SHIP DESIGN AND EVALUATION FOR A GHG CONSTRAINED FUTURE

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SUMMARY

The future is uncertain, but it is not unreasonable to imagine that it may herald higher energy prices and greater regulation of shipping’s Greenhouse Gas (GHG) emissions. With the adoption of the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) into MARPOL Annex VI there is already some movement towards such a future. It is suggested in this paper that understanding the many components of the “shipping system” can ensure the most robust analysis of economic viability and competitiveness of ship designs both relative to an existing fleet of ships and under possible future regulatory and cost environments. This paper describes the development of some of the methods in the RCUK project “Low Carbon Shipping - A Systems Approach” that can be used to explore ‘what if’ questions around the future of ship design - taking the perspective that a key challenge for design will be around increased energy efficiency and lower GHG emissions.

DEFINITION OF TERMS

The terms defined below, CRT and CRM, have arisen from the need for consistent use of language when modifying ships or ship operation with the prime objective of reducing Carbon Dioxide (CO2) emissions:

A Carbon Dioxide Reducing Technology (CRT) is any technology that can be incorporated into a ship (this could be either a retrofit or new build) that reduces the Carbon Dioxide (CO2) Emissions of the ship compared to the original ship design (before modification). A CRT is a type of Carbon Dioxide Reducing Measure (CRM) and can be categorised as reducing propulsion power, reducing auxiliary power or using fuel more efficiently (increasing energy/CO2 emissions, possibly by using alternative fuels to oil).

A Carbon Dioxide Reducing Measure (CRM) is any measure that reduces the Carbon Dioxide (CO2) emissions of a ship or a fleet of ships. A CRM can be categorised as an operational measure or a Carbon Dioxide Reducing Technology (CRT). An important non-technological CRM is reducing operational speed.

GLOSSARY OF EXISTING TERMS

A Greenhouse Gas (GHG) is a gas that contributes to the greenhouse effect by absorbing infrared radiation. The greenhouse effect is the trapping of the sun’s warmth in the planet’s lower atmosphere. Carbon Dioxide (CO2) is a GHG and therefore poses a risk of dangerous climate change. This is the GHG under consideration here.

1. BACKGROUND

A GHG constrained future refers to a future in which emissions of GHG are limited either due to regulation to reduce the risk of dangerous climate change, or because high prices of conventional GHG emitting energy products such as fossil fuels leads to energy efficiency and substitution of alternative energy sources. The credibility for such a future scenario is derived from both the ongoing UNFCCC (United Nations Framework Convention on Climate Change) Conference of Parties negotiations, and the energy scenarios generated by, among other organisations, the International Energy Agency [1].

The consequences of such a scenario will be significant changes in all sectors of the economy. The global shipping system will also be likely to change substantially due to the current dependence on conventional fossil fuels and an absence of options for easy substitution into the existing system (alternative transport modes or ship technologies). Already, a number of future concept designs have emerged. These are hypothetical solutions to a future design specification that limits emissions of GHGs. They range from minor modifications to an existing vessel (e.g. Green Ship of the Future [2]) to more radical zero carbon designs, such as the NYK ‘Super Eco Ship 2030’ [3] or the Wilh. Welmsen ‘Orcelle’ [4]. The pace of change is not certain, but even the more ambitious designs are being targeted for construction by 2030. At which point a ship on an order book today will be just 15 years old and half way through its structural life expectancy.

The RCUK Energy funded research project “Low Carbon Shipping – A Systems Approach” started in 2010. The project’s aim is to use understanding of the many components of the shipping system to explore how the shipping industry might respond to the challenge of a GHG constrained future e.g. from a combination of the technological, economic, logistical, operational and infrastructure perspectives. The scope of the overall project is described in Smith et al. (2010) [5]. This paper will focus on a specific research area within the project – the development of ship design and evaluation procedures for the estimation of the technical specification of newbuild and retrofit ships over the next 40 years.
Many of the concept designs produced to date have either focussed on the maximum practical reduction of emissions achieved using existing, mature technology, or how might emissions from a ship might be reduced to zero. This does not necessary represent the approach used by prospective ship owners when specifying new tonnage.

In practice, the technical specification of a new ship is tailored to an owner’s expectations of the market in which they intend to operate that ship. Considerations include expected revenue, costs and therefore the profitability of the specification. Constraints placed on the specific selection include the availability and performance of technology, availability of capital and/or finance and the regulatory backdrop to the ship’s operation.

