Article

LEANSHIP - DESIGN AND DEVELOPMENT OF A HIGH FIDELITY INTEGRATED SHIP MANAGEMENT SYSTEM FOR MATCHING ENGINE OPERATIONS TO SEA AND AIR CONDITIONS

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Abstract

This paper reports on a project that aimed to regulate the navigational equipment and engine performance parameters for minimum fuel consumption and exhaust emissions by taking advantage of wind and sea conditions while ensuring compliance with EEDI (Energy Efficiency Design Index) without the risk of intentional reductions of speed. The primary experiments have shown substantial fuel saving potential. To achieve this aim, key operating factors affecting the efficiency of ship operations were investigated and methodologies to optimise navigation and engine control systems for safe operations and efficient performance were developed. Also a set of high fidelity tools and processes for the accurate and efficient analysis of air and sea conditions were considered. The project included hydrodynamic analysis for ships' operational performance in normal running conditions as well as slow speed behaviour. The project work concerned the adaptation of multi-objective optimisation and integrated design environments for holistic operational performance and minimum powering requirement predictions; this is expected to ensure safe application of the design rules whilst guaranteeing the right balance between economic efficiency, environmental performance and safety. The main deliverable of this project was a decision support system to provide navigation knowledge to regulate engine running conditions for minimum fuel consumption and lowest feasible CO2 emission. The project is ongoing and the overall system is expected to comprise a standalone platform composed of all hardware and software systems.

Introduction - Concept and approach

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 learned societies, classification societies and maritime organisations, for instance, German Lloyd Academy (GL, EEDI in practice, 2012) give a clear view of the roadmap for reducing marine engine emissions 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 has developed a number of technical and operational measures that include: i) The Energy Efficiency Design Index (EEDI); ii) The Energy Efficiency Operational Index (EEOI) and iii) 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 ongoing. It should be noted that the EEDI represents one of the major technical regulations for marine CO_2 reduction. 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 its Flag State.

The ultimate aim of this project was to develop an intelligent ship management system (engine, navigation and transducers) – Figures 1 and 2 - to help reduce energy consumption and engine emissions, whilst simultaneously considering the hydrodynamic characteristics and above all safety of the ship and its crew. It was also intended to develop a means of monitoring emissions at ports as demonstrated by Figure 3 below. One of the partners (TRANSAS) is well-known for their knowledge of on-board navigation, simulation and Vessel Traffic Management Systems in the marine sector (see for instance https://www.youtube.com/watch?v=95rrRtGPmXw - as such TRANSAS shall provide some navigation tools for optimisation of fuel consumption).

Figure 1. Proposed Ship AutoSet System Is Based on New Knowledge – Innovation Is New Knowledge and in System Integration

