A Maintenance Software System for Healthcare Facilities

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Abstract

The maintenance software allows the recording and management of several processes involved in the maintenance operations of any company. It provides detailed information about maintenance of equipments, facilities, resources, spare parts and so on. A useful approach for a modern maintenance is the ability to integrate on condition maintenance modules. In the future, with the rapid development of wireless technology, like zigbee, bluetooth, wi-fi, we ought to expect a common healthcare tool to perform automatic diagnosis and report as well remote managing including for calibration of equipments. This approach could be achieved through monitoring the most important variables, like temperature, number of working hours of equipment or any other acting parameter.

The developed platform presented in this article, SMITH (Healthcare Terology Integrated Modular System for Hospital) uses open source software as the base technology, like the operating system, Linux, and the database system, PostgreSQL. It uses a client-server approach, using IDE windows technology, made in Delphi and web based access through php/apache. SMITH is a tool that integrates the main modules of a strong maintenance management system. The SMITH is exploited by users with group privileges like: administration, maintenance, stocks, working maintenance technicians, quality department, production department and end users. In each access, users have different features associated with the group they belong. Some of these can use the Gantt module to graphically plan/see work orders, interventions, plans, etc.

For on-condition monitoring (CM module), SMITH includes features for time series analysis using regression methods, support vector regression, and ARIMA models. The CM module can forecast time series to predict when the monitored variables reach some critical point and, with this information it gives an alert that the limit is closer. The SMITH can receive data using different methods to acquire the critical information from the equipment. The main methodology monitors critical variables using Simple Network Management Protocol, with an Ehternet hardware designed especially for easy sensor data acquisition integration, built with adaptive low-pass filters and adaptive amplifiers/attenuators, however the system can integrate any acquisition hardware with tcp/ip connectivity.

With this approach we believe that we are given a real contribution for a new way to manage the maintenance and to increase the reliability of equipment and facilities.

Key-words: Maintenance; renewable energies; environmental protection; terology.

1. Introduction

The Hospital maintenance department is a crucial element to a high quality healthcare facility. The excellent functioning or, by other words, the maximum reliability of facilities and equipment is a main rule for this department. The policy that permits such performance must always be based on planned maintenance including predictive maintenance. To be in advance to failures is mandatory. The other goal persuaded, it is to maintain costs as lower as possible. This is a truth for professionals, such doctors, nurses, administrative persons. The facilities and equipment are the background of all this activity.

In this article it will be presented a global perspective of a maintenance system for healthcare facilities, including also renewable energy for a sustained exploration of such facilities, in order to reduce exploration costs and, at the same time, reaching an excellent quality of service.

In the maintenance area, a large number of maintenance software with various levels of complexity is available. The main categories of maintenance software include maintenance management system, asset management software, facilities management and maintenance software, work order tracking software, vehicle maintenance software, and preventative maintenance software.

Work management, preventive and corrective maintenance, inventory and purchase order management, and reporting, are the basic functions of maintenance software. Work management involves the proper scheduling and maintenance of engineering and other operational departments. Most maintenance software allows supervisors to distribute work among employees and technicians. Preventive maintenance refers to

doing proactive maintenance with a view to prevent system problems. Corrective maintenance is performed to correct a problem that occurs within a system when it is working.

Maintenance software allows exact recording of data such as spare parts and other materials used in the production process. A purchasing module is also available as part of most maintenance software. It automatically initiates purchases when a particular item reaches a pre-determined reorder level. Reports generated by maintenance software usually include review of total expenses, equipment replacement reports, budget planning reports, and failure analysis and work history reports for specific equipments.

2. A System for maintenance management

A modern system for maintenance management should have integration of all fundamental information to allow the maintenance personnel to achieve a high performance in the execution of the daily tasks related with this activity. The proposed system (SMIT(H)) includes the integration of software, acquisition of relevant information, and gives alerts for helping maintenance decisions. SMIT(H) [2], [3], [4], [5], [6] is a Client/Server program, multi-database, allowing the installation of several clients and its configuration within the same platform. The program is accessed through the Windows environment.

