertise, it is hereby proven that maintaining a long term (lifetime lasting) coating is possible for ballast tanks. It is a matter of selecting a good coating and above all applying it with the necessary care when it comes to application parameters.

In general coatings are applied according to $PSPC_{15}$ which targets a coating useful life of 15 years, over which the coating is intended to remain in a "good" condition from initial coating application (Wei et al., 2011). Figure 3 shows that the average ship transfers from "good" to "fair" condition after approximately 18.5 years (95% confidence interval for CI after 18.5 years is [5.67 ; 10.98]). This implicates that the average vessel meets the objectives of $PSPC_{15}$. It should be noted that the latter also implicates that a lot of ships do not meet with the $PSPC_{15}$ requirements. For the logistic model on all 157 ships, the mean CI at 15 years is 4.02 with a one-sided 65% prediction interval of [0 ; 7.7]. This implies that more than 65% of all vessels are expected to remain in "good" condition (CI < 8) for at least 15 years. Ships are built with an economic life expectancy of typically 25 years and consequently $PSPC_{15}$ may not suffice. Therefore, a "good" $PSPC_{15}$ coating will only be maintained during the entire lifetime when the entire ballast tanks are recoated upon dry docking prior to reaching the fair status, implicating around 15 years. Figure 3 illustrates that owner "X**"** is able to maintain a "good" coating condition throughout a life span of 25 years and longer. The linear trend (yellow line) is the best possible model for the data at hand, but exact values for the age of 25 years must be used with caution. Nevertheless the extrapolated linear regression line gives a good impression of the evolution to be expected and predicted values for the age of 25 years stay well below a CI of 8, with a probability of 95% Hence we may assume that owner "X" will be able to keep his vessels in "good" condition even after 25 years, thanks to the use of more demanding standards.

An example of such a standard is for instance $TSCF_{25}$**.** The coating performance of company "X", will be referred to as the long term coating performance.

Figure 4 shows the regression curves, namely the logistic trend (blue line) of the traditional coating and the linear trend (orange line) of the long term coating. When considering a coated ballast tank area of 90,000m the regression curves can also be expressed in affected area in m^2 (left axis), in addition to being expressed in % CI (right axis). This is depicted in Figure 4.

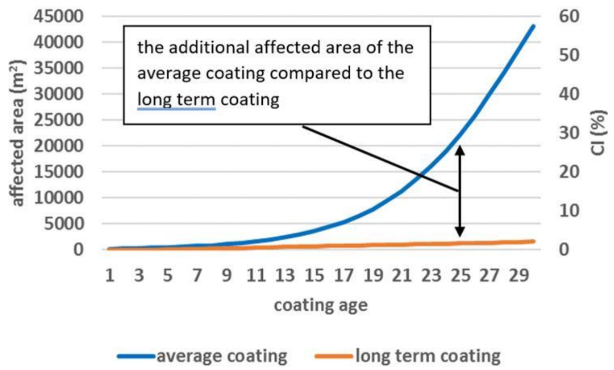

Figure 4: Regression curves of the average coating degradation versus the long term coating degradation expressed in affected area (considering 90,000m ballast tank area) and expressed in CI.

Without taking into account inflation and discount the avoided costs or benefit of a long term coating is 1,261,261 USD at the age of 25, measured as the difference between the blue and orange line in affected area multiplied with 60 USD per m^2.

It should be noted that it is impossible to only recoat the affected spots. The affected area, resulting from the corresponding CI, represents the sum of all locally corroded spots/areas. In order to recoat a corroded spot one should treat an area which is much larger than the rusted spot itself. Only performing refurbishments of the affected areas will locally ameliorate the condition but the surrounding coating is still aged and will rapidly deteriorate. Only full blasting and recoating is able to place the timer of the coating lifespan back to zero.

3.2 ECONOMIC ASSESSMENT

An average ship with an average ballast tank coating slips into a "fair" condition at the age of 18.5 years. In order to obtain a 'good' coating life of 25 years, the average coating will be recoated in dry dock at the age of 15. Each classed vessel is subjected to a specified programme of surveys based on a five-year cycle. At the end of this cycle a class renewal/special survey is held, which coincides with a dry dock inspection. Following this general survey regime recoating at the age of 15 was put forward and not at the age of 18.5. This can be compared to a ship coated according to $PCPC_{15}$. Following IMO $PSPC_{15}$ a useful coating life of 15 years is put forward. This demands that the ballast tanks will be recoated at 15 years, when in dry dock. As explained previously, maintenance is not included for the average coating strategy.

