MariEMS – Maritime Energy and Management System

Reza Ziarati, Professor Dr, C4FF, UK, **Basak Yucel Akdemir**, Dr, BAU, TR

Abstract

This paper reports on the findings of an EU Erasmus+ funded project, known as MariEMS, that aimes to develop the role of the ship energy managers and a training programme for these managers. The project is expected to contribute to regulate the navigational equipment and engine performance parameters for minimum fuel consumption and exhaust emissions by taking advantage of the wind and sea conditions ensuring also compliance with EEDI (Energy Efficiency Design Index) without the risk of intentional reduction of speed. The primary experiments (Ziartai and Akdemir, 2015) have shown substantial fuel saving potential. The experiment allowed the study of key operating factors affecting the efficiency of ship operations to be investigated and methodologies concerning navigation and engine control systems, for safe operations and efficient performance, to be optimised. In the experiments a set of high fidelity tools and processes (Autoset) for the accurate and efficient analysis of air and sea conditions were considered. The experiments included limited hydrodynamic analysis for ships' operational performance in normal running condition as well as slow speed behaviour. The experimental 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 guaranteeing, at the same time, the right balance between economic efficiency, environmental performance and safety. The reason for the experiments was a decision support system to provide navigation knowledge to regulate engine running conditions for minimum fuel consumption and lowest feasible CO_2 emission. The experiments are on going and the overall system comprised a standalone platform (AutoSet) composed of all harware and software systems. The intention of MariEMS project is to take advantage of the outcome of a recently conlcuded projects such as IdealShip (Sahayam , 2014), this latter project proved that it is possible to make considerable fuel saving when sailing the ship through the path of least resistance (sea and air) in its jouney from one location to antoher.

Introduction - Concept and approach

In 2007 the global shipping industry estimated to have emitted 1,046 million tonnes of CO2, 3.3 % of global emissions, and in 2015 this reached some 6 % of world total.

IMO has established a series of baselines for the amount of fuel each type of ship burns for a certain cargo capacity. New ships will have to beat that baseline by a set amount, which will get progressively tougher over time. By 2025, all new ships will be a massive 30% more energy efficient than those built in 2014 (Low carbon shipping and air pollution control, 2015).

A review of recent publications (Ziarati and Akdemir, 2015) including the reports by University College London (Revealed preferences for energy efficiency in the shipping markets, 2016), Lloyd's List (Maximising ship efficiency: Ending the debate, 2015), Lloyd's Register (Life Matters, June 2012) as well as 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, Germanischer 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 will become 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 now have to adopt the EEDI and prepare themselves for its full 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 new ships. The IMO aims to improve the energy efficiency of ships via the full implementation of the EEDI. 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 still 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 flag.

The ultimate aim of this the recent experiments was to develop an intelligent ship management system (engine, navigation and transducers) – Figures 1 and 2 - which helped 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. It was also intended to develop a means of monitoring the emissions at ports by novel means as demonstrated by Figure 3 below.

Ship AutoSet Systems

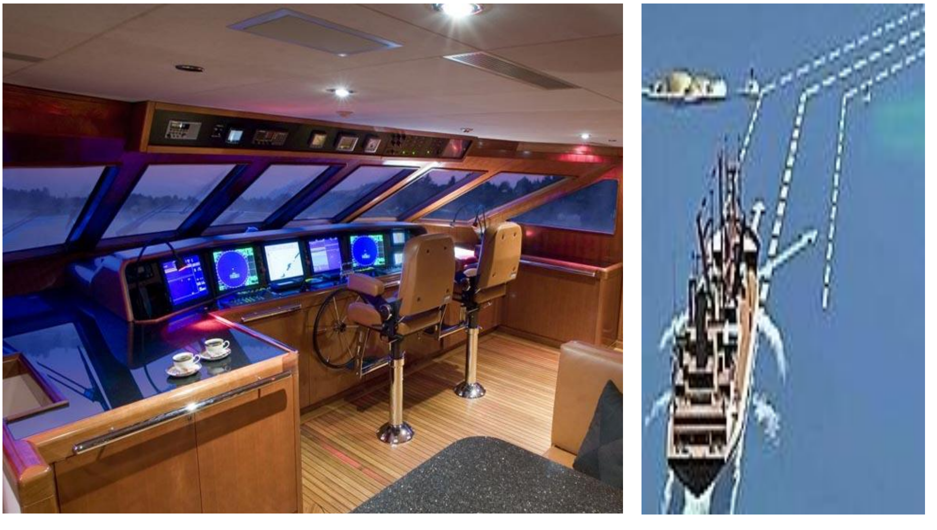

Figure 1. Proposed Ship AutoSet System is Based on New Knowledge-Innovation and New Knowledge-System Integration

