Looking into the Future – LeanShip
LeanShip: Development of an Integrated Ship Management System Ensuring Efficient Propulsion and Minimum Emissions of Pollutants

Ziarati, R.
Professor, Piri Reis University, rziarati@pirireis.edu.tr
Ziarati, M.
Doctor, Centre for Factories of the Future, martin.ziarati@c4ff.co.uk
Singh, L.
Mr, Centre for Factories of the Future, lakhvir.singh@c4ff.co.uk

Abstract: The paper reports on the outcome of research that investigates the key design and operating factors affecting the safety of ship operations, and develops methodologies to optimise navigation and engine control systems for safe operations and efficient performance, in view of the introduction of the new International Maritime Organisation (IMO) standards related to energy efficiency, in particular the EEDI (Energy Efficiency Design Index). Furthermore, the paper includes the necessary safety requirements of the vessels currently not covered by the EEDI, in anticipation of future energy efficiency requirements for these categories of vessels. There are references to the development of high fidelity tools and processes for the accurate and efficient analysis of safety and performance-sensitive hydrodynamic problems.

The paper also concerns the adaptation of multi-objective optimisation and integrated design environments for holistic operational performance and minimum powering requirement predictions, which enable the safe application of the design rules guaranteeing, at the same time, the right balance between safety, economic efficiency and environmental performance.

The main focus is on the design of a system to monitor sea conditions and hydrodynamic parameters for minimum resistance to ship motion, with the intention of regulating the navigational equipment and engine performance parameters for minimum fuel consumption and exhaust emissions, also ensuring no intentional risk of power reduction to satisfy EEDI requirements.

Keyword: Efficient Ship Propulsion, Ship Engine Management; EDDI, Lean Ships

1. Introduction

A review of recent publications (Lloyd's Register, Life Matters, June 2012) and the IMO's own reports (Marine Environmental Protection Committee (MEPC), 64 session, Agenda item 4, 29th June 2012) and similar reports by learnt societies and classification societies and maritime organisations, for instance, German Lloyd Academy (GL, EEDI in practice, 2012) which give a clear view of the roadmap for reducing the marine engine emissions in particular in the near future. The whole of Central and North America coastal areas are now almost an ECA (Emission Control Area) and it is expected that coasts of Mexico, Alaska and the Great lakes, Singapore, Hong Kong, Korea, Australia, Black Sea, Mediterranean Sea and Tokyo bay are currently considering becoming ECAs. What is significant is that these constitute 90% of shipping routes so the implications are serious.

The Lloyd's report (Life Matters, June 2012) contains a set of guidance notes to provide advice to owners, operators and shipyards who are perhaps looking to adopt the EEDI early on a voluntary basis, or prepare themselves for its future mandatory implementation. The guidance reflects the current status of the IMO regulations as well as providing information on what options are currently available for ensuring compliance. It is stated that the purpose of the EEDI is to provide a design index, primarily applicable to new ships, that has been developed by the International Maritime Organisation (IMO) and is to be used as a tool for control of CO_2 emissions from ships. The IMO aims to improve the energy efficiency of ships via (future) mandatory implementation of the EEDI.

The IMO, as the main regulatory body for shipping, has, in recent years, devoted significant time and effort in order to regulate shipping energy efficiency and thereby control the marine emissions. For this purpose, the IMO has developed a number of technical and operational measures that include:

- The Energy Efficiency Design Index (EEDI);
- The Energy Efficiency Operational Index (EEOI);
- The Ship Energy Efficiency Management Plan (SEEMP).

The IMO has also been working on a number of Market-Based Measures (MBMs) for the marine industry. The MBMs' development is still ongoing. It should be noted that the EEDI represents one of the major technical regulations for marine CO2 reduction and the IMO, under the banner of the Marine Environmental Protection Committee (MEPC) and its associated Energy Efficiency working group, has been finalising the regulations and guidelines for the EEDI, with input from each of the various flag states and other industry bodies.

Latest legislation regarding marine emissions controls

The Regulations on Energy Efficiency relating to the EEDI and SEEMP entered into force on 1st January 2013 within a new Chapter 4 of MARPOL Annex VI. Within the regulations, there remains the option for administrations to adopt a waiver up to 4 years from the entry-into-force criteria.

