PREFACE

The Maintenance Performance Measurement and Management Conference 2014 represents a forum where the academics and professionals converge to discuss the state-of-the-art of the conference topics and the future trends for those topics that are the following ones: Maintenance performance and measurement (Efficiency, effectiveness, productivity; Life Cycle Cost optimization; Quality, risk and maintenance services; International Standards and Certification); Maintenance technology and management (Maintenance management systems; Condition monitoring and prediction; E-maintenance; Maintenance tools and innovations; Performance measurement); Maintenance trends (New Technologies; Re-engineering maintenance process; Maintenance logistics; Maintenance around the world).

University of Coimbra together with Lulea University, Sunderland, Lapperanta and Oulu constitute a network of research centers actively involved in maintenance research and developing MPM methodologies and technologies in close cooperation with international organizations like EFNMS and SMRP. Moreover the dissemination of maintenance research in doctoral thesis, education programs, conference and journals is a relevant contribution from universities and research centers. These activities are needful in order to place maintenance in the position that deserves in the international arena due to its huge importance and impact on the industrial economy.

The competitiveness of the organizations is each time more and more dependent on the optimization of Life Cycle Cost (LCC) of its physical assets. The maintenance costs of these represent, in industry: 5 to 20% of value added; 5 to 12% of capital invested; 1 to 15% of gross sales; 3 to 10% of production costs. In hospitals they represent, in average, 10% of the initial investment. These are strong reasons to emphasize the importance of maintenance, in particular, and the LCC in general.

Maintenance field per si, and all its strands represent very difficult fields to manage and, probably, because of this, it corresponds to the last target variable managed that increase competitive advantages for the organizations. Approaches like on-condition maintenance, predictive maintenance, reliability, virtual reality, holography, certification, Key Performance Indicators, among others are only some of the many maintenance fields or, by other words, LCC fields that potentiate organizations to work better and win more money.

In fact, the most part of organizational areas have been rationalized and or optimized along time, but the maintenance had been left behind, because it is difficult to manage due involving many variables to conjugate simultaneously. Having as objective the unstoppable organization competitiveness, the maintenance sector, finally, is the target of attention of industrial managers, giving more and more importance to the Maintenance Engineering.

The Maintenance Performance Measurement and Management Conference 2014 represents an academic and professional place to discuss all those aspects, in which all experts see on MPMM2014 the privileged forum to upgrade their knowledge and share their research and experience with other colleagues. Additionally, it is a forum that permits to construct a referential repository of all subjects discussed in this Conference for all interested to add value for its future developments in their activities.

The committees in general, chairpersons, scientific, and local committee thank to all participants, speakers, keynote speakers, sponsors, and partners the efforts and commitment for the success of MPMM2014.

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Maintenance conceptual models and their relevance in the development of maintenance auditing tools for school buildings’ assets – an overview

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Abstract

Despite the importance of building and infrastructure maintenance and its role in cost control, savings in materials and life cycle enlargement of equipment and facilities, maintenance is often still regarded only as a disturbing factor which causes Public school infrastructures to often suffer from the negative effects of this philosophy.

It is important for managers to improve maintenance performance of school organizations, focusing on areas such as maintenance, building systems, safety improvements and technology, if possible anticipating problems and opportunities in time. To accomplish all of those goals, these organizations must be determined to manage their available resources effectively and to seek improvements for increasing efficiency.

In this context, and with the aim of characterizing the Portuguese situation concerning the age and preservation of both installations and fixed equipment of Educational Institutions, as well as their maintenance strategies and politics, maintenance auditing tools for school building assets were developed.

This paper presents an overview of maintenance conceptual models as well as a proposal for a maintenance conceptual model aimed at the Portuguese Educational Institutions.

The full version of this paper discusses the relevant role of maintenance conceptual models in the development of maintenance auditing tools and contains some results of a study regarding the Portuguese Educational Buildings.

Keywords – Maintenance management; Educational organizations, Maintenance strategies in asset management; Maintenance modelling and optimization; Maintenance audits.

I. INTRODUCTION

The resources dedicated to maintenance and operation of school building infrastructures come mainly from the state budget. Since education is one of the sectors that most absorb resources, it is becoming more and more important to improve its efficiency [1, 2]. In fact, financial constraints usually result in reduced maintenance and operation budgets and Public schools’ infrastructures often suffer from the negative effects of this philosophy, presenting in some cases early signs of disrepair and neglect generally as the result of the priority on allocating funds to items that directly affect education [3].

Equipment that is in poor condition may interfere not only directly in the economics of the organizations, but also in the reduction of the overall availability of buildings while simultaneously interfering with the occupants’ safety. This is why both installations and equipment associated with the operation of school organizations must be kept in good conditions [3,4].

It is important for managers to improve maintenance performance of educational facilities, focusing on areas such as maintenance, building systems, safety improvements and technology, if possible anticipating problems and opportunities in time. To accomplish all of these goals, educational and teaching organizations must be determined to manage their available resources effectively, and to seek improvements for increased efficiency. At the same time it’s vital that they implement a regularly scheduled detailed maintenance plan for all assets [5].

In this context, a study was developed regarding the Portuguese Educational Institutions’ maintenance management and organization. This paper contains some results of the study mentioned above. It identifies some areas needing improvements, as well as the suggestions made to improve maintenance efficiency, regarding management decision making and strategies employed in maintenance management.

With the aim of characterizing the Portuguese situation concerning the age and preservation of both installations and fixed equipment of Educational Institutions, human and material resources management, as well as their maintenance strategies and politics, maintenance auditing tools for school buildings assets were developed, with the purpose of collecting all the aforementioned information. Some results of the analysis carried out to the gathered global data are described. In addition to the outcomes of the global analysis performed to the collected data, the results of more specific analysis are also mentioned, according to the different levels of education.
Considering the complexity of the Educational System, there is an obvious need to review management and administration models, applying the principles of the Educational System Foundation Law published in 1986, in particular the principle of institutional autonomy [2, 3, 6-11].

Considering the relevant role of maintenance conceptual models in the development of maintenance auditing tools, this paper presents also an overview of maintenance conceptual models as well as a proposal for a maintenance conceptual model for Portuguese Educational Institutions and a school model that had supported the maintenance auditing tools’ development.

II. REFERENCES TO PORTUGUESE EDUCATIONAL FACILITIES MAINTENANCE

Within organizations, maintenance strategies must result from the consensus and from a clear coordination between those responsible for managing the organization and those responsible for its assets’ maintenance management and organization. Despite this, in teaching establishments the options concerning maintenance have been independent from the organization management within the educational system [3, 7-13].

The Portuguese Educational System Foundation Law, published in 1986, states that the dimensions of educational facilities must provide the possibility of receiving a reasonable number of students, in order to guarantee the necessary conditions for a good pedagogical practice and to promote a true school community. Simultaneously, the management of spaces, installations and equipment, human and material resources, as well as financial and administrative management, should contribute to the educational and academic success of each student [7].

The Portuguese Educational System Foundation Law also states that the construction and maintenance of buildings and equipment of the public school network, across the country, should be based on a policy that clearly defines the competencies for every stakeholder and that guarantees the availability of the necessary resources [7, 9, 12, 13].

In addition, the Portuguese Educational System Foundation Law stipulates that Governmental Bodies should develop “a contingency plan for construction and rehabilitation of school buildings and their equipment, in the sense that the needs of the school system are met, giving priority to basic education” [7, 9].

As regards the Educational System, the legislation published in Portugal is vast, but the reference to issues related to maintenance management and organization of school buildings is vague and sometimes even non-existent. The exceptions that could be found were exclusively oriented towards the assets assigned to preschool, elementary and secondary levels of education [3, 7-17].

Several studies concerning the Educational System have been carried out in Portugal. However, by the end of the twentieth century, the developed and published studies were almost exclusively dedicated to Primary, Preparatory and Secondary schools, and until 2006 they were focused on areas such as pedagogy, politics and administration [3, 14]. In fact, the importance of the buildings’ structure and equipment maintenance management and organization was far from being effectively recognized as a key element in the mission statements of the Portuguese school boards.

Until the beginning of the twenty first century, among the publications of the Portuguese Board of Education, a few consider the operational area of educational organizations and hardly any were found focusing on the importance of maintenance in educational facilities. As an exception the “Schools Operation, Maintenance and Safety Handbook” (MUMSE) may be emphasized, it is a 2003 reissue of the “Schools Maintenance and Utilization Handbook” earlier published in 2000 [12, 13].

Those publications were presented as informative documents, suggesting that “(...) each school board should develop its own operation, maintenance and security manual (...)” considering each building constructive characteristics as well as the installed equipment. They intended to raise awareness among school boards, and users in general, to the importance of preventing accidents, planning for safety and security. They also called the attention to the preservation of health conditions of buildings and equipment, as well as to the protection and preservation of their technical installations, and furniture [12-14]. The MUMSE suggests that when commissioning and at the acceptance of assets, namely of buildings and equipment, the management bodies of educational or teaching establishments “(...) should be handed over a set of elements that constitute an authentic operation, maintenance and safety handbook” [12-15].

Since the early years of this century, the market of building maintenance and rehabilitation has been experiencing a significant evolution and the growing importance of that market led to a significant number of national publications, as well as to a vast legislation regulating such activity. For example, the new regulation on energy efficiency of indoor air-conditioning systems in buildings, transposed into the Portuguese Legislation in 2006, also requires regular monitoring of maintenance practices over HVAC systems, not only as a condition of energy efficiency, but also to ensure the indoor air quality in buildings [16].

Although some parallels may be established, the specificity of the Educational System does not always allow documentation to be suitable to the reality of educational facilities. The educational establishments’ maintenance policy reflects the general scenario described for buildings’ maintenance, it is also the result of the evolution of the Portuguese Educational system over the last four decades, since the objectives defined for the educational system development have direct implications in the school assets preservation [3, 7-15].

The involvement of the central political authorities allowed the change of the described scenario up until 2006. Over recent years, it has been possible to find more publications, whether directly or indirectly related to the maintenance of educational...
illustrates a problem of equipment replacement, in a Lean Thinking context. [15] Says that the technological transformation as the motivation for replacement of the equipment. In scientific references is commonly assumed that technology continuously develops according to a well-defined function.

[16] Shows that combining continuous and discrete time models, the time to replace equipment is lower when the technology applied is superior.

According to [17], "the assessment of an profit is established by future benefits expected by cash flows referred to the present value by a discount rate that reflects the risk of the decision." Consequently, methods that consider the time value of money are the most suitable.

According to [18], the method of Equivalent Uniform Annual Cost CAUE is appropriate in the analysis of the company's operational activities, with investments that may repeat. Furthermore, the standardization of investment results equivalent to annual values makes the analysis of these results will ease the decision making. The use of this method is to determine what is the year with the lowest equivalent annual cost, which indicates the best time to replace the technical active [19].

The calculation of the equivalent annual cost is due to the use of the Capital Recovery Factor and it is through it that we can compare two or more investment opportunities and determining which ideal replacement of equipment time, taking into account information such as: value of the investment or acquisition; resale value or residual value at the end of each year; operating costs and cost of capital or minimum attractive rate [19].

The problem of determining the economic life of equipment for the purpose of replacing could be identified in four types of situation [20]:

1. When the good is already inadequate for the activity;
2. When the good has reached its limit of life;
3. When the good is already obsolete due to technological advances;
4. When more efficient methods show to be more economic.

In a certain point in the life cycle of a profit it is important to assess if keep it running or replaced. For this purpose, you must satisfy the following [12]:

i. Availability of new technologies;
ii. Fulfillment of safety standards or other mandatory;
iii. Availability of spare parts;
iv. Obsolescence that may limit its use.

After the listed aspects of the last point of the life cycle of the equipment, it is important to characterize some calculation methods for determining the appropriate time to replace it. For this purpose it is necessary to take into account several variables:

- acquisition value
- Value of expiration
- operating costs

- Maintenance costs
- Operating Costs
- Inflation rate
- Capitalization rate

The majority of previous values of the variables are obtained by history, with the exception of the value expiration. In this case, to get the market value for each particular equipment, that can be not easy for many goods. An alternative it can simulate several types of devaluation such as the following [21]:

- Linear method of depreciation - the decline of the value of the equipment is constant over the years.
- Method of the sum of digits - the annual depreciation is not linear.
- Exponential method - The annual depreciation charge is decreasing over the life of the equipment.

