Terology Beyond Tomorrow

Maintenance activity corresponds to a scientific area that has been under enormous development since the time of non-planned interventions; this stretches from the beginning of the industrial revolution until today and includes the concepts of RCM, Terotechnology, TPM, LEAN or Terology. The first author of this article introduced the latter of these concepts, which approaches a detailed view of the life cycle of equipment.

José Torres Farinha
tfarinha@isec.pt
Portugal
with Inácio Fonseca, António Simões, Alberto Costa, Pedro Bastos, Fernando Maciel Barbosa, Luís Andrade Ferreira and Amparo Carvas

The article tries to anticipate the above-mentioned horizon. The authors of this article have know-how in several maintenance areas. These areas are information systems for maintenance, on-condition maintenance in wind farms with online data acquisition, on-condition maintenance of Diesel engines based on the level of effluents, and fault diagnosis supported by Case Based Reasoning Systems and Fuzzy Logic.

Another important viewpoint is the integration of technologies, such as 3D models to aid fault diagnosis, training of technicians, upgrades and new developments of the equipment, and remote maintenance through the use of robots.

The maintenance field is possibly one of the most heterogeneous knowledge areas in the world. This can be verified by the experience of each professional in its organization. Usually, this is translated by the evolution of the career of each professional, being in the industrial field or in the academic field.

The article will show some well validated technologies that are in use today and some that will have practical results only in the next few years.

The Evolution of the Maintenance Concepts

The term "maintenance" has its remote origin in military vocabulary with the sense of "maintaining the combat units, the persons and the materials at a constant level". It was only about 70 years ago that companies began to recognize the importance of the maintenance of equipment as a specific and autonomous function.

The expansion of commercial aviation, starting from the 1940's, brought new challenges to the maintenance sector. Since the repair of faults during flight is rarely possible it was forced to develop preventative methods of maintenance, whilst simultaneously highlighting personnel safety.

In the 1970's an enlarged concept of maintenance appeared in Europe designated by Terotechnology (from the Greek word "teros" meaning "to take care of"). At the same time the Japanese notion of Total Productive Maintenance (TPM) appeared, which is based on five points: to maximize the effectiveness of the assets; to establish a global system of productive maintenance that covers the cycle of life of the assets; to obtain the involvement of all departments; to obtain the participation of all the members; to reinforce the personnel's motivation.

The concept of Reliability Centred Maintenance (RCM) assumed a new paradigm in the maintenance activity. This corresponds to an approach of the industrial manage-

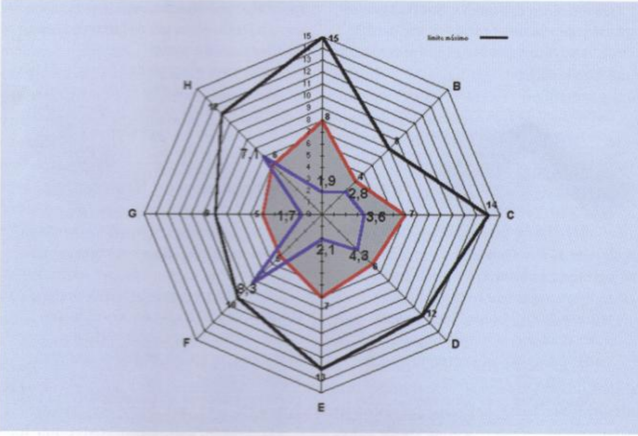

FIGURE 1. *Graph Radar.*

TABLE 1. *SMIT modules.*

MODULE	COMMENT
The Maintenance Objects (MO) Module	Allows characterization of the facilities and equipment, namely technical, economical and reliability data.
The Work Orders (WO) Module	Allows each intervention to be managed, planned or non-planned through a WO. This, when closed, spreads data over several modules.
The Suppliers Module	Intervenes since the insertion of MO data and is updated with data from WO, namely economical data.
The Technicians Module	Manages the internal and external technicians and is related to WO and planning modules.
The Tools Module	Namely the special tools; very important in certain interventions - this module manages this item, which interacts with planned and non-planned maintenance. Each maintenance intervention, planned and non-planned, uses Spare Parts that have a certain cost - this module manages this item, including ordering.
The Intervention Requests Module	Is used when there is a fault and, by consequence, it is necessary to open a WO.
The Fault Diagnosis Module	This is completed through the register of non-planned interventions. It helps this kind of maintenance, minimizing intervention time.
The Maintenance Plans Module	A module where the interventions are planned including the resources necessary for them.
The Withdrawal Module	Allows evaluation of the correct time to either replace or renew the MO, and completes the SMIT management cycle.