At MEPC 63 in March 2012, the IMO Guidelines relating to these Regulations were adopted under the following resolutions:

- Resolution MEPC.212(63) – 2012 Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for New Ships;
- Resolution MEPC.213(63) – 2012 Guidelines for the Development of a Ship Energy Efficiency Management Plan (SEEMP);
- Resolution MEPC.214(63) – 2012 Guidelines on Survey and Certification of the Energy Efficiency Design Index (EEDI);
- Resolution MEPC.215(63) –Guidelines for Calculation of Reference Lines for use with the Energy Efficiency Design Index (EEDI);

The EEDI will only affect new ships above 400 gross tonnes* and will be applicable to the following ship types:

- Bulk carriers; Gas carriers; Tankers; Container ships; General cargo ships; Refrigerated cargo ships; Combination carriers; Passenger ships**; Ro-Ro cargo ships** (including vehicle carriers); and Ro-Ro passenger ships**

*Excludes ships with steam turbine, diesel-electric and hybrid propulsion.
** Not initially subject to regulatory limits.

Each ship will require its own EEDI which will be verified by a recognised organisation (RO) as described further on in this document. Following verification, an International Energy Efficiency Certificate (IEEC) covering both EEDI and SEEMP will be issued by the RO on behalf of the Flag State and will be required to be maintained onboard the ship throughout its life. The certificate is valid for the life of the ship unless the ship undergoes major conversion, is withdrawn from service or transfers flag.

1.1 The EEDI

The EEDI equation calculates the CO2 produced as a function of a ship's transport work performed. In other words, the equation provides a measure of the ship's 'benefit to society' by establishing how much CO_2 is produced per transport work done which equates to g CO_2 / tonne.nm. The equation is highly complex and is made up of several expressions for:

- Main engine(s)
- Auxiliary engine(s)
- Energy saving technologies (auxiliary power)
- Energy saving technologies (main power) Transport work

The top line of the EEDI equation is characterised by four key terms, whereby the energy saving technologies terms may include, for example, waste heat recovery systems, use of wind or solar power. The CO_2 produced is based on the product of the power, specific fuel consumption and carbon factor for a particular type of fuel used. The bottom line of the equation relates to the total CO_2 generated by each of the four terms, to ship capacity and speed. In addition, there are a series of correction factors that moderate the equation. These account for:

- Ship design factors (e.g. Ice-Class and shuttle tankers)
- Weather factor for decrease in speed in representative conditions
- Voluntary structural enhancement
- Ships built to Common Structural Rules (CSR)
- Capacity correction for chemical tankers and LNG ships

The calculation of the EEDI is detailed within the recently adopted 2012 Guidelines on the Method of Calculation of the Attained EEDI for New Ships (IMO Resolution MEPC.212(63). Verification of the EEDI is comprehensive and will be in two stages:

- Pre-verification which commences at the design stage and
- Final verification upon completion of the sea trials and commissioning.

Details of the verification methodology are given in IMO resolution MEPC.214 (63) and the process. Full details of recent agreements regarding EEDI are given in the Marine Environmental Protection Committee, 64 session, Agenda item 4, 29th June 2012. It is worth noting that the report to the Committee was submitted by IACS, BIMCO, INTERTANKO, INTERGARGO and OCIMF. This Agenda item primarily reviewed the arrangements for EEDI as outlined in the above paragraphs and addressed one outstanding issue from 61 Session viz.: a ship's manoeuvrability in adverse conditions. Some delegates had argued that, in order to reduce installed power, a ship's designers may choose to lower a ship's design speed to achieve the required EEDI. To avoid negative impact, such as having under-powered ships, a provision was added to regulation 21 in the Chapter of MARPOL Annex VI, stating, in effect, that the propulsion power shall not be less than the propulsion power needed to maintain manoeuvrability of ship under adverse conditions, as defined in the guidelines to be developed by the organisation. What is significant is that pre-assessment will ensure that a ship has sufficient installed power to achieve the minimum required advance speed in head waves and wind conditions, defined to facilitate course-keeping in all wave and wind conditions. All guidelines are comprehensive and well documented. The only issue is how all these will be enforced. Although there is a clear verification processes and procedure, it is still unclear how ship builders and ship designers will respond.

