Wireless Modular System for Vessel Engines Monitoring, Condition Based Maintenance and Vessel's Performance Analysis

Serafeim Katsikas[1], Dimitrios Dimas[2], Angelos Defigos[3], Apostolos Routzomanis[4], and Konstantina Mermikli[5]

[1,2,4,5]Prisma *Electronics SA, Alexandroupolis, Evros, 68100, Greece*

sekat@prisma.gr
ddimas@prisma.gr
aroutzom@prisma.gr
kmerm@prisma.gr

[3]*Athens, Attica, 18648, Greece*

adefigos@gmail.com

ABSTRACT

Circumstances in shipping have rapidly changed within the past few years. The large increase of fuel cost, the decrease in the price of fares, the rapid progress in telecommunications, the crew reduction per vessel, the new environmental restrictions and the reinforcement of Green Shipping significance are facts that make remote monitoring and the evaluation of the vessel engines' performance an imperative need. The challenges occurring from changing the typical vessel engine monitoring and maintenance model are many, such as: equipment installation on moving vessels, lack of long-term vessel availability, experienced and trained crew being on land, many different types or ages of vessel and vessel manufacturers.

An extremely advantageous solution with proven positive results for this specific matter is the use of monitoring systems consisting of wireless smart sensors. These systems provide flexibility, adaptability, scalability and easy installation. The only system of this kind available in the global market, adjusted for Shipping and specifically for monitoring vessel engines, is the LAROS platform by NOMIA S.A. (member of Prisma Electronics SA).

In this paper we will present the current status of maintenance in maritime vessels and the abovementioned new innovative remote monitoring of a vessel's operational status electronic platform, which can greatly reduce the operational costs, enhance the operational vessel status and ensure the high quality of service a maritime company provides, as well as improve its environmental policy.

Moreover, a case study of performance analysis regarding a vessel with the LAROS platform on board will be presented, showing the possibilities and the dynamics of vessel performance monitoring.

1. INTRODUCTION

For the last 30 years the model of Condition Based Maintenance (CBM) in Industrial Production Lines has been implemented with spectacular results in operating costs, environmental effects, productivity and safety. Predictive Maintenance (PdM) and its predecessor, Preventive Maintenance (PM), is a great factor of product quality assurance and cost reduction in all kinds of applications. PdM evaluates the condition of equipment by monitoring the condition of various critical parameters and plays an important role in production lines, quality control systems, health and food industry, goods transportation etc. Additionally, by employing Wireless Sensor Network (WSN) technology for Condition Monitoring (CM) and data transmission, PdM systems have been further developed and have become more efficient and smart, due to the inherent characteristics of WSNs, such as compactness, ease of installation, low power consumption, local data processing and storing. WSNs have found their way to the market and are becoming a core factor of PdM systems. As a consequence, the total revenues for wireless sensors and transmitters in industrial applications in 2009 reached $526.7 million and are likely to reach $1.8 billion in the next four years (Thusu, 2010).

Goods and raw transportation is a key factor of the global economy, especially today where the global market is continuously growing, so the need for effective, qualitative and low cost transportation is becoming greater. Maritime companies have adopted control systems on modern vessels, in order to keep the functionality of their vessels in a high state and reduce maintenance and repair costs, since they present a large portion of the operational costs. The need of operational cost reduction, of vessels' reliability increase and of vessel crew reduction leads to the implementation of more sophisticated control and maintenance systems. The maintenance of maritime vessels is a subject of major interest for everyone that is involved in Maritime. Every unscheduled day of vessel maintenance costs a maritime company an average cost of at least $20.000, not including the repair costs. So it can be seen clearly that vessel maintenance is an important factor for the proper operation of a maritime company.

In our days, based on the new technologies it is possible to develop CBM systems in maritime industry. The cost in time and money to implement an on-line CBM system can be significantly reduced based on Wireless Sensor Networks for CM purposes. For the last 5 years, there are some pilot projects and a number of companies that offer condition analysis services to maritime companies. These off-line techniques can be used in a number of cases. With the new communication technologies it is possible to develop systems for on-line condition analysis which further maximize and enhance the benefits. A CBM system, based on wireless sensor nodes for monitoring various parameters which reflect the operational status of a vessel's engine or critical parts, will send a direct report to the maritime company headquarters when a fault or critical situation is inspected. In this way, the technical superintendents of the maritime company will have the ability to estimate the criticality of the situation and proceed rapidly to certain action steps to face the problem. This can lead to prevention of unpredictable machinery failures, repair time reduction, fewer spare parts usage. Regarding the vessels performance condition, wireless sensor nodes (Emmanouilidis Katsikas, Pistofidis and Giordamlis., 2009) can be easily installed to efficiently monitor various engine critical parameters, such as engine performance (produced torque and power), fuel and lubricant consumption, quality of fuel and exhaust emission, water temperature of the cooling system of the engine etc. By transmitting the available data to the company's headquarters' engineers, performance analysis can be easily made, so decisions and suitable actions can be taken in very short time and this can lead to significant vessel's working costs reduction due to fuel and lubricant consumption reduction and optimization of vessel's performance in general. Last but not least, the positive environmental impact of the reduction of fuel consumption can be a great factor for adopting this type of systems. As can be seen, adoption of a WSN system for condition monitoring on a vessel can have great benefits for a maritime company.