TABLE 2. *Eight components of maintenance audit.*

STEP	ACTIVITY
1	Maintenance Objects Management
2	Planned Maintenance (systematic)
3	On-condition environmental maintenance
4	Stocks and Spare Parts Management
5	RAMS Analysis (Reliability, Availability, Maintainability, Security)
6	Environmental Certifications
7	Life Cycle Environmental Analysis
8	Recycling and ecologic materials

ment, which is focused on the identification and establishment of politics of maintenance improvement and of the capital investments, with the objective to manage the risks of the faults more efficiently. This concept is defined by the technical standard SAE JA1011, "Criteria of Evaluation for RCM Processes".

Another recent concept that links with the previous ones is the Lean Maintenance concept (LM) that relates to the concept of TPM. Lean Maintenance can be defined as being the accomplishment of the activities planned and programmed proactively. In other words, using strategies developed through the correct application of RCM, of the 5´S, of the fault analysis FMECA, of Continuous Monitoring (predictive maintenance) and of the Computerised Systems of management.

Another concept is Risk Based Maintenance (RBM) that is based on the five key elements of the process of risk management (Risk Management Process, RMP), which are: identification, measurement, tax, estimation, and control and monitoring.

Information Systems for Maintenance

The complexity and diversity of asset management was strongly simplified with the introduction of information systems for maintenance. There are many programmes for maintenance management around the world, which can be easily found on the Internet.

The first author developed his first system at the beginning of the 1990's and formally introduced the concept of terology in 1994 (Terology is defined as the combined utilization of operational research techniques, information management and engineering, with the objective of accompanying the life cycle of facilities and equipment. Terology includes the definition of specifications of purchase, installation and reception, and also the management and control of maintenance, modification and replacement of facilities and equipment and their accompanying in service.), and in the same way the concept of the architecture of the system.

The system, called SMIT (Modular Integrated System for Terology), involves modules that start with the characterisation of the facilities and equipment and ends with the withdrawal of them, and has the following modules: Maintenance Objects (MO); Work Orders (WO); Suppliers; Technicians; Tools; Spare Parts; Intervention Requests; Fault Diagnosis; Maintenance Plans; Withdrawal. The interrelation among the SMIT modules is in **TABLE 1**.

SMIT manages complete aspects of the terology in the organization. One of its major advantages is modularity, which permits easy addition of the new modules and new features in complete dialogue with the existing modules. New developments are also going on in SMIT, in order to make it closer to the assets reality. This is the case with Maintenance Objects decomposition where the commercial traditional method is a hierarchical structure; the SMIT proposes a matrix structure which, obviously, also incorporates the original structure. With this new approach each organisation can decompose the assets as they are in reality.

A New Paradigm for Maintenance Organization

The restructuring of maintenance is based on the audit of the quality of the maintenance management. To be able to perform it there is a need for the structured methodology that will allow this. The authors are also concerned about environmental issues and therefore, the audit method that is proposed here is based on the eight components shown in **TABLE 2**.

The practical way to implement the auditing method is through a questionnaire with several questions. The result is usually translated to a Radar Graph with the objective of making it easier to understand the status of maintenance and the deviations from the standard.

The eight points of the radar graph, see **FIGURE 1**, represent the eight maintenance components covered by the enquiries. The grey area represents the minimum value that each component should obtain. As can be seen in the figure, only two components are acceptable in the organization.

The example contains eight components but, obviously, the analysis can be made with any number of components, according to the requirements. The initial problem is to adapt the model. One way to implement this method is by using a common worksheet designed for the present purpose.

On-line Predictive Maintenance

On-condition maintenance can be applied using some dozens of variables and techniques. However it is still an open field for new techniques and developments. This is what the team that has authored this paper has been doing. At the moment the focus is on the development of the wind farms and Diesel engines.

CASE 1: WIND FARMS

A wind turbine is a complex system that has several moving components. It is affected by strong forces and may have several problems such as vibrations, electrical failures and many other types of faults.

Additionally, wind farms are usually far from cities and from the companies that support their maintenance. Technical assistance is expensive and the combination of on-condition maintenance with the best practices of operational research to minimize distance costs are extremely important.

The main objective of the team is to implement a maintenance plan using on-condition maintenance through on-line instrumentation, acoustic techniques, vibration techniques, infrared images, stress measurement, zero crossing current analysis and artificial intelligence in a coherent and synergetic way. In FIGURE 2 there is an example of vibration spectrum using Fast Fourier Transform (FFT) from a motor data.