The intention of this LeanShip is not only to support IMO's EEDI application or any other related initiatives such as the 'Resolution MEPC 213(63) – 2012 Guidelines for the Development of a Ship Energy Efficiency Management Plan (SEEMP)', but also to review the existing arrangement for navigation on board vessels and consider the possibility of integrating the outputs of all navigation equipment with all the outputs from engine controls. The ultimate aim is to develop an intelligent management system which helps to reduce energy consumption and engine emissions to a minimum, whilst simultaneously considering the hydrodynamic characteristics and above all safety of the ship and its crew. We also intend to develop a means of monitoring the emissions at ports by novel means as demonstrated by Figure 1.

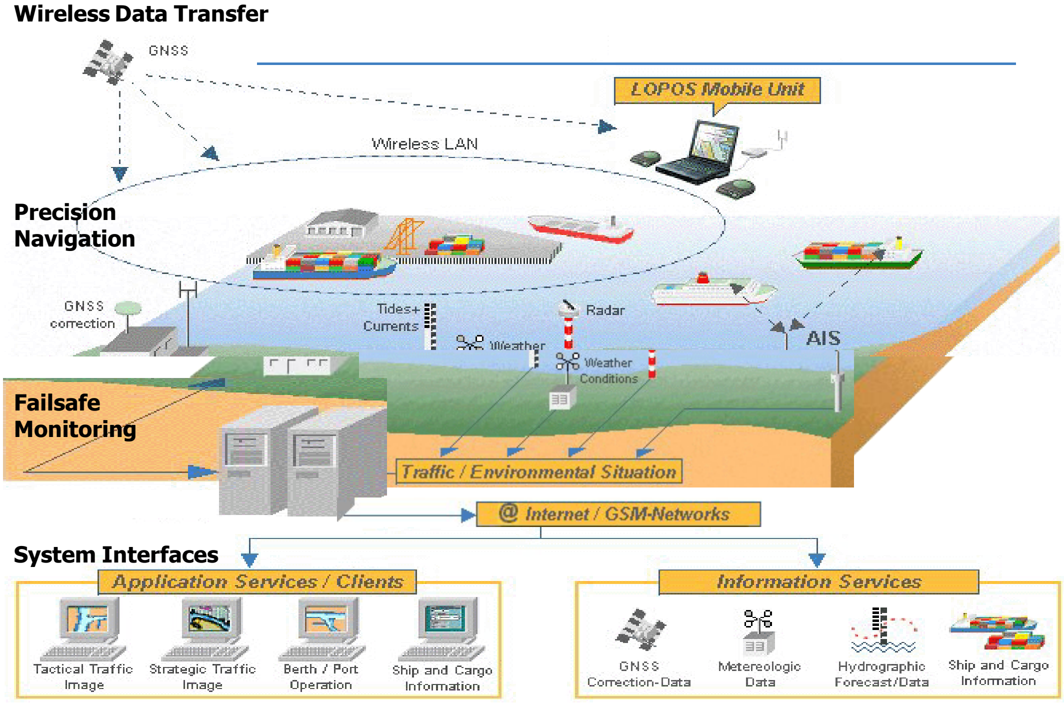


Figure 1 - Ports as controlled zones monitoring arrival of EEDI and non-EEDI vessels

It is assumed that ship designers/builders will have to abide by the EEDI requirements and hence, as part of this LeanShip, the EEDI will be used as one of the core equations for integration and fusion of data from various navigation and engine controls. It is also acknowledged that slow steaming has helped considerably with fuel saving and has resulted in a substantial reduction of emissions such as CO2. The advantages of slow steaming is documented in a report by Maersk Group, showing a reduction of bunker fuel use in 2007, dropping from 13.8 million tonnes to 10.7 million in 2010, which is reported to have saved 2 million tomes of CO2 and brought about a significant reduction of NOX and SOX levels. Slow steaming has already proven its merits worldwide, so much so that COSCO, K-Line, Yang Ming and Hanjin are already applying slow steaming throughout their fleets with the result of considerable energy savings and reduced emissions. The latest report from Maersk is that emissions reduced by 36.44% in 2007, 38% in 2008 and 42.67% in 2009 as a result of applying slow steaming, although the details of what these figures really mean and where the base lines lie are not yet clear as there is no mention of losses due to slowing down the engines and increasing journey times.