Another method commonly used is the "lifetime" that defines that ends when the maintenance costs exceed the costs of maintenance plus the amortization of the capital or equivalent new equipment. According to [12] there are several methods for determining the economic cycle equipment replacement. The most common are:

- Method of Uniform Annual Rent (MUAR);
- Method of Minimizing Total Average Cost (MCMT);
- MCMT method with the reduction of the present value (MCMT-PVR);

In [22], illustrates the effective use of fixed assets as a major objective in the management of companies in the urban passenger transport sector.

Companies in the urban transport sector, the efficient use of profits is linked to a well-structured policy assessment and fleet replacement. Some cases of fleet replacement applied to the city bus segment are reported in [22-25].

The adoption of a single decision criteria is restrictive, given that costs, efficiency and level of service should be evaluated simultaneously. Methods such as Multi Attribute Utility Theory (MAUT), Analytical Hierarchy Process (AHP) and Quality Function Deployment (Quality Function Deployment - QFD) have been used to accommodate multiple decision makers and multiple decision criteria. However, were not found in the literature approaches consolidated using these methods in the replacement of public transport vehicles. It is also referred the use of stochastic models in conjunction with neural networks to model the creation of a replacement vehicle.

[26] Presents a proposal of a generic stochastic process model based on neural networks called Stochastic Neural Process (NSP) that can be applied in problems involving stochastic phenomena or periodic behavior and characteristics. Through neuronal networks of the PEN models the behavior of the time series of these phenomena without requiring a priori information about the series, by generating synthetic time series equally adaptable to the historical series. Some cases of using neural networks and stochastic models are reported in the literature [27-33].
II. BUSES REPLACEMENT MODELS

The replacement of equipment is an umbrella concept that embraces selection of similar profits, but new ones, to replace the existing ones, to evaluate the profits that act in ways completely different performance of the same function. This is the case of obsolete buses may be replaced by new models that operate in a similar manner.

Replacement decisions are critical for the company, because they are generally irreversible, ie, have no cash and require large amounts of money.

There are several reasons to make economic action to do the replacement of equipment. The deterioration is one of the causes, and is manifested by excessive operating costs and by the increasing of the maintenance costs. There are situations here the replacement of a standard operation conduce to the loss of the device ability to operate efficiently, ie, it becomes inappropriate.

Importa fazer a caracterização de métodos de cálculo adequados para determinação da altura adequada à substituição dos autocarros de transporte urbano de passageiros. Para o efeito, é necessário ter em consideração diversas variáveis:

- Cost of acquisition (CA)
- Value of expiration (VC)
- The operating costs (EC)
  - Maintenance costs (CM)
  - Operating costs (CO)
- inflation rate (θ)
- capitalization rate (i)

The majority of previous values of the variables are obtained by history, with the exception of the value expiration. In this case, to get the market value for each particular equipment, that can be not easy for many goods. As an alternative it can simulate several types of devaluation such as the following: [21]

- Linear depreciation method– that lies on the assumption that the decline of the value of the equipment is constant over the years.
- Method of the sum of the digits - the annual depreciation is not linear.
- The Exponential method - The annual depreciation charge is decreasing over the life of the equipment.

A. Linear Depreciation Method

This method assumes that the decrease in the value of the device is constant over the years and is calculated by the following formula:

\[ d_j = \frac{CA - VC_n}{N} \]  

\( d_j \) Annual depreciation quota  
\( CA \) Acquisition cost of equipment

\( VC_n \) Residual value of the equipment at the end of N periods

\( N \) Lifetime corresponds to

\[ j = 1, 2, 3 \ldots n \]

\( V_n \) Value of the equipment over a period \( n = 1, 2, 3 \ldots n \).

The value of the equipment \( V_n \) in a period \( n \) lower N is given by:

\[ V_j = CA - j \cdot d \]  

B. Method of Sum of Digits

In this method, the annual depreciation is not linear and is calculated the following way:

\[ d_j = 2 \cdot \frac{N - (j-1)}{N + 1} \cdot \frac{CA - VC_n}{N} \]  

\[ V_n = CA - d_j \]  

C. Exponential Method

The exponential method emphasizes an annual depreciation that decreases over the life of the equipment. The calculation formula is as follows:

\[ d_j = VC_{j-1} \cdot (1 - \frac{VC_n}{CA})^j \]  

\[ V_n = CA - d_j \]  

According to [12] the equipment can be replaced by various criteria. The financial aspect, a usual criterion is the "economic cycle" which determines the optimal period which minimizes the average total costs of operation, maintenance and capital immobilization.

Another method commonly used is the "lifetime" that defines that the equipment ends when their maintenance costs exceed the costs of maintenance plus the amortization of the capital of equivalent new equipment.

However, despite being possible from the depreciation values of market power pass to the analysis of equipment replacement, should be taken into account two other variables, which are:

- The capitalization rate, called for \( i \)
- The inflation rate, called by \( \theta \)

These rates are related as follows:

\[ i_A = i + 1 + \theta \times \theta \]

According to [12] there are several methods for determining the economic cycle equipment replacement. The most common are:

- Method of Uniform Annual Income (MRAU)
- Method of Minimizing Total Average Cost (MCMT)
• MCMT method with the reduction of the present value (MCMT-PVR)

This article will use the Uniform Method of Annual Income (MRAU), this makes use of the following data:
• Acquisition cost of equipment
• Expiration values (calculated according to the methods exposed ago)
• Maintenance Costs and Exploration over the years
• Apparent rate

D. Net present value in year n (VPLn)

\[ VPL_n = CA + \sum_{j=0}^{n} \frac{CM_j + CO_j}{(1 + iA)^j} - \frac{V_n}{(1 + iA)^j} \]  

(6)

With,
- \( CA \): Acquisition cost of equipment
- \( CM_j \): Maintenance costs in year \( j = 1, 2, 3 \ldots n \)
- \( CO_j \): Operating costs in year \( j = 1, 2, 3 \ldots n \)
- \( iA \): Apparent rate
- \( V_n \): Value of the equipment over a period \( n = 1, 2, 3 \ldots n \).

E. Uniform Annual Rent (RAUn)

\[ RAU_n = \frac{iA(1 + iA)^j}{(1 + iA)^j - 1} \times \left( CA + \sum_{j=0}^{n} \frac{CM_j + CO_j}{(1 + iA)^j} - \frac{V_n}{(1 + iA)^j} \right) \]  

(7)

\[ RAU_n = \frac{iA(1 + iA)^j}{(1 + iA)^j - 1} \times VPL_n \]  

(8)

With,
- \( VPL_n \): Net present value \( n = 1, 2, 3 \ldots n \)

The minor RAU calculated value indicates the respective period (multi-year), in which the equipment must be replaced. This value is equivalent to a minimum income that the equipment would cost annually.

The MCMT determines the lowest average cost of ownership of the equipment and the respective it occurs that corresponds to the optimal time of replacement. They are not considered capital costs and the rate of inflation. The calculation procedure is as follows:

\[ C_n = \frac{\sum_{j=0}^{n} CM_j + CO_j}{n} \]  

(9)

With,
- \( n \): Number of years \( n = 1, 2, 3 \ldots n \)
- \( C_n \): Average total cost

The MCMT - RVP the calculation procedure is identical to the previous one, with the exception that are considered capital costs and the inflation rate. The various values of maintenance and disposal, over the years, are reduced to present value, according to the following procedure:

\[ C_n = \frac{1}{n} \sum_{j=0}^{n} \frac{CM_j + CO_j}{(1 + iA)^j} \cdot \frac{CA - V_n}{n} = C_n^+ + C_n^- \]  

(10)

III. APPLICATION OF THE MODEL IN THE TRANSPORT SECTOR

The demonstrational application of the equipment replacement model will be made then in the road transport sector, with an emphasis on passenger, which corresponds to a strategic sector of the national and global economy. Application of the Model in the Transport Sector

The aim of this paper to present a model replacement bus passenger transport leading to the rationalization of the reserve fleet in a global perspective, to create integrated models that allow:
• Optimizing the management of their lifecycle;
• Optimizing the time of replacement;
• Optimizing the fleet reserve.

To develop this study and the fulfillment of the objectives listed in the previous paragraph, should be taken into consideration variables related aspects such as the technological aspects, the duly itemized direct operating costs, downtime costs, as well as indicators economic applicable, such as inflation and interest rates, among others.

In the first phase of the data collection operation for preparation of LCC is made, a road transport company. Based on these data is initiated the development of simulation models from a small number of buses, taken as a pilot to validate the replacement model.

A. Characterization of buses

In this phase the variables relevant to the purpose have been defined such as: Operation, maintenance, service user and the environment. Further characterize aspects that significantly affect the operating performance of the buses (existence and type of air-conditioning, engine power, etc.).

In the preparation of the models the following variables were used: the year of manufacture of the buses; starting year of operation; trademark; model; type of vehicle; maintenance costs; cost of operation; etc.

10 cars divided into two brands and five different models of buses, as shown in Table 1 were selected.

<table>
<thead>
<tr>
<th>Bus</th>
<th>Characterization</th>
<th>Year of Manufacture</th>
<th>Year of Operation</th>
<th>Brand</th>
<th>Model</th>
<th>Type of Vehicle</th>
<th>Maintenance Costs</th>
<th>Cost of Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>2010</td>
<td>2010</td>
<td>Brand A</td>
<td>Model 1</td>
<td>Bus</td>
<td>1000</td>
<td>500</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>2015</td>
<td>2015</td>
<td>Brand B</td>
<td>Model 2</td>
<td>Bus</td>
<td>1500</td>
<td>750</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>2008</td>
<td>2008</td>
<td>Brand C</td>
<td>Model 3</td>
<td>Bus</td>
<td>2000</td>
<td>1000</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>2009</td>
<td>2009</td>
<td>Brand C</td>
<td>Model 4</td>
<td>Bus</td>
<td>2500</td>
<td>1250</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>2011</td>
<td>2011</td>
<td>Brand A</td>
<td>Model 1</td>
<td>Bus</td>
<td>3000</td>
<td>1500</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>2013</td>
<td>2013</td>
<td>Brand B</td>
<td>Model 2</td>
<td>Bus</td>
<td>3500</td>
<td>1750</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>2014</td>
<td>2014</td>
<td>Brand C</td>
<td>Model 3</td>
<td>Bus</td>
<td>4000</td>
<td>2000</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>2012</td>
<td>2012</td>
<td>Brand C</td>
<td>Model 4</td>
<td>Bus</td>
<td>4500</td>
<td>2250</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>2016</td>
<td>2016</td>
<td>Brand A</td>
<td>Model 1</td>
<td>Bus</td>
<td>5000</td>
<td>2500</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>2017</td>
<td>2017</td>
<td>Brand B</td>
<td>Model 2</td>
<td>Bus</td>
<td>5500</td>
<td>2750</td>
</tr>
</tbody>
</table>

Fig. 1. Table Characteristics of Buses

B. Background data of Buses

At this stage, the focus corresponds to the identification and collection of primary data that are the basis for the analysis. The data should be relevant to the description of fleet costs and related activities, and should support the understanding of strategic economic and business information. Should be given priority to the information concerning procedures of operation, maintenance and planning. In this context, the historical data
for each vehicle target of the study were collected, as can be seen below in Tables 2-6.

Fig. 2. Table Kms / year traveled by bus

Fig. 3. Table of Litres of Fuel consumed / year by bus

Fig. 4. Table of Operating Costs

Fig. 5. Table of Maintenance Costs

Fig. 6. Intervals and systematic preventive maintenance schedule

In the next section will be analyze the method of Uniform Annual Rent (RAU) for determining the economic cycle of buses replacement, we are analyzing a company in the sector of urban transport. Table 7 presents the values related to Linear Depreciation Method, Table 8 the method of Sum of Digits, and Table 9 the Exponential Method.