SMIT system is able to acquire wind speed, axis rotation, active and reactive power and vibration signals. The techniques used to monitor and predict the condition of the wind system include:

- Vibration monitoring on generator and gearbox
- Measurement of wind speed using an analogue anemometer and an ultrasonic anemometer
- Active power measurement
- Classification using artificial intelligence
- Time series analysis using regression techniques
- Weather monitoring

The data is acquired and transmitted on-line. The transmission of the data can be done through commercial networks using HSDPA or for offshore applications by satellite.

CASE 2: DIESEL ENGINES

As mentioned earlier environmental perspective is an important part of the culture of the team. In the case of Diesel engines, the best solution would be to eliminate this type of engines. Since the economy is supported by petroleum it is not possible to change things overnight, the objective must be achieved step by step.

Some pollutants and other emissions are regulated by international standards. FIGURE 3 shows the development of the restrictions of the pollutants emissions of Diesel engines from EURO I to EURO V.

The maintenance management methodology adopted for Diesel engines is an on-condition model based on a prediction that uses a Hidden Markov Model (HMM). It is a statistical model in which the system being modelled is assumed to be a Markov process with unknown parameters. The challenge is to determine the hidden parameters from the observable data that, in this case, are the consecutive registrations of effluents from Diesel engines.

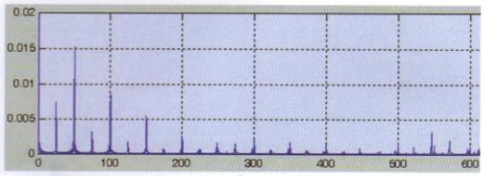

Figure 2. Example of vibration spectrum.

The measurements are made through the Diesel engine exhaust system and also through control system that includes, among others, air mass meter, air temperature sensor, air pressure sensor, water temperature sensor, crankshaft position sensor and camshaft sensor. The prediction model follows the evolution of the variables according to FIGURE 4.

The evolution of this system intends to use the technology developed for the on-line reading of data used for wind farms and has the objective to detect the pollutants emitted by the engine of a vehicle passes. This is done when the vehicle passes through

FASE	DATE	TEST	CO (g/kWh)	HC* (g/kWh)	NO_x (g/kWh)	CO (g/kWh)	OPACITY (m^{-1})
EURO I	1992 < 85 kW	ECE R-49	4.5	1.1	8.0	0.612	
	1992 > 85 kW		4.5	1.1	8.0	0.36	
EURO II	Oct. 1996		4.0	1.1	7.0	0.25	
	Oct. 1998		4.0	1.1	7.0	0.15	
EURO III	Oct. 1999 Only EEVs	ECS e ELR	1.5	0.25	2.0	0.02	0.15
	Oct. 2000	ECS e ELR	2.1	0.66	5.0	0.10 0.13**	0.8
EURO IV	Oct. 2005		1.5	0.46	3.5	0.02	0.5
EURO V	Oct. 2005		1.5	0.46	2.0	0.02	0.5

Figure 3. EU Norms for emissions of vehicles powered by Diesel engines.

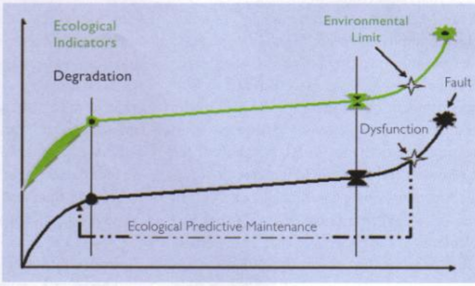

FIGURE 4. *Prediction of the next intervention.*

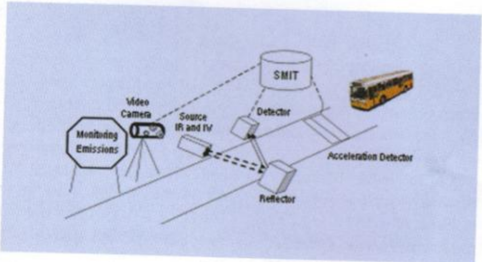

FIGURE 5. *Layout example of emission monitoring.*

the beam of a calibrated instrument on the road; this seems to be an efficient method for determining the tailpipe emissions from passing vehicles.

An infrared light source containing at least two different frequency regions is shone across the road to a detector. When a vehicle goes by, its exhaust gasses traverse the optical path of the laser light causing some absorption, which is detected and recorded. The analysis of the relative absorption permits the quantification of a ratio of two gases, such as NO/CO_2, which is the primary result of the technique, FIGURE 5.