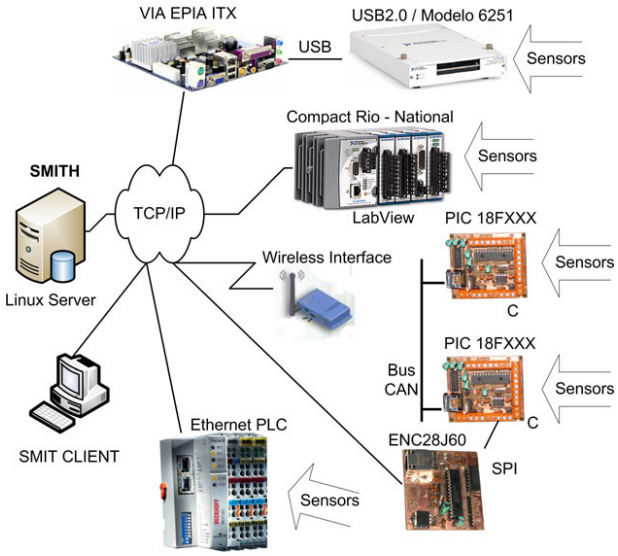

Fig. 1 – Maintenance Management System – SMIT(H) and respective hardware for data acquisition

SMIT(H) allows the optimization of maintenance resources through the following tools:

- Characterization of maintenance objects;
- Suppliers (of equipments, parts and services);
- Human Resources Management;
- Tools Management;
- Stocks and Spare Parts Management;
- Fault Diagnosis;
- Work Orders;
- Planned Maintenance Management (including on-condition maintenance);
- Emission of Reports, Analyses and Improvement Plans.

Fig. 2 – Two perspectives of Gantt Module

SMIT(H) always has the advantage to make the maintenance management easy because it includes the complexity of management in its structure but with a front-end that interacts with the user with the minimum

complexity and minimum of operations and data. SMIT(H) was developed using the scientific knowledge in this area and it is permanently up-to-date.

One of the great advantages of SMIT(H) is the minimum human resources required to work; the use of SMIT(H) could be carried out by a person with basic knowledge of computer science in the user optics.

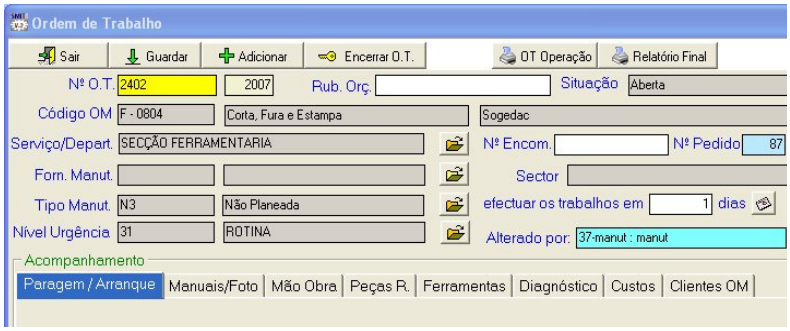

Fig. 3 – Launching a working order in SMIT(H) program

This approach was used because the complexity, quantity of variables and diversity of situations that maintenance implies; they are reduced at a minimum with SMIT(H) as explained below:

- To reduce preparation time and emission of Working Orders (WO);
- To print detailed WO with definition of resources and prediction of time for execution of the maintenance interventions;
- To establish priorities, taking in account the importance of equipment, the urgency of intervention and resources available (human and materials);
- To develop daily intervention plans, management of delays and work load, with the objective to minimize the response time, reply time and down time of the maintenance objects;
- To perform planned maintenance through the analysis of historic data and fault diagnosis;
- To perform detailed preventive inspection plans to fulfill all requirements for a good operation of maintenance objects;
- To manage spare parts, taking into account the adequate quantities adjusted in function of the level of equipment importance, the urgency of the intervention and the response of respective suppliers to supply the spare parts, in order to make possible its provision on time;
- To adjust the priorities of interventions, taking into account the evolution of parameters of duration and functioning among other variables, like reliability parameters;
- To compile the provisional costs for budget analysis, filtered by maintenance object, cost centre, location or others;
- To automatically calculate maintenance indicators allowing the emission of reports for periodic control by the responsible persons;
- To carry out the systematic accompaniment between the prevision and real needs for the resources: time, costs, people and suppliers;
- To perform the inventory management (equipment, parts, tools...) and financial calculation of depreciation of goods;
- To perform the management of spare parts, tools, …, and the indent orders to suppliers;
- To perform a dynamic planning of maintenance, updating automatically the maintenance object plan in function of the evolution of WO carried out.