Fig. 7. Linear depreciation method Styling

C. The application the Method of Uniform Annual Rent (RAU)

For the application of UARM we used historical data for a group of vehicles. These were grouped into homogeneous groups, in a period between 1993 to 2012 it were studied the vehicles with 19,16,14,10 and 9 years were studied. Table 10 shows the calculation of Annual Income Uniforms for homogeneous group: Brand A, Model A, with three cars of 19 years. We also analyzed data of buses designated as X2 and X3, the results are shown in Figures 11 to 13.

Fig. 8. Method of Sum of Digits

Fig. 9. Exponential Method

Fig. 10. Tablet RAU – Bus X1

Fig. 11. Grafic RAU – Bus X1
Fig. 12. Grafic RAU – Bus X2

Through the analysis of previous data can be seen that the values of rents vehicles are very similar. On Table 10 and the Depreciation Method Exponential it appears that the Uniform Annual Cost is minimal between the twelfth and the sixteenth year (economic life), with an approximate value of € 25,000 / year.

The minor RAU calculated value indicates the respective period (multi-year) in which the equipment must be replaced. This value is equivalent to a minimum income that the equipment would cost annually. It can be concluded that this period corresponds to the ideal time to proceed to the replacement of buses based on the Exponential Method for depreciation. If the methods of depreciation are used and the Linear Sum of Digits it appears that the RAU values decrasing; however there is an increase in the period where the value of RAU is minimal, that is between the sixth and the sixteenth, that creat problems to the decision of the ideal moment to replace the equipment.

We can then verify the calculation of Uniform Annual Rent for homogeneous group: B Brand, Model B and C, consisting of two cars of 16 and 14 years (Table 14 and 15).

Fig. 13. Grafic RAU – Bus X3

The analysis of previous data can be seen that the values of rents vehicles are very similar. On Table 10 and the Depreciation Method Exponential it appears that the Uniform Annual Cost is minimal between the twelfth and the sixteenth year (economic life), with an approximate value of € 25,000 / year.

The minor RAU calculated value indicates the respective period (multi-year) in which the equipment must be replaced. This value is equivalent to a minimum income that the equipment would cost annually. It can be concluded that this period corresponds to the ideal time to proceed to the replacement of buses based on the Exponential Method for depreciation. If the methods of depreciation are used and the Linear Sum of Digits it appears that the RAU values decrasing; however there is an increase in the period where the value of RAU is minimal, that is between the sixth and the sixteenth, that creat problems to the decision of the ideal moment to replace the equipment.

We can then verify the calculation of Uniform Annual Rent for homogeneous group: B Brand, Model B and C, consisting of two cars of 16 and 14 years (Table 14 and 15).

Fig. 14. Tablet RAU – Bus Y1

Through the analysis of previous data can be seen that the values of rents vehicles are very similar. On Table 10 and the Depreciation Method Exponential it appears that the Uniform Annual Cost is minimal between the twelfth and the sixteenth year (economic life), with an approximate value of € 25,000 / year.

The minor RAU calculated value indicates the respective period (multi-year) in which the equipment must be replaced. This value is equivalent to a minimum income that the equipment would cost annually. It can be concluded that this period corresponds to the ideal time to proceed to the replacement of buses based on the Exponential Method for depreciation. If the methods of depreciation are used and the Linear Sum of Digits it appears that the RAU values decrasing; however there is an increase in the period where the value of RAU is minimal, that is between the sixth and the sixteenth, that creat problems to the decision of the ideal moment to replace the equipment.

We can then verify the calculation of Uniform Annual Rent for homogeneous group: B Brand, Model B and C, consisting of two cars of 16 and 14 years (Table 14 and 15).

Fig. 15. Tablet RAU – Bus Y2

Through the analysis of previous data can be seen that the values of rents vehicles are very similar. On Table 10 and the Depreciation Method Exponential it appears that the Uniform Annual Cost is minimal between the twelfth and the sixteenth year (economic life), with an approximate value of € 25,000 / year.

The minor RAU calculated value indicates the respective period (multi-year) in which the equipment must be replaced. This value is equivalent to a minimum income that the equipment would cost annually. It can be concluded that this period corresponds to the ideal time to proceed to the replacement of buses based on the Exponential Method for depreciation. If the methods of depreciation are used and the Linear Sum of Digits it appears that the RAU values decrasing; however there is an increase in the period where the value of RAU is minimal, that is between the sixth and the sixteenth, that creat problems to the decision of the ideal moment to replace the equipment.

We can then verify the calculation of Uniform Annual Rent for homogeneous group: B Brand, Model B and C, consisting of two cars of 16 and 14 years (Table 14 and 15).

Fig. 16. Grafic RAU – Bus Y1

Through the analysis of previous data can be seen that the values of rents vehicles are very similar. On Table 10 and the Depreciation Method Exponential it appears that the Uniform Annual Cost is minimal between the twelfth and the sixteenth year (economic life), with an approximate value of € 25,000 / year.

The minor RAU calculated value indicates the respective period (multi-year) in which the equipment must be replaced. This value is equivalent to a minimum income that the equipment would cost annually. It can be concluded that this period corresponds to the ideal time to proceed to the replacement of buses based on the Exponential Method for depreciation. If the methods of depreciation are used and the Linear Sum of Digits it appears that the RAU values decrasing; however there is an increase in the period where the value of RAU is minimal, that is between the sixth and the sixteenth, that creat problems to the decision of the ideal moment to replace the equipment.

We can then verify the calculation of Uniform Annual Rent for homogeneous group: B Brand, Model B and C, consisting of two cars of 16 and 14 years (Table 14 and 15).

Fig. 17. Grafic RAU – Bus Y2

Through the analysis of previous data can be seen that the values of rents vehicles are very similar. On Table 10 and the Depreciation Method Exponential it appears that the Uniform Annual Cost is minimal between the twelfth and the sixteenth year (economic life), with an approximate value of € 25,000 / year.

The minor RAU calculated value indicates the respective period (multi-year) in which the equipment must be replaced. This value is equivalent to a minimum income that the equipment would cost annually. It can be concluded that this period corresponds to the ideal time to proceed to the replacement of buses based on the Exponential Method for depreciation. If the methods of depreciation are used and the Linear Sum of Digits it appears that the RAU values decrasing; however there is an increase in the period where the value of RAU is minimal, that is between the sixth and the sixteenth, that creat problems to the decision of the ideal moment to replace the equipment.

The Table 18 illustrates the calculation of the RAU to the bus XX1 of the homogeneous group: Brand A, Model B, composed of three vehicles of 10 years; Figures 19 to 20 illustrate the evolution of RAU for XX1, XX2 and XX3.

Fig. 18. Tablet RAU – Bus XX1
By the data showed it appears that the replacement period varies from homogenous group to homogeneous group of vehicles and there are several variables that can influence the outcome and the final decision of the manager, such as the apparent rate of each year as well as the depreciation model used. Another very important variable that can significantly influence the results is the maintenance cost. This, in turn, depends heavily on the policies and management of maintenance that is performed at public transport companies.

IV. CONTRIBUTIONS TO THE FLEET RESERVE

The urban transport companies always have a given rate of buses reservation, which varies from company to company. A low reserve ratio is a synonym of high reliability, relying essentially on implementation of an efficient planned maintenance, which results in the application of new methods and maintenance techniques that lead to the assessment of the state of the equipment and the decision of replacing or renewing the equipment’s.

There is a common set of factors that affect the optimal size of the number of vehicles in a reserve fleet, that are:

- Composition of the bus fleet;
- Brands and models;
- Age of the fleet;
- Annual rolling of the buses;
- Commercial speed that buses are subject;
- Surrounding and the operating environment;
- Daily fluctuations in the demand for transport;
- Policies and maintenance plans;
- Ratio of vehicles per mechanic;
- Planes maintenance training;
- Number of interventions picket;
- Tunings introduced the routes;
- Tunings introduced in services;
- Inventory management;
- Administration and Finance.

To assess the management practices in transport companies the FTA (Federal Transit Administration - USA) conducted a survey of the 36 North American and Canadian companies, which included eight small companies with fleets of between 33 and 199 buses eight medium enterprises with fleets between 225 and 472 bus, 12 large companies with fleets ranging between 537 and 963 buses and eight very large companies with fleets between 1009 and 3664 buses. A synthesis of indicators of activity distributed by classes can be analyzed in Table 2.

Survey responses indicate that efforts are being made in the sector to find ways to reduce the number of units vehicles spares. Many maintenance managers not only follow the guidelines of the FTA regarding the target of 20% of vehicle spares, as they have adopted the philosophy of “the smaller the better” in the managing of their fleets.

Ten percent of the buses are in daily standard repairs. On average, each bus of external service uses the pickets intervention nine times a year. The combined effects of the restrictive legislation of pollution in California, the dedicated maintenance, the high demand of transports and a skewed distribution on age and type of the impact of bus effects have led to an increased rate of reserve vehicles.

As a corollary, it may be noted that the definitions of the indicators of management of urban passenger transport shift
from company to company. It also appears that the technologies used, the accuracy and frequency of collection of values of operating variables and indicators of buses network, the methodology and handle of the data vary significantly from operator to operator.

In urban transport companies there is a great diversity of reserve rates of vehicles, which seems to show empiricism in its determination. It is therefore important to study this discrepancy in terms of optimizing an integrated model of replacement that necessarily implies a rationalization in the reserve fleet. Intends to implemented mathematical modeling of final decision support for replacement of buses of a fleet indexed to the reserve buses fleet. This model will be validated in all is extension in an enterprise of collective to transports not only with the aim of the validation, but also to incorporate the goods of the contributions of the managers who will use it.

V. CONCLUSIONS

This article presents a new approach to the economic models to the determination of the most adequate time for a replacement of buses in a urban fleet of an enterprise. The economic aspects were defined in concordance with the pertinent indicators and the cash flow, driven by the cost associated to the acquisitions, maintenance, and operation, among others.

The study presented allows the equipment’s life cycle assessment by the managers and obviously it is a decision support tool.

It was demonstrated in the study that exist a variation of ideal moment for as replacement of a vehicle of a fleet, given by the analyses performed by the model of the annual uniform lease. Despite this still to be an anchor point and a useful tool to be used in future models that support the better take of decision. This new models should take in account not only the economics criteria but also non-economics as strategic and management assessed by the multi-dicision tools.

The new model should allow a detailed assessment of the present buses performance against the potential substitutes that turn viable a constant motorization of the goods of the enterprise and keeping high levels of quality and satisfaction of the customer service.

VI. REFERENCES

Life Cycle Cost Optimization through an Asset Management based on Risk Principles

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Abstract — When someone talks about assets life cycle optimization, the objective is mainly related with the reduction of operational and maintenance costs. However, regarding the newly asset management concept based on PAS 55 and the recent ISO 55000 standards family, this optimization should take into account and consider other issues like the risk associated with those decisions. Risk can be identified for each potential failure mode using a simplified FMEA (Failure Modes and Effects Analysis) and ranked or included into categories upon a determined and assumed criteria. Based on the previous risk level the decision making process aims to identify which hard time maintenance activities can be delayed in time in order to reduce maintenance costs and thus optimize the asset life cycle cost. The present paper presents a case study of equipment installed on a war vessel (diesel generators) and tries to assess if some relative hard time maintenance can be delayed without compromising safety. The amount of money to keep risk under the acceptable limits is then compared with the earning value related to the delay of maintenance activities. This work is supported by effective data gathered along the years for this specific equipment, which permits to have a realistic approach of the proposed decision. The chosen system operates on a maritime environment, has its last overhaul on 2010 and has been operating worldwide since then.

Keywords — FMEA, diesel generator, cost, risk.

I. INTRODUCTION

One of the main concerns of engineers and technicians with responsibilities on asset management is to keep risk under acceptable limits and at the same time promote an optimised life cycle cost.

Usually the problem is to combine these two areas of conflict in a way to achieve the best compromise. Frequently there is some difficulty to identify the probability of occurrence of undesired events and the severity of such situations and thus calculate the risk associated to the potential failure modes, although the several methodologies and tools available to reach such objective.

In almost industrial fields maintenance activities follow the manufacturer instructions and recommendations and so hard time maintenance programmes are followed and accomplished. Sometimes the frequency established for those activities is not the appropriate considering the working conditions of the assets. The decision to modify maintenance intervals is not so simple and must be based on trusted and proven information.