This paper is structured as follows. Section 2 presents the current status of vessels' maintenance and operation monitoring. Section 3 presents the idea of adopting WSNs for CBM purposes, how this can be implemented and which can be the benefits. Section 4 describes the proposed solution named LAROS, a system for monitoring and diagnosing the operational status of a vessel and presents a use case. Section 5 presents the financial benefits of adopting LAROS for vessel maintenance and performance monitoring purposes. Finally in section 6 few conclusions are presented.

2. VESSELS MAINTENANCE CURRENT STATUS

In order to define the needs of the maritime companies that can be accommodated by a CBM model, we must analyze the operational procedures and the methods that are currently used.

2.1. Company Structure

Depending on the number of the ships, the fleet is organized into groups of 5 to 10 ships. For each group, there is a fleet manager with his technical and mechanical team. The fleet manager coordinates the execution of the scheduled tasks, observes the vessels' operational condition and is responsible to solve any technical or operational problem. The fleet managers report to the operational and to the technical manager of the company. The operational manager is responsible for the operational schedule of the ships and the technical manager is responsible for the operational condition of the ships. Finally the operational and technical managers' report to the general manager the maintenance schedules and the new buildings of ships. Figure 1 presents the typical structure of a maritime company, analyzed above.

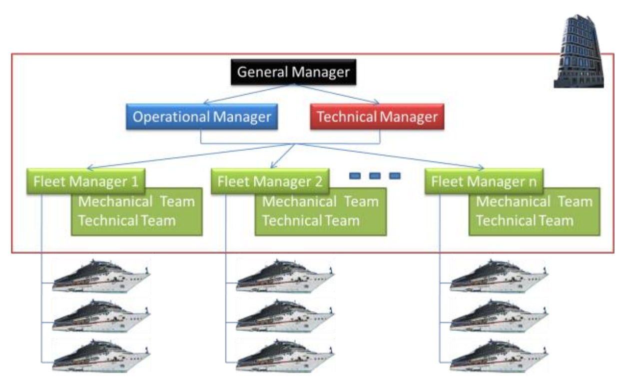


Figure 1. Typical Structure of a Maritime Company

The vessel crew technicians either on a scheduled time basis or when an alarm from the control system appears, record some basic parameters from the control system's sensors. This report is given to the captain, who along with other data are sent to the fleet manager. The fleet manager along with its team revises a scheduled maintenance plan and provides solutions to technical problems. These decisions are sent to the captain for execution. So, the fleet manager has overview of the ships' conditions based on oral communication with the vessel captain and on periodical reports of various factors from the ships engineers, see figure 2.

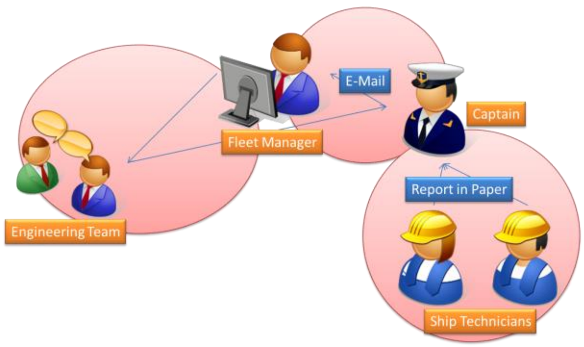


Figure 2. The information flow diagram during a scheduled inspection or an alarm

2.2. Current Maintenance Model in Maritime

Regarding the maintenance operations, the model that is followed today and defined by the international regulations is the following: the various vessel parts, at least the critical ones, have a certain operation life cycle, based on asset's OEM specifications and after this period these parts must be changed, no matter their actual operational condition. No matter if a specific part is in good condition and can be further used without risking the vessel's operating status, it must be changed.

2.3. Disadvantages of the Current Maintenance Model

At the above mentioned model of information flow, the inspections of the engines and other critical parts are basically time scheduled. Additionally, there is a very considerable human factor in the reports, since various reports are based on the data that the vessel crew records. Also the communication between the fleet manager and the engineers is not direct.

So, this type of communication presents the following problems.

- The ship technicians carry out scheduled inspections and the results are not always accurate due to sensors fault or false measurements by the crew.
- The fleet manager has periodical indirect communication with the captain. The description of each situation is subjective and depended on the captain's approach.
- The decisions taken for the determination of repair actions and maintenance by the engineering team are not based on actual and real-time data, but on incomplete and unreliable data. Moreover, it is rather difficult to measure the effects of the execution of the various actions.
- The various part maintenance actions are working-time scheduled, no matter the actual condition of the parts.

As a consequence of the maintenance model disadvantages reported above, the scheduled maintenance results in high cost of spare parts and maintenance procedures. The incomplete technical reports offer limited and unreliable data and cause difficulties in decision making and crew evaluation. Moreover, in most vessels there is no monitoring of the fuel and oil consumptions compared to the vessel instantaneous performance, or in most occasions depends on human observation, something that is in many occasions debatable, so a common policy to reduce fuel and oil consumption is difficult to be determined. Furthermore, the absence of a prognosis system makes it difficult to prevent breakdowns and provokes high cost and time-consuming repair procedures.

2.4. Environmental Impact

Maritime fuel oil type use is nowadays defined in several Sulphur Emission Control Areas (SECAs) by International Maritime Organization (IMO) in order to reduce specific vessel engine exhaust emissions such as CO, SO_2, NO_X. In the near future more SECAs are going to be defined and stricter rules are going to be adopted for maritime vessel gas emissions.