The objective of this modelling work is to produce a simulation of the decision making process used in the specification of a newbuild ship or the retrofit of an existing ship, and combine this with a suite of ship design synthesis tools. This allows different input parameters to the decision process (e.g. regulation, fuel and carbon price or other market based instruments yet to be defined) to be varied to explore how they result in different predicted ship specifications.

This analysis is deployed in a system model. The system model is a time-domain simulation of the evolution of the global shipping fleet including investment in new ships, retrofit of existing ships, ship operation, trade flows, shipping logistics, shipping economics and shipping energy demand and emissions. The model represents fleets of different ship types which are broken down further into aggregations of ship size and age. It is the technical specification of the ship size and age categories of a given ship type at a given point in time, which is the focus of the work described in this paper.

2. GENERAL APPROACH

Ship design has been presented as a paradigm of the design of complex products [6] and ships have been described as the most complex artefacts designed and assembled by man on a regular basis [Graham, quoted in 7]. Although freight ships do not have the additional complexities of service vessels (e.g. combat systems for a warship), their design still requires the consideration of a wide range of interlinked parameters. The structure of the design models that result has been described using a complex interconnected network [8], [9].

This complexity means that the level of automation in a ship design process must be carefully considered. Nowacki [10] provides a historical review of how computer aided tools and automation have been applied to all aspects of the ship design process since the 1950s. Parsons [11] describes the various types of parametric models that can be used in computer aided ship design, whilst Schiller et al [12] illustrate both the utility and limitations of automated parametric models, specifically that they are only applicable to ships based on their fixed topology (although dimensional ratios may change).
This introduces a challenge in the Low Carbon Shipping project, of assessing the impact of approximately 70 CRTs over 5 fuel choices and 10 design speeds, a total of 3500 design points for each ship type (before different combinations of CRMs are considered). The solution is to produce a suite of modelling tools that operate at different levels of detail. The high detail models can be used to define modifications to the topology or scaling relationships in simpler parametric models, thus allowing the design space to be explored.

On the left of Figure 1 a high level of technical detail is being considered. To the right of the figure a low level of technical detail is being considered on an individual ship and technology level, however the shipping system model is looking at a very wide scope, the international shipping fleet.

3. CARBON DIOXIDE REDUCING TECHNOLOGIES AND DETAILED PARAMETRIC SHIP MODEL

3.1 CARBON DIOXIDE REDUCING TECHNOLOGIES

Most of the CRMs that are being investigated in the Low Carbon Shipping Project when taken in isolation have a relatively small effect on CO₂ emissions. This can also be seen from existing studies by DNV [13] and IMO [14].

Several single CRMs have already been investigated and in some cases implemented in order to reduce fuel costs, especially those which have a short payback period or are quick to implement, such as slow-steaming, trim or voyage optimisation. These practices have been adopted by some ship operators such as Maersk and Teekay [15][16]. Rising fuel prices in the late 1970s and early 1980s [17] lead to widespread work on sail assisted propulsion [18] in order to reduce fuel costs, but this has not seen widespread adoption, possibly due to long payback periods.

Within the system-wide context of the Low Carbon Shipping project, three key points arise when considering CRMs:

- Existing studies of CRM performance should be used where possible to allow a wide range of technologies to be included.
- Combining CRMs needs to be considered, especially when individual technologies only lead to small savings and interference effects may exist.
- The flexibility to change the operational speed and its resulting large effect, both on baseline emissions and the effectiveness of CRTs.

These considerations require that the CRMs be assessed both in combination and at a range of both design and operational speeds. The practice of adopting “packages” of CRTs, specified by marine engineers and naval architects, to be applied together to a ship design was not adopted. Instead, the overall shipping system model, including the engineering assessments of the performance of the technologies, will be used to determine which “packages” are desirable, taking into consideration the overall operational and economic environment.

Although the project aims to use as much information from previous studies as possible, the individual CRTs must still be assessed for effectiveness and ship impact. This analysis, in some cases essentially a double check of published data, is required for two reasons. Firstly, equipment suppliers may quote best-case performance, or only have data for a limited range of ship types and sizes [19]. Secondly, the wide scope of the shipping system model introduces the need for more detailed information in order to represent the CRT correctly. For example, quoted savings from marine coatings are typically unclear because the surface the coating is being applied to and the condition of the ship before docking make a difference to the potential fuel savings [20]. Whilst technologies such as waste heat recovery may not offer uniform savings over the complete operational speed range if they are optimised for the design speed. A waste heat recovery system being only in full operation above a certain engine load limit [16].

