CASE STUDIES

"SMART" REMOTE-CONTROLLED GEOGRAPHICAL SYSTEM FOR MAINTENANCE OPERATIONS: DESIGN AND DEVELOPMENT OF A PROTOTYPE

1. Organisations involved

University of Rome "Sapienza", CNIM – National Italian Committee for Maintenance, ISPESL – National Italian Institute for Occupational Health and Prevention – Department of Safety Technologies

2. Description of the case

Key points

- Maintenance
- Technical plants result management
- Tele-maintenance

2.1. Introduction

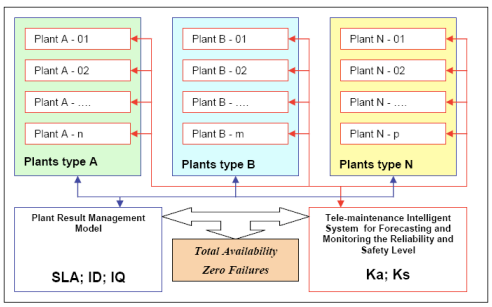
Maintenance systems designed specifically for each individual workplace are easier to set up thanks to the wider availability of new and cost-effective technologies.

Intelligent tele-maintenance systems can now effectively monitor the technical and administrative management of plants across a wide geographical area, even though each plant may have very different technical features.

Such systems provide both management and maintenance service contractors with the possibility of "total availability" of information about the machinery in a wide variety of factories, and of "zero failures" thanks to monitoring and control from a remote center. These systems (Figure 5) have two main elements:

- a Plant Result Management Model, and
- a Tele-maintenance Intelligent System to forecast the reliability and safety level of each plant, and to plan and schedule maintenance operations.

Figure 1: General diagram of the system



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These two complementary elements, used in an integrated manner, have led to the development of a management tool capable of guaranteeing "Total Availability" of the plants.

2.2. Aims

The system had to allow for the checking and monitoring of machinery from a geographically distant control centre so that an effective maintenance strategy could be followed and emergency interventions could be avoided. Better follow-up of necessary maintenance tasks and fewer emergency maintenance interventions would have a positive impact on the safety of maintenance workers.

2.3. Scope of the project

Plant result management model

After the analysis of a specific plant by using the 'Plant Result Management Model', it is possible to arrive at a global quality index value (IQ).

The series of phases that lead to the IQ value are described in detail and are shown below in a block diagram.

The IQ can only be calculated if certain indices are available. These indices have to be calculated by using information from the Service Level Agreement (SLA) and the indicators – the explanation below shows what these two aspects of the analysis involve and how they are carried out

After the classification of the different elements of a plant system, the necessary maintenance activities related for that plant will be identified. There are three types of maintenance activities possible: scheduled, condition-based and failure-based. (UNI EN 13306:2003 "Maintenance - Terminology"[1]) For each of these activities, taking different strategies into account, an SLA will be formulated. The different indicators which come together in this single performance index are defined by the combination of guaranteed results (RG) and monitored results (RM) corresponding to each technological line.

In addition to the SLA, the indicators have to be known in order to calculate the global quality index. Therefore, plant technical data (data sheets, operator's handbook, maintenance instructions, etc.) has to be collated to allow the allocation of indicators. There are four types of indicators:

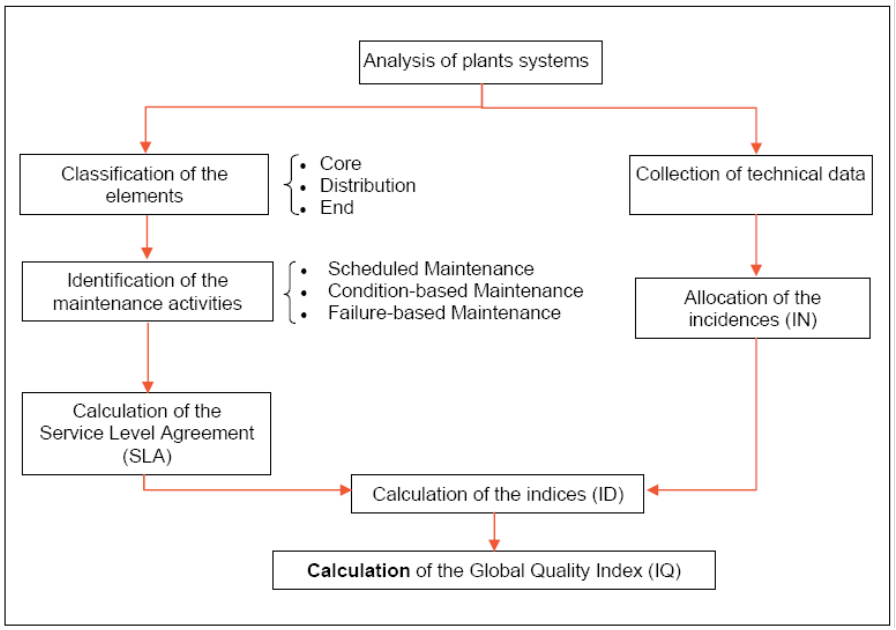
- Indicator of Well-being: degree to which a technological line influences well-being as perceived by the people in the buildings.
- Indicator of Image: the degree to which a technological line influences the image that the contract provider transmits to his customer and to the users.
- Indicator of Availability: the degree to which a technological line influences the availability of the infrastructure.
- Indicator of Safety: the degree to which a technological line influences the safety of the users.