Moreover, monitoring the chemical composition of the vessel gas emissions can provide a detailed analysis of the burning process that can help a maritime company reduce the gas emissions, reduce the fuel consumption and optimize the engine's burning process. So, the operational costs of a vessel will be reduced due to lower consumption, but also the vessel gas emissions will be reduced, so there is a reduced environmental impact.

2.5. Vessel Maintenance Current Status Conclusions

As analyzed above, after recent research experience and operation analysis of maritime companies, the two main problematic issues they face is the absence of a complete remote monitoring system of the fleet as well as the environmental consequences of the vessels operation.

3. CONDITION BASED MAINTENANCE FOR VESSELS

3.1. Introduction

In all kind of industrial, manufacturing and transportation services, maintenance costs are among the most considerable factors of the operational costs. In plant production lines, transportation services, etc. maintenance requires significant time and amount of money. Efforts for reducing the maintenance costs through various technological solutions and asset management strategies have been presented (Holmberg, Jantunen, Adgar, Mascolo, Arnaiz and Mekid., 2010). The basic strategy of maintenance is Corrective Maintenance, where an asset is operated until it fails or breaks and then is replaced. A more advanced one is Preventive Maintenance or time-based maintenance or scheduled maintenance, where maintenance actions take place on regular, prescheduled time, based mostly on asset's OEM specifications. This kind of maintenance can be considered "over-maintenance", due to in many occasions assets are replaced before completing their actual life cycle. In recent times, where cost is a key factor for the sustainability of an enterprise, maintenance costs are driven to be as less as possible. So, a new type of maintenance has arisen, where all actions take place just before an asset reaches the end of its life cycle. This kind of maintenance is called Condition Based Maintenance and its most advanced representative is called Predictive Maintenance (Neelamkavil, 2010). In this kind of maintenance, critical parameters of a process, machine or asset are continuously monitored and analyzed in real-time and maintenance is performed just before breakdown. By adopting this type, maintenance takes place only when necessary, so asset availability costs, maintenance time and operational costs are reduced, efficiency is increased and generally the time and money spent for maintenance are reduced.

CBM refers to a maintenance strategy that recommends maintenance decisions based on the information collected through CM. The main steps that CBM consists of are: data acquisition, data processing and maintenance decision-making (Jardine, Lin and Banjevic, 2005). Technologies, human skills and various layers of communication are involved in the CBM process in order to make timely decisions about the maintenance requirements of critical equipment and to organize the available condition data, such as diagnostic and performance data, maintenance histories, operator logs and design data (Cheng, 2007).

According to recent advances, new regulations by international maritime organizations and insurance companies are going to be adopted in the recent future that will allow the use of assets further to OEM specifications, if these assets are monitored regarding their operating condition and good operational condition is concluded.

3.2. Benefits of Vessel's Operational Status by Using CBM

In our days, maritime companies have to face the limited crew number, the low technical quality of the crew and the big competition in rates along with the increase of the fuel and assets costs. Additionally, they need to increase the reliability and reduce the environmental impact that a vessel creates due to its inherent operation. These are the basic reasons for adopting a CBM model in Maritime.

A very important issue is the reduction of fuel and lubricant costs. This can be achieved by monitoring the fuel quality and the fuel and lubricant consumption, as well as the exhaust emissions; various sensors can monitor the fuel loading process, the fuel and lubricant consumption and the exhaust gases for identifying the chemical composition and quality of fuel oil and lubricants. This can lead to detailed reports for the fuel consumption process, in order to identify possible actions for reducing these costs.

Another issue is the frequency and context of the reports that are sent from the vessel to the maritime headquarters. The reports are sent in a steady daily basis, so the engineers at the headquarters are not informed in real-time when a maintenance task must take place. Also, the reported values have been instantly taken and no long asset operation monitoring time is adopted. So, as can be easily understood, they are not able to safely estimate a critical situation when needed. An on-line remote health monitoring system can be a trustful source of information crucial to take decisions, reschedule the maintenance plan and provide specific repair instructions to the crew.

By adopting an additional CBM system that works independently from the vessel's control system, provides a safe diagnosis method in an alarm situation. The engineers have extra information for the problem that has arisen in order to take the right decision. This can lead to reduction of the costs and time required for the repair actions.

In Maritime, Preventive Maintenance is the main maintenance model, where various parts are being replaced or repaired on steady time basis, based on the technical specifications of the parts. This leads, as abovementioned, to unneeded replacements and maintenance actions that cost more time and money. A PdM system that collects sensor data and processes them with advanced algorithms, can provide maintenance alarms only when is truly needed. So, the parts are repaired or replaced when they reach the end of their life cycle and the maintenance costs and time are greatly reduced. This can also lead to increase of the time interval between drydockings, where drydocking is called the process of removing the vessel from the water in order to enable work to be performed on the exterior part of the ship below the waterline. Moreover, unscheduled vessel immobilization due to engine failure that costs a great amount of money is greatly reduced. Another advantage is the independence of the maintenance tasks from the human factor, since sensor data are directly sent to the vessel's Bridge and Headquarters, without human interference.

A critical issue for a maritime company is when wants to buy a used vessel. The old vessel maintenance technical reports are probably destroyed and a great amount of money and time is spent for the appropriate inspection before the transaction. A system that can help in extracting critical data before the transaction, as well as during the early operation phase is really helpful in order to effectively monitor the general operational vessel status.

The communication expenses are another main issue of a vessel's expenses, because the costs depend on the volume of data that are sent. So, sending technical reports and communicating, when a breakdown occurs, burdens the communication expenses. Adopting a system that sends updates only when the operational status is changed or data only when required reduces this kind of expenses.