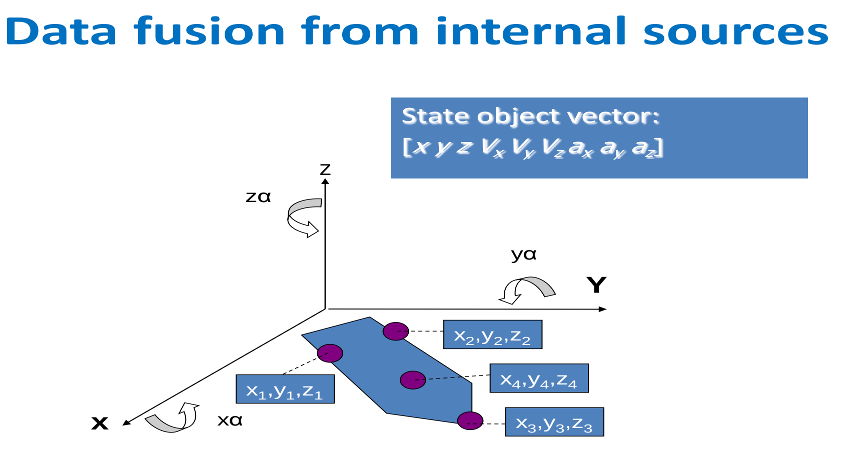

Figure 2. Navigation Automation – Novel Means of Changing Course

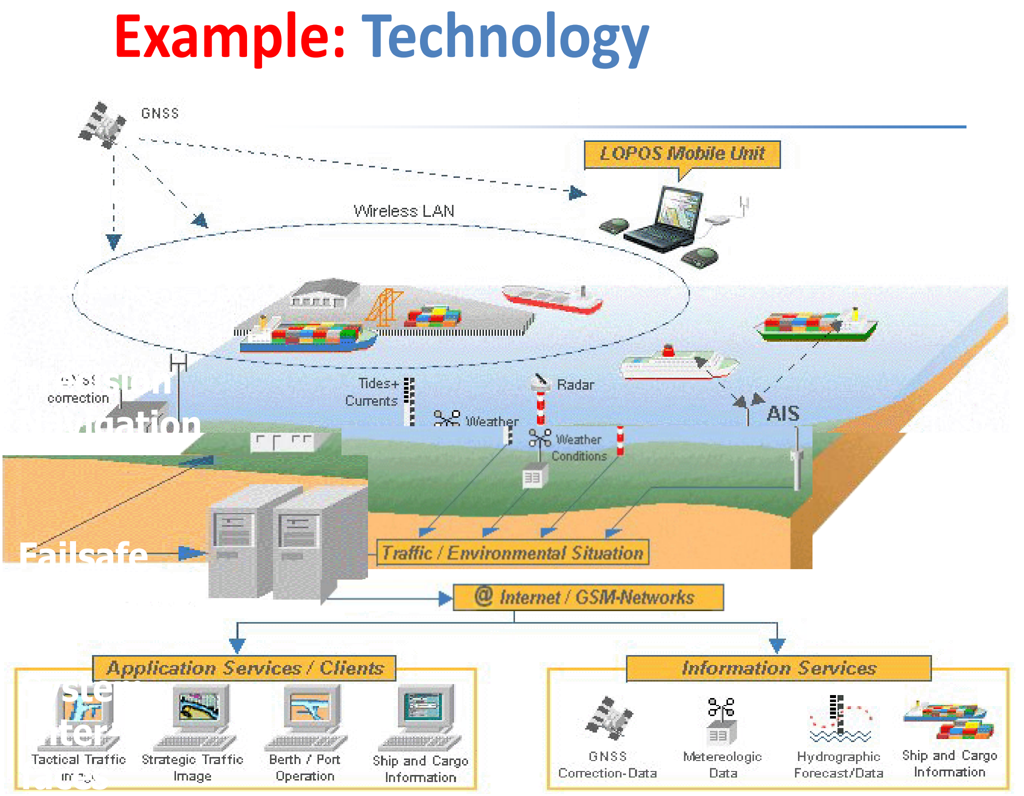

Figure 3. Ports as Controlled Zones Monitoring Arrival of EEDI and Non-EEDI Vessels