In the Portuguese Navy this concept is also applied and mostly systems installed in war vessels fulfil the requirements of hard time maintenance (HTM). This complies with some activities of condition based maintenance (CBM) and sometimes the necessarily corrective maintenance.

This paper intends to analyse specific equipment that exists in a vessel and verify if some hard time maintenance activities can be delayed in time taking into account the maximum risk acceptable once it is critical equipment. The objective is to compare the amount of money saved with this decision with the cost to keep risk under a pre-defined level.

To accomplish this work a Failure Mode and Effects Analysis (FMEA) was applied, including some additional studies. The paper is structured in four sections. Section II refers the Failure Mode and Effects Analysis (FMEA) methodology, its characteristics, benefits and drawbacks and Section III presents diesel generators as the equipment under study describing the use of such equipment on a war vessel and on maritime environment. Section V corresponds to the development of the case study and section VI points out some conclusions and future works that can be done on the sequence of the present study.

II. FAILURE MODE AND EFFECTS ANALYSIS (FMEA)

A Failure Mode and Effect Analysis (FMEA) is an engineering technique used to define, identify and eliminate known and potential failures, problems, errors, design process and/or service. It is a systematic approach and a mental discipline that an engineer normally goes through in any manufacturing process [1]. A FMEA is a living document based on experience, past concerns and key performance
indicators. Most of times FMEA is an inductive approach to support risk assessment studies.

This methodology was first proposed by NASA in the 1960s in order to fulfil reliability requirements. From then, it has been extensively applied as a powerful technique for system safety and reliability analysis of products and processes [2].

Several studies applying FMEA can be observed in a huge variety of subjects, since automotive, aeronautical, military and nuclear, among others. For example, Arabian-Hoseynabadi [3] applies this methodology to study the reliability of a wind turbine system and compares the results to reliability field data from real wind turbines systems and their assemblies.

A criticism of FMEA is usually related to the possibility of failure modes with lower RPN could have some factors (like severity) with high values and sometimes it is not observed when someone only looks to the RPN value. After determining RPN some recommendations or corrective actions should be performed with the objective:

- To increase the detectability of the failure before its occurrence.

When the analysis of failure modes is developed on a system, people can go into a desired level of detail just to identify potential failure modes before they occur and may cause undesirable events. So, the risk of failure is minimised by proposing design or operational changes.

A FMEA is a team work including experienced engineers and people familiar with project as well as experts who have a deep understanding of the product or process. The expertise team can vary according to the scope and complexity of the focused problem.

The FMEA process covers the following steps:

- Analysis of the process, product or system;
- Description of each function;
- List of the identified potential failures (functional failures);
- Evaluation of their frequency, severity and detection technique;
- Global evaluation (includes RPN analysis);
- Identification of corrective actions or recommendations

III. DIESEL GENERATORS IN A VESSEL

The physical assets analysed in the present work are diesel generators consisting in diesel engines coupled to alternators. These systems are installed in a vessel and mainly work in a maritime environment. This type of generator is prepared to work in a maritime condition, due to utilization of seawater for refrigeration purposes.

At the present study, it was considered the example of diesel generators from a modern Portuguese Navy vessel (frigate). The frigate platform has four diesel generators, each one with 655kW, in a total power of 2620kW. The generators provide 440V/60Hz to two main switchboards that distributes energy for the entire platform. The vessel in a sailing situation requires two generators in permanent function and, when alongside, only one is required. Figure 1 shows a view of the diesel engine analysed in the present work.

Figure 1. Diesel Generator MTU 8V 396 TB53
Maintenance Support Wireless System for Ram of Forming Presses

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Abstract – In the paper, an innovative wireless system for press ram stress monitoring will be presented as component of a decision support system for predictive maintenance. This system involves low power consumption wireless nodes and energy harvesting techniques to gain autonomy for the whole solution. The monitoring systems output signals serve to extract and generate “virtual sensor” signals. These represent actual load and stress situations on locations that are crucial for machine stability but are inaccessible for real measurement or even buried inside the frame structure. In addition, the monitoring system is embedded into a networked environment of an e-maintenance cloud, linking a variety of information sources like enterprise resource planning.

Keywords – condition monitoring, maintenance, forming, fatigue, simulation, wireless.

I. INTRODUCTION

Breakages at highly stressed components of forming presses like frame, crown, table, and plunger often cause very high direct and indirect costs for the machine owner. To prevent or minimize this, the monitoring of mechanical stresses is a very important field of research. Although the facility manufacturers are trying to prevent crack formation by oversizing of highly stressed parts, the high number of failure cases high-lights the relevance of this problem. An example of a repaired fatigue breakage of a press crown is shown in Fig. 1.

A promising approach to solve this problem is the monitoring and evaluation of stresses in production presses and its embedment into a preventive maintenance strategy. To reach this goal, three main challenges have to be solved:

- development and integration of embedded in-formation devices with data pre-processing capabilities in order to capture relevant information like loads, strains and stresses
- definition of new algorithms and techniques in order to provide intelligent data processing and knowledge extraction from production equipment
- development of reliability & maintainability de-sign practices/methods to predict and assess the availability of equipment already at an early de-sign stage

Fig. 1. Repaired fatigue breakage at a press

A basic technology – the monitoring of mechanical stresses – actually is not applied to industrial forming machines, but is well-known from a number of different industries. One important example is the ship building industry, where the strain of ship hulls [1-2] and motor shafts is measured. Also concrete buildings are equipped with strain sensors in order to obtain data concerning their structural health [3]. But the direct measurement of strains or stresses can be done only locally and at the previously identified critical places. The estimation of the stresses in the whole geometry corresponds with the need of a high number of sensors or relatively uniform stress gradients that allow a mathematical description of the non-sensored areas. That’s why – on the one hand – it is done mostly on relatively simple geometries like bars, drive shafts or plates.

In conclusion, the stress monitoring in forming presses with its complex mechanical structures like welded parts or ribbed frame components and under varying load conditions is a core challenge of the project. The reasons are the partial inaccessibility of the required measurement locations, the high number of potential fracture critical locations and their dependence on varying load conditions based on the ram stroke or tool geometry.
On the other hand, mostly fatigue breakages are the reasons for press breakages, while static overloads normally can be avoided by overload protection units.

The common strategy to avoid fatigue breakages is to operate forming machines below the fatigue limits. These limits are estimated by static simulations (e.g. finite element methods) during the design stage, based on pre-defined load scenarios. But in practice the high numbers of breakages show that not every critical load scenario can be considered during design stage, not least because of the unknown future production spectrum and the resulting real loads.

To learn more about real mechanical loadings and the reasons of breakages, and to minimize future failures in forming presses, in the iMAIN project a novel stress and condition monitoring system is in development, embedded into a cloud-based maintenance concept. In chapter 2 this overall concept will be introduced and in the following chapter 3 the Wireless system concept will be explained.

II. iMAIN SYSTEM CONCEPT

To address the maintenance challenges listed above, a novel concept has been developed, that is based on intelligent information agents. These agents combine different data and information sources like control-inherent sensors, additional real sensors and model-based virtual sensors, that allow continuous, real time, remote, and distributed monitoring and analyzing of forming machinery. The chosen approach to get knowledge from data and information is planned to be demonstrated on forming machines, but can be applied also to other industries with highly and dynamically loaded systems, e.g. power plants, transportation sectors or aircraft industries.

The prediction of the remaining service life, as one of the core challenges of the project, needs information about the actual deterioration of components (deterioration history) and about future load scenarios. The deterioration is estimated by the monitoring of maximum strain or stress values of every forming cycle under real process load and its accumulation during the life cycle via cumulative damage hypotheses. For this, a load and deterioration history has to be stored, covering the whole lifecycle of the forming equipment.

Considering the challenges in stress monitoring, a special approach – the so-called “virtual sensor technology” – has been developed (Fig. 2). It extends the information of a limited number of real sensors (especially strain gauges and force sensors) by additional virtual sensor signals that are processed in real-time. These “live” calculations continuously derive how stress on virtual locations is determined by signals from the surrounding real sensors. The respective models that represent these relationships are developed by reduced-order finite elements (FE) models. This allows the observation of all potentially critical points of the press mechanics with minimized effort and even overcoming physical limitations. The crucial calculations are implemented as a part of the embedded condition & energy monitoring system (ECEM system). Stress monitoring on both real and virtual sensors together with the assessment of a wide variety of additional machine related sensors and data contributes to building an extensive history of machine life. The so-called Smart Service Life Prediction (SSLP) system will then combine data from load and deterioration history as well as actual sensor and production planning information and allow for intelligent and predictive maintenance strategies.

Based on the functionalities described above, such a monitoring and maintenance system consists of a number of distributed components that are networked for close cooperation (Fig. 3). These are:

- press machines to be monitored, which are each associated with an ECEM system, including a SSLP system
- multiple machines/ECEM

The ECEM systems are typically installed in close proximity to the associated machine. Such units in turn are distributed over a wide area industrial installation that can extend across a single facility or company and even across multiple sites, industrial entities, companies and even countries. The overarching networking structure of this setup is called the “eMaintenance Cloud”. It provides mechanisms and services to allow multiple clients to participate in the condition monitoring process. These clients can be:

- data center providing IT infrastructure, processing services and database information
- monitoring operators
- press manufacturer
- scientific experts

While operators typically control the process and selected machines in an interactive or automated way, manufacturers and scientific experts can also contribute in adding additional information and input in order to optimize the process.

III. FUNCTIONALITY AND STRUCTURE OF THE WIRELESS SYSTEM

The wireless network that has been thought for interfacing with the ECEM system is intended for capturing temperature from the moving slide since this parameter has a direct relation with excessive friction due to its misalignment.

The press operation scenario considered in this case is a press’ running mode of 30 cycles per minute with a working period of 16 hours/day during 5 days per week (Monday to Friday). Moreover, a photovoltaic (PV) system was dimensioned in order to supply the wireless sensor nodes.

The system proposed comprises the wireless monitoring system with 4 "sensor nodes" that measure the temperature of each linear guiding rail. For this purpose, each sensor node should be able to measure two temperature points and send the information to the remote network system gateway. Furthermore, each wireless sensor node should be autonomous.
Therefore, in order to fulfill this aim, a mixed power supply system based on batteries and energy harvesting technologies is developed. Following the low power requirement, during the "ON mode" the sensor nodes are able to send frames to the data collector upon request. If there are no requests during this mode, the Sleep mode is set up.

Since the sensor node cannot identify when the press operation cycle begins, an automatic start up system by detecting movement in the press is implemented. The movement detection system consists of a high-sensitivity accelerometer that turns on the node when a press movement is detected.

A. System’s blocks

The monitoring system is divided in the following functional blocks (Fig. 4):

- Power system
- Wireless Sensor node
- Wireless communication bridge
- Data collector and communication gateway

The power system is composed by an energy harvesting module based on a high-capacity capacitor. It is powered with...
a solar panel that recollects energy from the ambience light. Moreover, for ensuring that the wireless sensor node is able to work in case of insufficient light conditions it was also included a high-capacity battery. Using both energy sources it is possible to ensure a wireless sensor node life cycle up to a year. Moreover as an energy saving task, during the non-operation period two low consumption modes can be set up in the wireless sensor nodes: low-power mode (~μA ) and ultra low-power mode (~nA).

The Wireless Sensor node is an IEEE 802.15.4 compliant wireless sensor node based on the original open-source "TelosB" platform design developed and published by the University of California, Berkeley (“UC Berkeley”). The node has the following general characteristics:

- IEEE 802.15.4 WSN platform
- TI MSP430F1611 Microcontroller
- TI CC2420 Radio Transceiver
- TinyOS 2.x & ContikiOS Compatible
- Temperature, Humidity, Light sensors
- User & Reset Buttons
- 3xLeds
- USB Interface
- 2xAA Battery Holder

In order to transmit the information collected by the wireless sensor nodes to the communication gateway, wireless 802.15.4 to Modbus RTU is used. The selected device is the Advanticsys® DM-124 wireless communication bridge. The main function is to collect all the data sent by the wireless sensor nodes and transmit them automatically to the central gateway, which is in charge of the data and energy saving management, so the mote life cycle is optimized. Moreover, due to the use of the DM124 device it is possible to reduce the amount of cables needed in RS485 installations by bridging devices through IEEE 802.15.4 based wireless networks. This provides legacy industrial installations the versatility and ease of deployment of wireless sensor networks (WSN).