Once the SLA and these indicators are known, it is possible to calculate the indices described below.

- Well-being Index: measure of the well-being perceived by the users.
- Image Index: measure of the image that the contract provider transmits to his customer and to the users.
- Availability Index: measure of the availability of the infrastructure.
- Safety Index: measure of the safety level of the infrastructure.

[1] UNI EN 13306, "Maintenance -Terminology", UNI EN standard, 2003.

Figure 2: Functional chart of the plant result management model (source: data by the authors)



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The combination of these different factors results in a value for the global quality index. This can also offer a way of taking into account economic factors, providing a figure which can be used in a price versus quality ratio.

For the health and safety of employees, it is important to pay particular attention to three of the four indices: the 'index of safety' which estimates how the technological line influences safety of the users; the 'well-being index', which gives information about the level of well-being perceived by employees; and finally, the 'safety index' which addresses the safety level of the infrastructure. If the results of these evaluations show that employees' health and safety might be endangered, it would obviously be important to take action.

Table 1 (below) gives a summary of the indices/indicators and specifies references, range and measuring method.

Table 1: Indices/Indicators for contract management

INDICES/INDICATORS	REFERENCE	RANGE	MEASURING METHOD
Service Level Agreement	Technological Line	0-1	Calculated for each technological line as a measure of the variance between the value of the guaranteed result and the measured value of the result.
Indicators % (IN)	Technological Line and performance factor (e.g. Well-being, image, etc)	0-100%	Assigned for each type of Technological Line and each type of performance factor based on the type of line and on several technical-identity characteristics of the line.

INDICES/INDICATORS	REFERENCE	RANGE	MEASURING METHOD
Performance Indices (ID)	Contract and performance indicator	0-100	Calculated for each performance factor as weighted average of the SLA of each line, assuming the % indicators as weight factors.
Quality Indices (IQ)	Contract	0-100	Calculated for the contract as weighted average of the partial indices.

Table 2 (below) gives an example of the model applied to a defence industry case study:

Table 2: an example of the model application

		QUALITY INDEX (IQ)			
		88			
		Performance Indices (ID)			
		Well-being	Image	Availability	Safety
		87	91	91	82
Technological Lines	**SLA**	**INDICATORS %**			
		Well-being	**Image**	**Availability**	**Safety**
LT 01	Heat Production	70%	35%	30%	25%
LT 02	Lifting/Elevators	15%	40%	25%	35%
LT 03	Electrical Distribution	15%	25%	45%	30%

Tele-maintenance Intelligent System

The second component, the Tele-maintenance Intelligent System, is a failure (Ka) and safety level (Ks) forecast tool. The system allows efficient planning and scheduling of maintenance tasks, sends warning signals whenever the forecasted level of reliability and safety drops below a determined threshold, and provides the control center with all the useful information it needs for a precise analysis promptly. Moreover, the tele-maintenance system makes more effective management possible. For example, prompt maintenance interventions are easier to organise when the supplier of the maintenance service responsible for managing a large number of difficult-to-access plants systems has an overview of the work that needs to be done.

In short, the main objectives of the Tele-maintenance Intelligent System are:

- forecasting and monitoring plant reliability/availability [Ka];
- forecasting and monitoring plant safety levels [Ks];
- managerial optimisation (effectiveness and efficiency of the maintenance process).