Moreover, the safety of the vessel's crew during operation, as well as during maintenance can be increased with a monitoring system. For example by monitoring the presence of explosive and toxic gases during maintenance may prevent life threatening cases for the maintenance crew. At last by monitoring the environmental impact of a vessel operation via continuous monitoring of the fuel consumption and exhaust gases a maritime company can manage more effectively and reduce fuel consumption and improve its environmental policy.

Also a common monitoring system (independent from the type and age of a maritime enterprise vessels), may strongly simplify all the internal processes of the enterprise and manage more effectively the human resources.

As can be easily understood an operational status monitoring system can provide great benefits at a maritime company, ensure the high quality of maintenance and operation of ships, reduce operational, repair and maintenance costs, increase crew safety, promote the environmental policy of the company, as well as ensure the high quality of service that the company provides

3.3. Wireless Sensor Networks for Vessel Maintenance Purposes

Advances in wireless communications, digital electronics, MEMS technology, miniaturization, low power circuit design and computing enhanced the effort of developing sensor nodes that are small size, lightweight, compact, autonomous, rather cheap, have low power needs, communicate wirelessly and can process and store the sensor data locally (Karl and Willig, 2003; Akyildiz, Su, Sankarasubramaniam and Cayirci., 2002). Their inherent compactness, autonomy, low power consumption, data processing and storing capability and wireless communication have given a great leap forward for implementing an effective monitoring tool for maintenance purposes.

But why using a WSN for monitoring a vessel's engine status? One main reason is the low cost and ease of installation of a WSN. For deploying a WSN no wires are needed for communication purposes between the sensor and the coordinator (gateway). The deployment of extra wires for the sensor network purposes are an additional concern, with significant cost in money and time, difficulties in expansion or changes of the network and drawback for the sensor deployment. This leads to a considerable amount of new wires, which add complexity on the sensor network installation process, as well as on the overall complexity of the sensor network. Furthermore, a wireless sensor node is much easier to be recollected when for various reasons, such as the placement of a new one with different specifications, this is needed.

When installing a sensor network for developing an effective maintenance model many factors are going to change on the way to finally achieve this, because the process of developing a maintenance model is a continuous one. You don't just install the sensors and you are done. The amount of sensors needed, as well as where to be installed, what specifications they should have etc. are more or less assumed at the beginning of the development of a maintenance model. On the way to finally have an effective maintenance model, the sensor network must be easily adoptable and expandable. The above mentioned are the two main factors for adopting a WSN compared to a wired one.

4. LAROS PLATFORM STRUCTURE DESCRIPTION

LAROS is a hardware and software platform that monitors various critical parameters at a vessel in order to identify the vessel operational status. It is not a control system; most of the ships, especially the new ones, have very advanced control systems with more than 300 sensors. LAROS is a monitoring system based on collection of data and signals from sensors, instruments and systems that are present in a vessel. The platform is specifically developed in order to be able to collect most of the signal and data types that are available in the various systems that are present in a vessel, either these are just simple analog/digital signals from sensors (i.e. voltage, current, pulses etc.) or complicated data types from various control interfaces (data extracted from various serial protocols). It can be installed on all kind of vessels, whatever the vessel's age and type is. Monitoring is direct with the maritime headquarters via satellite link.

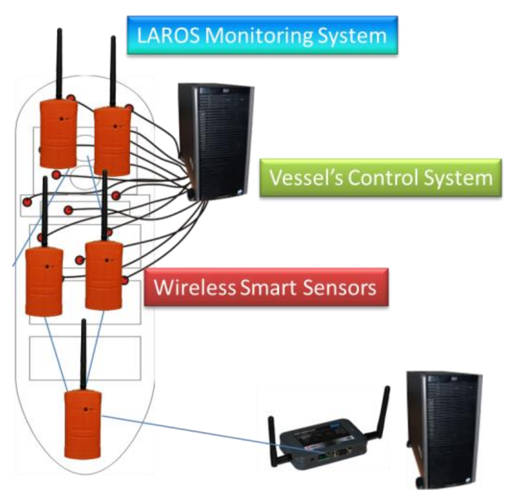


Figure 3. LAROS system vessel basic components along with the main control system.

LAROS is completely independent from the main control system. It consists of several smart collector nodes most of them wireless and each one with the ability of preliminary local processing of the selected data. Furthermore, it is fully adaptable, expandable and configurable in order to be able to add new services and procedures and has an inherent distributed nature. All these collector nodes take real-time measurements, estimate the status based on pattern recognition algorithms and send the results wirelessly to a server located somewhere inside the vessel via a gateway, see figure 3. Each node can have either single or multiple inputs, depending on the type of the input, either from sensors of the same type and/or system or from different ones. Moreover can be powered either with AC or with DC voltage supply. The nodes can be easily placed at any metallic surface, thus eliminating the need for any mechanical modifications.

After data processing a variety of conclusions can be derived concerning the vessel's operational status. In case any change is observed, a notification in the form of either a report or an alarm will be sent to the headquarters of the maritime company. Along with the notification, the Fleet Manager and the technical team will acquire detailed measurements from the sensor network in order to plan the appropriate actions. A more detailed description of the LAROS system is shown in figure 4.