Finally, an Advanticsys® controller MPC product line is used as data collector. It is mainly in charge of managing the information from the wireless sensor nodes and the integration with the iMain platform.

B. Operation

The temperature reached in the press linear guides must be supported by the wireless sensor node. According to the press documentation, the temperature range of this part of the press is from 0 degrees up to 250 degrees. The response time is also a relevant aspect as this parameter has influence on the “ON” time of the node (if the response time is big we have to power it more time to have a valid measure).

In order to achieve the aim of monitoring the press temperature during working cycles, it has been defined a system prototype according to the measurement requirements (Fig. 5). During the press working cycle the sensor node is switching from the ON mode to the Low-Power mode alternatively. In the low power mode, when the T_Threshold is reached, the node turns to Ultra-Low-Power mode and all the electronics power down except the energy harvesting module and the wake up accelerometer, which is the responsible of switching on the sensor node when motion is detected or several samples without motion are detected (time of inactivity, this is to avoid that the node never wakes up again in case of failure). In the next ON mode, all the peripheral should be initiated again (microcontroller, RF transceiver, accelerometer, RTC, flash memory, etc.).

![Fig. 5. Continuous-operation Software/Hardware cycle](image-url)
IV. CONCLUSIONS

Frequent occurrences of fatigue fractures and failures of forming machines have motivated the development of a novel strategy for stress monitoring and predictive maintenance of high-loaded mechanical components. The smart combination of advanced monitoring and knowledge-generation approaches like the virtual sensor technology, life cycle histories or the merging of location independent information sources requires the development of new IT infrastructures. In the paper, the high-level structure of such a system has been presented along with the concept of a wireless system for data acquisition. This structure will be the base of an advanced and modular condition monitoring and maintenance system for forming machines as well as other highly stressed systems from different industries.

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Maintenance Management in Web ASP.NET MVC Applications

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Abstract – Maintenance presents itself as one of the key factors for increasing the productivity of companies. Its importance is increasingly recognized due to the need for greater efficiency in the management of physical assets and resources that are associated with it, thus avoiding unnecessary costs.

This article presents a management system to support maintenance management, which is being developed, named GESP, designed with the help of ASP.NET MVC Web program, which transacts the data through a base data developed in SQL. This system intends to perform inventory management, human resources outsourcing (subcontracting) and maintenance of the activity itself. The differentiating feature of this tool stems from its ability to measure in real time variables of control (hours, kilometer...) of physical assets and the ability to automatically schedule working orders, even taking into account the physical structure of the active targeted for intervention.

Keywords—Maintenance management; Stocks management; Maintenance resources; Outsourcing; CMMS.

I. INTRODUCTION

Maintenance presents itself today as one of the primary factors that contribute to the productivity of enterprises. Its importance is recognized because the aim for greater efficiency in resource management, thus avoiding unnecessary expenditure of funds.

Maintenance management is an arduous task that involves human resource management, physical assets, including stocks, and yet, when applicable, the management of subcontracted services. All of this should be done in harmony with the production sector to minimize the losses caused by the stoppage of production. However, it is impossible to predict all the failures in physical assets, being mandatory some unplanned interventions, forcing sometimes a re-schedule of previously planned maintenance interventions.

Mainly in large organizations, the maintenance cannot be only focus on an expert, existing systems that store and keep updated detailed information about the overall physical assets of an organization. The systems commercially available are differentiated by their ability to share information with different departments of the organization, data collection, data management, including artificial intelligence applied in several processes, giving to the maintenance manager a set of information in order to improve the efficiency of maintenance management.

Considering all the precedent characteristics, this paper presents a tool, which stills under development, to support maintenance management encompassing stock management, human resources outsourcing (subcontracting) and own maintenance activity, scheduling maintenance events and classifying them according to their AFNOR standards, [1]. Current system version is being designed in ASP.NET MVC Web [2] linked to a model database in SQL [3]. This system has the peculiarity to communicate in real time with the physical assets in order to check their variables of control (hours of work, kilometers...), analyze them and so pre-scheduling its planned maintenance interventions. It is mainly useful for non-periodic / aperiodic interventions.

The paper is structured as follows:

• Chapter two is the approach to programming in ASP.NET MVC C#;
• Chapter three, maintenance data management, presents a general approach to manage data maintenance, including the following items:
  o The permissions system;
  o The technological decomposition;
  o The management of planned maintenance;
  o The stock management;
  o The scheduling of working orders (WO);
  o Analysis of the history;
  o Classification of the maintenance tasks.
• Chapter four presents the GESP application;
• Chapter five defines future development application for GESP;
• The chapter six presents the conclusions and finally;

II. APPROACH TO PROGRAMMING IN ASP.NET MVC C#

The GESP system is developed in ASP.NET [2] which is a Microsoft’s platform for developing Web applications. It is a component of IIS (Internet Information Services) that allows, through an integrated programming language in the .NET Framework to create dynamic pages. ASP.NET is based on NET Framework [4], which inherits the features of .NET application. The platform offers advantages such as the development of the following applications:
The code is written in several languages, in this case the GESP is developed in C# [5] NET that can be developed in Visual Basic NET [6];

Application development in Visual Studio.NET [7] facilitates the programming work, with visual components to create forms of Web pages. Whilst it is possible to develop ASP.NET applications using only a text editor and compiler. NET;

It is possible to reuse the code of any other draft written for NET platform, even if the language is different;

Despite the code of the application is not written in VB.NET [8], this tool allows you to call components written in C# and Web Services written in C++ [9];

The ASP.NET applications are compiled before execution, giving a sensitive performance gain;

Allows you to run ASP.NET applications on other platforms (Linux [10]) through the module that enables the Apache HTTP Server to work in conjunction with NET Framework and ASP.NET applications running on the , or is, mod_aspdotnet project.

The MVC pattern [2], represents an important role in computing, particularly with regard to the creation of architectural patterns related to the construction of UI (User Interface). A key feature of this pattern is the separation of responsibilities, thus contributing to the code used in a given area is isolated from that used in the construction of graphical interfaces. Thus, the division of responsibilities contributes to simplify development (simplifies the modularization), simplifies testing of the various components and improves the maintenance of the application at the expense of a small increase in complexity. Thus, a single standard lists three elements: model (Model); control (Control); and the view (View) - The model is a class or set of classes that encapsulates the data and business rules that are applied to them; The view is responsible for generating a graphical user interface presented to the user; Control is responsible for managing the interaction between the model and the view.

III. MAINTENANCE DATA MANAGEMENT

The management of all information affects the maintenance activity which is a complex process including the influence of some processes against others in a bi-directional way. Often a multi-criteria analysis is performed, but it may be too complex that only with the aid of computer tools is can be solved and thus manage efficiently the overall maintenance sector of an organization [11-12].

A. System permissions

The proposed maintenance management system has several pre-defined access patterns, manage by the system administrator, depending on individual background and position of each collaborator. People on the same positions but different background may have different access to information, position of each collaborator. People on the same positions but administrator, depending on individual background and pre-defined access patterns, manage by the system technician. Although the system has a pre-defined set of accesses, as schematised in figure 1, the administrator of the system can set new levels of access to different profiles and others background specialties.

Fig. 1. Permissions of the GESP users

B. Technological decomposition

Technological decomposition of each physical asset is important and highly relevant to the performance of the proposed system. Each asset is classified according to its condition, family, manufacturer's recommendations as well as their references, especially useful in the selection of replacement parts.

Thus, each asset is classified according to its state of condition such as:

- Operational - meets all requirements of normal operation;
- Out of order - when a failure occurs and the physical asset is under maintenance works;
- Slaughtered - physical assets whose life cycle has ended.

Regarding family, each physical asset is identified as follows:

- Equipment Parent - category of physical assets;
- Integral Part - indicates the main equipment of which the physical asset in question is an integral part;
- Alternative Part - alternative to part.

In the case of a physical asset be a part of a production line (an induction motor for example), that line is the Integral Part and the alternative part a similar production line wht the same characteristics as the Integral Part because in case of an engine failure the whole production line is stopped. If the physical asset is one defibrillator, it is itself the Integral Part being the alternative another defibrillator. Highly important are the recommendations of the manufacturer about regular operational conditions and maintenance plans in order to extend as much as possible the life cycle of each physical asset and not lose the warranty, which is sometimes lost due the improper use of physical assets or for not fulfilling their maintenance plans.

The references, these are used to manage orders and for market analysis and acquisition of physical assets, aiming to achieve better prices and identify alternative parts that allow similar performances.
C. Management of planned maintenance

The management of planned maintenance interventions is performed through the maintenance events following the structure shown in Fig. 2. The order of creation of a new maintenance event is given by temporally periodic or aperiodic maintenance interventions. In the latter case, the creation of a maintenance event depends on a variable of control and a prediction of the event scheduling. This is supported by a communication module, connected to assets, in order to obtain the data from the variable of control and analyze operating periods in order to make the best possible prediction to the planned maintenance intervention that should occur.

Created the event, it is selected the tasks that must be performed, not only based on the specifications from the technological decomposition but also from the analysis of the physical asset’s history and or its family, which may result in additional tasks.

Each task is classified according to the AFNOR standards in order to manage efficiently the human resources available for the period in which the maintenance works are performed. The system will be prepared to indicate not only the internal organization’s human resources as well as the outsourcing services if applicable or demanded. The availability of parts that need to be replaced in stock is also important for scheduling interventions.

After all this information is gathered, it will be the maintenance manager who will decide the exact moment when the maintenance intervention should occur and identify who is responsible for carrying out each task by issuing working orders (WO).

In spite of what were presented above, it will be able not only for the technician but also the operator to report failures or evidences that will be evaluated by the maintenance manager and, if applicable, create an event with appropriate tasks to ensure adequate operational conditions of physical assets. Given the nature, this is considered a "preventive Event".

All the parameters to schedule interventions are pre-defined in a database. The management system will compare the pre-defined in the database with the values from the variables of control that are monitored in real-time, being the communications carried out via a PLC, following the structure shown in Fig. 3.

D. The stock management

A good stock management of reserve parts predicts the required resources for a certain period of time, thus ensuring all necessary parts will be available on time. Throughout the historical analysis, the maintenance manager may provide the
CMMS – An integrated view from maintenance management to on-line condition monitoring

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Abstract—Nowadays, Enterprise Asset Management (EAM) systems or, more specifically, Computer Maintenance Management Systems (CMMS) need to fill requisites like the following ones: To work in all platforms, independently of operating system, being this cross-platform and multi operating system. However, CMMS also need to work in any language, being this native, where they were developed or any other, like English, Greek or Arabian.

Even the precedent challenges weren’t big enough it is also necessary that CMMS receives and manages data from any type of sensors, independently where they are placed, locally or remotely, and the signals transmitted through wire or wireless.

In consequence, the on-condition predictive maintenance reached a new level to enlarge the availability.

Furthermore, it is also necessary to manage the configuration of the EAM itself to be able to communicate with the several existent platforms.

There are new technologies that represent new limits, not beyond tomorrow but for today. Such technologies like Augmented Reality, Artificial Vision and even holography have potential to increase maintenance performance.

The physical assets are each time more and more strategic to the organizations competitiveness then the EAM need to manage not only the maintenance of assets but also all their Life Cycle Cost, including investment, renewal and withdrawal aspects, and also resources optimization. This is a complex equation that increased in complexity along the time and, simultaneously, ought to be managed in a friendlier way by the final user and, yet more, its cost must be, each time, cheaper than before.

These are the main subjects that will be discussed in the paper and also the proposed solutions, both the software and hardware solutions in an integrated view, that represent not only a state-of-the-art but a step ahead in the physical asset management area, in general and in maintenance management, in particular.

Keywords—Maintenance; CMMS; EAM; Operating System; On-condition Maintenance.

I. INTRODUCTION

The Enterprise Asset Management (EAM) systems and or Computer Maintenance Management Systems (CMMS) are being entering in a new phase with a lot of challenges that are occurring simultaneously and are transforming the current systems into a new position that will put the present systems in a pre-historic position.