It was assumed that ship designers/builders will have to abide by the EEDI requirements and hence, as part of the recent experiments, the EEDI was used as one of the core equations for integration and fusion of data from various navigation and engine controls. It was also acknowledged that the outcome of the experiments also used slow steaming when considered beneficial for saving fuel or reducing emissions such as CO_2. The advantages of slow steaming is documented in a report by Maersk Group (Lloyd's Register (Life Matters, June 2012), 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 CO_2 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 CO_2 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. The earlier research by Ziarati in 1970s and 1980s (Ziarati, 1987) and subsequent papers in (Ziarati and Cole, 1995) using variable geometry and high pressure fuel injection systems, reduced engine heat losses and shown that lighter engines and engine components can considerably reduce CO_2. Mert et al. (2002) also provides a means of better management of propulsion system on board vessels is an important consideration in reducing fuel consumptions with lower engine emissions. Ziarati and Cole (1995) provide one significant area for improvement, namely, improved matching of turbochargers with the engines. While Ziarati's (1995) 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 CO_2, NOx and of course, SOx. The emergence of novel catalysts and filters (DPFs) has shown that some harmful diesel particulates also be effectively removed. The recent developments with regard to **Selective catalytic reduction** (SCRs) clearly shows that NOx can also be broken inot N_2 and H_2O. It is also worth noting that Scrubbers have proven to be effective in reducing SOx, this together with better choice of fuels could remove the problems associated with SOx. Furthermore, uses of variable geometry turbochargers, higher injection pressures and used of novel SCRs and DFPs together with injection of the small amount of water at the right place and time during the combustion period is considered a way forward to developed cleaner diesel engines in the future. The Lloyd's Register supported project, funded through an EU non-nuclear initiative (Ziarati, 1995) 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).

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 (see Figure 4 below), 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); and is built using the outcome of the IdealShip management strategy, see Figure 4).

The Main Aims

The main aims of the project when developing the AutoSet were 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 (860 MTon per ship per year) and ensuring no compromise with power requirements (EEDI, etc) for safe shipping (Sahayam, 2014).

The earlier experiments demonstrated that the AutoSet can provide at least the benefits observed at experimental stage i.e. 20 MT of fuel oil (Intermediate) for a 30000 MT DWT vessel and 50 MT of fuel for a 75000 MT DWT ship, in any given year. Such a demonstration clearly indicates the fuel saving would run into millions of Euros. What is significant is that there will be substantial saving in CO_2, on average, some 220 MTons of CO_2 per year and similar reduction in other greenhouse gases and such as methane and harmful pollutants such as PM. The table below shows the projections:

Vessel Size (MT DWT)	Fuel Saving (MT)/year	CO_2 (MT)/year	Money (€)/year
30000	168	524	93000
75000	420	1310	231000
Average	280	870	154000

NB1: Sailing days: 275; NB2: Fuel Cost (MT): 550 EUR; NB3: Other GHGs such as N_2O, CH_4 and so forth and harmful pollutants such as PM, SOx will be proportionally reduced.

Long-term (2-4 years after the end of the project) - There are over 6000 sizable vessels in the target market at the moment (106000 commercial vessels overall reported in 2012). Therefore multiplying the above saving by 6000 would lead to gigantic savings. It is expected that each year some 10 to 15 units would be produced in this period per month. In 2 years, the numbers installed could be 15x12x2 = 3600 ships. Considering that larger vessels are to benefit more and that the companies operating such size vessels are more likely to install the system, taking the average size vessel for macro benefit analysis, thus:

Number of vessels (2 to 4 Years)	Fuel Saving (MT)/year	CO_2 (MT)/year	Money (€)/year
3600 ships	1,008,000	3140,000	554,400,000

NB4: Market target size: 3600 (2 to 4 years); NB5: Market target size: 6000–8000 (4 to 6 years) and NB6: Market target size: 18000 (over 6 years); ultimately over 100000.