3.2 DETAILED PARAMETRIC SHIP MODEL

The detailed parametric ship model is needed to correctly size CRTs to fit the ship and the ships have to be designed with enough accuracy and detail to ensure that the ships realistically reflect the overall impact on cargo capacity and cost. Thirty-six parametric ship design models were generated (specific to ship types, sizes and design speeds), based on common design assumptions and a common data set. This covers container ships, bulk carriers, oil tankers and LNG tankers. These four ship types are modelled in four size categories - corresponding to limits such as Panamax, and two or three design speeds (assumed to be at 75% MCR). This provides coverage of the main ship design topologies (overall layout) and the simplified ship impact model (described in section 4) can be used to size ships that have not been described by the detailed parametric ship model.

The detailed parametric ship model is used to investigate and characterise the ship impact of CRMs, particularly those of a technological nature, so that they can be applied to a wider range of ships in a simpler parametric model. The technical information needed to incorporate the CRMs into the ship design model is obtained from references and, importantly, the partner subject matter experts in the Low Carbon Shipping project (hydrodynamicists, marine engineers, etc.).

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Figure 2 illustrates one of the detailed parametric models produced in the Paramarine software. It is important to note that this model contains both a geometric model of the ships arrangement and numerical sizing and performance data, so allowing the full impact of CRTs such as sail assistance and LNG fuel, which effect the overall general arrangement, to be assessed. The effect of LNG was examined in detail in two previous papers by Calleya et al. (2011) [21] [22], adopting LNG causes large changes to the ship that have to be considered carefully in the ship impact model [21] (described in section 4).

3.3 VALIDATION

The detailed parametric ship design models were generated using a combination of UCL data [23], data from equipment suppliers catalogues and ship design textbooks [24]. Although the UCL data is detailed, it is derived from warships and some aspects, such as structural weight and distributed systems, were of uncertain applicability to cargo vessels. In some cases, weight estimates could be replaced with those known to be more suitable, but as a validation exercise, the resulting ships were checked by comparing information such as deadweight/displacement against detail given by [25] and Clarksons [26], in order to check the assumptions such as installed power to power usage were correct.

4. SHIP IMPACT MODEL

4.1 MODEL OVERVIEW

The difficulty with the high technical detail models described in Section 3 is that there is not adequate time or resource in the Low Carbon Shipping project to perform a full detailed ship design to examine every conceivable design point and package of CRMs. It is thus necessary to make a number of assumptions in order to simplify the process of generating ship designs in order to investigate the effect of combinations of CRMs on the ship. This model applies the CRM impact data derived from the detailed ship model to a wider range of ships, that can have design displacements and speeds different from the thirty-size example ships used.

Figure 3 shows a basic flow diagram of the ship impact model:

- The input ship is described by 52 parameters that can either be described by the user or the user can select from 1 of the 36 ships that have been created by the detailed parametric model. The user also selects which CRM or CRM combinations they want to examine.
- The model then sizes the ship and CRMs by initially providing information to the CRMs about the ship characteristics in order to correctly size the CRMs to fit the ship.
- The cargo impact can then be calculated from the sum of the cargo impact due to the technology and the cargo impact due to changes in the ship such as main engine size and auxiliary engine size (generally, changes in main and auxiliary engine power have the bigger effect on emissions, rather than cargo weight impact). After this the resistance model is run at different speeds and different ship conditions, with the new characteristics of the CRM combination at the new speed being found before running the resistance model again. This is an iterative process but the iteration is ignored because the changes to the overall ship are generally small.
- An operating profile is then used that provides the time spent at each speed and in each condition in order to work out the average fuel consumption and CO₂ emissions.

On the first time through this process default values are used in order to work out the emissions of the baseline ship. The next time looks at the effect of the selected CRMs. The main engine cannot be changed for retrofits and CRMs have a description as to whether they can be retrofitted or not.