Integration of International Standards

There are several management methods such as Quality, Safety, Environment, Energy and Maintenance management. However, there is a lack of integration between them.

There is a new methodology that is being developed by the team which is based on the standards of different areas: quality management ISO 9001, safety OHSA 18001/BS 8800, environmental ISO 14001, energy EN 16001 and maintenance EN 13000 series. This new management model will allow organizations to define concerted planning strategies aiming towards better asset performance.

Ultimately, the management system will include the social accountability based on SA 8000 standard, a main unifying feature for economic activity value. It is applied in the way that the competitiveness of organizations also depends on the public view of their social awareness.

The approach also includes a cost-benefit analysis of this new view over management and economics. This will point a new code of ethics carried out by companies with a vision over a new social and environment perspective as a leverage for a "sustainable business as usual". This unifying methodology for production management will allow organizations to improve their competitiveness and add value in three areas: economical, environmental and social.

The logistics, supply chain and the LCM (Life Cycle Management) are also playing a major role in this new integrated management system. One of the outcomes of this approach is the Sustainable Production Level (SPL) as a performance indicator for companies, customers and suppliers.

Integrating Technologies

All developments performed by the team are supported and enriched by SMIT. The hardware and software solutions require complex integration and communication among the several pieces of this complex "puzzle". FIGURE 6 shows a real configuration that integrates several pieces of terology. The simplicity, user friendliness, and low cost of the overall system has been a guideline from the beginning.

The recent developments of SMIT include:

a) Wireless communication to IP devices to receive measurements from any module, Wind Generators and Diesel engines to mention but a few
b) On-condition modules to predict planned interventions based on variables that are regularly measured either remotely, by physical connection or by being read by personnel on-site.

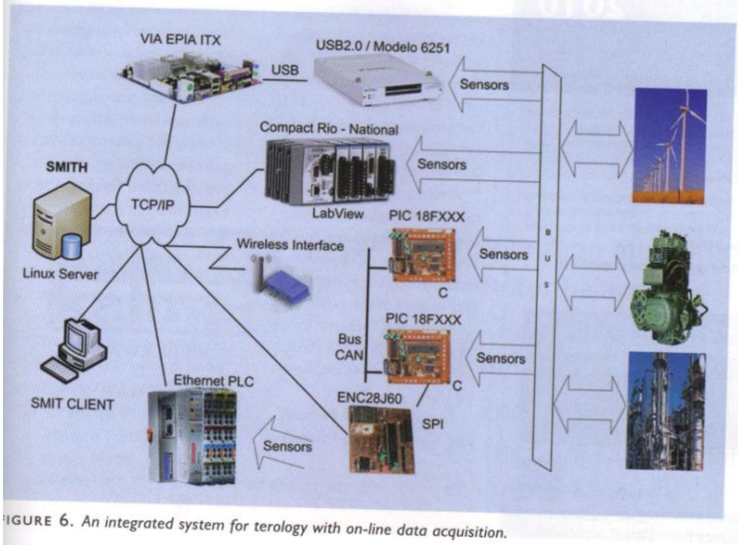

FIGURE 6. *An integrated system for terology with on-line data acquisition.*

Conclusion

The paper presents the state-of-the-art of the development made by the authors throughout the last year of their research and professional experience, and points new ways for the future.

All the developments are supported by an information system called SMIT. The new hardware and software solutions require complex integration and communication among the several pieces of these complex technological devices, but are presented to the final user as a friendly solution.

The implementations presented in the article were performed taking into account two main fields, wind farms and Diesel engines. The combination of low-cost hardware, open-source software with time series and genetic algorithms gives a complete approach not only for these fields but also for many others industrial ones.

In any situation where distance or the requirement of on-line and on-condition maintenance of equipment can engender difficulties in establishing connections to a fixed installation, the developments presented can be used to solve these types of problem trough TCP/IP communication.

3D collaborative manipulation can also be supported by these tools. This may open a new door for the future of fault diagnosis, maintenance planning and training: It is possible to conjugate it with the remote control of robots, in order to design the future maintenance interventions through virtual reality, lowering costs and increasing safety. ■

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»**WHO** is José Manuel Torres Farinha?

José is Licentiate in Electrical Engineering by Coimbra University and PhD in Mechanical Engineering by Oporto University. He is a Senior Member and Specialist in Industrial Maintenance by "Ordem dos Engenheiros", that is the Association that represents the long-cycle theoretically scientific studies in-depth in Portugal (CLAIU member).