Fig. 1 represents the SMIT(H) system. The system has client/server architecture. The server is based on Linux [18] and a Desktop/Laptop client for windows environment [17]. The Linux server incorporates the following functionalities: database PostgreSQL [19]; web [21], fax and email server [20]; a TCP/IP server for reception of data acquired from different acquisition points; SNTP/NTP Server; SNMP [31] and ftp server. To dialog with other applications, the system supports insert/update/delete using web services technology and also import/export in csv/xml format. The system is very portable; it can run on Windows/Unix/Linux/Mac OS, if PostgreSQL and PHP are available.

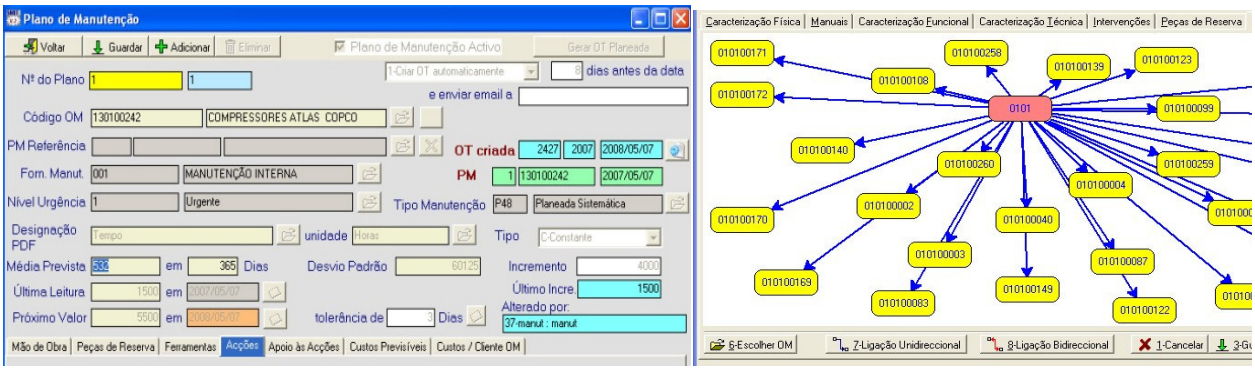

Fig. 4 – Maintenance Plan, and the Relation between MO-Maintenance Objects (matrix relation)

2.1 Integration with hospital equipments

For data acquisition, SMIT(H) can incorporate different equipments with serial link like RS232 or RS485, with TCP/IP connectivity by RJ45 cable or Wi-Fi, and ZigBee networks (some equipment performs self diagnosis, and is capable of sending information through any communication link, as it is usual in some hospital equipment) - ZigBee is a protocol created for wireless sensor networks, especial designed for data acquisition for a long period without power supply. However this or similar protocols can be used in any task related with data acquisition, depending on the sampling rate needed. Normally ZigBee is the protocol indicated for wireless sensors, where a gateway between ZigBee and TCP/IP is considered. Nowadays, many protocols are under development in this area; for example there are wireless sensors “talking” ProfiBus [33], [34].

Additionally, in lack of a self acquisition system on the equipment, SMIT(H) includes hardware for measuring on-line relevant variables like number of working hours, temperature, humidity, whatever using for this task a special connectivity hardware. The following hardware can work on SMIT(H) and any other should be easily integrated with minor changes, like the following:

1. *High Performance hardware*:
   - LabView Software – acquisition boards with special hardware.
2. *Middle Performance hardware*:
   - Ethernet PLCs – acquisition boards with special hardware.
3. *Low Cost hardware*:
   - MicroControllers – Microchip ethernet and CAN solutions;
   - Adaptative Filtering, and signal condition - accepts 10 channels of 100 Khz max sampling.

Some comments about the three past approaches:

1. The first choice is highly recommend for very special conditions where performance is necessary. It uses third party hardware with high performance capability (depends from the model chosen), normally with inclusion of a mini-PC to run labview.
2. The second is recommended for integration on industry and in buildings, where standard environment like OPC and SCADA technology are used and necessary. Usually, this option depends on the structural equipment on buildings, but an air condition system normally used on hospitals should include this technology.
3. The third is the special hardware design, namely from the first author of this paper, for low cost acquisition system, maintaining a good performance. This hardware is developed using Microchip technology, although not being top microcontrollers, they are sufficiently popular and cheap, keeping a good relation cost/performance. We consider that this development reaches two important objectives that are the scientific and commercial, because it adds scientific knowledge and it has a promising potential to be used on day-to-day basis in a near future.