This process assumes that any changes to the ship impact on deadweight, keeping the draft, displacement and hullform unaffected. This means that a new draught from a new displacement does not have to be calculated each time the ship is modified by a CRT, which may be an intensive calculation.
The CRMs, including fuel changes, are described in single files, external to the main executable, so that the ship impact model software does not need to be modified when a new technology is defined. The CRM files can include changes in stability, layout or any other additional changes if they are found to exist in the detailed ship model for specific CRTs. For example, to estimate the performance of solar power, the deck area of the ship is required. The simplified ship impact model does not contain this information, but the assessment performed using the detailed parametric model allowed the derivation of a relationship between ship type, waterplane area coefficient and the resulting available deck area. Thus, the ship impact model can represent layout sensitive technologies without itself containing a model of the ship’s layout.

4.2 COMBINATIONS OF CRMs

The ship impact model allows combinations of CRMs to be assessed quickly. This allows “packages” of CRMs, and their resulting ship impact and combined performance, to be examined. Combinations of CRMs may have no interaction, may be incompatible (possibly by altering the performance of each other). Incompatibilities are a function of the nature of the technology, e.g. pre-swirl vanes and contra-rotating propellers are inherently incompatible. For some CRMs the ship impact model can detect when two CRMs are attempting to alter the same ship characteristic in how the CRMs are described. For example two or more CRTs requesting a change in the auxiliary engine fuel (denoted
by a change in carbon factor will not be allowed to be used together.

Similarly, compatible interactions can be modelled. For example, if a technology such as sails reduces the MCR required for a given speed, then the performance of other CRTs that are dependent on MCR (e.g. waste heat recover, propeller design) will be changed appropriately.

5. SHIP IMPACT DATABASE

As shown in Figure 1, the Ship Impact Database (SID) provides the interface between the detailed descriptions of the ship impact and emissions reduction potential of CRTs and the overall shipping system model. The population of this database involves two main tasks:

- Simplification of the representation of the impact and emissions reduction of a CRT in a manner that retains the key characteristics but can be rapidly computed in the shipping system model.
- The presentation of the data to the shipping system model in a uniform, consistent and human comprehensible manner.

This second task is significant in that a simplified representation of the emissions reduction and ship impact of a CRT, derived from the parametric or ship impact model, can thus be used in discussions with project partners and other stakeholders to elicit expert opinion on the results obtained.

The SID consists of an Excel spreadsheet, with titled columns of numerical and textual data, which can be read in by the Matlab based shipping system model. For each CRT, seven types of information are held in the database:

5.1 Emissions Reduction Potential

The emissions reduction potential of the CRT is given both as a maximum that could be achieved for the ship design; i.e. that achieved at the “optimum” operating point, and that achieved in service. This means that the maximum achievable saving with a given CRT could, for example, scale linearly with ship design speed, but also be reduced by operational conditions above or below this design speed.

Emissions reduction potentials are described algorithmically. As the LCS project is ongoing, the exact choice of algorithms is constantly under review, but the latest database structure under development will allow reductions to be; constant, proportional or inversely proportional, maximum at a design point (i.e. quartic) or a step function. Currently they scale with; cargo deadweight, design speed and operational MCR. A slight complication is that different CRTs will reduce the emissions in different ways. Some will reduce main propulsion power directly (e.g. hydrodynamic improvements) while others achieve it indirectly and intermittently (e.g. kites), this has implications for propeller performance. Yet others will reduce auxiliary power (e.g. waste heat recovery), whilst others will reduce carbon dioxide emissions per unit of energy (e.g. LNG fuel or diesel engine improvements). Practically, the algorithmic relationships are described by giving the coefficients and stating the type of relationship and input variable.

Figure 4 illustrates these relationships for a generic technology. It also shows another advantage of this method, in that potentially complex relationships may be captured with relatively little input data. For some CRTs, it will be possible to generate the curve based on two estimates (minimum and maximum) and an understanding of the underlying physics (e.g. proportionality to Froude number).

It is important to note that this simplified representation of the savings offered by a CRT is not attempting to be absolutely accurate at all points and for all ship design parameters. Instead, it is attempting to capture the broad characteristics of the technology, with the emissions reductions and ship impacts described to a level of accuracy commensurate with that of the overall shipping system model inputs. This description should prevent certain types of errors from occurring; for instance a CRT whose performance is dependent on MCR (e.g. waste heat recovery) should not be assumed to be constant, as this will over-estimate the benefit from a combination of WHR and slow-steaming. The identification of potentially superior combinations of technologies is one of the outputs of the shipping system model.

