1985

Economical aspects of hull paint system

Djebaili Bernard
World Maritime University

ECONOMICAL ASPECTS

OF A HULL PAINT SYSTEM

)

)

THESIS

by Djebaili Bernard
Maritime Education Engineering
July 1983 - July 1985
Course Professor: C.E.MATHIEU

Approved:
Charles E. Mathieu

ABSTRACT

The paper discusses the economic advantages of self-polishing antifouling copolymers on advanced antifouling paints. The Average Hull Roughness is introduced in a mathematical model to quantify the fuel-oil savings on a 150 000 dwt tanker. A computer simulation model for the comparison of wetted hull surface management is described. The Net Present Value concept is utilised to assess the most economical alternative on both new building and existing ships. It shows that self-polishing copolymer paint, despite its higher investment price, challenges other paint systems at today's marine fuel-oil price.

TABLE OF CONTENTS :

I PREFACE :

The study I am presenting here is not an attempt to determine concisely which paint system is most economical for a given ship but rather presents the methods to use in making such a determination when specific detailed input data is available.

The economical recession which began in 1973 has and will continue to make the energy users more aware of the fact that marine fuel-oil cost takes a large part of the total ship running cost.

Thus,the main objective of the following development is to produce a data-based program which takes into consideration the inter-connection between a hull paint system and the global ship running cost.The program is composed of several sub-programs providing a means which eases an otherwise tedious and laborious economical study based on the Net Present Value concept. This shows the time elapsed before a more expensive alternative starts to be profitable.

II INTRODUCTION :

The total cost of hull roughness of the United-Kingdom's Merchant Fleet in terms of extra fuel-oil needed to maintain the new ship speed and assuming no fouling, has been evaluated by a team of the University of Newcastle upon Tyne -1980- to £ 400 Million per year, taking an initial hull roughness of 125 um MAA and an annual increase of roughness of 25 um and an average fuel cost of all types burnt of £70 per ton .

A similar study was also done to evaluate the extra fuel cost due to both roughness and fouling of the Royal Navy fleet and is approaching 20% .

Undoubtedly, hull bottom roughness and fouling are two parameters which play a significant role in a ship running cost . Shipowners cannot indefinitely neglect the fact that a well controlled hull roughness is synonymous with consequential savings .

In the following, I am tackling the possible savings which can be earned if a proper and adequate paint system is chosen on a VLCC vessel. The hull paint system will be limited to: (i) an advanced antifouling paint, (ii) a self polishing copolymer. However, due to the sophisticated and different quality of each of those named above, the program should allow alteration of data whenever it might be needed in order to approach the reality as near as possible . This would give one a more flexible program .

The study includes new ships as well as existing ones.

Energy conservation is widely dependent on four main factors which are:

1. Hull efficiency improvement
2. Engine efficiency improvement
3. Propulsion efficiency improvement
4. Operational improvement

The last three factors will not be in the scope of this work. However, the first factor i.e. Hull efficiency improvement is itself dependent on two parameters :

(i) Frictionnal resistance
(ii) Residual resistance

The latter has much to do with the hydrodynamic form of the hull while the former is directly concerned with the phenomena of fouling and roughness .

The marine field people have known for centuries that fouling roughness caused by marine growths is responsible for a decreased ship's performance.

Today, research work is showing that fouling roughness is not the only parameter producing ship performance changes but also the hull roughness which has much to do with the plating material itself, the paint quality and behaviour etc...

It is this latter consideration I intend to develop i.e. what are the influences of hull roughness on ship economics ?

III HULL ROUGHNESS :

Hull roughness embraces not less than four components . These four components are successively :

(i) Plating

(ii) Paint/Coating

(iii) Corrosion

(iv) Fouling .

(i) The plating

The plate roughness is the initial roughness of the bare metal used for shell plating , right from the steel-mill factory . It should be noted that nothing can be done in this area unless new materials are found or much more expensive materials with smoother surface are employed in ship building .

(ii) The paint/coating

The paint/coating roughness represents the additional roughness added by the application of various anticorrosion and antifouling paints or coatings and is highly dependent on the type of coatings, the application techniques and the quality of workmanship during application .

(iii) Corrosion

The corrosion roughness represents the increase in hull roughness caused by surface pitting and cracking in areas where anticorrosion measures have failed .

(iv) Fouling

The fouling roughness represents the marine growths on hull surface wether or not protected by antifouling paints - if antifouling coatings have failed or exceeded their effective life - .

IV ROUGHNESS QUANTIFICATION

The measure of hull roughness used in this paper is the so-called AVERAGE HULL ROUGHNESS ,AHR expressed in microns per 50 millimeters - um/50mm - .

At some 100 or more positions evenly spread over the hull wetted surface the Mean Hull Roughness , MHR, is measured from about a dozen 50mm sampling lengths . The average of the MHR values is the Average Hull Roughness .

Where the measurement positions have not been uniformly distributed over the bottom and sides , some weighting may be necessary in the averaging process .

The MHR is obtained from the separation of two parallel lines touching the highest peak and lowest trough in each 50mm sample . In recent measuring instruments this slope is judged by a skid surrounding the measuring probe which is then able to measure and output the peak to trough separation directly , thus avoiding the manual analysis of smoked glass slides using a freehand envelope curve judged by eye .

The BSRA's method is one way of approach of quantifying the hull surface topography. It is certainly a good step to evaluate the roughness effect on the ship's power. But one has to consider that although the BSRA's method is based on statistical computation it is not yet the best solution to hull roughness identification. As a matter of fact, two equal AHR might not necessarly represent two identical configurations. Figure 2 shows two surfaces of different topography but of equal AHR. Because of those differences, a correction factor should be included while determining the hull roughness effect on ship power. In the following study this correction factor is not taken into consideration.

V FOULING ROUGHNESS EVOLUTION

grasses which initially appear in the fouling process and non-pliant fouling represented by higher level organisms such as barnacles , which require a suitable fouling substrate prior to attaching themselves to the hull .

The hull fouling roughness is evaluated taking into account the following parameters :

(i) Antifouling coating effective life if any
(ii) Ship's time in port
(iii) Port fouling severity .

Each type of antifouling coating has a particular effective life depending upon the toxicant concentration and efficiency .

The fouling caused by time spent in port is highly depending upon the length of the stay and the port fouling characteristics . The latter factor is easily determined as data of port fouling factor coming from long date observations are nowadays available from all the measure ports all around the world .

This fouling aspect will merely be incorporated in the ship's trading pattern i.e. the number of day in port or anchorage and the geographical operation by choosing the proper toxicant grade of the antifouling . Days at sea are not taken into consideration as it has been worked out that fouling do not occur if the ship's speed exceed 3 knots .

Once fouling occurs , it is rather difficult to make an assessment of the fouling grade . The effect of fouling on ship's power is not yet precisely defined and research work based on widely collected data information should lead in a near future in an improvement of the 1978 ITTC's formula which will be touch upon further on in this study .

For the purpose of this study the assumptions of having a sound anticorrosion paint system applied on a well pretreated hull surface i.e. grit-blasted to SA 2 1/2 and with a blast-primer coat are made .

VI ROUGHNESS EVOLUTION DURING THE BUILDING STAGE

Usually the average roughness of shot blasted and primed stock plate lays between 40 and 60um/50mm. A typical wetted surface paint system has a dry film thickness of about 300um to 500um. The cause of the observed roughness of hulls prior to delivery is clearly due to the nature of the applied paint together with any inadequacies in the application process. The roughness increase is also observed after each drydocking, the new paint system being the cause. This is even true for self-polishing paint where after water washing of the old SPC and applying a new SPC, the hull roughness at the outdocking is actually higher of 25 to 30um/50mm than the indocking figure.