The system also makes it possible to:

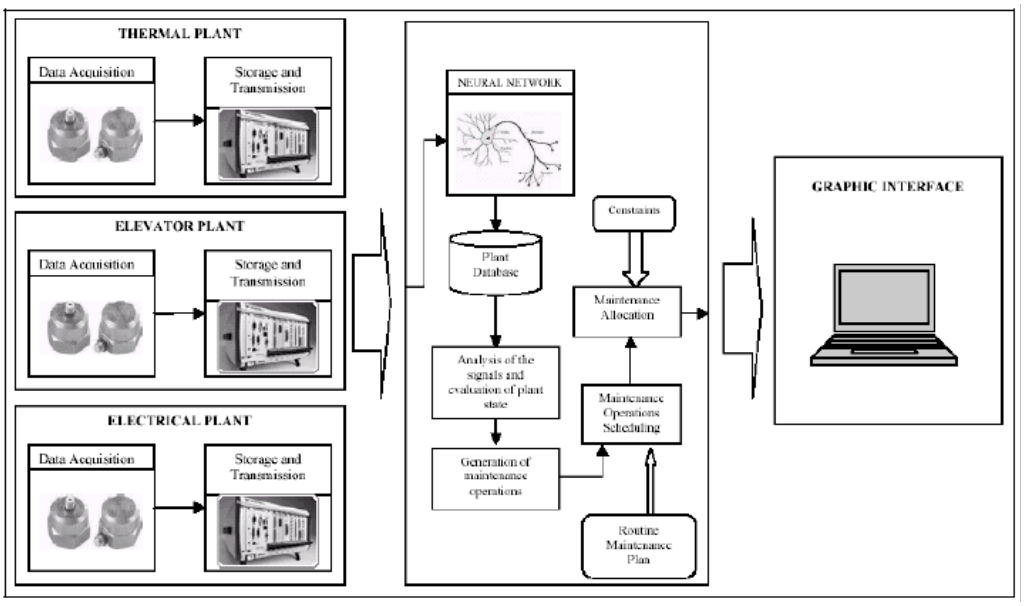
- support and optimise the planning and scheduling of maintenance operations
- maximize production and/or service performances
- minimize maintenance costs
- optimize plant performance

- improve service through more effective maintenance, prompt response to failure situations and follow-up preventative action when signs of poorer performance are detected
- increase safety for technicians and users by preventing failures which could lead to potentially dangerous situations

The system identifies and signals even intermittent failures so that technicians are easily able to target problems and solve them at the first attempt, thus preventing repeated failure situations.

As illustrated in Figure 3, a sub-system for the detection of the monitored parameters (functional parameters) and a sub-system for the processing of some of the monitored parameters are installed in each plant. All the information detected on each plant is sent to the control center by a signal transmission and conversion sub-system. The control center uses dedicated software to record the information in the individual plant identification file and schedules the maintenance operations, taking into account the plant safety level and the plant reliability forecast. The system can also send a signal to shut the plant down immediately if a shut-down is necessary. for safety reasons. The control center is staffed by the maintenance provider.

Figure 3: General diagram of the Tele-maintenance Intelligent System



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Through the Tele-maintenance Intelligent System's data-gathering processes, the technical plant becomes capable of "learning" and of improving its operational efficiency. The sub-system for processing some of the data collected from the plant uses software tools based on the logic of artificial intelligence and neural networks, capable of forecasting the evolution of events and signalling the preventive maintenance needed to correct the problems it foresees.

The artificial neural networks allow the development of a user-friendly "intelligent" software tool for technical plant management optimization.

Designing the Tele-maintenance Intelligent System involved the following steps:

- identification of the technical characteristics of the plants and choice of which parameters to monitor

- design of the parameter-recording system
- definition of the sensor type and its characteristics
- design of the neural network and the diagnostics system
- design of the signal transmission system
- development of the prototype.

In particular, through the study of failure modes (FMECA method – Failure Modes Effects Critical Analysis Method) and through a risk analysis (conducted with reference to the method suggested by AISS – International Committee "Safety Machines" Method), events which determine the change of one or more properties of the system in a given time interval were isolated, and their possible effect on the plant and the immediate environment was evaluated. This made it possible to identify those critical conditions which could be monitored remotely, with particular attention being paid to each of the three plant types.

The monitored parameter detection sub-system was installed in each plant; it consists of an electronic control unit equipped with a microprocessor. The sub-system picks up the signals from the sensors installed in the plant, comparing them to the pre-selected parameters. The information is sent to the remote control center through data transmission systems such as a telephone line (by cable or GSM), the Internet, or a dedicated line (ISDN). The choice of the data transmission system depends on what technology is available to each individual plant and the remote control center.

The parameters are processed with the help of the neural networks. The following steps were involved in the design of the neural network:

- definition of the inputs and outputs of each type of plant;
- data collection and allocation of target values;
- definition of the neural network architecture;
- training of the neural network;
- analysis of the training results;
- testing of the neural network.

The following reliability/safety parameters were introduced:

1) Ks – plant safety index;

2) Ka – plant reliability/availability index.

The Ks index can have a value between 0 and 1 according to the scale of values given in Table 3:

Table 3: Ks range

Ks	Safety	Actions
0	Plant is safe	None
0.25	Plant is safe but to be kept under control	Check the parameters during the scheduled routine maintenance visits
0.5	Plant is safe but to be kept under strict control	Schedule specific controls during routine maintenance visits.
0.75	Plant requires attention	Schedule specific action to check the safety conditions and, if necessary, restore them.