5.2 Ship Impact

As noted above, the ship impact of a CRT is expressed as a loss in cargo deadweight. This significantly reduces the effort required to assess the impacts of the large range of CRTs in the LCS project, and can be used to generate larger ships to carry the same cargo. The ship impact is described as coefficients in an algorithm, as per the emissions reduction potential. Currently most impacts are linear with size or propulsion power, but additional relationships are being added to represent efficiencies of scale found in some technologies. Ship impacts can be positive or negative.

5.3 Fuel Type Compatibility

A simple flag is used to represent the compatibility of a CRT with each of five fuel types (HFO, MDO, LSHFO, LNG and H2).

5.4 Specific Fuel Consumption

Changes in the SFC caused by the addition of a technology can also be represented. These are with reference to baseline SFC values.
5.5 Incompatibilities

A list of incompatible technologies is provided for each CRT. This is of primarily of interest for the various hydrodynamic and flow control devices. A flag is also included to indicate when a technology is incompatible with NOX and SOX scrubbing technologies.

5.6 Refitability

A yes/no flag indicates if a technology can be added in a refit. It is assumed that a refitted technology has the same savings and ship impacts as the technology fitted at build.

5.7 Availability

The availability of a technology (when it first becomes available and when it becomes a mass-market item) is represented in two ways. For some technologies that have a clear division into short, medium and long term concepts, multiple CRT entries are included. For all CRTs, a date is provided for the technology becoming available, and another for it becoming developed. This allows some degree of technology learning to be represented. Dates are broadly divided into 5 and 10 year increments for simplicity of estimation.

5.6 Applicability

Some CRTs will be inapplicable to one of more of the four ship types under consideration. More commonly, the savings and ship impacts will vary between ship types. These are represented using an indication of the applicability of the CRT. Where different relationships are needed for different ship types, the CRT can be repeated with different applicability statements.

6. SHIPPING SYSTEM MODEL

The purpose of the shipping system model is to represent the whole shipping system, in order to understand how the components of the system (economics, logistics, technology, regulation, trade) interact with each other. This presents a challenge: to find the right balance between the level of detail required to produce meaningful and realistic whole system analysis, whilst at the same time maintaining solubility.

In practice, this requires the representation of shipping CRMs in enough detail to explore their relative and combined technical and economic impacts, but with the minimum level of detail required in order to ensure transparency, clarity and computational tractability. The CRMs are represented in less detail and fidelity than the ship parametric and impact models, but by regularly feeding back the outputs of system model ship specifications, any shortcomings in accuracy can be assessed and corrected for as required.

An overview of the conceptualisation of the model is provided in Smith et al. (2010) [5], in this paper, and for brevity only the components of the model that focus on the technical and economic characteristics of ships and CRTs are focused on here.
The shipping system model can be used to explore the feasibility of a wide range of CRMs over the entire global fleet of ships (if so desired). The CRMs that are suited to a VLCC (large tanker) might be very different to those suited to a small container ship. This is due to the specificity of operation, economics and technology of different ships. For this reason, the system model divides the global fleet into ship types, and each ship type is divided into sub-categories of ship size and age. Specific operational parameters, economic parameters and technical parameters are derived for each of these sub-categories and deployed to find their individual expected specification. This is consistent with the way that the data is developed and presented in both the ship impact model and the ship impact database and enables the specifics of impact on a given ship type/size to be considered.

6.1 TECHNICAL MODELLING

At each time-step of the system model’s analysis, a technical specification for a newbuild ship in a given ship type/size category is derived, and the existing fleet of ships is evaluated for the viability of retrofit or operational change.

The shipping system’s technical modelling provides the input to the economic modelling, which requires estimates for calculation of annualised operational expenditure e.g. fuel consumption, carbon emissions, loaded and ballast speed, capacity utilisation (including deadweight, etc).

The technical specification of the ship is also used in order to calculate the cost of a technology, as the costing information is held as an algorithm relating it to different ship parameters.

In the current version of the system model, a ship’s technical specification is defined by 25 parameters including deadweight, installed main and auxiliary power, design speed, operating speed, length, beam, draught, main engine specific fuel consumption, scrubber and ballast water treatment specification etc.

Those 25 parameters are used to define the deviation between a baseline ship’s characteristics, and those of a new design point. For example, the ship impact data describes the impact of a CRT (e.g. bulbous bow) on a given parameter (e.g. main engine installed power). The new design point associated with the implementation of that CRT has an adjusted installed main engine power and this is then used to calculate change in the overall design’s energy consumption. For the case of the main engine this can be thought of as a change in the ship’s ‘as designed’ fuel consumption per day (TPDd).