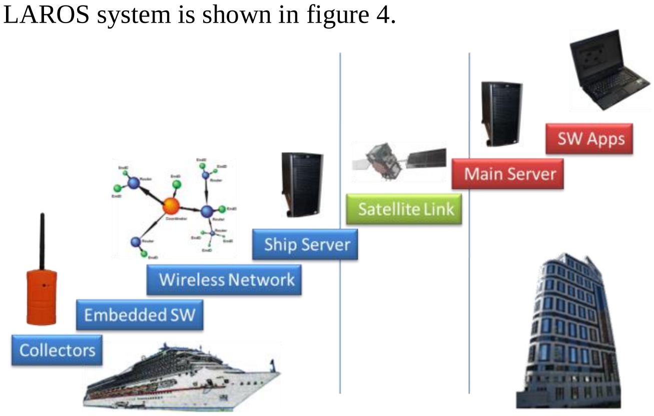


Figure 4. LAROS system vessel basic components along with the main control system

The collector nodes monitor various parameters, such as engine performance parameters (RPM, torque, power, fuel oil and lubricant oil consumption, various pressures and temperatures), engine's cooling water and sea temperature since sea water is used as water for the cooling system, the opening rate of the fuel's supply valves, the propeller's shaft vibration, as well as the electric generators' produced power and operating pressures, the exhaust gas temperature and chemical composition, the turbochargers' rpm and incoming and outgoing air temperatures, bearings' temperatures etc. Moreover a variety of navigation and weather parameters are recorded, such as vessel's speed, drafts, inclination, geographical position, wheel position, water longitudinal and transverse speed, wind angle and speed, environmental temperature and humidity.

With all this variety of parameters monitored, the operating and performance status of the vessel can be greatly analyzed and various actions can be followed in order to enhance performance, monitor and reduce fuel consumption, reduce gas emissions, extend assets lifetime.

The sensors that are used employ various technologies like MEMS, photonic, organic electronics and mechanical. The sensor nodes or collectors are based on either a microcontroller with embedded software or a digital signal processor (DSP) for more demanding signal analysis applications like vibration and acoustic analysis. The operating system is developed with main characteristics: the low power consumption, the increased communication reliability, the improved system adaptation and the reduced time and complexity for the development of new applications.

The wireless network is an implementation of the ZigBee protocol based on the IEEE 802.15.4 standard. There is a gateway that sets and coordinates the wireless network and all the collector nodes are connected to this gateway, either directly, or in case there cannot be a direct connection with the help of other collectors or routers. As has been pointed in other research projects (Kdouh, Brousseau, Zaharia, Grunfeleder and El Zein, 2012) the connectivity between wireless collectors inside a vessel, where metallic surfaces are the common, is not a problem even when the collectors are placed in different rooms, where theoretically it is very difficult to have an unproblematic connection. The collectors transmit the processed data via the gateway in order to be stored to a MIMOSA-type database at a server located inside the vessel. The data can be accessed by the captain and the vessel's engineers. Reports, alarms and all the monitored parameters are sent via satellite link to the main server at the company headquarters, in order to be available to the Fleet Manager and its team of engineers for further evaluation.

To the abovementioned stands the advantage and uniqueness of LAROS platform compared to similar solutions by other vendors. LAROS is adaptable in order to collect signals and data from most of the various different sensors, instruments, systems and controls inside a vessel, not just offer a solution for collecting and monitoring a short range of data, such as for example Fuel Oil consumption monitoring or just Main Engine (M/E) Torque and Power monitoring. Independent of the various systems, LAROS has the ability to collect data from them and give to the engineers all these data to a single unified platform, where doing data analysis provides much more information and knowledge for the vessel performance and maintenance.

5. A USE CASE OF THE LAROS PLATFORM IMPLEMENTATION

We will present here some experimental measurements and results of the LAROS platform installed on a container vessel. At figure 5 you may see the architecture of the WSN installed at a vessel regarding the vessel's performance. The installed platform can of course be customized to the Maritime Company's specific needs. The platform monitors various engine performance parameters such as Main Engine RPM, torque, power and fuel oil consumption, turbochargers' rpm. Moreover, in order to have specific navigation data, vessel's drafts and two-axis inclination are continuously monitored, as well as wheel position, vessel's speed, water longitudinal and transverse speed, wind angle and speed from the bridge various instruments.

A data analysis and monitoring software tool is also provided presenting all these data, in all kind of waveforms, analyses them, produces alarms if needed and gives specific guidelines. Moreover, certain customized rules can be inserted in this software. By these means a comprehensive and analytical monitoring overview for performance analysis and maintenance is available.

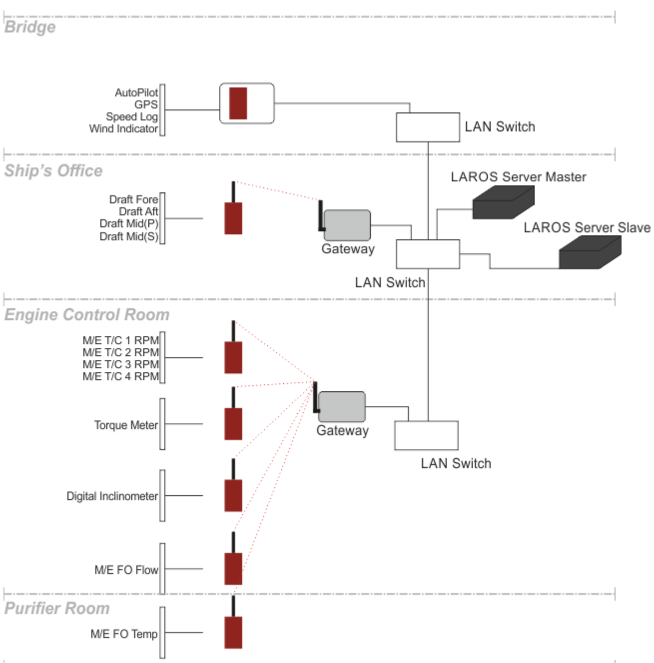


Figure 5. LAROS system network architecture

5.1. Specific Fuel Oil Consumption (SFOC) Analysis

On the next figures you may see an analysis that is performed for a certain period of time with the help of the LAROS data analysis and monitoring software by the maritime company headquarters engineers. The goal is to measure the SFOC (Specific Fuel Oil Consumption) for this vessel. For this reason, we present the M/E power over time at a diagram, see figure 6.