However, considering a surplus of ships, due to the current economic crisis, the decision to slow down the ships may not be a major issue now but will be an issue in the future when business is expected to pick up. It is also true that slow steaming can mean a drive to cutting energy consumption through optimal hull designs, waste heat recovery systems, use of wind power wherever and whenever feasible or solar power. Recent research by Ozkanak et al [1] and Ziarati [3] using high pressure fuel injection systems, reduced engine heat losses, lighter engines and engine components has shown a considerable reduction in CO2. Mert et al [2] also argues that better management of energy on board vessels is an important consideration in reducing fuel consumptions with lower engine emissions. One significant area is an improved matching of turbochargers with the engines. While his engine designs are used worldwide, and his lab in Bath University is reported to have been supported by almost all oil majors and engine and engine component manufacturers, he believes there is a long way to go to make diesel engines consume less oil and produce reduced amount of pollutants. He is also of the view that fuel types make a difference and that lower Sulphur fuels often produce lesser CO2, NOX and of course, SOX.

As a result of a LeanShip with Lloyd's Register, funded through an EU non-nuclear initiative, Ziarati (Sited in [1]) produced the UK's first revolutionary hybrid engine for cars and trucks using dual power systems. The work led to development of engine 'finger printing' that would be an easier means of monitoring a ship's engine efficiency and exhaust emissions. The findings from these pieces of research will be built into the intended set of tools, which are expected to be developed as result of this proposed programme of research and development.

For a dive support vessel, for example, this would mean finding an expression for the Service provision at station under DP conditions and safe provision of the dive services, accounting simultaneously for the efficient travel from station to station.

2. Concept and Objectives

There is no dispute that an intelligent integration of ship navigation and engine controls for accurate and efficient analysis of safety and performance sensitive hydrodynamic problems in complex and/or extreme sea operational conditions, including intact stability performance (surfing/broaching, rolling, extreme motions) would help realise the ultimate aim of improving the efficiency of waterborne transports by the reduction of ship emissions through energy systems' integration. The intention is continuous assessment and minimisation of the risks. Risk awareness and management will play a major role in developing the intended tools and system measurements and their integration. The LeanShip will further strengthen the competitiveness by focusing on innovative vessel designs and automatic manufacturing techniques. The research will also contribute to cross-thematic marine and maritime research ("The Ocean of Tomorrow 2013") and the Commission's 'Marine Knowledge 2020.' The results of the LeanShip will contribute to enhancing the safety of vessels in compromised situations, while respecting regulatory environmental constraints. The results will also contribute to the strengthening of technical knowledge as inputs to negotiations at IMO committee meetings.

What is the reason for inventing a new platform and methodology for the systematic implementation of ship manoeuvring in globally acting ship operations and practices? What is new in this solution?

Safety is a critical success factor for shipping companies that want to survive; this means that, whatever benefits a new tool brings, safety should not be compromised. The second factor is the IMO and its requirements. These have to be respected, even if some requirements have not been fully tested. The IMO's recently introduced new standards related to energy efficiency in particular the EEDI is not as clearly understood as it first appears. A careful review of the EEDI clearly shows that the formula used to arrive at the Index is more rigid than first appears. The formula itself has not been fully tested, but EEDI signals the introduction of emission controls at sea and there are more regulations to come. The mid-eighties brought the beginning of the end for many engine designers as the EU started discussing future emissions levels for several pollutants such as CO2, NOX and so forth, yet failed to limit the unacceptable levels of particulates from combustion of diesel fuels responsible for many cancer cases. Nevertheless, the imposition of emission levels brought new ways of designing and producing cars and this process is continuing. The same is expected for the shipping industry. If the shipping industry fails to regulate itself, EU or USA and some others will take the lead. This is already happening with the introduction of the North America Emission control Area (NCA).

With regard to the high fidelity tool itself, the present methodology proposes the use of Agile Methodologies to systemise the operational processes and accelerate the adoption (or adaptation) of the situational-based options (simulation first, validation and then action), offering a multi-agent-centred approach rather than a procedure-centred one and facilitating the creation of a tailor-made methodology for a given situation in line with its own specific characteristics. Furthermore, LeanShip proposes the creation of a radically new platform to help ship crews to successfully implement the optimum navigational course and engine power for given navigational manoeuvring situations and sea conditions.

LeanShip involves a high number of well-known ship science centres, and companies with leading edge technologies in propulsion and navigation systems; one of the companies (C4FF, UK) has one of the largest accident data-bases with substantial experience of data and engineering system modelling. The methodology and platform designed under the scope of LeanShip will be validated in at least on ship builder/operator company and tested in a test tank.