Table I shows the roughness history of one vessel from the shot blasted and shop primed plates, through fabrication and the various stages of painting to subsequent drydockings.

	AHR um/50mm
Shot blasted and primed plate	55
After 3 coats anti-corrosive	135
After antifouling	160
At first drydocking;indocking	160
At first drydocking; outdocking	180

Table I : Roughness during building

VII ROUGHNESS EVOLUTION OF NEW SHIPS

The hull roughness of new ships beginning service is highly dependent of the shipyard careness and the ability of handling the hull plating.

A set of data produced by BSRA for ships built between 1966 and 1975 gave a mean value of 129um/50mm, with a modal value of 125 um/50mm.

It is nowadays possible to get values of less than 100um/50mm and some shipyard argue on the possibility of delivering ships with a roughness of 60um/50mm. On the other hand, values exceeding 200 um/50mm are still encountered on new ships.

VIII ROUGHNESS EVOLUTION WITH AGE OF SHIP

The evolution of hull roughness with the age of the ship is mainly depending upon the following:

(i) the coating systems used and their performance
(ii) the cathodic protection if any
(iii)the number of drydockings and the quality of work carried out at each.

As a common rule, the AHR increases with the age of ship but the relationship between roughness and age is far to be simple. This is clearly demonstrated in fig.1 showing the wide scatter of data points. The data exclude hulls which have been fully re-blasted at any stage.

8.1 Evolution of hull roughness with SPC paint systems

The evolution of hull roughness on ships painted with self-polishing copolymers depends mainly on the smoothing and polishing rates and the anti-corrosion paint system. The smoothing rate of the best quality paint may be as high as -3um/50mm per month and the polishing rate as high as 10um. The polishing rate is generally chosen accordingly with the ship's speed pattern. A slow ship will usually have a paint which has a high polishing rate.

After each drydocking, the AHR becomes higher than the in-docking value (+25 to 30um/50mm) due to the new paint application. A five year ship has an AHR average of 150 um/50mm while a 10 year ship has an AHR average of 230 um/50mm.

8.2 Evolution of hull roughness with advanced antifouling paint system :

An average of 30um/50mm yearly increase has been reported by a BSRA study over a number of year. However, a well maintained wetted hull surface might have a figure as low as 10 to 15um/50mm increase per annum. On the contrary, a bad maintained hull may have a yearly AHR increase of up to 50um/50mm. A five year ship has as an average an AHR of 275um/50mm while a 10 year ship has an average AHR of up to 600um/50mm.

IX PAINT MATERIALS

Paint systems of a ship's wetted surface have two main functions:

(i) to protect the plating against corrosion
(ii) to avoid marine growths.

The paint manufacturers have not yet elaborate a paint which could be able to give both protections. Consequently, the ship's paint system is composed of two paint types, each one fulfilling a determined task, namely a primer system giving protection against corrosion and an anttifouling system giving protection against marine growths.

9.1 Anti-corrosion paint systems :

The ship's wetted surface steel plating is at sea subject to an electro-chemical corrosion process.

The corrosion development is relatively important due to the fact that sea water is a good electricity conductor and has a high oxygen concentration. This electro-chemical corrosion can be stopped by applying a coating working as a barrier avoiding any contact between the steel plate on one side and the sea water and the oxygen on the other side. This coating needs also to have a very high electrical resistance.

The other requirements are that it should have a very high adhesion and mechanical strength. There are todays quite a number of paints which fulfill the above requirements and the types which are prevailing are based on vinyl tar and coal tar epoxy.

To give an effective corrosion protection, those paints require however a well shot blasted surface and eventually a blast primer or shop primer paint. The surface is then given a two to four coats with a total dryfilm thickness of up to 400um.

9.2 Antifouling paint systems :

All the antifouling paints,despite their different mechanisms of action, have one thing in common: all use biocides in order to control marine growth fouling. The biocides used are mainly organotins, cuprous oxide and cuprous thiocyanate.

9.2.1 Conventional antifouling paints :

For many years ships were drydocked on an annual basis and conventional antifouling paints were applied year after year.

The mechanism of action of such paints is based on the release of biocides from a soluble rosin matrix. A flood of biocides is released as soon as the ship is launched.

The leaching rate decreases in an exponential manner and after 6 to 12 months, the release is not high enough to give adequate protection. The porous film left after the biocides leach out presents a weak substrate for the newly applied coatings. This, together with the accumulation of paint year after year, coat after coat, can give rise to detachment problems and thus increase the hull roughness of the ship.

9.2.2 Advanced antifouling paints :

This type of paints functions in a similar manner to the conventionnal paints, but gives somewhat longer protection. The film is reinforced with a strong, insoluble resin such as chlorinated rubber or vinyl resin. Paint accumulation, again, represents a problem and after a few dockings, peeling off and flaking will occur and, consequently, roughness will increase.

Reactivable antifouling paints are based on a principle similar to that named above but can provide even longer protection. The porous layer, formed as the toxicants leach out, can be easily removed by especially designed brushes, exposing a new fresh layer of antifouling. This reactivation process can be performed afloat without the need for drydocking. However, attention must be paid to the fact that in-situ brushing i.e. brushing while the ship is afloat is -no matter how carefully performed - source of fouling problems because a certain percentage of antifouling is obviously removed while brushing is carried out.

9.2.3 Self-Polishing Copolymer antifouling paint systems :

The early 1970's saw the introduction of self-polishing copolymer antifouling paints SPCs. These are based on organotin copolymers, which, unlike the conventionnal and long life antifouling paints, release the biocides in a controlled manner.

On highly sophisticated SPCs, this leaching rate is almost linear and constant. The organotin biocides are chemically bound to the polymer and are released in contact with sea water, by the hydrolysis and/or ion exchange. The remaining backbone then dissolves or is washed away, allowing a new, fresh surface to be exposed. This mechanism provides a much better and more linear rate of biocide release. Thus, the antifouling action is extended to the last layer of paint. This surface hydrolysis / ion exchange makes the antifouling protection directly proportional to the thickness of the coating. This latter characteristic allows a longer fouling free period, thus a longer drydocking interval is practically feasible.

However, an important remark has to be mentionned when it concerns the effective life time of an SPC paint system. Theoritically, it is particularly true that the antifouling protection is proportional to the dryfilm thickness of the SPC coats but a practical limit has to be set because of the mechanical property of the paint. The paint is subject to gravity force and depending on the adhesion and strength characteristics detachment problems may occur.

Today, some SPC paints are able to give a sixty months fouling protection.

This type of protection can only be offered by the self-polishing paints and the reactivable paints. The difference lays in the case of self-polishing antifouling paints, that the ship's wetted surface actually becomes smoother in operation due to the fact that turbulent water flow will have a higher effect on the dissolution of the peaks of the paint surface. Thus, a decrease in roughness is noted between that observed on a newly painted ship and the same ship returned for the next drydocking.
Figure 3 shows the different mechanisms of antifouling paints with time at sea.

X HULL MAINTENANCE STRATEGIES

A shipowner has nowadays the utmost hard task of choosing the adequate hull maintenance strategy for each particular ship of his fleet since the fleet might be composed of several different ship types or ships of the same model might operate in a different manner.

A well designed hull maintenance strategy will certainly lead to considerable savings whereas a non adequate one might be a consequent burden on the operating costs of the ship.