He is Coordinator Professor at Engineering School of Coimbra and a member of the Mechanical Engineering Centre of Coimbra University – CEMUC since 1994. He began his professional career in the area of hospital maintenance, namely in hospitals in Central Portugal. Additionally he collaborates in national technical studies in the maintenance area.

The main research of Jose Manuel Torres Farinha is in the field of Maintenance Management but through an enlarged view called Terology that is supported by a maintenance information system, that includes fault diagnosis, and on condition maintenance, with emphasis in an ecological approach. He has written a book, chapters of books and has many papers published in national and international journals and conferences. More information at (www.torresfarinha.com).

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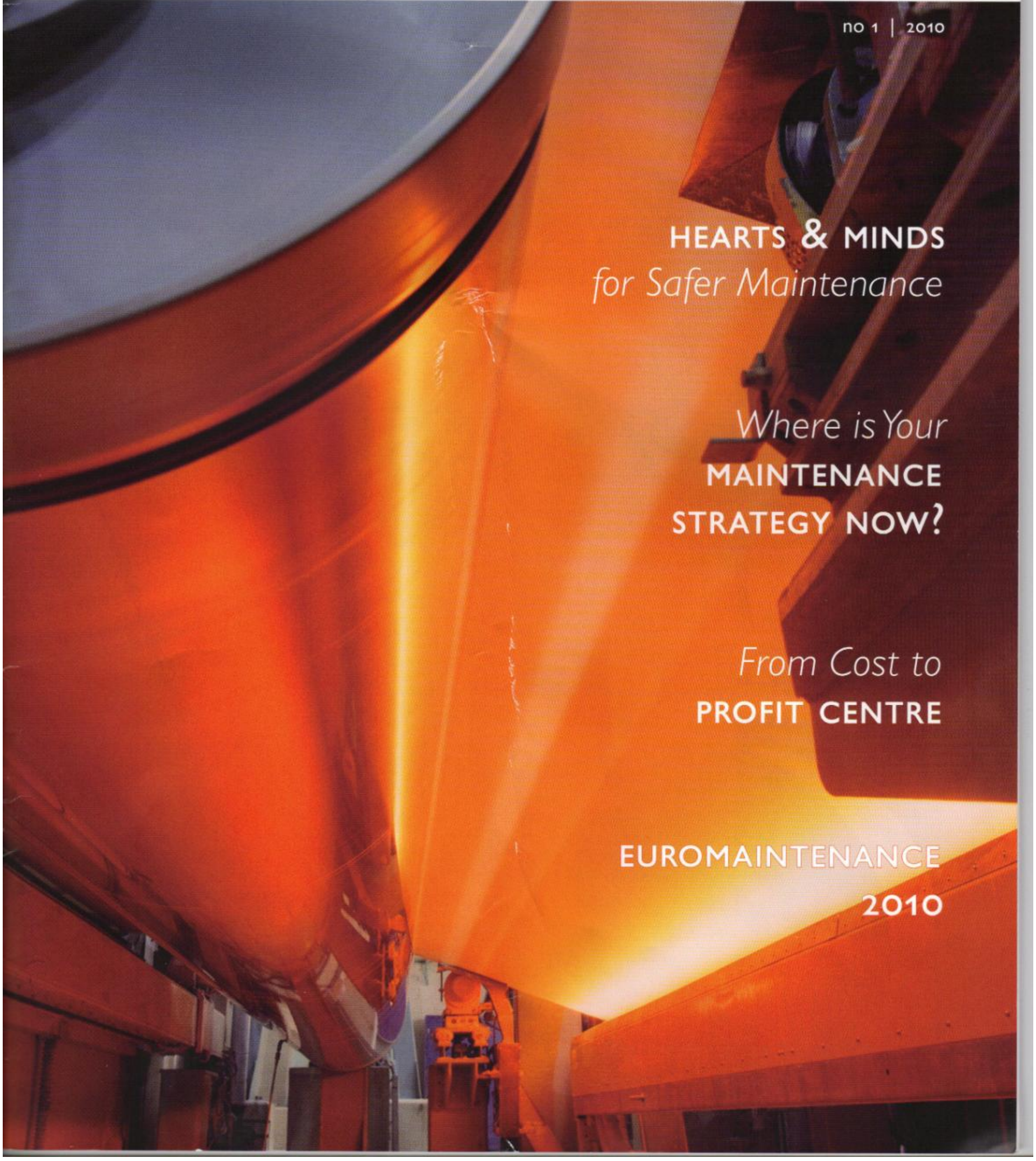
no 1 | 2010



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