The ‘as designed’ fuel consumption can be thought of as the fuel consumption that might be measured on a sea trial in ideal conditions, immediately after the ship has been built. In real operation, it is rare to achieve the same performance, particularly as the ship ages and the hull fouls, engines wear etc. It is also the case, that the ship may not be operated at the speed at which it was designed [16] and this can have a significant affect on the fuel consumption. To allow for these considerations, the corrected fuel consumption TPD at a given state i.e. (e.g. loading condition) is calculated according to equation 1,

\[ TPD_i = TPDd_i \cdot \left( \frac{V_i}{V_d} \right) \cdot f(L_i) \cdot \frac{1}{\eta_p} \cdot \frac{1}{\eta_w} \]  \hspace{1cm} (1)

where \( V \) is the operating speed (average over a voyage), \( V_d \) is the vessel’s design speed, \( L \) is the ship’s loading condition, \( \eta_p \) represents the deterioration due to wear, fouling etc and \( \eta_w \) represents a correction due to metocean effects (wind, waves etc).

As calculations are performed on annualised figures for fuel consumption \( FC_{pa} \), this is obtained using the corrected fuel consumption in each state and the time spent \( t \) (in days) in each state, as shown by equation 2

\[ FC_{pa} = \sum TPD_i \cdot t_i \]  \hspace{1cm} (2)

The GHG emissions (and any other emissions) associated with this are calculated by multiplying the fuel consumed by its associated emissions factor e.g. using the data in Bauhaug et al (2009) [14].

Whilst these equations are only for the main engine fuel consumption, they are also performed for the auxiliary engine and a boiler (e.g. in the case of crude tankers). Calculations are performed for each fuel used so should the main engines consume heavy fuel oil and the auxiliaries marine diesel oil, this will be accounted for.

6.2 ECONOMIC MODELLING

There are three main components of economic modelling, for the purposes of this paper only a high level overview is provided – more detail will be available in future publications. They include:

- Operational cost estimation
- Capital costs estimation
- Investment evaluation

The operational costs referred to here are the voyage costs. These include the fuel (and carbon if included) costs, the port dues and the canal charges. The fuel costs are calculated for each year as a function of the fuel consumption and the fuel price. Fuel price scenarios are an input to the shipping system model. If the CRT increases a ship’s energy efficiency, relative to a baseline ship it will reduce the fuel consumption per annum and therefore the fuel costs. Additional to those operational costs are the annualised component of any through life cost (e.g. maintenance, consumables) of the CRT.
Capital costs in this instance are the capital costs of the CRT. They are estimated by scaling based on an indicative ship parameter e.g. the cost of waste heat recovery data is scaled according to the installed main engine power.

Other operational costs (crewing, maintenance, other consumables etc) are included implicitly based on historical datasets.

The justification for the inclusion of a CRT on a ship is that it will be economically rational. That is to say that due to cost savings (fuel savings or carbon reduction if there is carbon pricing), any costs incurred in fitting the CRT are justified. A standard accountancy tool for calculating this is NPV (net present value), as shown by equation (3).

\[
NPV = C_0 - \sum_{t=0}^{T} \frac{(R - C)}{(1 + d)^t}
\]  

(3)

Where \(C_0\) is the capital cost of the CRT, \(R\) is the revenue that the ship will generate (including any changes due to the presence of the CRT e.g. loss of dwt), \(C\) is the cost (e.g. including cost savings due to the CRT and the operating costs associated with the CRT), \(d\) is the discount rate (the interest rate or ‘cost of money’ for the ship owner) and \(T\) is the number of years over which the evaluation of NPV is applied.

A modified version of this equation is used in the shipping system model in order to consider the implications to a ship owner’s profits as a result of the installation of an individual CRT or a suite of multiple CRTs. The CRM or suite of CRMs (because as well as CRTs, this evaluation also includes options such as switching fuels, changing speed or implementing other operational measures such as weather routing) that maximises the ship owner’s profits is then the solution that is used to specify the newbuild or existing ship (of a given type/size).

6.3 FEEDBACK TO SHIP IMPACT MODELLING AND ANALYSIS

Feedback from the system modelling (shown in Figure 1) gives an indication of what combinations of CRMs are most probable in future scenarios. These combinations have been assessed on the basis of the simplified technical modelling described in Section 6.1. The purpose of the feedback is to validate these simplified calculations and to check that the performance and ship impact estimates are correct and to further assess their feasibility with detailed ship design models.