Figure 6. Main Engine produced power vs time

In order to find the vessel's SFOC, we have to find a certain time period where the power produced by the vessel's engine has the minimum deviations, so is rather stable. We find this time period and we focus at it, see figure 7.

Figure 7. Main Engine produced power vs time for the specific time period

For this time period, we check that specific rules are true, that are:

- Minimum vessel's inclination distribution.
- Minimum vessel's speed distribution.
- Minimum M/E RPM distribution.

We can see that the abovementioned rules are true for this time period, see the figures 8 to 11.

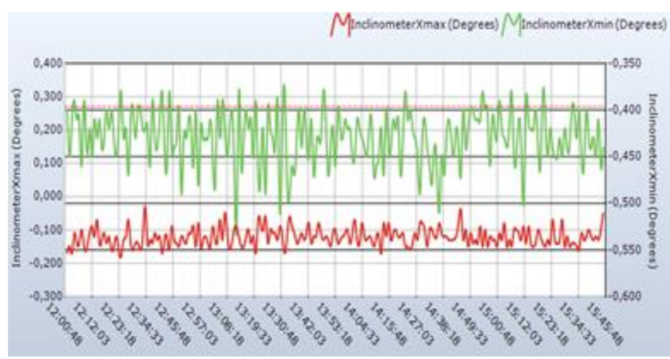


Figure 8. Vessel's inclination at x-axis for this time period

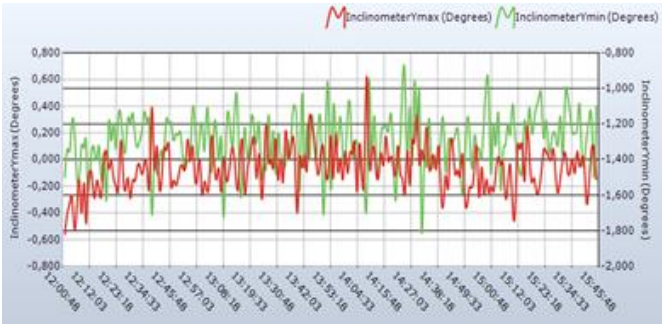


Figure 9. Vessel's inclination at y-axis for this time period

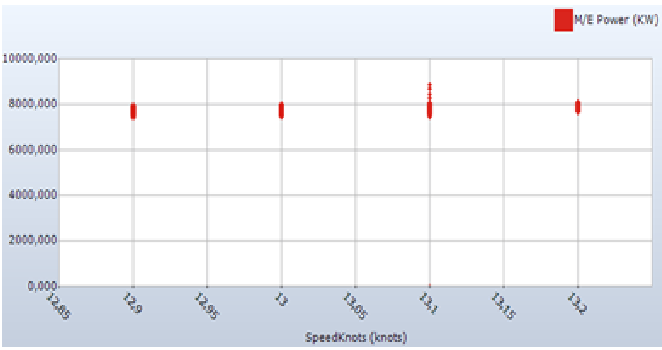


Figure 10. Vessel's speed distribution for this time period

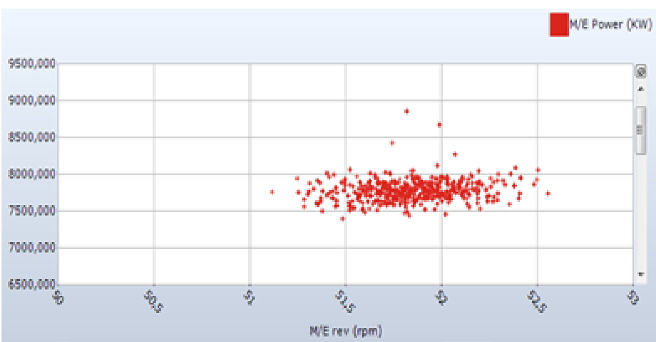


Figure 11. M/E RPM distribution for this time period

So, for this specific period, safe results can be obtained regarding the vessel's SFOC, see figure 12.