The large paint spectrum available today on the market makes the choice the shipowner will have to realize soon or later rather difficult. The wide variety of paints offered by each major paint makers added with the relative small feature differences within a group of paints might be somewhat bewildering.

In a hull maintenance strategy one has to define clearly the task to be accomplished by the paint system. By paint system I mean the paint quality, the paint type and the coat thicknesses applied on the outer hull. Paint systems are very much dependent on the substract i.e. the state of the bare hull surface.

XI DRYDOCKING INTERVAL

The drydocking interval i.e. the time between two consecutive outdocking and indocking may, at present, technically be extended to periods of 48 to 60 months with the paint quality available. The Classification Societies and the Governmental Agencies are in fact the new barrier to an extended drydocking interval. No matter how well preserved the wetted surface might be, other underhull features like the tailshaft sealing, the sea-water intake and outtake, the bow thruster or the rudder, are subject to control and/or maintenance which require drydocking.

Another parameter which ought to be taken seriously is the uncertainty of either the time the ship will belong to that particular shipowner or the lenght of time the ship will operate on a previously established long-term program. Those uncertainties play a great deal in terms of possible greater earnings due to proper hull maintenance strategy.

The best study one could do concerning the comparison of costs induced by various paint systems would be to take two syster ships having the same trading pattern over a period of several years. Each ship should have the same speed, the same new ship hull roughness but one having an advanced antifouling paint as a permanent paint system, the other ship having a sophisticated selfpolishing antifouling paint as a permanent paint system.

Then, the drydocking interval for each ship should be clearly defined as to avoid any fouling start which would otherwise affect our evaluation of the hull roughness as a measurable quantity. Indeed, the mathematical model of the fouling effect on ship's resistance is not yet clearly defined. Further studies and data accumulation should lead to such a model in the same aspect as the one related to roughness development.

Because of roughness development or let one say roughness increase for the ship having an advanced antifouling paint, the ship's operator will soon after drydocking notice an engine load increase. The very first months the ship's speed may easily be maintained as naval architects always provide a service power margin sufficient enough to make or exceed the designed speed.

However, after a few months the ship's resistance increase is too high to be permanently matched by the service power margin as it was commonly done before the oil crisis. A common practice was to keep a permanent engine load i.e. either by reducing the engine speed or by reducing the propeller blade area, both alternatives leading to a ship's speed loss. An other alternative is to use a controllable pitch propeller where the engine load can be kept constant by merely adapting the blade pitch. In all those previous cases keeping a constant engine load is proving detrimental to the final ship's speed. This is easily understandable as the blade pitch changes are there simply to adapt the engine to the changes of the hull resistance i.e. keeping a maximum output of the engine whereby the specific fuel consumption can be kept constant. In other words the extra load created by the hull resistance increase is subsequently changing either the ship's speed or the engine power both leading to an increase of fuel oil consumption.

On particular ships such as liners, the service power margin was still kept sufficient in order to maintain the ship's speed from its original figure, drydocking interval and fouling level being then well matched.

XII IMPACT OF HULL ROUGHNESS ON THE SHIP's PERFORMANCE

The shaft horsepower (SHP) needed to propel a ship at a given speed and displacement, includes several parameters and is the sum of:

$$SHP_{required} = SHP_{clean\ hull} + SHP_{roughness} + SHP_{wind} + SHP_{waves}$$

For ease of calculation, the variation of shaft horsepower due to changes of wind and wave pattern shall be neglected. Thus, I assume that weather conditions has no effect on shaft horsepower which is indeed absolutely wrong.

Let one then investigate the effect of roughness changes on the SHP required.

The increase of hull resistance due to fouling is a well known fact among mariners. However, the changes of hull resistance due to changes of hull roughness is somewhat new. A first estimation made by Scott and Lackenby of the relationship between roughness and power was a linear function stating that a 10um/50mm increase of roughness will cause an increase of 1%.

The International Towing Tank Conference held in 1978 has adopted the relationship of Bowden and Davison. The relationship gives :

$$\frac{P1 - P2}{P} * 100\% = 5.8 * \left[(K1)^{1/3} - (K2)^{1/3} \right]$$

where

P1 = power increment due to roughness of a rough ship
P2 = power increment due to roughness of a smooth ship
K1 = average hull roughness of a rough ship (um/50mm)
K2 = average hull roughness of a smooth ship (um/50mm)
P = total power at maximum continuous rate (MCR)

This non-linear relationship shows that power increases are more significant for changes of hull roughness of smoother hulls than for rougher hulls, which is more realistic than the previous 1% rule. However, large AHR differences tend to overestimate the roughness effect on delivered power.

Using the following formula will aim towards what is practically observed in real life :

$$\frac{P1 - P2}{P} * 100\% = 3.8 * \left[(K1) - (K2) \right]$$

The table below shows the power increase versus roughness increases using the latter formula :

K2	K1	P%	K2	K1	P%
125-	135	+.49	125-	225	4.11
135-	145	.47	225-	325	3.01
145-	155	.45	325-	425	2.44
155-	165	.43	425-	525	2.08
165-	175	.41	525-	625	1.83
175-	185	.40	625-	725	1.65
185-	195	.38	725-	825	1.50

The interpretation of the above table shows that changes of AHR of smoother hulls have a greater influence in power changes than of rougher hulls for the same changes of AHR.

Example: A 10um/50mm change from 125 to 135um/50mm increases the power with 0.49% while a 10um/50mm change from 185 to 195um/50mm increases the power with 0.38%.

One can already argue that higher savings will be made if SPC is applied on a smoother hull which is true only if a sound shot-blasting and a high performance anti-corrosion system are applied beforehand.

XIII COMPUTER SIMULATION MODEL

The simulation model is worked out on an IBM PC, 126 kbytes. Advanced Basic is the language used on the program composed of several subprograms. Table X shows the flow chart diagram of the model simulation program.

Six subprograms are computing the global cost of a paint system. They are in fact the six possible alternatives to two paint types i.e. SPC and Advanced antifouling. The six different alternatives are supposed to represent one of the best protection.

Those six subprograms compute the paint quantity in liters knowing the number of coats, the losses while spraying, the dryfilm thickness, the surface area bottom and sides, the solid by volume content and the percentage of hull being painted.

The paint and paint spraying costs are then computed knowing the following parameters:

- (i) the various paint type price per liter
- (ii) two different spraying costs per square meter (antifouling paints have a higher spraying cost)
- (iii) the shot-blasting and / or water cleaning cost per square meter
- (iv) the hull area percentage

For the purpose of the study, the paint prices per liter represent the price of the paint which give the best protection. However, one can introduce other paint qualities at lower prices but one has then to take into account the differences of the in-service roughness development, the safe coat's dryfilm thickness, the number of coats etc... .In fact this would lead one to alter the hull paint system procedure by introducing more alternatives into the simulation model.

One may also make the assumption that each time the ship is drydocked, 10% of the wetted hull surface has to be shot-blasted and is

given a new anticorrosive system.
Paint spraying losses is usually between 30% and 50%. It is a general trend that the spraying losses with sophisticated paints such as SPCs are much lower because the application is performed more carefully due to the relative high price of those paints.

In general, the paint spraying losses do vary from shipyard to shipyard and a careful shipyard do account for 30% losses.

Sometimes the shipowners are willing to have different coat numbers on the sides and the flat bottom as flat bottom polishing rate is higher with SPCs and on the other hand that the flat bottom is subject to less fouling due to less luminosity. However, the total thickness of either SPC or advanced antifouling must be well planned not to exceed the effective life time of the system.