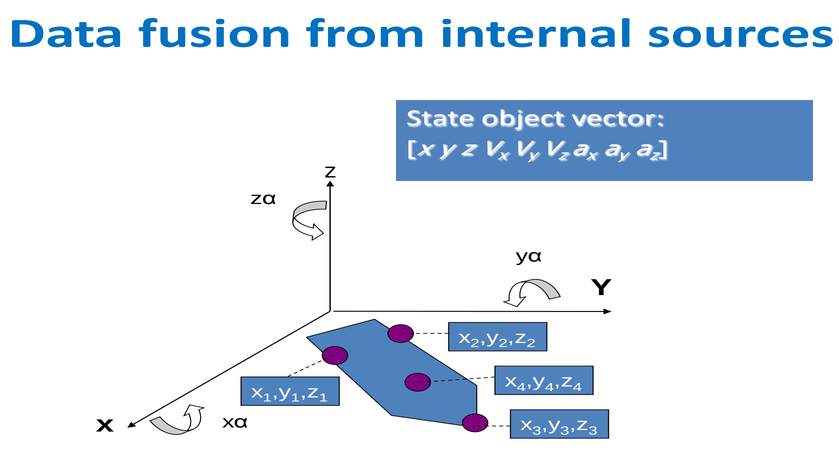

Figure 2. Navigation Automation – Novel Means of Changing Course

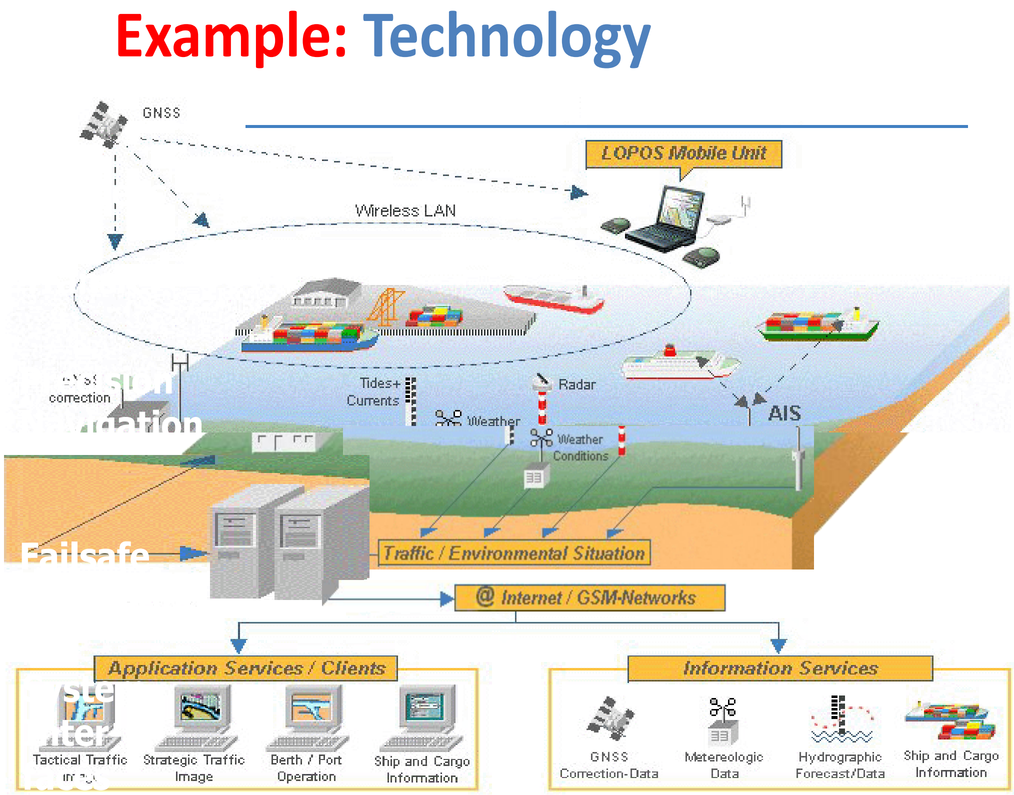

Figure 3. Ports as Controlled Zones Monitoring Arrival of EEDI and Non-EEDI Vessels

It was assumed that ship designers/builders will have to abide by the EEDI requirements and hence, as part of this project, the EEDI was used as one of the core equations for the integration and fusion of data from various navigation and engine controls. It was also acknowledged that the project used slow steaming when considered beneficial for saving fuel or reducing emissions such as CO2. The advantages of slow steaming are 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 resulting in considerable energy savings and reduced emissions. The latest report from Maersk is that emissions were 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 the surplus of ships, due to the current economic crisis, the decision to slow down 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. The earlier research by Ziarati in 1970s and 1980s (Ziarati, 1987) and subsequent papers in (see for example http://www.c4ff.co.uk/history/papers/AutoTech_95_paper.pdf) using variable geometry and high pressure fuel injection systems, reduced engine heat losses and show that lighter engines and engine components can considerably reduce CO2. Mert et al., 2002 also provides a means of better management of propulsion systems on board vessels. One significant area is an improved matching of turbochargers with the engines. While his engine designs are used worldwide, and his laboratory 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. The emergence of novel catalysts has shown that some harmful diesel particulates also be effectively removed.

As a result of a project with Lloyd's Register, funded through an EU non-nuclear initiative, Ziarati (1995) 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 were built into the intended set of tools, which are expected to be developed as result of this proposed programme of research and development (Ziarati, 1990 and, Ozkaynak, S., Ziarati, R., and Bilgili, E., 2009).

This was a near market project. The intention was to test and evaluate a set of tools and validate a new knowledge in the form of new ship management system. This project comprised several key tasks:

Technological outcomes

1. A tested tool for monitoring sea surface condition.
2. A tested and refined tool for ship hull stress concentration and possible navigational movements to relieve pressure.
3. A tested and refined tool to estimate ship hull resistance, specifically wave-making resistance in order to support the work done by IACS for IMO regarding minimum power requirements.
4. A tested tool for engine management and control.
5. A tested tool for coordinated navigation guidance and control.
6. A new tool, known as the AutoSet, introducing new knowledge for engine management and take the output from tools 1 to 5 above to provide a decision support for consideration by the crew. The new knowledge includes the latest and sophisticated neural network (Ziarati, 2013).

Business outcomes

The business outcome was to reduce the cost of operating ships (test results leading to a saving of 150,000 EUR per ship per year for 50 KTon tanker) by reducing fuel consumption (275 MTon of Fuel per ship per year) and emissions (220 Ton per ship per year) and ensuring no compromise with power requirements (EEDI, etc) for safe shipping. This was achieved (Norra, 2013).

The Socio-Economical and Environmental Outcomes

The outcomes were to substantially reduce marine engine exhaust emissions (by around 275 MTon/per year for a 50 KTon Tanker), which was expected to revolutionise shipping as did the Clean Diesel project (Ozkaynak, S., Ziarati, R. and Bilgili. E., 2009), developed by two of the partners, which revolutionised the use of diesel engines worldwide in all transportation sectors.