The Socio-Economical and Environmental

The tasks was to substantially reduce marine engine exhaust emissions (by around 860 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 and Ziarati and Akdemir, 2015). Similar % savings for NOx, SOx and PMs burning or using SCR, Scrubbers and DRFs respectively which is expected to revolutionise the use of diesel engines worldwide in all transportation sectors. The tasks were grouped into a number of work packages. Figure 4 shows the data sources and types, data collection methods and novel means of modelling and forecasting path of least resistance to ship movement.

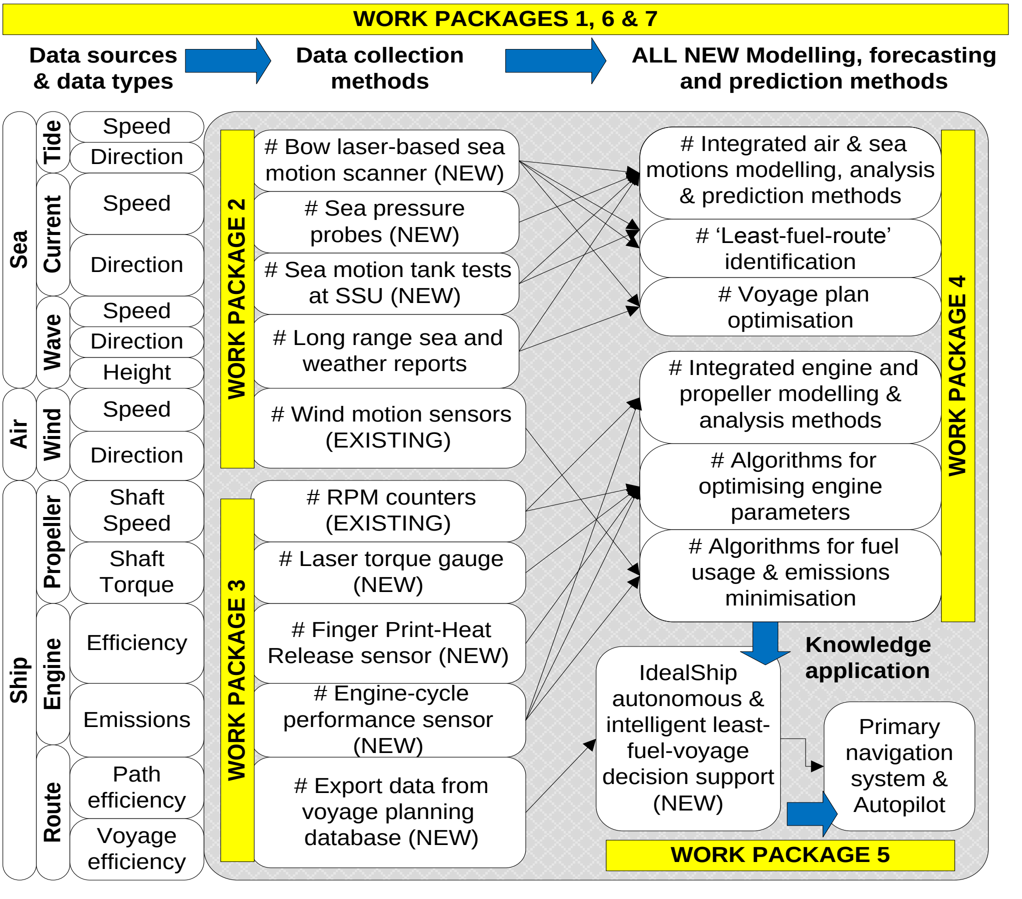

Figure 4. IdealShip AutoSet System Strategy Showing the Work Packages

Technical Innovation

Technical innovation was also significant and pushes the boundaries over and beyond current leading-edge fuel and emissions reduction technology by its first time use of A&I systems to provide autonomous control of novel sensors, modelling and analysis functionality and intelligent decision-support systems.In this respect the autonomous processes developed as a result of the recent experiments made use of the work of Schlitt and Brazma (2007). Through experience, gained by the authors through two previous UK Government TSB R&D projects (Stockton and Ziarati, 2011-14 and 2013-16), that involved 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 when accumulated achieved least-fuel-voyages (L-F-V). Autonomous control systems enabled fast responses to the high levels of sea and air condition variability that enabled 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 which least-fuel-voyages system identified and followed. There are no existing systems capable of this level of technical innovation and it represents a significant step in the management of fuel usage in the maritime sector but also with potential in other transport sectors particularly rail.