The drydocking cost is evaluated knowing that the in-docking and out-docking plus one day drydocking is calculated using a formula which is today used in a north european country.The formula is:

$$0.047 * LOA * BM * DM \qquad \text{in US Dollars}$$

and for each extra day by:

$$0.023 * LOA * BM * DM \qquad \text{in US Dollars}$$

where
LOA = length overall
BM = breadth moulded
DM = deapth moulded

The off-hire cost is also included in the global paint system cost and for the case of the VLCC taken into consideration a value of $ 10 000 per day was chosen. It should be noted that an off-hire of $ 10 000 is what is prevailing on today's depressed time charter's market and do only cover the operating costs and a very small part of the capital cost.

A global figure is used as a daily ship running cost which embraces the crew cost i.e. the wages and leaves,the overtime, the pensions, the crew travel, the manning expenses, the storing cost i.e. provisions,general purpose stores,cabin stores, the lubricating oils, the insurance cost including the insurance premiums and the P&I club premiums etc..... . An amount of $ 8 000 a day has been taken for the study.

The off-hire cost, running cost and daily drydocking cost do play an essential factor when comparing two different hull paint systems as any difference in drydocking duration will highly enlarge the total cost. Thus, a right estimation of those latter parameters is of crucial importance and is actually influencing the decision making of the hull maintenance policy.

XIV DESCRIPTION OF THE SUBPROGRAMS

14.1 First Subprogram :

It computes the cost of a paint system using self-polishing copolymer paint on a new building ship. The drydocking cost as well as the off-hire cost and the ship running cost are obviously omitted as such considerations are not involved at that particular stage. The subprogram computes the cost of a 100% area of one coat of shop primer (30um), two coats of coal tar epoxy anticorrosion of 125um each, three coats of self-polishing copolymer of 125um each with reinforced toxic substances and medium polishing rate (8um/month) to match the trading pattern and the ship's speed operation giving a comfortable safety margin at the end of the thirty months operation i.e. avoiding any fouling starting on the entire hull.

The out-docking AHR value will be 125um/50mm. The in-service polishing rate is 8um per month, while the smoothing rate is of 0 to -3um/50mm per month.

14.2 Second subprogram :

It computes the cost of a paint system using an advanced antifouling paint on a new building ship. The various costs as ship running cost ,off-hire and drydocking cost are also omitted in this calculation as it was done in the first subprogram.

The hull is given the same anticorrosion system as the previous program. Two 60um coats of advanced antifouling of adequate quality and toxicity should ensure a fouling free period of thirty months.

The out-docking AHR is 125um/50mm. The in-service roughness increase would be in the range of 2 to 3.5um/50mm per month.

14.3 Third subprogram :

It computes the cost of drydocking the ship which has already a self-polishing paint system and is going to have a new self-polishing paint system.

The wetted hull surface is spot blasted on 10% of the total surface because of various hull damages and/or paint failure. Water cleaning of the entire hull and a new anti-corrosion system is put on the spot blasted area. Then, three coats of self-polishing paint (125um each) are directly applied on the hull.

The drydocking cost, the ship's running cost and the off-hire cost have now to be computed and added to the paint cost eventhough the ship is having a general repair, maintenance work and inspection obligation at the same time. As it will appear in the sixth subprogram, one has to consider the various costs named above because some paint systems do require or, more exactly, would be more efficient if the hull is entirely shot blasted. In many countries, shot blasting is not allowed to be performed during day time but only by night, so as a consequence this will incure a lenghtening of the drydocking duration. By including the various costs involved during drydocking in the third, fourth, fifth and sixth subprograms, any extra cost due to lenghtening of the ship's drydocking time will appear while comparing the global total cost of two different paint systems.

Drydocking time is six days. The out-docking AHR will be somewhat higher (average of +25um/50mm) than the in-docking AHR because of the increase of AHR while applying new paint coatings.

14.4 Fourth Subprogram :

It computes the cost of drydocking a ship which has already a self-polishing paint system but which would go over to an advanced antifouling paint system.

The hull is spot blasted on 10% of the wetted surface then totally water cleaned. A new anticorrosion system is put on spot blasted area, followed by a 40um sealer coat on the entire wetted surface. The hull is then given two 60um coats of advanced antifouling.

Drydocking time is six days. The out-docking roughness,depending upon the ship's age and previous hull policy, is about 25 to 30um/50mm higher than the in-docking value.

14.5 Fifth Subprogram :

It computes the cost of a ship which has an advanced antifouling paint system and is going to go over to a self-polishing paint system.

Because of the non compatibility of self-polishing copolymer paints to other antifouling paint types and that self-polishing copolymer are the most benificial if a sound anti-corrosion system is applied, the entire wetted hull surface is shot blasted to SA 2 1/2 standard. This measure is having a direct consequence on the drydocking time which is largely extented compared with other paint maintenance schemes. The hull is 100% water cleaned followed by one coat of blast primer. The anti-corrosion system consist of two coats of coal tar epoxy of 125um each. The self-polishing paint system is composed of three coats of 125um each.

The out-docking AHR is 125um/50mm. The drydocking time is twelve days.

14.6 Sixth Subprogram :

It computes the cost of drydocking a ship which has an advanced antifouling paint system and is going over to a new advanced antifouling paint system.

The wetted hull surface is 10% spot blasted, entirely water cleaned and a new anti-corrosion system applied on the spot blasted area. A 40um sealer coat is applied on the entire hull followed by two coats of advanced antifouling paint of 60um each.

The out-docking AHR would however be higher than the ship of the same age which has always had a self-polishing paint system in the past.A five year old ship which has always had an advanced antifouling paint system previously will have as an average figure an AHR of 250 to 350um/50mm. However, no sensible increase of the AHR is noticed during the first drydocking interval.

14.7 Seventh Subprogram :

The subprogram output is a table consisting of six columns.

The first column shows the drydocking interval on a month per month basis.

The second column shows the fuel-oil quantity in metric tons saved each month. This is computed using the 1978 ITTC's formula with a coefficient change from 5.8 to 3.8 . The percentage of power increase or fuel-oil consumption increase represents the savings earned by comparing two different paint systems each one having a different in-service roughness evolution e.g. the self-polishing paint system has a -0.5um/50mm per month evolution (smoothing) and the advanced antifouling paint system has a +2.5um/50mm per month evolution (roughning) which gives a percentage savings at the end of the second month of :

$$3.8 * \left[(125+2.5)^{1/3} - (125-0.5)^{1/3}\right] = 0.15\%$$

of the fuel-oil consumption if the self-polishing alternative had been chosen instead of the advanced antifouling system for a same out-docking AHR value of 125um/50mm. This percentage is then multiplied by the daily fuel-oil consumption and the number of days at sea per month which gives the fuel-oil consumption difference in metric tons per month of the two alternatives.

The third column indicates the present value of the fuel-oil price month after month. The program has the flexibility of changing the monthly rate of increase of the fuel-oil price.

Assumptions can be made with no marine fuel-oil price increase during the whole drydocking interval period or that fuel-oil price will steadily increase during the first months then stabilizes during few other months and finally decreases steadily until the end of the drydocking interval. The marine fuel-oil price variation has indeed a great repercussion on the pay-back period especially if a sensible fuel-oil price variation occurs towards the end of the drydocking interval period were the compared savings in terms of fuel-oil quantity are highest.

Tables 11 and 12 show the influence of marine fuel-oil price changes on the pay-back period.

The fourth column represents the fuel-oil saving value also on a month by month basis. This saving value represents actually the compounded value of savings to that particular time within the drydocking period.