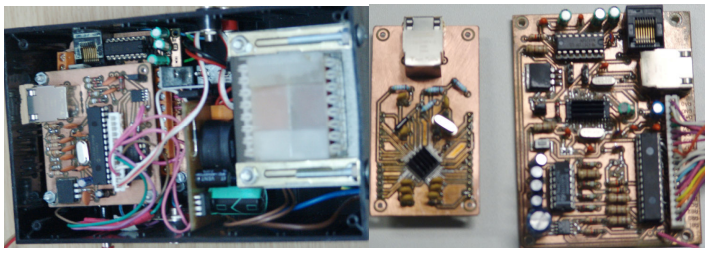

Fig. 5 – Top: PIC18F2685, down right: PIC18F2620, down left: PIC18F67J60

For accomplish the task for low cost hardware, four prototype boards had been tested:

- PIC18F2685 + ENC28J60 (Ethernet and CAN);
- DSPIC18F4310 + ENC28J60 (Ethernet and CAN, for high sampling rate);
- PIC18F2620 + ENC28J60 (Ethernet only);
- PIC18F67J60 – Ethernet only.

For adaptative filtering and signal condition, a board has been also assembled, allowing the user to setup the gain and the cut-off frequency of a low pass Butterworth filter.

The system accepts 5 channels of 100 KHz (shared) max sampling (PIC18), and 5 channels of 1 MHz (shared) max sampling (DSPIC).

To upload the software (firmware) remotely from the SMIT(H) Linux Server into the PICs, a special boot loader was programmed. The Client for upload the new firmware that can run under Windows or Linux.

The bootloader can download firmware to any node (including CAN and Ethernet), using an Ethernet node as gateway. The bootloader uses an encryption algorithm for transmission (based on a 87 bytes key). The main characteristics of this hardware are the low cost and the possibility for RTC (Real Time Clock) synchronization. The RTC synchronization through IP network can be achieved using SNTP (Simple Network Time Protocol), NTP (Network Time Protocol), IEEE 1588 PTP (Precision Time Protocol) and SynUTC, among others.

To manage the RTC synchronization between 10ns intervals, special hardware is necessary for timestamp packets at the moment it is received. For this high demanding task, the timestamp is performed in hardware (the chip receiving Ethernet packets, should save the timestamp), and National Semiconductor released the DP83640 chip during the first months of 2008, supporting the 1588 PTP protocol. The IEEE 1588 can also be used only in software implementation, which can achieve good performance. In this implementation, the SNTP has been used to synchronize Ethernet boards and the other modules using the CAN network.

3. Renewable energies in Hospitals

The energy and water will be the gold of the future. Renewable energies are one of the most important resources to replace energy based on fossil resources. Photovoltaic, wind energy, thermal energy, thermo-dynamic solar panels, etc, they assume an important aspect and, obviously, its maintenance.

It is possible to acquire commercial devices at competitive prices, to install at several places, to generate energy that can help to eliminate the dependence from an external supplier or, in case of hospitals, can reduce significantly that dependence.

It is possible to install wind generators that are not, necessarily, the towers that we can see, each time more frequently, at horizon. These generators are necessary because their high capacity to generate energy, but it is also possible to generate large amounts of energy trough mini wind generators. Fig. 6 shows an example of a large building with several generators on its roof. May be it will arise a new kind of architecture with these new challenges.

Fig. 6 – Example of Mini wind generators placed on a big building

This is because of these new questions and, in particular, the maintenance problems that wind generators, in particular, places to researchers and technicians, namely because its complex mechanical problems or, more exactly, electromechanical questions, that our team took these equipment as a target for a new approach for planned maintenance or, more exactly, for on-condition maintenance.