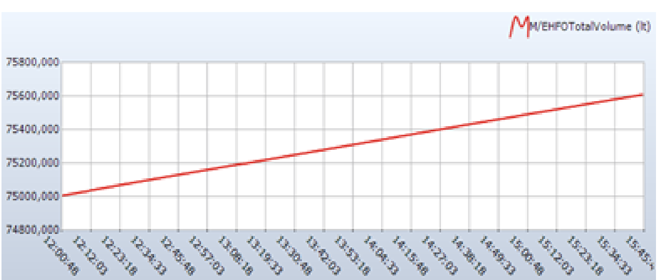
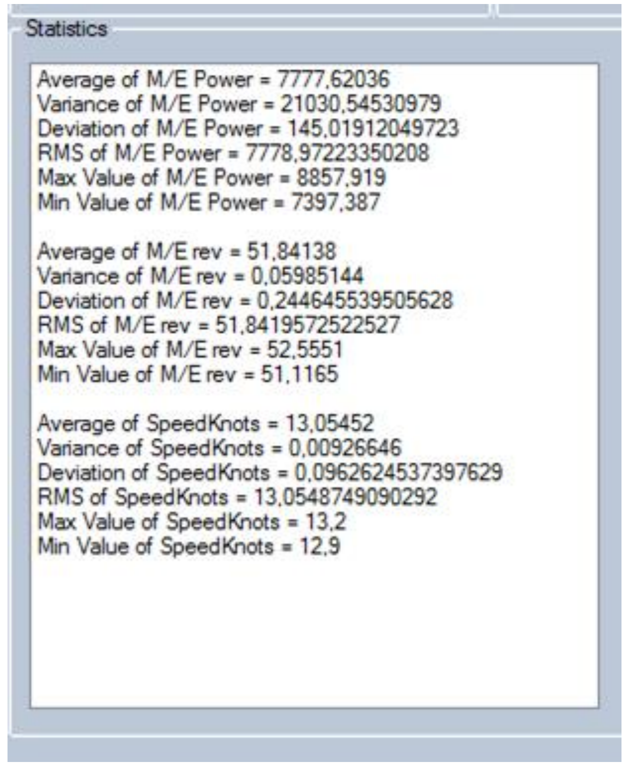


Figure 12. M/E Heavy Fuel Oil (HFO) consumption for this time period

Moreover, various statistics concerning the parameters monitored can be extracted, see figure 13.


Statistics

Average of M/E Power = 7777,62036
Variance of M/E Power = 21030,54530979
Deviation of M/E Power = 145,01912049723
RMS of M/E Power = 7778,97223350208
Max Value of M/E Power = 8857,919
Min Value of M/E Power = 7397,387

Average of M/E rev = 51,84138
Variance of M/E rev = 0,05985144
Deviation of M/E rev = 0,244645539505628
RMS of M/E rev = 51,8419572522527
Max Value of M/E rev = 52,5551
Min Value of M/E rev = 51,1165

Average of SpeedKnots = 13,05452
Variance of SpeedKnots = 0,00926646
Deviation of SpeedKnots = 0,0962624537397629
RMS of SpeedKnots = 13,0548749090292
Max Value of SpeedKnots = 13,2
Min Value of SpeedKnots = 12,9

Figure 13. M/E Power, RPM & Speed statistics for this time period

By studying the vessel's performance at this period of time, the SFOC can be extracted and can be compared with the SFOC that the vessel's manufacturer has provided by the sea trials. If the SFOC extracted by this kind of analysis has great difference to the sea trials, further reasons can be investigated, like wind speed and direction, vessel's drafts, vessel's rudder angle.

In the below figures you may see another time period where the M/E power had low deviation, so it was chosen for a SFOC analysis as well.

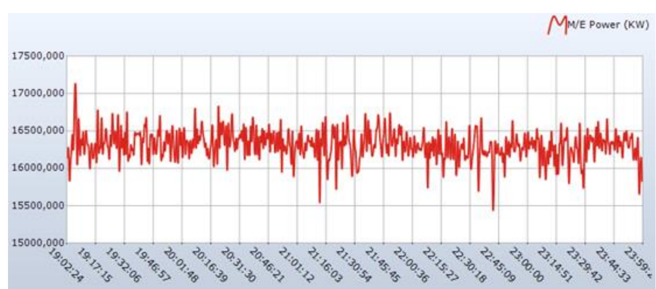


Figure 14. Main Engine produced power vs time for the specific time period

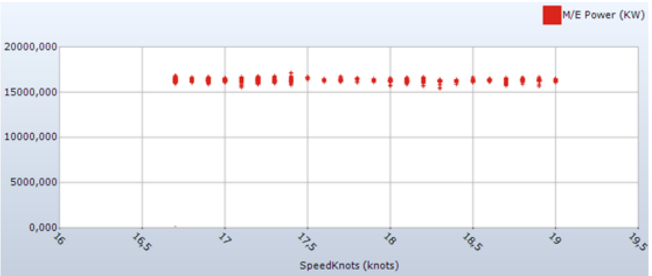


Figure 15. Vessel's speed distribution for this time period

But, as it can be clearly seen, due to high fluctuations of vessel's speed during the period under consideration, safe results cannot be obtained in this case.

6. FINANCIAL BENEFITS FROM ADOPTING LAROS PLATFORM

As it is rather obvious, when a maritime company uses LAROS system, its engineers are provided with a very powerful tool for various parameters overview that can help them for vessel performance analysis. Moreover, it is better to predict and prevent a situation of lowered operational capability, than to deal with the consequences after an incident has occurred. This statement implies a simple logic that can be supported by actual numbers, showing the benefits for a maritime company that will choose to change its philosophy towards the predictive maintenance. The operational expenses are defined at a ratio of 37% by the crew payment expenses, 40% by the communication, maintenance, repair and fuel expenses, while the rest represent insurance expenses, tolls, docking, loading and unloading procedures. LAROS targets the percentage that represents the communication, maintenance, repair and fuel expenses.