The fifth column represents the Net Present Value of fuel-oil savings. The decision of choosing a particular paint system instead of an other paint system involves a difference in costs. The savings of fuel-oil earned by choosing the most "energy saving" alternative can in fact be considered as a flow of revenues that are received in the future while the difference in cost considered above has to be paid right at the out-docking of the ship. This introduces us to the concept of Net Present Value.

A dollar received today is worth more than a dollar received next year, which in turn is worth more than a dollar received the following year. The reason for this is that a dollar held today may be deposited in a bank or other interest earning security and at the end of one year it will be worth the original dollar plus the interest earned on that dollar. Looking at this from the reverse aspect, a dollar earned one year from today is worth less than a dollar that is held today.

The discounting rate is depending on the shipowner's policy. This appropriate discounting rate is called the "Opportunity" discount rate.

This is actually the rate of interest or return the shipowner could earn in his best alternative use of funds at the same level of risk. The alternative use of the funds must involve the same level of risk or uncertainty, since many other alternative uses of the funds will be more or less risky or uncertain and are, thus, not strictly comparable with the present proposal.

An opportunity discount rate of 15% is what is generally encountered among shipowners today.

The sixth column represents the pay-back period of one alternative against the second one. The figure on the first row represents the cost difference of the two alternatives which has,as explained above, to be paid in one way or an other when the ship is leaving the drydock. Then, the net present value of the fuel-oil savings is substracted to the previous figure. This gives a very clear pay--back period image and one can easily plot whenever profits may be realised or not.

XV RUNNING OF THE PROGRAM

The major parameters needed to run the program are either fixed parameters or variable parameters. These are:

- (i) ship measurements
- (ii) daily fuel-oil consumption
- (iii) number of steaming days a year
- (iv) running cost per day
- (v) off-hire cost per day
- (vi) fuel-oil price per day
- (vii) paint type prices per liter
- (viii) out-docking roughness of two different paint systems inquired depending upon the age of the ship.

The operator then chooses two of the six maintenance program alternatives which are:

Alternative 1 : new building with advanced antifouling system

Alternative 2 : drydocking of an advanced antifouling going over to a self-polishing copolymer system

Alternative 3 : drydocking of an advanced antifouling going over the same paint system as previously

Alternative 4 : new building with a self-polishing copolymer system

Alternative 5 : drydocking of a SPC system going over to a new SPC system

Alternative 6 : drydocking of a SPC system going over to an advanced antifouling system.

Then, the monthly hull roughness changes have to be given for both alternatives.

The output is a table showing the pay-back period followed by the drydocking interval end period hull roughness of both alternatives.

XVI DISCUSSION

For all the tables in the appendix, the following fixed parameters have been taken:

* 150 000 dwt tanker
* 15 390 square meters total wetted hull surface (to fully loaded line)
* $ 10 000 off-hire
* $ 8 000 running cost a day
* $ 8 self-polishing copolymer per liter
* $ 6 advanced antifouling per liter
* $ 3 coal tar epoxy per liter
* $ 4 sealer coat per liter
* $ 3.5 blast primer per liter
* $ 3.5 shop primer per liter
* $ 1 spraying of antifouling per square meter
* $ .5 spraying of other paint types per square meter
* $ 10 shot blasting per square meter
* $ 180 per metric ton of marine fuel-oil
* 100 metric tons a day fuel-oil consumption
* 300 steaming days a year
* 15% opportunity discount rate
* 8% yearly compounding rate of fuel-oil price

16.1 First case study: Cost and pay-back period comparison at the new building stage. See tables IV and V.

Total cost of SPC paint system: $ 246 955
Total cost of advanced antifouling system: $ 115 810

Cost difference of the two above alternatives: $ 131 145

The two alternatives have the same out-docking roughness of 125um/50mm. The SPC ship's hull smoothes at a rate of -0.5um/50mm per month. The advanced antifouling ship's hull roughens at a rate of +2.5um/50mm per month. No fuel savings are made at the end of the first month in-service because of the same out-docking roughness of the two alternatives.

The pay-back period is between the 21st and 22nd month and the total savings at the end of the 30th month are $ 113 565.

The following in-docking roughness of both alternatives are:

SPC ship: 110um/50mm
Advanced antifouling ship: 200um/50mm

The savings would have been greater if the ship had a greater number of steaming days per annum. A lower opportunity discount rate than 15% would also give a higher saving value. A discount rate of 12% gives a final saving value of $ 124 880 which represents an additional saving of $ 11 315 compared with a 15% discount rate.

16.2 Second case study: Cost and pay-back period comparison after the second drydocking i.e. ships of five year age. See tables VI and VII.

The first alternative is the ship with advanced antifouling system going over to an SPC system while the second alternative is the same ship which keeps the same paint system as previously i.e. an advanced antifouling system.

Here, the total paint cost difference between the two alternatives is very high: $ 438 279. This is explained by the fact that the ship going over to an SPC system has to be shot-blasted entirely. The drydocking duration is therefore much greater (12 days) than the ship keeping the same paint system (6 days).

However, the out-docking AHR of the ship keeping the same paint system is much higher than the ship going over to an SPC system. The latter will recover its new-building AHR of 125um/50mm while the advanced antifouling alternative will have an out-docking AHR of 250um/50mm.

During the first month in-service, large fuel-oil savings are already noticeable. The pay-back period is 18 months and the total savings at the end of the drydocking interval are $ 354 081.

16.3 Third case study: See tables VIII and IX.

Let one imagine that the shipowner decides to sell the tanker at the next drydocking period. He has then to decide wether it is worthwhile to paint the ship which had a previous SPC system with a new SPC system or with an advanced antifouling system.

The cost difference of the two alternatives is $ 51 641. Let one assume that the ship is 10 years of age . The in-docking AHR is 230um/50mm and the out-docking AHR would most probably be around 260um/50mm for both alternatives.

The pay-back period is 17 months and the total savings at the end of the drydocking interval is $ 104 869.

It is interesting to notice that the shipowner still has the freedom of selling the ship even before the date fixed previously without loosing money. The other bonus is that a ship having an SPC system would probably be sold at a higher price than the same ship having an advanced antifouling paint system.

XVII CONCLUSION

The study has been built on a number of assumptions. The backbone of the study lays on the quantification of fuel-oil saved while comparing two different alternatives. This was based on the ITTC's formula of 1978.

This may not be the proper formula for all kinds of ships since it derives from ship model research and ship trials of a specific ship type. However, the percentage of fuel-oil saved given by using the above mentioned formula does agree with what is generally found out by the technical management departments where engine performances have been well followed from the new building stage. Therefore, the fuel-oil consumption changes are surely correlated with the increased hull resistance solely and not with changes of engine efficiency.

The program is opened to any further research. New factors as well as factors which were not taken into consideration e.g. the loading factor, can be easily introduced to assess the effect of hull roughness and fouling on ship efficiency.

The last but not least assumption concerns the quality of work while the ship is being painted. Although it is reflected by the AHR figure, the savings expected will be made only if the right application scheme has been chosen since a non proper paint or dryfilm thickness or shot blasting quality may lead to a huge loss of money.

The study of a whole ship's life may easily be achieved assuming that the hull roughness evolution is known.

XVIII ACKNOWLEDGMENTS

I am grateful to all those who have been helping and encouraging me in this study, to Mr. Svend Johnsen of the Hempel company in Copenhagen whose expertise has been drawn upon and finally to Koc-

kums shipyard for their great support.

XIX LITTERATURE

Erik Naess, "Fuel-oil saving hulls" 1983
Norwegian Ship Research Institute NSFI.