In fact these systems must work over Operating Systems (OS) like Linux, Windows, iOS, or others, and in any type of platforms, as a Personal Computer, a Tablet and a Smartphone. Additionally, they must communicate with data acquisition systems even each one has its own specific protocol to transfer data to other devices.

The heterogeneity of the systems also implies an additional difficulty in the communication among them, namely in the relationship between maintenance companies and their customers, mainly when both have an EAM and the potential common data that must be shared.

Moreover the EAM also needs to incorporate components like Expert Fault Diagnosis Systems (ES), Augmented Reality (AR), Geographic Information Systems (GIS), among others.

These are the main subjects that are treated in this paper that is organized as follows:

- The chapter two makes the discussion of EAM versus CMMS;
- The chapter three deals with the problem of CMMS multiplatform;
- The chapter four deals with the On-Condition sensing and CMMS communication;
- The chapter five deals with the problems of Communication among different CMMS;
- The chapter six deals with questions referring to the incorporating new technologies in CMMS;
- The last chapter presents the conclusions and some tendencies for tomorrow.

II. EAM VERSUS CMMS

A Computer Maintenance Management System (CMMS) software package is an information system which main purpose is to support the management of maintenance activity. This information is intended to help technicians to do their work more effectively, to monitor the equipment performance and to aid the maintenance staff decision. CMMS data may also be used to verify regulatory compliance.

An Enterprise Asset Management (EAM) is an information system to manage the whole life of the Physical Assets of an organization. It covers such things as the acquisition, commissioning, operations, maintenance and decommissioning/replacement of plant, equipment and facilities. "Enterprise" refers to the management of the Physical Assets across departments, locations, facilities and, in some cases, business units. By managing assets across the facility, organizations can improve its utilization and performance, to reduce capital costs, and asset-related
operating costs, extend Physical Assets life and subsequently helps to improve Return Of Investment (ROI).

As can be seen there are several differences between a CMMS and an EAM; however, they are commonly understood as the same.

Nowadays, because the enormous evolution of the maintenance sector, and by consequence their standards, the EAM tend to reach a widely field of application than CMMS. The following standards correspond to the most recent Physical Asset Management view:

- ISO 55000:2014 - Asset management — Overview, principles and terminology;
- ISO 55001:2014 - Asset management — Management systems — Requirements;

The NP 4492:2010 (Requirements for the provision of maintenance services) and associated standards, as will be seen in chapter four, corresponds to an approach within the CMMS systems that have their core in the maintenance activity.

However, this is an approach that has given its first step. It is necessary to wait before giving the next step in order to understand when the right time reaches to make the convergence and the synergy between them.

III. CMMS MULTIPLATFORM

Nowadays, some of the most important commercial OS in the world are Linux, Windows, iOS and Android, where the CMMS must work. Additionally, it must work in any type of platforms, as a Personal Computer, a Tablet or a Mobile Phone.

The main problem of the existing EAM/CMMS is their functioning that is mostly based on a Client-Server platform; over a browser that directly connects to the server using a TCP-IP connection, among others. Usually they work with a relational database, based on a Structured Query Language (SQL), with a user interface developed in a specific tool.

The biggest challenges start from this point because it is necessary to “convert” old programs for new platforms with new tools.

Additionally, it is also necessary to consider the new challenge that arises from Cloud Computing, where both clients and suppliers can host their data and share or not them when customer and supplier establish a commercial maintenance contract.

Some of the challenges related to the creation of new platforms, namely the mobile devices, are the following ones,

- Generic Model for a Mobile Application
- Selecting a Template

This application can be separated in two big sides, the server side where all information is stored and processed and the mobile side where all information is accessed or entered.

Fig. 1. Interaction between the server side and the Mobile side

The server side is running a Rest server (Fig. 1) which receives and manages all requests to the server. This Rest server is a PHP script, that is able to receive HTTP requests, either GET or POST requests, and it is able to respond in XML, HTML or JSON.

The Rest server is also used as a form of security, because it works between the database and all requests from outside, not allowing direct access to database. On the other hand the database should be SQL type, for easy development and integration with the Rest server (Fig. 2).

Fig. 2. Server Side Diagram

The mobile side must be able to communicate with the server in order to obtain all the required information, for this the device must be able to connect to the network via wireless or via General Packet Radio Service (GPRS). It is also necessary that the device is capable of reading barcodes; this can be achieved through image capture or scan which requires the mobile to have a camera or a laser scan. The device must also have in its hardware list a touch screen sensitive enough to capture signatures, a camera to take photos to store on the database and a Global Positioning System (GPS) system to gather the location of the device. Linking all this, the mobile device must also have to be able to run an internal database to implement an offline mode. For several years all these features could only be found in expensive industrial devices, such as the PDA Datalogic Lynx. But, nowadays, any Smartphone is capable to fulfill these requirements; because these reasons it was decided to use a Personal Digital Assistant (PDA) and a Smartphone for this work.
At the beginning, the application should check if the device is connected to the network and that the server is functional before starting work. After this check, the application should ask the server to get the list of all types of perishable equipment and if all goes well displayed. After this the user needs to choose the type of item that he wants to catalog.

On the next stage, the application will be allowed to scan barcodes, and after that, it should ask the database if the barcode was already been previously taken. If so, ask the user if he intends to overwrite the previous entry and if he says yes or is a new entry, the App should jump to its third stage.

In the third stage the user should collects photos, information about the location of equipment, comments about the equipment’s state, and finally getting the signature of the user.

After all the information has been collected on the third stage it should be sent and processed by the server. The application should revert back to stage two and wait for a new barcode reading process. This behavior is illustrated in the flowchart of Fig. 3.

This new and friendly access to CMMS is a step away to manage the maintenance interventions, work orders, maintenance auxiliary tools, and so on.

IV. ON-CONDITION SENSING AND CMMS COMMUNICATION

Nowadays the EAM/CMMS have more and more modules associated to several data acquisition systems, being these ones aimed to control temperatures, vibrations, effluents, among others. However, these new capacities that are added to EAM have specific, proprietary, communication protocols, what difficult their s connection to other system beyond the proprietary; the proprietary systems predominate, but this situation tends to change progressively.

The standardization of the communications protocols is a big problem in order to put the EAM/CMMS in a new level of development, price and market generalization, what is an urgent step to give to reach the best availability and Life Cycle Cost (LCC) of physical assets.

The OSA-CBM (Open System Arquitecture for Condition-Based Maintenance) under the MIMOSA (Machinery Information Management Open Standards Alliance), that is a standards organization that manages open information standards for operation and maintenance, tries to define the architecture of an open system for maintenance conditioned with seven levels, [1] (Fig. 4):

1. Data Acquisition;
2. Data processing;
3. Monitoring the condition or state;
4. Evaluation of the operating state / fault detection and isolation;
5. Forecast / prediction of dysfunction;
6. Decision Support / recommended actions to correct the dysfunction;
7. Presentation - User interface.

Under this context, the implementation and monitoring of the condition of physical assets, and interconnection with a CMMS that manages Working Orders (WO) is not dependent on any proprietary software vendor. This means that the end user (owner / operator) can select the data it deems appropriate without having to worry about integration problems or be forced to choose a single supplier to provide data in the format it need for integration and maintenance management of assets in your CMMS.

From this perspective, SMIT (Integrated Modular System for Terology) treats Physical Assets, integrating them in a modular information system that communicates with any database engine in a completely transparent and independently of the manufacturer and operating system involved [2].

V. COMMUNICATION AMONG DIFFERENT CMMS

Nowadays there is more and more necessity that each CMMS communicate among them and, particularly in the case of the providers certification, because the sharing of physical assets data in order to make possible the communication between client-supplier. About these problems it is particularly interesting to discuss the NP4492:2010 that is supported in the following standards:

- NP 4483:2009 - Guide to the implementation of a maintenance management system;
- NP EN 13269:2007 - Maintenance - Instructions for preparation of maintenance contracts;
- NP EN 13306:2007 - Maintenance Terminology;
- NP EN ISO 9000 - Quality management systems - Fundamentals and vocabulary (ISO 9000:2005);
VI. INCORPORATING NEW TECHNOLOGIES IN CMMS

One situation that can be more efficiently managed is during and after maintenance interventions, because, usually, the WO are printed to be used during interventions and its fulfillment is done after these. What happens is that there are several data that have the risk to be forgotten due to lack of time between intervention and WO fulfillment in office.

The above situation will be easily solved by the mobile solution referred in this paper (chapter 3), permitting to fill all WO data immediately after each maintenance action is done.

Other value-added can occur during the interventions itself, namely when these ones are not planned, because the technician can access on-line to a fault diagnosis tool, if it exists.

But the interest of the technology under discussion begins since the moment that equipment is purchased, because it permits to make its registration in site, including bar-code reading and so on. In fact, a correct registration of equipment dossier in database is determinant for a correct accompanying of its Life Cycle Cost (LCC), including WO, human resources, materials, and so on, as it was above referred.

When an intervention request reaches, namely the most urgent ones, and needs a quick response, a digital tool, like a tablet or a similar one, can immediately receive the information and the respective WO can be created; then, the technician, without loss of time, can, immediately treat it, make the interventions, and fulfill the WO.

Additionally, with the introduction of new technologies, like Augmented Reality (AR), 3D models, Expert Systems (ES), and so on, this new devices and applications create synergies in order to minimize intervention time, increase quality, minimize risks, and maximize availability. Fig. 6 shows an example of a flow chart of an inference operation of a CBR-ES [3-4].

In fact, if a technician use an integrated system with all these tools, AR, 3D and ES, the maintenance intervention time can be reduced, the errors minimized, and the efficiency incremented, [5]. But there are some additional benefits as is the fact that technicians less experienced can work like the fact that technicians less experienced can work like the most experienced ones, due to all the auxiliary tools that they have integrated to aid them (Fig. 7).
VII. CONCLUSIONS

The paper makes a short discussion of the CMMS in an integrated view from maintenance management to on-line condition monitoring, with emphasis to the communication among heterogeneous systems and multiple platforms.

It also discusses the relation between EAM and CMMS, in a time where everything is changing.

The communications among different systems, platforms and acquisition systems, where OPC/MIMOSA is trying to give a step ahead it is also proposed a Data Interchange among Multiple Platforms (DIMP) to make possible the data interchange among suppliers and clients, permitting a relation win-win.

Finally, the incorporation of new technologies in CMMS is also treated, namely the expert systems, that are not extensively used in this type of systems, even having very rich history files.

Additionally, 3D technologies, Augmented Reality, among others, are nowadays tools that have to be incorporated in EAM/CMMS to permit the maintenance activity be the key success to the organizations competitiveness.

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Practical challenges in determining periodic maintenance intervals on the Norwegian Continental Shelf (NCS): Some expert views and opinions

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Abstract—Maintenance is one of the key success factors for ensuring safe and reliable operations on the Norwegian continental shelf (NCS). Periodic maintenance is still a large part of the maintenance portfolio even if the ambition is to shift towards dynamic strategies. Therefore, one can conclude that, currently, the availability of offshore production facilities on the NCS is significantly influenced by maintenance programs that are based on predetermined periodic maintenance tasks.

This paper reviews current practices and experiences for determining intervals for performing maintenance tasks. The mapping is performed by comparing theoretical and practical industrial approaches to determine the preventive maintenance task intervals. The paper highlights some practical issues and challenges that maintenance engineers face in the determination of task frequencies/intervals on the NCS.

The study shows that the biggest challenge for the maintenance engineers is to determine the “optimal interval” for the maintenance tasks. A frequent task will increase the maintenance costs, whilst an extended interval could increase the risks related to unexpected failures. The maintenance engineers use their engineering judgment by combining manufacturer recommendations, regulatory requirements and operational needs to determine optimal intervals. The NCS, however, needs more dynamic maintenance strategies that are data driven but without the inhibiting computational and practical issues currently available in existing theoretical mathematical models.

Keywords—Preventive maintenance, maintenance interval

I. INTRODUCTION AND BACKGROUND

Predicted periodic maintenance is a part of the broader concept of Preventive Maintenance (PM). Hence, drawing from standards such as EN 13306 [1], ISO 14224 [2], NORSOK Z-008 [3] and other literature, predetermined periodic maintenance may be defined as planned maintenance carried out on the basis of regular time intervals intended to reduce the probability of failure or the degradation of the function of an item1.