Conclusions

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** by the reduction of ship emissions through energy systems' integration. The intention was 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 project further strengthened the 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 recent experiments 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 was, and still is, the IMO and its requirements as well as the recent EU's Measurement, verification and recording (MVR) requirements for ships visiting EU ports. 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 CO_2, 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, EU or USA and some others will take the lead. This is already happening with the introduction of the North America emission control areas.

The most important message to the countries who manufacture diesel engines is for them to realise that there are ways of burning NOx and in fact authors have experimented with several new engines burning NOx as fuel so there is no reason for these harmful by-products of diesel combustion not to be burnt as part of the exhaust gas recirculation. Furthermore, the Governments are aware that the harmful particulates of Diesel can be filtered (**Diesel Particulate Filter** - DPF) or transformed by special catalyst. Authors are of the view that diesel engines should be modified to burn gas as is the case with some of gas engines developed by one of the authors. In the marine world, Wartsila have already reconfigured two of the diesel engines into gas engines, one 4-stroke and on 2-storke, with a great deal of success. The future is hybrids with gas as the main source of engine fuel.

To this end, the role of new energy manager and the content of the training programme being developed as part of the MariEMS should take into consideration the core competencies and methodologies outlined in this paper and take into consideration any new guidance by the IMO and/or EU. Furthermore, the topic of energy management of propulsion systems should be studied in parallel with the ways to reduce the harmful pollutions. The current focus of the US administration with diesel emission should not detract our mind on harmful emissions of petrol engines and their relatively inferior efficiencies compared to the diesel propulsion systems.

A paper is being prepared on the role of the ship energy manager with a proposed programme of training for them.

References

NB: This project is an EU funded project and is based on an industrial project which was initiated based on the work of Reza Ziarati (1975-2015).

Ziarati, R., 1987. An Investigation into Fuel Injection Equipment & Combustion Performance of Medium Size Diesel Engines, IMechE Symposium, London, November 1987.

Ziarati, R., 1990. Mathematical Modelling and Computer Simulation of Medium Size Diesel Engine, COMODIA 90 - Paper No.47, September 1990, Kyoto, Japan.

Ziarati, R., 1995. Emerging Transport Systems", IRTE, Scottish National Lecture and Exhibition, SECC, Glasgow. Journal of Transport Engineers, November 1995. Awarded the Mackenzie Junner Technical by IRTE, for Best Annual Lecture and the IRTE National Diploma for Best Paper, 1996.

Mert, A., Ozkaynak, S., Ziarati, R., Ozkaynak, Su., and Kucuk, H., 2009. Design and Development of a Computer Controlled Marine Diesel Engine Facility for Maritime Engineering Research and Training', IMLA 2009, Ghana, 2009.

Schlitt, T. and Brazma, A., 2007. Current approaches to gene regulatory network modelling", BMC Bioinformatics B (Supplement 6):59, pp 1 to 22.

Ozkaynak, S., Ziarati, Z., Bilgili, E., 2009. Design and development of a diesel engine computer, simulation program, 13th Congress of Intl. Maritime Assoc. of Mediterranean, IMAM 2009, Istanbul, Turkey, 12-15 October 2009.

Ziarati, R., and Cole, A., 1995. Design and development of Variable Geometry Diesel Engines, AutoTech95, Paper C498/02/001, IMechE, Birmingham, 1995.

Ziarati, et al., 2013. Design and Development of an Emulated Human Cognition Using Novel 3D Neural Networks, ICMR 2013.

Sahayam, N. B. V., 2013. C4FF's Idealship Report, C4FF Report, 2013, based on Ziarati, R., Ziarati, M., and Koivisto, H., Ideal Ship – Proposal to develop the next generation of ship command structures. International Association of Maritime Universities (IAMU), IAMU 2013.

Sahayam, N. B. V., 2014. Strategic Analysis of IdealShip, Masters Internship Report, MBA International Business (2013-2014), Coventry University, 2014

Stockton and Ziarati (2011-2014), Development of an Autonomous Systems Development Tool (ASDT) for application within manufacturing operations-planning, UK Goverment TSB Project Nomber 5908-45002

Stockton and Ziarati (2012-2016), Development of an Innovative Autonomous & Intelligent Demand Management Tool (AIDMT) for Refrigerated and Shelf-Life Constrained Food Supply Chains, UK Government TSB Project Number 23792-161273