3.1 SMIT(H) – Maintenance of wind generators

Wind turbines maintenance uses many techniques similar to the other maintenance objects. In this field many authors [9], [10], [11], [12] are working using acoustic techniques, vibration techniques, infrared images, stress measurement, zero crossing current analysis, artificial intelligence, only to name a few. The main objective of this project is to perform the fault detection through on-line data instrumentation, using a mix of those

techniques, aided by algorithms of prediction based on time-series adapted for this ambit. The techniques used for monitoring the wind systems condition are based in the following aspects:

- Vibration monitoring on generator and gearbox;
- Measuring the wind speed, using an analogue anemometer (inexpensive) and a ultrasonic anemometer WMT50 from Vaisala Company (for geographic signature of normal wind behavior);
- Active power measurement;
- Weather forecast using information from weather sites, tracking the wind velocity (using time series analysis);
- Classification using artificial intelligence;
- Time series analysis using regression techniques;
- Using a weather monitoring station (future development).

The whole fault detection system is built around MATLAB Software routines for spectral analysis of current and vibration to extract essential information from the sampled time domain data, time series regression and artificial intelligent classification.

3.1.1 Algorithms for maintenance of Wind Generators

Our approach uses combined techniques of acoustic techniques, vibration techniques, infrared images, stress measurement, zero crossing current analysis, artificial intelligence, among others, as it was referred above. The value-added that we introduce, until this moment, is what is described in the following algorithms:

1. The first algorithm uses an accelerometer to monitor vibrations on the gearbox and in the generator where the line currents are also monitored. To identify faults, two assays were performed. The first, an induction motor was used as motor and the second one as generator. In the first test, four induction motors were used, one healthy and three motors with some kind of damage provoked, like broken bars. The motors were tested with full load, half load and without any load. The same test was performed using now the motor as generator, and introducing loads. The acquisition was performed with a National Company USB 2.0 – Model 6251, the accelerometer Monitron MTN/1100CQ, a MTN/1100C and current sensors SEFRAM, model “SP 261”.
2. The second step in this study was to monitor the wind speed. To accomplish this task a WMT50 from Vaisala [15] was used. This sensor uses ultrasonic technology to measure the wind speed and direction and can be used for precise measurements, and for geographic signature of normal wind behavior. An RS232 interface communication permits to send and receive data. However, for a large scale implementation, the WMT50 is very expensive and in this case an analogue anemometer is recommended (costs about 50 Euro). The maintenance system only needs the wind speed. So, tests with an analogue cups anemometer were performed in this case. The number of revolutions per minute is registered electronically after some electronics.
3. From wind and power measurement it is possible to predict the power curve. The main idea is to relate the power curve with normal or faulty condition.
4. Weather forecast is done based on web sites information, and by using the measurements given by the anemometer. The combination of this information is performed using time series analysis.
5. Classification using artificial intelligence is performed basically using Support Vector Machines (SVM) only for deciding between a good situation and a fault situation [22].
6. Time series analysis using regression techniques is used to track some frequencies (see [13], [16] for more information) along time. This will give a time series to monitor and to check when they will tend to a situation where some fault will occur in the future. The regression is made based on SVR, ARMA and ARIMA models [23], [30].

These algorithms are all implemented in MATLAB Software where the simulations are performed and regression algorithms based on time series are compared.
Many of these techniques that were developed for Wind Generators are appropriate to normal equipment, as time series analysis can be carried out with any important variable related to maintenance.

4. A local and a national database

It is an enormous advantage to share knowledge among hospital, because, usually, they have equivalent equipments. As focused above in the text, SMIT(H) includes the Linux Server PHP technology witch allows sharing information between different information systems, as at the same time among different SMIT(H) databases. This is an enormous advantage to implement some solutions, for example:

- A national database for fault diagnosis;
- A national database for spare parts;

- Local database for work orders, technicians and so on, but working in connection with national databases.

Having a national and local database it enables relevant information to be shared among different hospital to give support in detecting the source of faults, and so on. However, specific data should not be shared, like costs, suppliers, working orders, and planning policy. Web services make this task very easy. About these subjects see also [32].

One example of this methodology is under the Wind Turbines Maintenance, where many relevant data can be inserted in a national database, like types of faults, the way to solve them, maintenance indicators, like MTBF, MTTR, and so on. This is important not only to share knowledge (considering any worry about company competitions), but also to plan the produced power and risks to fulfill expected wind production (by failure or no wind).

But, the same technology can be used in so different equipments like portable RX, Ultrasound equipment, and so on, where the sharing of its maintenance plans, faults and the respective diagnosis and historic, can improve its performance and, simultaneously, reducing risks for patients and users.