According to Mobley et al [4], predetermined periodic maintenance is based on the assumption that equipment will degrade and fail within a time frame (operational hours/calendar) that is typical of its particular classification. This assumption is accepted to be generally true. Experience, on the other hand, suggests that degradation and failure can occur outside this typical time frame, even for similarly classified equipment. Nonetheless, it is this assumption that forms the basis of why predetermined periodic maintenance is mathematically rooted in the concepts of statistics and probability. Three interpretations of probability are acknowledged in probability theory: classical, relative-frequency and subjective interpretations [5]. The relative-frequency interpretation of probability satisfies the scientific requirements of objectivity and repeatability. It also provides a probability interpretation that is closest to the assumption underlying predetermined periodic maintenance. This interpretation, understandably, forms the principal element of several models used for the determination of predetermined periodic maintenance intervals.

Maintenance activities and intervals are defined in a typical PM program. However, on the Norwegian continental shelf (NCS), developing a PM program also includes preparing PM task routines, specifying the requirement for spare parts, estimating the duration for executing each maintenance activity and assigning a discipline responsible for each maintenance activity. The study presented in the ensuing section will therefore be limited to determining the interval of maintenance tasks for a PM program on the NCS.

In this paper, we briefly review how predetermined periodic maintenance intervals are theoretically determined and compare these general concepts with practices on the NCS. We present two perspective views of the process of determining maintenance intervals on the NCS and also discuss some challenges in the PM program determination. The paper is primarily based on interviews with maintenance experts. Expert opinion from practicing engineers was sought in establishing the role that predetermined periodic maintenance plays in ensuring oil and gas (O&G) asset availability. A brief literature survey was also undertaken, discussing general theoretical approaches to establishing predetermined periodic maintenance programs.
II. THEORETICAL ESTIMATION OF PREDETERMINED PERIODIC MAINTENANCE INTERVALS

The determination of periodic maintenance intervals begins by finding the appropriate probability distribution to describe the equipment failure process. Establishing the probabilistic nature of the underlying failure process may be attained either by a parametric method or a non-parametric/empirical method [5]. Whichever method is chosen, a statistical analysis of equipment failure data is required. Most often though, real-life failure data fits the Weibull distribution [5] [6] [7]. The Weibull distribution is therefore considered the most appropriate probability distribution for inspection and preventive maintenance activities because of its possible application to a wide range of scenarios and its ability to approximate several other distributions.

The failure rate (number of failures per unit of time), often used to derive the statistical parameter known as the mean time to failure (MTTF), is a key reliability measure in the determination of periodic maintenance intervals. In addition to the failure rate, a description of the failure process requires the determination of the following: 1) the probability density function of the time to failure, 2) the cumulative density function, 3) the reliability function; and 4) the hazard function.

Once the probabilistic nature of the failure process has been defined, and the relevant parameters determined, any of the numerous theoretical models might be used to determine the most appropriate interval. These models suggest an optimal time for replacements [8] [9], inspections [6] [10] [11] [12] [13], and overhauls [14] [15] [16] [17]. Complex analysis techniques, such as Markov chains, Bayesian modeling, simulations, fuzzy logic, expert systems and genetic algorithms, form the basis for some of these models. Hence, they require a considerable amount of time, research and analysis to define a specific scenario. Furthermore, the analyst requires competence and skills in applying the methods and in assessing the assumptions to be applied to the system in question.

Models are developed with a specific target objective in mind. Either minimizing maintenance cost, reducing downtime, enhancing reliability, availability, maintainability or a combination of some or all of these objectives has been discussed and modeled in research works. The determination of periodic maintenance intervals thus transcends the intrinsic failure characteristics of the equipment. Applications of such models thus require the collection and storage of detailed information (both qualitative and quantitative). Such detailed information includes equipment failure, operation regimes, maintenance actions, modifications and related costs [18]. The intervals determined via these models are, therefore, a translation of specific corporate/business objectives and operating strategies.

III. THE NORSOK GUIDELINES FOR PM INTERVAL DETERMINATION

The maintenance management process defined in NORSOK Z-008 [3] also acknowledges the derived theoretical influence of specific corporate/business objectives and operating strategies on PM intervals and programs. Hence, the maintenance programs on the NCS are developed on the basis of the goals and requirements specific to each O&G company but with a focus on:

- Reducing risks, increasing production and lowering cost
- Compliance with applicable regulatory requirements
- The technical condition of the facility (in particular the performance of safety systems and critical processes)
- Improvement of the overall maintenance process.

Consequence classification is the main foundation for the development of PM programs on the NCS. The classification is an analysis that determines the effects of potential equipment functional failures on HSE, production and costs by breaking down all the installation’s functions into main and sub functions. Once the groupings and the classifications have been completed, maintenance activities and intervals are then determined.

For equipment classified as safety critical, testing intervals are determined on the basis of the performance requirements of their safety functions (OLF 070 [19] or IEC 61508). For non-safety critical equipment, one of the following options is employed:

- Referring to standardized/ generalized strategies/concepts. These standardized concepts are developed by performing detailed reliability-centered maintenance (RCM) analysis on equipment and documenting results such that they can be used for similar equipment of the same classification. Company-specific operational and maintenance experiences (best practices) as regards specific equipment are also used to enhance the RCM analysis results. Thus, within the framework of NORSOK Z-008, generalized strategies/concepts on the NCS are regarded as an efficient mode of capturing standardized company knowledge. The use of generalized maintenance strategies/concepts is considered an indirect RCM analysis on the specific equipment being examined.
- Performing detailed RCM analysis and risk-based inspection (RBI) methods to determine the specific maintenance activities, intervals and plans for execution for the equipment/system.
- Referring to original equipment manufacturers’ (OEM) recommendations on maintaining the equipment/system.
- Deciding to run the equipment/system to failure.

Performing a cost/benefit analysis is one of the recommended steps to determine cost-effective maintenance activities for selected equipment. For low consequence class assets, however, an interpretation of the guidelines suggests that risk analysis and/or cost/benefit analysis may not always be a necessary activity.
Kanika Gandhi; Diego Galar; P. C. Jha

maximization of performance and minimization of carbon considers three objective functions as minimization of costs, A typical multi objective supplier selection model which includes both selecting suppliers and allocating optimal procurement distribution problem is considered as quality and delivery time criterion. In this study a multi objective fuzzy optimization programming problem. The process provides balance among three objective functions and finds best supplier with optimal procurement distribution and penalty cost.

As per the data provided, we receive negligible deteriorated quantity; hence cost of disposal is also near to zero. Further, optimal carbon emission penalty cost was calculated on the basis of distance which is converted in per unit of each product. Table XIII shows the carbon emission (in gms) along with penalty cost per gram per unit.

TABLE XIII. CARBON EMISSION PENALTY COST

<table>
<thead>
<tr>
<th>Product</th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>133</td>
<td>26</td>
<td>122</td>
</tr>
<tr>
<td>RC</td>
<td>167</td>
<td>124</td>
<td>122</td>
</tr>
<tr>
<td>BP</td>
<td>135</td>
<td>124</td>
<td>123</td>
</tr>
<tr>
<td>OWB</td>
<td>129</td>
<td>136</td>
<td>136</td>
</tr>
</tbody>
</table>

VII. CONCLUSION

The supplier selection problem of multiple sourcing includes both selecting suppliers and allocating optimal order quantity among the selected suppliers, based on quality and delivery time criterion. In this study a multi sourcing procurement distribution problem is considered as a multi objective fuzzy optimization programming problem. A typical multi objective supplier selection model which considers three objective functions as minimization of costs, maximization of performance and minimization of carbon emission penalty cost with fuzzy aspiration levels respectively and fuzzy parameters are employed to construct fuzzy mathematical models. Each fuzzy parameter is represented mathematically by using an appropriate membership function. To solve the model, fuzzy goal programming with priority based is applied. The process provides balance among three objective functions and finds best supplier with optimal procurement distribution and penalty cost.

REFERENCES


Reliability Analysis on Crucial Subsystems of a Wind Turbine through FTA Approach

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Abstract – The wind turbine reliability is a crucial factor for the successful operation of a wind power plant, affecting its availability and efficiency. Operation and maintenance costs affect the performance of the whole system and reinforce the necessity of redesign of specific sub-assemblies achieving lower energy production costs.

At the first stage, field data make up Weibull sets in order to form the appropriate distribution-curve of the failure rate in each corresponding top event, are presented. These sets are limited to sub-systems having not only adequate data of the corresponding top events, producing more realistic results, but also having great risk priority, according to FMEA approach. These Weibull sets are linked with the corresponding top event of each subsystem and used to quantify the failure rates.

The validation of previous studies made on wind turbine reliability FMEA analysis through the FTA method is investigated in this paper, as well as the results from previous studies made on reliability of wind turbines using the FMEA method. Though, the reliability and importance results as derived from a quantitative analysis, seem to be following the same trend like previous studies from different and various approaches. As a result, Electrical and Control systems as far as the Hydraulic System need to be re-designed with better performance and reliability since they are crucial for the operation of each WT separately as well as for the whole wind farm.

Keywords: Wind Turbines, Reliability, Fault-Tree Analysis, Weibull Analysis, Isograph Reliability

I. INTRODUCTION

During the last decades many changes in the electricity demand and generation have taken place in a global scale, promoting renewable energy resources instead of fossil fuels which are starting degrading. Markets have started turning to alternative and renewable energy resources accompanied with increasing demand and production of electricity. A renewable energy source that is used for the production of electrical power is wind power. Wind power has become one of the world’s fastest growing renewable energy resource making it more attractive to even more companies and enterprises around the globe for use as a main source of power for their facilities. By all means, wind energy should not perceived as a complete alternative to common means of electricity production but it turns out to be a competitive and sustainable energy source. Fig.1 shows the globally installed wind power capacity from 1997 to 2011. As a result, Wind Turbines (WT) have become very popular among other renewable energy resources.

Fig.1. Wind energy: global capacity (blue) and forecast (red). [5]

Even though at a first glance, wind farms and the installation of wind turbines may seem simple, many factors must be considered such as the selection of the location of the wind farm, the layout of the wind turbines etc. All these operations and functions have proven quite costly. Operation and maintenance costs occupy a great share of the cost of a wind farm after its installation. Thus, the energy production of a wind farm depends on its reliability, meaning the reliability of each individual wind turbine as well as its subsystems. Fig.2. [7] presents the main parts of a WT for the conversion of wind energy to electricity.

Fig.2. Mechanical-electrical functional chain in a wind turbine [7]

The reliability analysis methods used in the design stage of a WT are mostly qualitative while after some time of operation more evidence of components and sub-systems reliability are becoming available, providing engineers with adequate data to improve the design and the maintenance planning.

The fault tree analysis (FTA) has been widely used to measure and quantify the reliability of complex electromechanical systems, not only by identifying the most...
critical parts of the system, but also combining field data obtained from maintenance sheets and highlighting the most frequent top events. FTA is one of the most commonly used methods for reliability analysis along with Failure Modes and Effects Analysis (FMEA) [1] which supplement each other. FTA approach aims to quantify the reliability and availability of a complex system, in our case the Wind Turbine. The latter information provide useful data to engineers and end-users for maintenance planning reducing O&M costs and finally leading to lower energy production costs. It is considered that wind turbines follow the bathtub curve illustrated in Fig. 3 which best describes the failure rates of a WT during its operational life considered between 20 to 25 years. At the first period, about 2 to 3 years of operation, it is clear that a high failure rate is presented which also is known as period of early failures. During the next period of useful life, there is a drop to the failure rates until the period of wearout comes after about 20 years of operation and the failure rates are starting increasing again, indicating the end of operational life of the WT.