Figure 2 - Ship Autopilot System proposed will not be dissimilar with aeroplane autopilot system

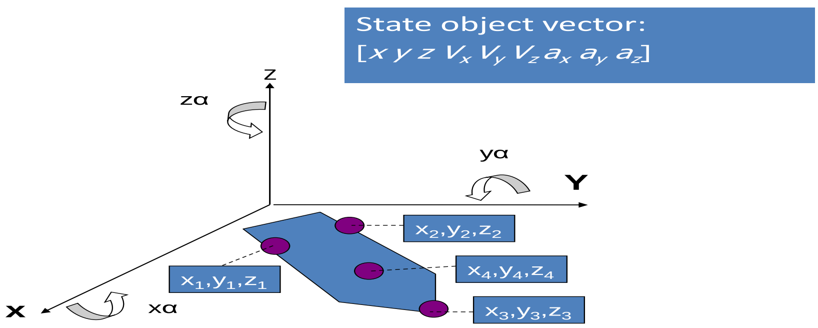
Figure 3 - Proposed LeanShip System is based on current practice – Innovation is in integration

3. Key Questions and Objectives

The LeanShip objectives were decided after posing several questions. The LeanShip intends to use the results of several successful and recent EU funded projects such as MAIDER (www.maider.pro) and SURPASS (www.surpass.pro) as well as several others such as MarTEL (www.martel.pro), EBDIG (www.ebdig.eu) and EGMDSS (www.egmdss.com). Four of the partners in this Project were the key partners of the aforementioned LeanShips. Recent work on ship automation [3] and application of Artificial Intelligent [4] will be used in the development of the proposed LeanShip system.

Every vessel has some form of navigation system to allow it to sail safely in normal operating conditions. The challenge occurs when ships encounter storms and have to reduce stress on the ship hull to reduce the risk of capsizing, grounding or collision. A very well equipped ship often has sophisticated engine and navigation systems, to some degree. The navigation tools are also rather limited to scenario based cases and do not give detailed guidance for complex hydrodynamic conditions. The concept of integrating navigation equipment with engine management is also in its infancy.

Data fusion from internal sources



Mathematical model of data fusion

Equations of the state :

$$x(t+1) = \Phi x(t) + \Gamma w(t)$$

$$y_i(t) = H_i x(t) + v_i(t)$$

where:

$x(t)$, $y_i(t)$ – state vector of the proces

$w(t)$, $v_i(t)$ – errors of the proces

Φ, H_i, Γ – constance matrix

Figure 4 - Application of data fusion for integrated solutions to navigation

4. Description of the Solution

The solution is twofold. One concerns the development of data/knowledge sets regarding ship operations and their integration, and the other is the information and communications technology aspects of the LeanShip. The intention is to develop five tools as well as a main tool here referred to as **LeanShip**. A diagrammatical of current practice based ‘Previous Knowledge’ and those on ‘Current Developments’, as against the proposed LeanShip solution, are presented in the following **Figures 5, 6 and 7.**