7. SUMMARY AND FUTURE WORK

7.1 SUMMARY

This paper has described the modelling techniques used in the ongoing project “Low Carbon Shipping – A Systems Approach”. It has been noted that, in order to realistically assess the application of CRMs, a more complete socio-techno-economic analysis is required. This has implications for both the breadth of ship impact analyses that must be carried out, and also necessitates the development of a transport-system level model incorporating ship impact and abatement option performance.

The technical analysis uses separate models of high detail level to populate a simpler ship description that can be incorporated in the whole system model. This allows the complete range of influences on the adoption of a CRM to be considered, including basic technical feasibility, return on investment or profit, regulatory compliance and broad economic consequences.

The shipping system model allows a wide range of possible future scenarios to be investigated, incorporating CRMs with a range of economic factors. This allows the application of abatement options to be undertaken on an economic basis in response to the broader scenario.

7.2 DISCUSSION

The shipping industry may soon experience combinations of new regulations, uncertain fuel prices and the arrival of new and potentially disruptive technology. Understanding what broad trends (e.g. speed and fuel choice) and desirable CRM packages might be most suitable over the medium and long term is complicated, and requires more than a purely design oriented approach; it also needs to bring in consideration of economics, logistics and regulation.

Given the difficulty in predicting the future, the shipping industry can benefit from tools to help it cope with the anticipated changes and to investigate which CRTs/CRMs are robust enough to be applied in different socio-economic scenarios.

A potential difficulty in examining the complete shipping system is that, by necessity, calculations must be performed using lower detail levels, leading to a loss of accuracy. Within this project, this is being addressed by the retention of high detail level models, to allow potentially desirable CRM combinations to be assessed. This parallel modelling approach should ensure that this work is credible both from the detail engineering, and overall system perspectives.

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7.3 FUTURE WORK

The Low Carbon Shipping project is moving into a new phase of analysis, with the incorporation of more detailed versions of the ship impact database into the shipping system model. This will allow the main campaign of simulations to be carried out over the following months. It is expected that this investigation will allow the identification of several CRMs and combinations of CRMs that, when subject to a socio-techno-economic analysis, are of interest for more detailed examination. This information will be fed back into the detailed parametric ship model to allow further investigation of these options.

8. ACKNOWLEDGEMENTS

The work presented in this paper contributes to the much wider ‘Low Carbon Shipping – A Systems Approach’ [4]. This project in unique in the concurrent procedure it is analysing CRMs in shipping jointly from an economic, operational, logistic and engineering perspective. Low carbon shipping is funded by Research Councils UK (RCUK), grant reference is EP/H020012/1. We would also like the opportunity to express our gratitude to a number of industry and government partners and subject matter experts, they include:

8.1 INDUSTRY AND GOVERNMENT PARTNERS

BP, Chamber of Shipping, Clarksons, David MacBrayne Ltd., James Fisher, Lloyds Register, Maersk, Ministry of Defence, QinetiQ, Rolls Royce, Shell, UK Major Ports Group, WS Atkins, WWF.

8.2 SUBJECT MATTER EXPERTS

Prof James Corbett (University of Delaware) was the task leader for “emissions and scenarios” in the 2009 IMO study of GHG emissions from ships. Prof (Emeritus) Henry Marcus (retired, MIT) has had a distinguished career combining research into oceanic transportation and ship building with international logistics and maritime transportation policy.

9. REFERENCES


10. AUTHORS BIOGRAPHIES

John Calleya completed his MEng in Naval Architecture at University College London in 2010, which included a 14 month placement working as a submarine naval architect for BAE Systems at a shipyard in Cumbria, UK. This placement provided the opportunity to work in design, operations, commissioning and classification/verification. John is currently a doctoral researcher investigating the influence of carbon emission reducing regulations on international shipping as part of the RCUK project ‘Low Carbon Shipping - A Systems Approach’.

Richard Pawling completed the MEng in Naval Architecture and Marine Engineering at University College London in 2001 and in 2007 completed a PhD thesis on the application of the Design Building Block approach to innovative ship design. Richard has continued his research both in the department and via a secondment in industry, investigating subjects ranging from concept ship design methods to the fire safety of passenger ships. He has been awarded both the Samuel Baxter and W H C Nicholas prizes by RINA for papers reporting his research.

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