Svend Johnsen, "The economic aspect of self-polishing antifoulings." The Propeller Club of the United States International Port of Monaco.

J.A.Malone, D.E.Little and M.Allman
"Effects of hull foulants and cleaning/coating practices on ship performance and economics" 1980.

D.Byrne and G.Ward, "The cost of hull roughness versus the cost of hull smoothness."

H.B.Moller Pedersen and E.Kongsted,
"Modern ship management"
5th Transport Symposium. Hamburg 1983

R.L.Townsin, D.Byrne, A.Milne and T.Svensen
"Speed, power and roughness: The economics of outer bottom maintenance."
Royal Institution of Naval Architects. 1980

APPENDIX

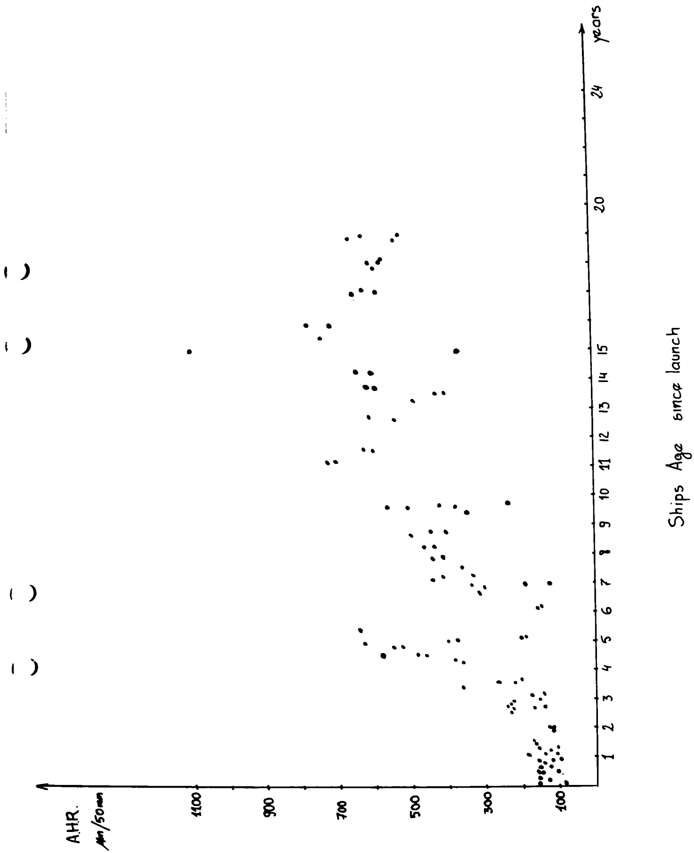


Fig. 1 : Roughness of hulls of various ages, excluding re-blasted hulls

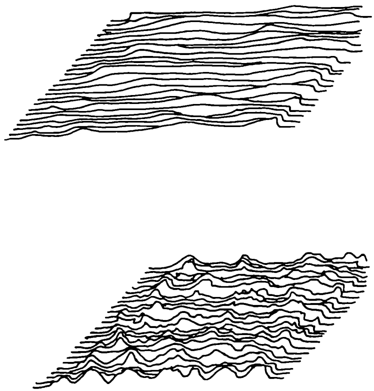


Fig. 2: Two surfaces of different topography but equal A.H.R.

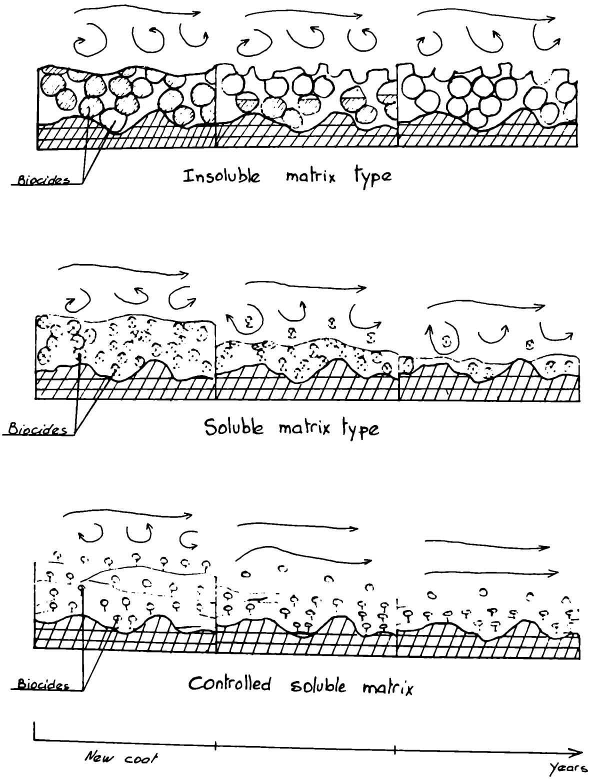
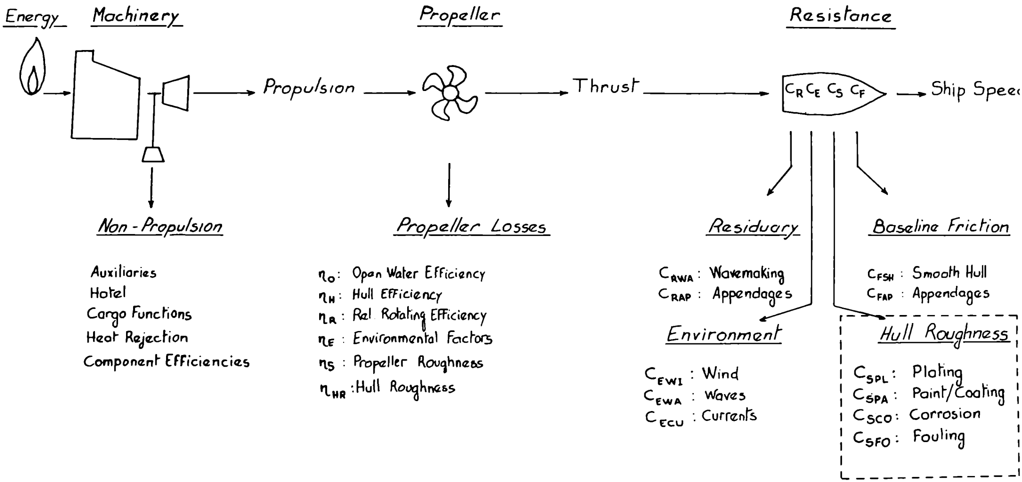


Fig: 3 : Advanced Antifoulings and SPC Mechanisms



Energy
Machinery
Propulsion
Propeller
Thrust
Resistance
C_R C_E C_S C_F
Ship Speed
Non-Propulsion
Auxiliaries
Hotel
Cargo Functions
Heat Rejection
Component Efficiencies
Propeller Losses
η_O: Open Water Efficiency
η_H: Hull Efficiency
η_R: Rel. Rotating Efficiency
η_E: Environmental Factors
η_S: Propeller Roughness
η_{HR}: Hull Roughness
Residuary
C_{RWA}: Wavemaking
C_{RAP}: Appendages
Baseline Friction
C_{FSH}: Smooth Hull
C_{FAP}: Appendages
Environment
C_{EWI}: Wind
C_{EWA}: Waves
C_{ECU}: Currents
Hull Roughness
C_{SPL}: Plating
C_{SPA}: Paint/Coating
C_{SCO}: Corrosion
C_{SFO}: Fouling