II. SYSTEM CHARACTERISTICS AND FAILURES

The system analyzed in the current study is the WT. In Fig.4 a typical horizontal axis WT and its subsystems are illustrated. The main subsystems of a WT are:

A. Rotor
   - Blades
   - Hub
   - Nose cone/spinner
   - Pitch regulation systems

B. Nacelle
   - Drive train
   - Couplings
   - Mechanical brake
   - Generator
   - Nacelle support frame
   - Nacelle cover/enclosure
   - Yaw systems

C. Tower

D. Foundation

E. Electrical and Control System
   - Sensors
   - Actuators
   - Hardware/software

F. Hydraulic System

These subsystems together with failure data are further examined from the reliability point of view. The current Reliability Analysis and Data Failure Analysis regards a wind farm which consists of 10 horizontal axis wind turbines, located in a Greek island.

During the studied period, failures among all the subsystems took place with different failure rates and severities of failures. Some failures demanded the temporary shut down of the wind turbine for hours or even days. Such factors were not considered in the particular research, since our purpose is to propose a methodology for applying FTA using failure data of maintenance sheets which were provided by the personal record of the wind farm owner. During the development of the complete Fault Tree of the WT it was concluded that the main mechanisms that occur often and cause failures are the Corrosion, Mechanical overloads, Vibrations and Exposure to climatic extremes. According to a previous reliability analysis using the FMEA method [1] the above causes appear to be among the top 10 root causes. Table I shows the number of recorded failures that occurred during the 7.5-year studied period in all of the subsystems of the ten installed WTs of the wind farm. In Table II the failure rates from the subsystems were computed taking under
consideration the examined period and the number of the WTs. From Tables I and II it is clear that the most crucial and important subsystems of the wind turbines of our studied wind farm are the Electrical and Control Systems and the Hydraulic System. The Gearbox is also considered to be a crucial wind turbine subsystem from Tables I and II, but it was not further analyzed with the proposed methodology since the wind farm owner did not provide detailed data for gearbox failures. So, the failure data from the gearbox failures were not able to be included in the proposed methodology.

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Number of failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gearbox</td>
<td>105</td>
</tr>
<tr>
<td>Brake system</td>
<td>8</td>
</tr>
<tr>
<td>Hydraulic System</td>
<td>97</td>
</tr>
<tr>
<td>Generator</td>
<td>42</td>
</tr>
<tr>
<td>Yaw System</td>
<td>44</td>
</tr>
<tr>
<td>Rotor</td>
<td>19</td>
</tr>
<tr>
<td>Electrical &amp; Control Systems</td>
<td>184</td>
</tr>
</tbody>
</table>

TABLE II. SUBSYSTEMS FAILURE RATES

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Failure rate, $\lambda(t)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gearbox</td>
<td>1.4</td>
</tr>
<tr>
<td>Brake System</td>
<td>0.1</td>
</tr>
<tr>
<td>Hydraulic System</td>
<td>1.3</td>
</tr>
<tr>
<td>Generator</td>
<td>0.6</td>
</tr>
<tr>
<td>Yaw System</td>
<td>0.6</td>
</tr>
<tr>
<td>Rotor</td>
<td>0.3</td>
</tr>
<tr>
<td>Electrical &amp; Control Systems</td>
<td>2.5</td>
</tr>
</tbody>
</table>

III. RELIABILITY ANALYSIS

Reliability, Availability and Maintainability and (RAM) are the most important factors that affect both the design and the life cycle of a machine, product or a system [9]. In order to perform reliability analysis using the Fault Tree Analysis approach of a system we need to have adequate data in order to construct its fault tree. At a prime stage the Tree will be more qualitative, determining the main events after analyzing the maintenance report sheets and deciding which gates should be used and defining main events interconnections. In the proposed study we used as failure data the times that each particular event (in hours) took place, having as a reference date the time that the farm owner started operating the farm. In our case this is the 1st of January 2005. In the next stage these failures were grouped into main events of the fault tree. After deciding which failure corresponds to each event, appropriate Weibull sets were developed using the Isograph Reliability Workbench [6] in order to estimate the Weibull set parameters which comply with each main event. The Weibull distribution is quite often used in reliability analysis applications rather than other distributions because it has the advantage to adapt its form depending on the samples values. So we can have as a result a variety of distribution shapes.

The 2-parameter Weibull distribution [6] probability density function as well as some reliability indicators in their mathematical form is described in eq. (1) to (4):

$$f(t) = \frac{\beta t^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^\beta}}{\eta^\beta}$$  \hspace{1cm} (1)

Where:
- $\eta$: characteristic life parameter
- $\beta$: shape parameter

Unreliability:

$$F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^\beta}$$  \hspace{1cm} (2)

Failure rate:

$$r(t) = \frac{\beta t^{\beta-1}}{\eta^\beta}$$  \hspace{1cm} (3)

Mean Time To Failure (MTTF):

$$MTTF = \eta \Gamma \left(\frac{1 + \beta}{\beta}\right)$$  \hspace{1cm} (4)

Where:
- $\Gamma =$Gamma function

Availability:

$$A = \frac{\text{uptime}}{\text{uptime} + \text{downtime}}$$  \hspace{1cm} (5)

Isograph Reliability Workbench receives as inputs the failure times in hours for each main event and then estimates
the parameters to form a unique distribution for each main event of our fault tree. Due to some inadequate data, to obtain more accurate parameter estimation and a whole perspective of the failures of the wind farm, the Weibull sets for each main event formed from failure data regarding the whole wind farm and not each wind turbine separately.

In the next stage, the Weibull sets with their parameters are linked with their corresponding Failure Model which indicates a specific main event in the Fault Tree. Due to the lack of information regarding the whole system and to make a simpler analysis approach, the Fault Trees of the Wind Turbine’s Subsystems were constructed under the assumption that all gates are type ‘OR’.

The fault tree of a Wind Turbine with its main subsystem as illustrated in Fig. 5 includes the following branches:

A. Foundation

![Fault tree of a WT with its basic subsystems](image)

B. Tower

C. Nacelle

D. Hydraulic System

E. Rotor(Blades & Hub)

F. Electrical & Control Systems

Fig. 6-9 illustrates the Fault Trees of the Electrical and Control System combined, the Electrical System, the Control System and the Hydraulic System, respectively.

Tables from III to VI present the analysis results for each discussed sub-system. Due to the lack of sufficient data, only certain reliability indicators are presented in the current study. In the reliability analysis is included the Availability, the Frequency of failures, the Reliability and the Mean Time To Failure among all components of the subsystems in hourly scale.
Fig. 7. Electrical System Fault Tree

Fig. 8. Control System Fault Tree
Along with the reliability analysis it is useful to present the importance analysis of each component of each sub-system. Importance measures establish the significance for all the events in the Fault Tree in terms of their contributions to the top event probability. Both intermediate events (gate events) as well as basic events can be prioritized according to their importance [8]. The importance analysis is based on three basic Fault Tree Importance measures which include the Fussell-Vesely (FV) Importance, the Risk Achievement Worth (RAW) and the Risk Reduction Worth (RRW) [8]. The Fussell-Vesely importance indicates the relative contribution to the system failure probability from a component failure. Increasing the availability of components with high important values will have the most significant effect on system availability, consequence frequency or risk. The Risk Achievement Worth indicator represents the worth of the component associated with the Fault Tree event in achieving the present level of risk and indicates the importance of maintaining the present level of reliability for the component. The Risk Reduction Worth importance represents the maximum reduction in risk for an improvement to the component associated with the Fault Tree event.

Table VII summarizes the Electrical and Control Systems importance into one system, considering the Electrical System as one component and the Control System as the other. Table VII confirms that in the Electrical and Control System, the Electrical system has a more important role and is more critical than Control System. According to Table VIII, the more important components into the Electrical System include Power feeder cables and the Lightning protection system. According to Table IX, the most important component in the Control System, indicating a very high rate, appears to be the Controller. Table X regards the Hydraulic System and
indicates Pipings as the most important component of the system.

**TABLE VII. ELECTRICAL & CONTROL SYSTEM IMPORTANCE**

<table>
<thead>
<tr>
<th>Components</th>
<th>Fussell-Vesely</th>
<th>Risk Achievement Worth</th>
<th>Risk Reduction Worth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical System</td>
<td>0.6024</td>
<td>53.04</td>
<td>2.515</td>
</tr>
<tr>
<td>Control System</td>
<td>0.3976</td>
<td>53.25</td>
<td>1.66</td>
</tr>
</tbody>
</table>

**TABLE VIII. ELECTRICAL SYSTEM IMPORTANCE**

<table>
<thead>
<tr>
<th>Components</th>
<th>Fussell-Vesely</th>
<th>Risk Achievement Worth</th>
<th>Risk Reduction Worth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power feeder cables</td>
<td>0.8356</td>
<td>87.41</td>
<td>6.081</td>
</tr>
<tr>
<td>Lightning protection system</td>
<td>0.1580</td>
<td>88.08</td>
<td>1.188</td>
</tr>
<tr>
<td>Electrical protection system</td>
<td>0.0039</td>
<td>88.24</td>
<td>1.004</td>
</tr>
<tr>
<td>Capacitor box</td>
<td>0.0013</td>
<td>88.24</td>
<td>1.001</td>
</tr>
<tr>
<td>Converter</td>
<td>0.0011</td>
<td>88.24</td>
<td>1.001</td>
</tr>
<tr>
<td>Transformer</td>
<td>0.0001</td>
<td>88.24</td>
<td>1</td>
</tr>
</tbody>
</table>

**TABLE IX. CONTROL SYSTEM IMPORTANCE**

<table>
<thead>
<tr>
<th>Components</th>
<th>Fussell-Vesely</th>
<th>Risk Achievement Worth</th>
<th>Risk Reduction Worth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controller</td>
<td>0.9329</td>
<td>132.4</td>
<td>14.91</td>
</tr>
<tr>
<td>Meteorological station</td>
<td>0.0600</td>
<td>133.3</td>
<td>1.064</td>
</tr>
<tr>
<td>Switches</td>
<td>0.0053</td>
<td>133.3</td>
<td>1.005</td>
</tr>
<tr>
<td>UPS</td>
<td>0.0017</td>
<td>133.3</td>
<td>1.002</td>
</tr>
<tr>
<td>Sensors</td>
<td>0.0007</td>
<td>133.3</td>
<td>1</td>
</tr>
<tr>
<td>Signal cables</td>
<td>0.0005</td>
<td>133.3</td>
<td>1</td>
</tr>
</tbody>
</table>

**TABLE X. HYDRAULIC SYSTEM IMPORTANCE**

<table>
<thead>
<tr>
<th>Components</th>
<th>Risk Achievement Worth</th>
<th>Risk Reduction Worth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipings</td>
<td>0.8458</td>
<td>232</td>
</tr>
<tr>
<td>Oil pump, motor &amp; tank</td>
<td>0.1334</td>
<td>232.7</td>
</tr>
<tr>
<td>Hydraulic oil</td>
<td>0.0208</td>
<td>232.8</td>
</tr>
<tr>
<td>Rotating union</td>
<td>0.0001</td>
<td>232.9</td>
</tr>
<tr>
<td>Accumulator</td>
<td>0.0001</td>
<td>232.9</td>
</tr>
<tr>
<td>Centrifugal release unit</td>
<td>0</td>
<td>232.9</td>
</tr>
<tr>
<td>Actuators</td>
<td>0</td>
<td>232.9</td>
</tr>
</tbody>
</table>

1. CONCLUSIONS AND FURTHER RESEARCH

Performing a reliability analysis through FTA approach a sufficient amount of data is needed, along with information from maintenance sheets and diagrams indicating connections between all components of the systems. The reliability and importance results, as derived from a quantitative analysis, seem to be following the same trend like previous studies from different and various approaches [5]. Electrical and Control systems as far as the Hydraulic System need to be re-designed to demonstrate better performance and reliability, being crucial to the operation of the WTs and the total efficiency of the wind farm. Many failures appear to be of minor consideration, but when it comes to measure the reliability of the systems involved them, their importance seems to affect it. When more failure data are available from other subsystems, a relative research could illustrate a more holistic view of the reliability of a WT. The full fault tree of the studied WT is available from the authors upon request.

As an expansion from the current study, a sensitivity analysis on the parameter estimation of the Weibull sets using Monte Carlo simulations would indicate the variation of each system’s reliability. Drawing directions for better maintenance planning and promote new and more reliable WT designs achieve high rates of reliability and availability, reduce failure rates of subsystems and components and improve the reliability of a whole wind farm.

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