Company "X" demonstrates (see Figures 3 & 5) that a lifetime protection of ballast tanks is possible by using a well selected coating and an application without compromises. The company is able to maintain a "good" coating condition of his ballast tanks up to the age of 25 and beyond and thus may be considered as a "good" reference standard. This long term coating strategy can be compared to a ship with ballast tanks coated accruing to $TSCF_{25}$. Here dry-docking is not necessary, however maintenance is considered.

In this economic assessment of the long term coating, the avoided costs (=benefits) are compared with the initial additional coating costs and the additional maintenance costs of long term coating.

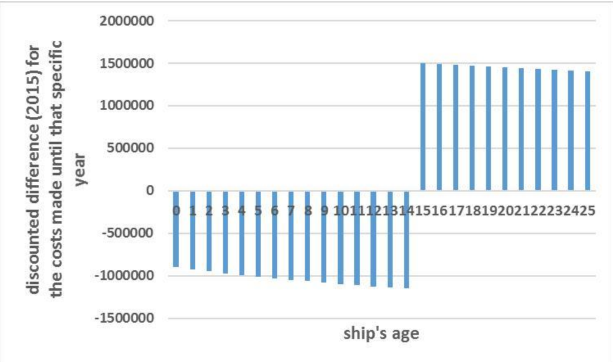

Figure 5: Difference of the costs between long term coating and average coating, expressed in USD, spent to have both ships in the "good" condition during its lifetime. (inflation 3.2% and discount rate 8.17%; 100% of the coating replaced during the 15 year dry-dock at a cost of 60 USD/m^2, 25,000 USD/year on ballast tanks maintenance spent by "X").

Figure 5 shows that coating repairs during dry-dock are an overwhelming factor. The blue bars with negative values implicate a more expensive long term coating, whilst the blue bars with positive values implicate a more expensive average coating. Knowing that a 100% recoating replacement is necessary to guarantee a "good" condition, a long term coating is clearly the best solution with a difference in cost of 1,407,834 USD (3,875,000 USD in case of non-discounted values), when envisaging a lifetime of 25 years.

Following discussions with tanker companies we learned that the ILO salary wages are not always representing the actual salaries, which brings our calculation to a possible maintenance cost of about 35,000 USD/year. On the other hand, from literature study (OceanSaver, 2011) we conclude that touch-ups/maintenance can also be much cheaper. Therefore, a sensitivity analysis with maintenance costs of 15,000; 25,000 and 35,000 USD was applied as illustrated in Table 6. As to the recoating/refurbishing cost in dry dock, we notice a variety in figures ranging from 40 USD/m^2 (OceanSaver, 2011) to 60 USD/m^2 (Safinah, 2007) and even up to 100 USD/m^2 (Kattan, 2010); again a sensitivity analysis was used, ranging from 40 to 80 USD/m^2.

Table 6: Difference in costs with discounted and non-discounted values for ships aged 25 years with a variation in the recoating cost in dry dock of the average coating strategy and the maintenance costs of a long term coating strategy

Recoating cost for the average coating strategy	Maintenance cost for the long term coating strategy	Difference: average coating cost minus long term coating cost USD/year	
USD/m^2	USD/year	index = 0% discount = 0%	index = 3.2% discount = 8.17%
40	15,000	2,325,000	662,486
40	25,000	2,075,000	518,908
40	35,000	1,825,000	375,331
60	15,000	4,125,000	1,551,411
60	25,000	3,875,000	1,407,834
60	35,000	3,625,000	1,264,257
80	15,000	5,925,000	2,440,337
80	25,000	5,675,000	2,296,760
80	35,000	5,425,000	2,153,183

4. CONCLUSION

$PSPC_{15}$ is developed to guarantee a coating in IACS "good" condition for at least 15 years. In-situ investigations learned that on average, a ship with an average traditional ballast tank coating slips only into a "fair" condition at the age of 18.5.

The ballast tank condition is a crucial element during vetting inspections. If the tanks are in a "good" condition the ship-owner will have access to better paying cargoes.

However, the advantages of a ballast tank coating well applied, maintained and repaired go beyond economic considerations. If less coating has to be applied less toxic components will find their way to the marine environment and less volatile organic compounds will be expelled into the atmosphere.

When a traditional ship owner envisages to sail with "good" ballast tanks for more than 18.5 years, a full recoat is necessary. Following a general survey regime this will take place at 15 years of age.

Figure 5 demonstrates clearly that if a ship-owner sails 15 years or less with his ship, $PSPC_{15}$ will always be the cheapest solution. Expensive coating application and maintenance are only making sense if the ship-owner sails for extended periods with his ships (cradle to grave policy).

If ballast tank coatings become more sustainable there will be less need for coating repair and ship building improving the impact of shipping on the environment.

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