PAINT COST NEW-BUILDING WITH ADV.AF

LITERS	USD	
7465	37785	Anti-corrosion paint
1500	12946......	Shop-primer "
5716	65077......	Advanced Antifouling paint
TOTAL	115810	

BLAST. AND WATER CLEAN.	0
BLAST. AND WATER CLEAN.	0
TOTAL	0

TOTAL PAINTING COST: $ 115810

OUT-DOCKING ROUGHNESS: 125 um/50mm

PAINT COST NEW BUILDING SPC

LITERS	USD	
7465	37785....	Anti-corrosion paint
1500	12946....	Shop-primer
18756	196222....	Self-Polishing Copolymer paint
TOTAL	246955	

BLAST. AND WATER CLEAN.	0
BLAST. AND WATER CLEAN.	0
TOTAL	0

TOTAL PAINTING COST: $ 246955

OUT-DOCKING ROUGHNESS: 125 um/50mm
MONTHLY AHR INC. WITH ADV.AF: 2.5 um/50mm
MONTHLY AHR INC. WITH SPC : -.5 um/50mm

Table IV : First case study

** PAINT ECONOMICS **

MONTHS	FO SAV. 100 / 300	FO PRICE $/TON	SAVING VALUE	NPV FO SAV. 15 %	PAY-BACK
	Dayly F.O. Consumption / Days at sea per year				-13114
1	0	181.2	0	0	-13114
2	3.7	182.4	689	672	[illegible]
3	7.5	183.5	1380	1330	[illegible]
4	11.2	184.7	2074	1975	[illegible]
5	14.8	186	2769	2606	[illegible]
6	18.5	187.2	3467	3225	[illegible]
7	22.1	188.4	4166	3831	[illegible]
8	25.6	189.5	4869	4422	[illegible]
9	29.2	190.7	5573	5010	[illegible]
10	32.7	192	6280	5582	[illegible]
11	36.1	193.2	6990	6145	[illegible]
12	39.6	194.4	7702	6698	[illegible]
13	43	195.6	8421	7232	[illegible]
14	46.4	196.9	9144	[illegible]	[illegible]
15	49.7	198.2	9870	[illegible]	[illegible]
16	53.1	199.5	10599	8778	[illegible]
17	56.4	200.8	11332	9274	[illegible]
18	59.6	202.1	12068	[illegible]	[illegible]
19	62.9	203.4	12809	[illegible]	[illegible]
20	66.1	[illegible]	[illegible]	[illegible]	[illegible]
21	69.3	[illegible]	[illegible]	[illegible]	[illegible]
22	72.5	[illegible]	15051	[illegible]	[illegible]
23	75.7	[illegible]	[illegible]	[illegible]	[illegible]
24	78.9	[illegible]	16565	[illegible]	[illegible]
25	82	211.3	[illegible]	[illegible]	[illegible]
26	85.1	212	[illegible]	[illegible]	[illegible]
27	88.2	214.1	[illegible]	[illegible]	[illegible]
28	91.2	215.5	[illegible]	[illegible]	[illegible]
29	94.3	216.9	[illegible]	[illegible]	[illegible]
30	97.3	218.2	[illegible]	[illegible]	[illegible]

INDOCKING ROUGHNESS ADV.AF SHIP: 200 um/50mm
INDOCKING ROUGHNESS SPC SHIP : 110 um/50mm

Table V First case study

PAINT COST DRYDOCKING ADV.AF TO SPC

LITERS	USD	
7465	37785	Anti-corrosion
1500	12946	Blast-primer
18756	196222	S.P.C.
TOTAL	246955	

BLAST. AND WATER CLEAN.	153900
BLAST. AND WATER CLEAN.	15390
TOTAL	169290

DRYDOCK	60381
RUNNING COST	96000
OFF-HIRE	120000

TOTAL PAINTING COST: $ 692627

OUT-DOCKING ROUGHNESS: 125 um/50mm

PAINT COST DRYDOCKING ADV.AF TO ADV.AF

LITERS	USD	
746	3778	Anti-corrosion
1600	14097	Sealer Coat
5716	65077	Advanced Antifouling
TOTAL	82953	

BLAST. AND WATER CLEAN.	15390
BLAST. AND WATER CLEAN.	15390
TOTAL	30780

DRYDOCK	32615
RUNNING COST	48000
OFF-HIRE	60000

TOTAL PAINTING COST: $ 254348

OUT-DOCKING ROUGHNESS: 250 um/50mm
MONTHLY AHR INC. WITH ADV.AF: 2.5 um/50mm
MONTHLY AHR INC. WITH SPC : -.5 um/50mm

Table VI : Second case study

** PAINT ECONOMICS **

MONTHS	FO SAV. 100 / 300	FO PRICE $/TON	SAVING VALUE	NPV FO SAV. 15 %	PAY-BACK
					-43827
1	123.4	181.2	22371	22095	-4161[illegible]
2	126	182.4	22992	22436	[illegible]
3	128.6	183.5	23628	22774	-3709[illegible]
4	131.2	184.7	24[illegible]	23108	-3470[illegible]
5	133.8	186	24902	23437	-3244[illegible]
6	136.4	187.2	25545	23763	-3006[illegible]
7	139	188.4	26197	24085	-2765[illegible]
8	141.5	189.5	26845	24404	-2521
9	144.1	190.7	27501	24720	-2274[illegible]
10	146.6	192	28161	25032	-2024
11	149.2	193.2	28825	25341	-1770[illegible]
12	151.7	194.4	29494	2564[illegible]	1514
13	154.2	195.6	30181	25920	1[illegible]
14	156.7	196.9	30814	26192	-993[illegible]
15	159.2	198.2	31570	26460	7286
16	161.6	199.5	32272	26726	-4[illegible]
17	164.1	200.8	32979	26991	-1914[illegible]
18	166.6	202.1	33690	27251	8102
19	169	203.4	34405	27510	3561[illegible]
20	171.5	204.7	35126	27767	63[illegible]
21	173.9	206	35851	28022	9140[illegible]
22	176.4	207.3	36581	28275	1196[illegible]
23	178.8	208.6	37315	28526	1480[illegible]
24	181.2	209.9	38054	28774	17[illegible]
25	183.6	211.3	38817	28989	2059[illegible]
26	186	212.7	39585	29202	2351[illegible]
27	188.4	214.1	40359	29414	[illegible]
28	190.8	215.5	4113[illegible]	29624	2942[illegible]
29	193.2	216.9	41921	29834	3240[illegible]
30	195.6	218.3	42710	30042	3540[illegible]

INDOCKING ROUGHNESS ADV.AF SHIP: 225 um/50mm
INDOCKING ROUGHNESS SFC SHIP : 110 um/50mm

Table VII Second case study

PAINT COST DRYDOCKING SPC TO SPC

LITERS	USD	
746	3778	Anti-corrosion
12504	130814	S.P.C.
TOTAL	134593	

BLAST. AND WATER CLEAN.	15390
BLAST. AND WATER CLEAN.	15390
TOTAL	30780

DRYDOCK	32615
RUNNING COST	48000
OFF-HIRE	60000

TOTAL PAINTING COST: $ 305988

OUT-DOCKING ROUGHNESS: 260 um/50mm

PAINT COST DRYDOCKING SPC TO ADV.AF

LITERS	USD	
746	3778	Anti-corrosion
1600	14097	Sealer Coat
5716	65077	Advanced Anti Fouling
TOTAL	82953	