A great amount of maritime companies are based at three geographical areas; Greece, Japan and North Europe. These three areas represent 47% of the global fleet. This market spends about 11 billion dollars every year for maintenance, repair and fuel costs. We estimate that the use of a fully deployed LAROS system will lead to an up to 40% reduction of maintenance and repair costs, along with reduction of vessels' operational cost by 15%, reduced possibility of engine breakdown and increased crew and cargo safety. Along with the direct economic benefits the maritime enterprise that will choose to embody the LAROS architecture will also have a solid and reliable control on all environmental issues that emerge from an operational vessel. In terms of efficiency, along with an optimized maintenance schedule, the key economical features are listed below:

- Fuel consumption cost reduction by 8%
- Repair costs by 40%
- Maintenance costs by 40%

The statistical analysis we have conducted is based on the most recent market data and provides interesting conclusions about the actual profits of a potential adoption of LAROS system. The figure that follows shows a linear prediction regarding the reduction of operational costs per year. Additionally, one must take into account the long term development of this solution. LAROS is not a monolithic solution but an expanding and continuously adaptive system to meet all the new needs that will emerge during the operation of a fleet. It works as "multiplication factor" in the whole effort to minimize operational costs and organize systematically a maintenance schedule.

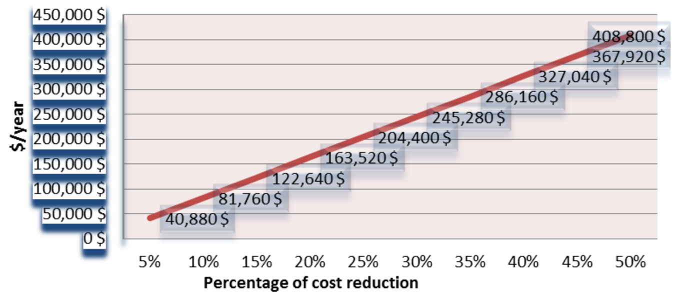


Figure 16. Cost reduction when using LAROS platform

7. CONCLUSIONS

The development of Wireless Sensor Networks with intelligent characteristics, like data processing capabilities, along with the development of new communication protocols has enabled the use of WSNs on a new market like Maritime. WSNs as part of a Condition Monitoring system can be employed in order to monitor the condition of various engine parameters and extract conclusions about the vessel operational and performance status. These data can be also available to the headquarters engineering team in real-time, in order to have a more complete and comprehensive solution for every problem that occurs. This can lead to a significant reduction of a vessel's operational expenses, as well as the environmental impact.

LAROS platform has all the abovementioned characteristics that can provide to a maritime company a complete monitoring system for Condition Based Maintenance and performance analysis.

NOMENCLATURE

CBM	Condition Based Maintenance
PdM	Predective Maintenace
PM	Preventive Miantenace
WSN	Wireless Sensor Networks
CM	Condition Monitoring
SECAs	Sulphur Emission Control Areas
IMO	International Maritime Organization
M/E	Main Engine
SFOC	Specific Fuel Oil Consumption
RPM	Revolutions Per Minute

HFO Heavy Fuel Oil

REFERENCES

Akyildiz I. F, Su W., Sankarasubramaniam Y. & Cayirci E. (2002). *Wireless sensor networks: a survey*. Computer Networks: The International Journal of Computer and Telecommunications Networking, volume 38 (Issue 4), pages 393-422. doi: 10.1016/S1389-1286(01)00302-4

Cheng H., (2007). *Implementation Strategies and Tools for Condition Based Maintenance at Nuclear Power Plants*, (pages 1011–4289). International Atomic Energy Agency, IAEA-TECDOC-1551 (ISBN:92-0-103907-7)

Emmanouilidis C., Katsikas S., Pistofidis P. & Giordamlis C. (2009). A Wireless Sensing Development Platform for Ubiquitous Condition Monitoring. *22rd International Congress on Condition Monitoring and Diagnostic Engineering Management* (pages 657-664), June 9- 11, San Sebastian, Spain. Fundacion TEKNIKER, Eibar, ISBN:978-84-932064-6-8

Holmberg K., Jantunen E., Adgar A., Mascolo J., Arnaiz A. & Mekid S. (2010). *E-maintenance*. Springer. ISBN 978-1-84996-204-9

Jardine A.K.S., LinD. & Banjevic D. (2005). *A review on machinery diagnostics and prognostics implementing condition-based maintenance.* Mechanical Systems and Signal Processing, volume 20 (Issue 7), pages 1483-1510. doi : 10.1016/j.ymssp.2005.09.012

Karl H. & Willig, A. (2003). *A short survey of wireless sensor networks*. TKN Technical Report TKN-03-018. Technical University Berlin, Telecommunication Networks Group.

Kdouh H., Brousseau C., Zaharia G., Grunfeleder G. & El Zein G. (2012). A Realistic Experiment of a Wireless Sensor Network on Board a Vessel. *9th International Conference on Communication COMM 2012* (pages 189-192 , June 21-23, Bucarest . doi: 10.1109/ICComm.2012. 6262594

Neelamkavil J., (2010). *Condition-based Maintenance Management in Critical Facilities*. Institute for Research in Construction, National Research Council Canada. Available from http://www.managementparadise.com/arunvani/documents/531/condition-based-maintenance-management-in-critical-facilities/ [Accessed 2014/03/05].

Thusu R., (2010). *Wireless Sensor Use Is Expanding in Industrial Applications.* Sensors Magazine. Available from http://www.sensorsmag.com/networking-communications/ wireless-sensor/wireless-sensor-use-is-expanding-industrial-applications-7212 [Accessed 2014/03/05]