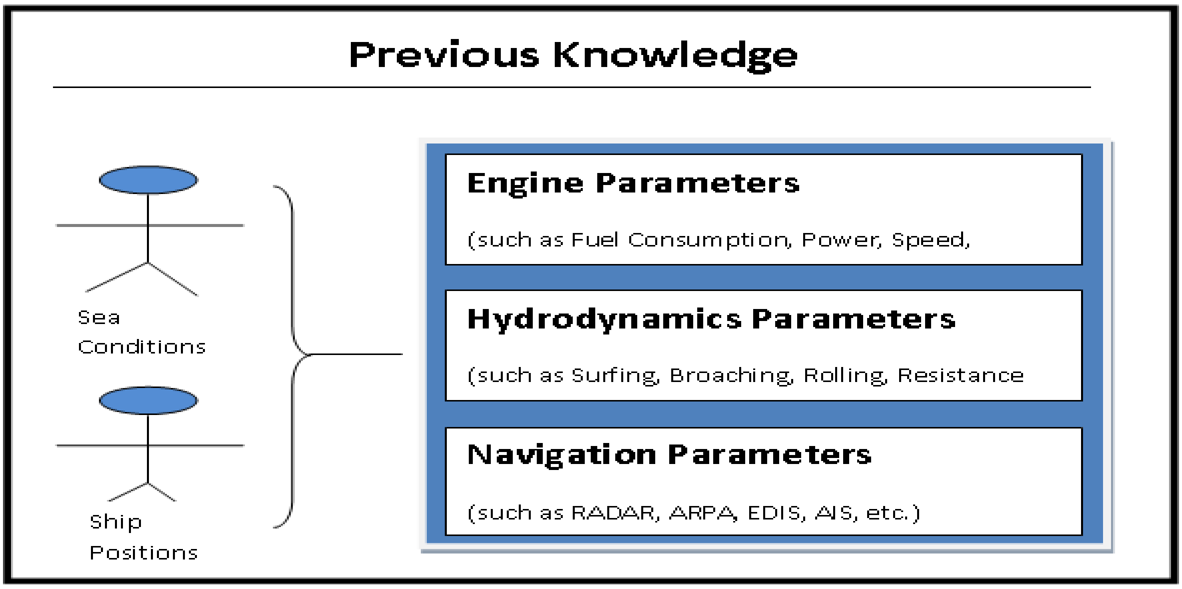


Figure 5 - Previous Knowledge

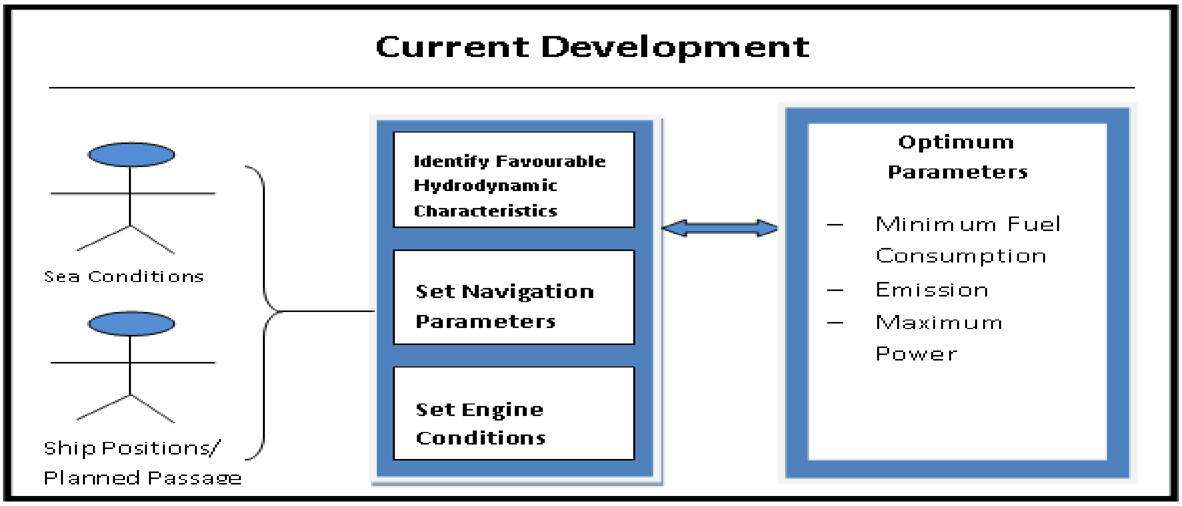


Figure 6 - Current Development

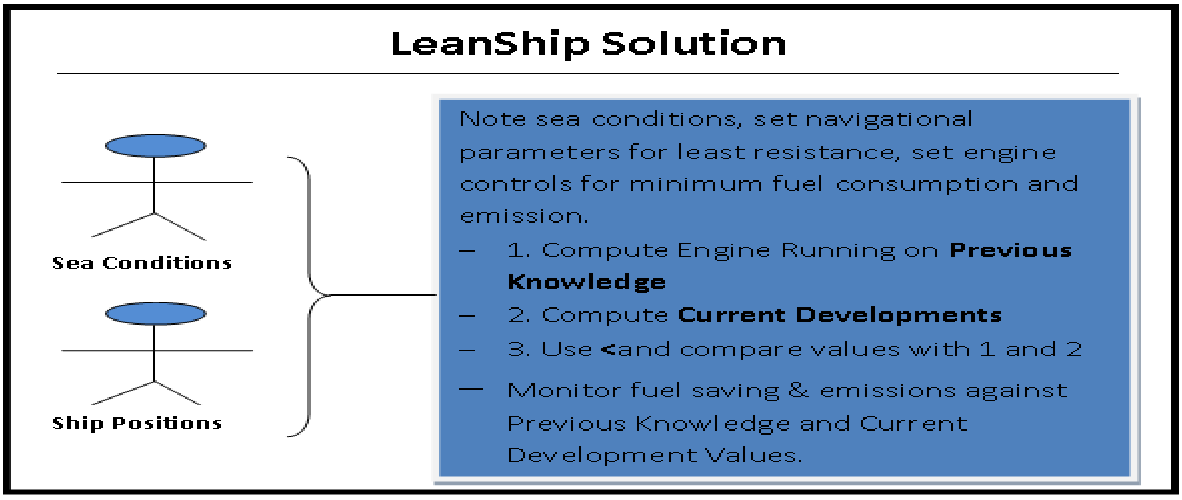


Figure 7 - LeanShip solution

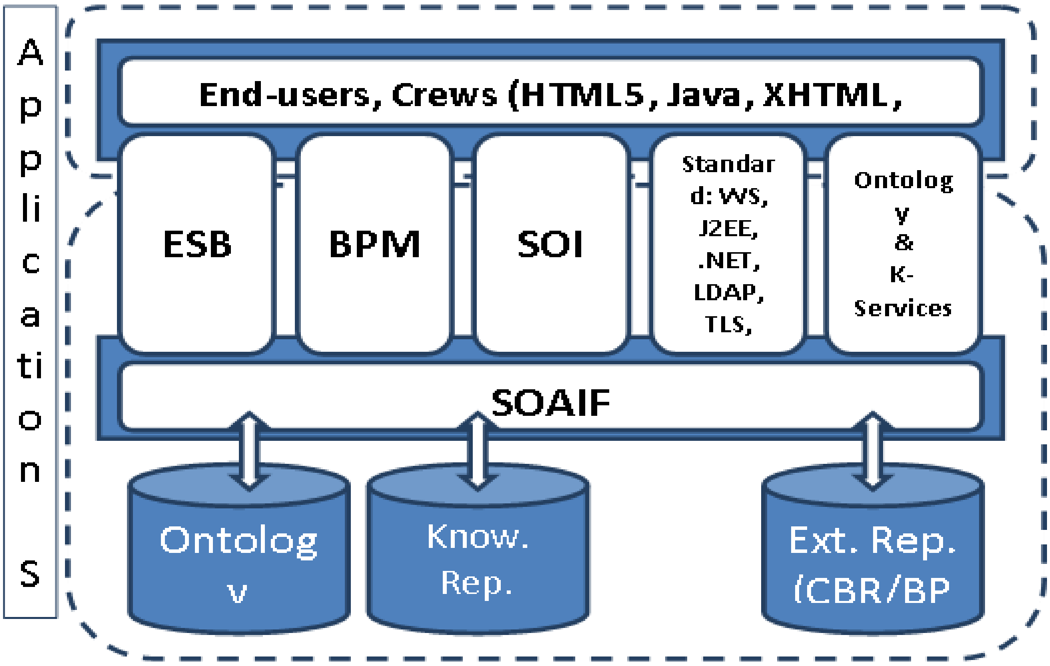


Figure 8 - A possible LeanShip Implementation (the system may provide a Web concept by not rely on it to operate as standalone) – Source [5].

5. Conclusions

The key issue in this paper has been the business opportunity that this project is keen to addresses. The business opportunities are substantial. The size of the market is an opportunity to consider as there are over 100000 ships sailing on the main sea routes at this moment in time. Considering the identified business opportunity and the size of the market the project is economically sustainable. The technical approach being considered is also novel and takes advantage of current state of art used in navigation and engine controls. The risks (technical, commercial and environmental) are manageable and do not pose a barrier to the expected success of the project.

In summary the LeanShip if successful it could save tons of fuel and CO2 but would require a thorough investigation as to how various main types of ships operate, what equipment they use, the form and level of interaction between navigation equipment, and the form and level of integration between navigation and propulsion systems. There has been no similar LeanShip that has considered the ship's position and sea conditions in a 3D map to reduce resistance to ship motion by taking into account all design parameters with the ultimate aim of reducing fuel consumption and exhaust emissions through the development of LeanShip as described earlier in this Project. This project has been developed by several ship owners and operators, classification societies, ports and research centres/universities and software system developers. Several equipment producers have been nominated as members of the Steering Committee to ensure their knowledge is taken into consideration and that they are in a position to support dissemination and exploitation activities, but are not in the position to influence the development of the intended tools and processes. The LeanShip product will be made available to all European shipping companies soon after the LeanShip is concluded.

6. References

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