BLAST. AND WATER CLEAN.	15390
BLAST. AND WATER CLEAN.	15390
TOTAL	30780

DRYDOCK	32615
RUNNING COST	48000
OFF-HIRE	60000

TOTAL PAINTING COST: $ 254348

OUT-DOCKING ROUGHNESS: 260 um/50mm
MONTHLY AHR INC. WITH ADV.AF: 2.5 um/50mm
MONTHLY AHR INC. WITH SPC : -.5 um/50mm

Table VIII : Third case study

** PAINT ECONOMICS **

MONTHS	FO SAV. 100 / 300	FO PRICE $/TON	SAVING VALUE	NPV FO SAV. 15 %
1	0	181.2	0	0
2	2.3	182.4	424	413
3	4.6	183.5	852	821
4	6.9	184.7	1283	1222
5	9.2	186	1717	1616
6	11.5	187.2	2155	2005
7	13.7	188.4	2596	2387
8	16	189.5	3041	2765
9	18.2	190.7	3489	3136
10	20.5	192	3941	3503
11	22.7	193.2	4396	3864
12	24.9	194.4	4854	4221
13	27.1	195.6	5310	4567
14	29.3	196.9	5786	4909
15	31.5	198.2	6258	5245
16	33.7	199.5	6733	5576
17	35.9	200.8	7213	5902
18	38	202.1	7696	[illegible]
19	40.2	203.4	8182	6542
20	42.3	204.7	[illegible]	[illegible]
21	44.4	206	9167	[illegible]
22	46.6	207.3	9665	[illegible]
23	48.7	208.6	10166	[illegible]
24	50.8	209.9	10672	[illegible]
25	52.9	211.2	11186	[illegible]
26	55	212.7	[illegible]	[illegible]
27	57	214.1	12227	8911
28	59.1	215.5	12754	9184
29	61.2	216.9	13285	9454
30	63.2	218.3	13820	9721

INDOCKING ROUGHNESS ADV.AF SHIP: 335 um/50mm
INDOCKING ROUGHNESS SPC SHIP : 245 um/50mm

Table IX : Third case study

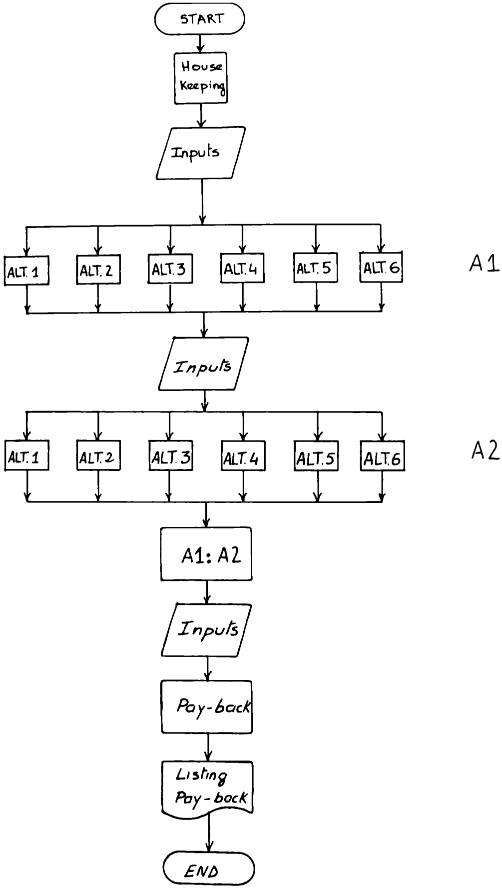


Table X
Flow chart diagram of the model Simulation program.

New-Building stage.

** PAINT ECONOMICS **

MONTHS	FO SAV. 100 / 300	FO PRICE $/TON	SAVING VALUE	NPV FO SAV. 15 %	PAY-BACK
					-13114
1	0	181.2	0	0	-13114
2	3.7	182.5	689	673	13041
3	7.5	183.8	1382	1322	12914
4	11.2	185	[illegible]	1978	1271[illegible]
5	14.8	186.[illegible]	2775	2612	-12455
6	18.5	187.6	3476	3233	-1213[illegible]
7	22.1	189	4189	3844	-11[illegible]4
8	25.6	189	48[illegible]	441[illegible]	1130[illegible]
9	29.2	189	55[illegible]1	49[illegible]	-108[illegible]
10	32.7	189	6182	5495	-102[illegible]
11	36.1	189	6838	6012	-9659
12	39.6	189	7489	6512	-900[illegible]
13	43	189	8133	6985	-8309
14	46.4	189	87[illegible]3	7441	7565
15	49.7	189	9408	7889	-677[illegible]
16	53.1	189	10037	831[illegible]	5945
17	56.4	189	10662	872[illegible]	5072
18	59.6	189	11282	9126	-416[illegible]
19	62.9	189	11898	9514	320[illegible]
20	66.1	187.6	1247[illegible]	981[illegible]	22[illegible]
21	69.3	186.3	12933	10109	-121[illegible]
22	72.5	185	134[illegible]	10383	1[illegible]
23	75.7	183.7	13921	10642	865
24	78.9	182.4	14398	10886	1975
25	82	181.2	14863	11100	3085
26	85.1	179.9	15318	11300	4[illegible]15[illegible]
27	88.2	178.6	1576[illegible]	11488	523[illegible]
28	91.2	177.4	16196	11662	652[illegible]
29	94.3	176.1	16620	11828	771[illegible]
30	97.3	174.9	17034	11981	891[illegible]

INDOCKING ROUGHNESS ADV.AF SHIP: 200 um/50mm
INDOCKING ROUGHNESS SPC SHIP : 110 um/50mm

Table XI Infuence of marine fuel-oil price changes on the pay-back period and Total Savings

New-building stage

** PAINT ECONOMICS **

MONTHS	FO SAV. 100 / 300	FO PRICE $/TON	SAVING VALUE	NPV FO SAV. 15 %	PAY-BACK
					-13114
1	0	180	0	0	-13114
2	3.7	180	680	667	[illegible]
3	7.5	180	1357	1304	[illegible]
4	11.2	180	2020	1924	[illegible]
5	14.8	180	2680	[illegible]	[illegible]
6	18.5	180	3333	3100	[illegible]
7	22.1	180	3981	3660	[illegible]
8	25.6	180	4622	4202	[illegible]
9	29.2	180	5258	[illegible]	[illegible]
10	[illegible]	180	5888	[illegible]	[illegible]
11	36.1	180	6512	[illegible]	[illegible]
12	39.6	180	[illegible]	6201	-91883
13	43	180	7746	[illegible]	-85231
14	46.4	180	[illegible]	[illegible]	-78147
15	49.	180	[illegible]	[illegible]	-70634
16	53.1	180	9559	[illegible]	-62718
17	56.4	180	10154	[illegible]	-54408
18	59.6	180	10745	[illegible]	[illegible]
19	62.9	180	11331	9060	-36657
20	66.1	180	11913	9411	-27246
21	69.3	180	12491	9763	-17977
22	72.5	180	[illegible]	10098	[illegible]
23	75.	180	[illegible]	10423	3044
24	78.9	180	14202	10738	[illegible]
25	82	180	14764	11026	24006
26	85.1	180	[illegible]	11304	36111
27	88.2	180	15879	11573	47699
28	91.2	180	16431	11832	[illegible]
29	94.2	180	16980	12084	71601
30	97.3	180	17525	12327	83928

INDOCKING ROUGHNESS ADV.AF SHIP: 200 um/50mm
INDOCKING ROUGHNESS SPC SHIP : 110 um/50mm

Table XII: Influence of marine fuel-oil price changes on the pay-back period and Total Savings.