Work Package Diagrams – AutoSet System and data flow diagram

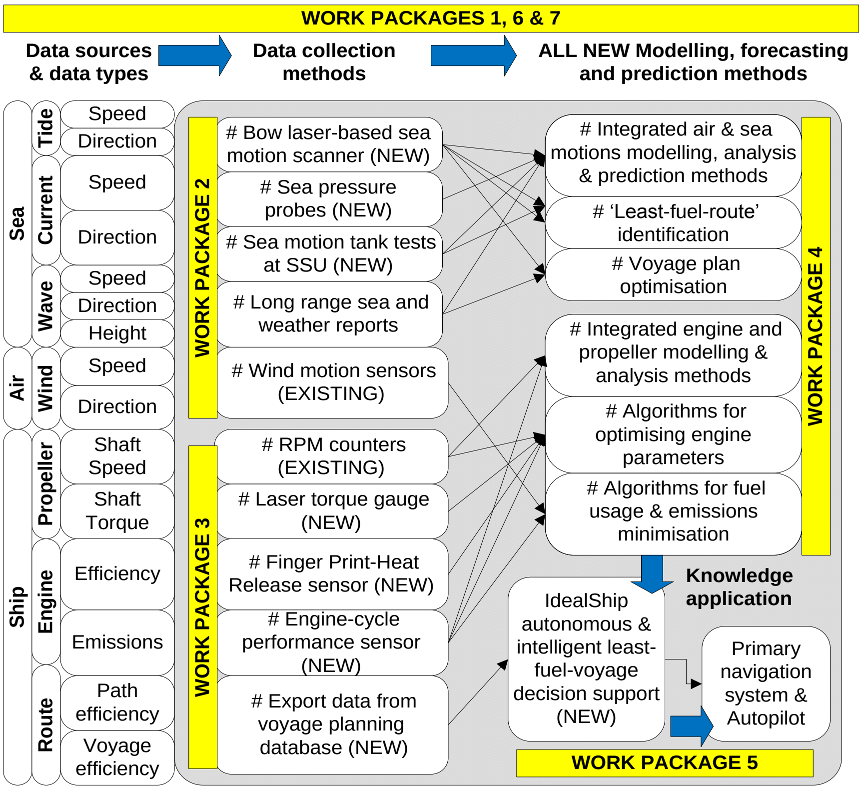

Figure 4. AutoSet System and data flow diagram

Technical Innovation

Technical innovation was also significant and pushed the boundaries over and beyond current leading-edge fuel and emissions reduction technology by its first time use of AI systems to provide autonomous control of novel sensors, modelling and analysis functionality and intelligent decision-support systems. In this respect the autonomous processes developed within this project made use of the work of Schlitt and Brazma (2007). Through experience gained by the C4FF team through 2 previous UK Government Innovate UK / Technology Strategy Board CRD projects, that involved the use of autonomous control techniques within operations planning, this biological modelling approach was adapted for use in fuel and emissions reduction through improved navigation and engine control. In this respect the innovative sensor data-collection, autonomous control and artificial intelligence modelling and analysis technologies developed were able to identify alternative direction changes and from these select those that contribute most to minimising the amount of fuel used during a vessel's entire voyage, i.e. selected paths which when accumulated achieved least-fuel-voyages (L-F-V). Autonomous control systems enabled fast responses to sea and air condition variability that enabled the synchronisation of engine management with such changes. Innovative Artificial Neural Network (ANN) based advanced modelling and analysis functionality was used involving adapting existing ANN network structures, and using data collected from sensing devices to directly train ANNs and test their accuracy and reliability with the least-fuel-voyages the system identified and followed. There are no existing systems capable of this level of technical innovation thus this project represents a significant step in the management of fuel usage in the maritime sector with potential applications in other transport sectors particularly rail.

Conclusion

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 normal and extreme sea and air operational conditions, including intact stability performance, would help realise the ultimate aim of improving the efficiency of waterborne transports and achieve a reduction of ship emissions. The intention of the projects tools was continuous assessment and minimisation of the risks. The project further strengthened competitiveness by focusing on innovative vessel designs and automatic manufacturing techniques. The research also contributed to cross-thematic marine and maritime research ("The Ocean of Tomorrow 2013") and the Commission's 'Marine Knowledge 2020.' The results of the project contributed to enhancing the safety of vessels in compromised situations, while respecting regulatory environmental constraints. The results also contributed to the strengthening of technical knowledge as inputs to negotiations at IMO committee meetings (Sahayam, 2013).

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 of consideration by the project was and still 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 relating to energy efficiency, in particular the EEDI, is not as clearly understood as 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 trucks/cars and this process is continuing. The same is expected for the shipping industry. If the shipping industry fails to regulate itself then the EU or USA and others will take the lead. This is already happening with the introduction of the North America Emission control Area.

The most important message to the countries who manufacture diesel engines is for them to realise there are ways of burning NOXs and in fact C4FF has experimented with several new engines burning NOXs as fuel and so there is no reason for these harmful by-products of diesel combustion not to be burnt as part of exhaust gas recirculation. Furthermore, Governments are aware that harmful particulates emitted by Diesel engines can be filtered or transformed by special catalysts. C4FF is of the view that diesel engines should be modified to burn gas as is the case with gas engines developed by C4FF. In the marine world, Wartsila have already reconfigured two diesel engines into gas engines with a great deal of success. The future is hybrids with gas as the main source of engine fuel.

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NB: This project is an industrial project and was initiated based on the work of Reza Ziarati (1975-2009).

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