The diversity of suppliers, the price of equipment and spare parts, the small number of some equipment, the location of some suppliers of maintenance services and many other singular situations, are reasons enough to consider the hospital equipment a case study for the approach under discussion.

```
<?php
require_once('libSOAP/nusoap.php');
$wsdl="http://smitserver.pt.pt/smit/
              webservices/serverSOAP.php?wsdl";
$client=new soapclient($wsdl, 'wsdl');
if ($client->getError()) {
    echo '<h2>Client Error </h2><pre>' .
      $client->getError() . '</pre>';
    die(0);}

$param=array(
  "database"=>"smit",
  "login"=>"adm",
  "passwd"=>"adm",
  "sql"=>"select * from
           insertom_p15('parameters');");

$lv_value=$client->call('runSQL', $param);
if ($client->fault) {
              echo '<h2>Fault</h2><pre>';
              print_r($lv_value);
              die(0); }
if ($client->getError()) {
  echo '<h2>Error calling functionx</h2><pre>'
     . $client->getError() . '</pre>';
   die(0);}

echo $lv_value . "<br>";
  // returns from SQL function insertom_p15:
  //    'OK' – update done,
  //    'OK-INS' – First insert
  // By default, the service returns the following values
  // ------------------------------------------------------
  //    'ERROR: 1' – No permissions to run the SQL
  //    'ERROR: 2' – Database connection failure
  //    'ERROR: 3' – The user does not exist
  //    'ERROR: 4' - Error running SQL
print_r($lv_value);
 ?>
```

Fig. 7 – WebService example to run queries from third party software against SMIT(H) database

To include new modules in SMIT(H) is very easy; because the framework is developed in Delphi for windows client/server architecture and for web development Symphony PHP Web Framework. The database is documented in web pages (every table and field, expected values, etc). The module to receive data from field measurements is fully configured in the database (number of clients, sockets to receive data, acquisition method, etc).

Nowadays, almost one hundred of on-condition techniques are known and many others could be developed. It is because of this that SMIT(H) was developed with an architecture that can support new modules, namely for predictive maintenance. But, this integration is not a sum of more modules but a real integration where each

new on-condition component dialogues dynamically with the main modules, like planning and work orders, among others.

The new predictive modules can receive data through keyboard, PDA, specific tools, like thermographic cameras, noise meters, or on-line acquisition. This makes SMIT(H) not only one more maintenance management system but an asset management system and a system that makes this kind of management available 24 hours a day in a more easy and powerful way, and an alert system for the complete accompanying of behavior of equipment and systems.

5. Further Developments

Based on this point of development, where the maintenance management system was enriched by new areas, namely the SMIT(H), there are also new opportunities to improve, namely:

- New maintenance methodologies for general combustion engines;
- New on-condition modules;
- The increase of life cycle of vehicles based on its transformation through the implementation of new technologies;
- Renewal methodologies for equipment in an environmental approach;
- Withdrawal of equipment in an environmental approach;
- Improvements based on new approaches based on fuzzy theory;
- Integration of SMIT(H) with other software tools for a general management in any organization;
- Risk analysis in the several areas of asset management.

6. Conclusion

When equipment is in pre-dysfunction state it sends out signals or symptoms that are not within the perception range of human senses. To search for an early detection of these signals, techniques that enable to model and predict environmental effects, like emissions, including noise effects, oil degradation and infrared thermography, are an evolution in the direction of ecological predictive maintenance.

Several of these techniques have their limitations. However, in certain applications they are the best choice. In this paper, a maintenance strategy applied to a renewable energy was presented.

The developed software SMIT(H) that is totally stabilized at the present date, is a powerful tool for maintenance management and is used as the background for these new developments.

Because the tendency in the future is to use typical house/industrial equipment that includes a communication network like ZigBee (now with a great expansion in the area of wireless sensors), the inclusion of a new software module for on-condition monitoring based on on-line instrumentation is relevant. The paper points out a methodology that is under development.

Additionally, the equipment sends out signals or symptoms that are usually not within the perception range of human senses but can translate environmental dysfunctions. The accompanying and forecasting based on these signals it aims to manage on-condition maintenance approach not only in the perspective to reach the maximum reliability but also with the objective to conjugate this with the environment.

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