Ks	Safety	Actions
1	Risk unacceptable	Shut down the plant and emergency action required.

The Ka index can have a value between 0 and 1 (Table 4):

Table 4: Ka range

Ks	Reliability/availability	Actions
0	Plant is reliable and available	None
0.25	Plant is reliable and available but to be kept under control	Check the parameters during the scheduled routine maintenance visits.
0.5	Plant is reliable and available but to be kept under strict control	Schedule specific controls during routine maintenance visits.
0.75	Incipient failure	Schedule specific action to check the safety conditions in order to restore the reliability and availability level.
1	Failure	Failure condition imminent; emergency action required on the plant to avoid shutting down the plant and reducing the plant availability time.

The Ka and Ks output values of each plant, as processed by the neural network, taken together with other monitored parameters detected by the plant control system, make it possible to create an intelligent plant maintenance system.

The system analyses the signals recorded from each plant on a regular basis (Ka, Ks calculated by their respective neural networks and the other monitored signals) and evaluates the “state of health” of the plant in question. When operating conditions are found to be less than optimal - estimated, if dependent on the analysis of the Ka and Ks values, or real, if derived from the other monitored signals - the system generates a list of maintenance actions required to restore normal operating conditions.

The process of selecting those actions takes into account the Ka and Ks values, the maintenance history of the plant and the state of the other monitored signals, using statistical and probability techniques. Once all the plants managed by the system have been analyzed and all the maintenance actions required have been selected, the subsequent processing will result in the general “scheduling” of the tasks taking into account the previously devised routine maintenance plan.

The system then draws up a detailed schedule of maintenance tasks and allocates them to technicians, taking into account constraints established by the user, such as:

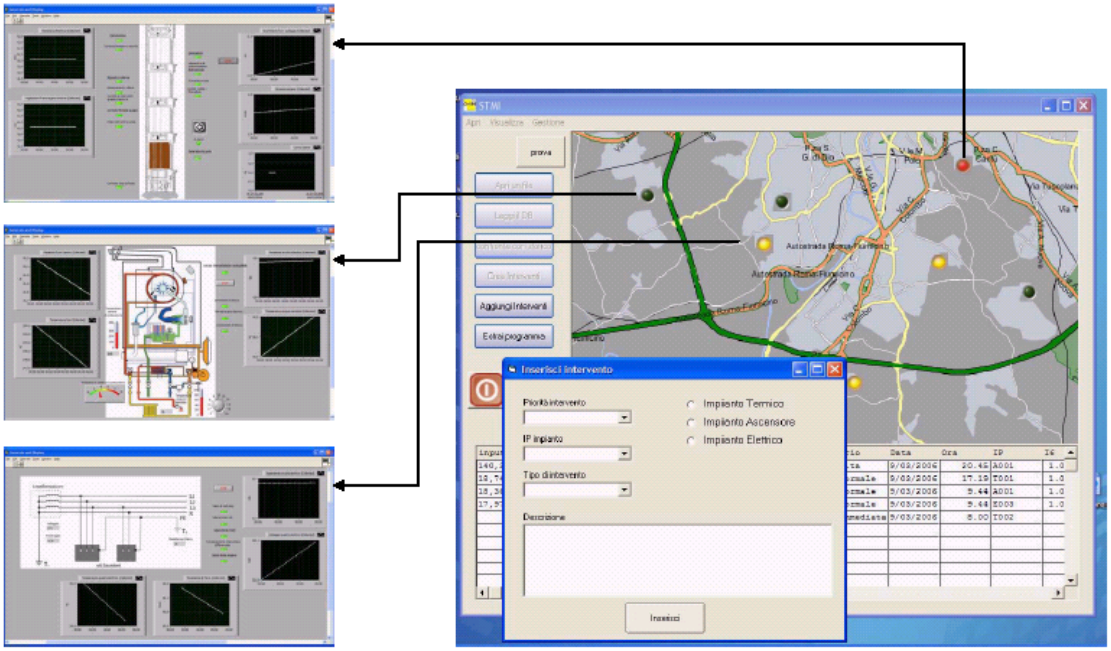
- number of tasks to be carried out each day by each technician
- geographical location of the plants on which the tasks are required
- constraints of a contractual nature
- tasks already scheduled through previous processing
- tasks scheduled in the routine maintenance plan
- emergency situations (hospitals, hotels, etc.)

2.4. *Results and evaluation*

The system was developed and tested in the field in cooperation with specialized companies. In order to fully test the system, it was tried out alongside the maintenance and management contracts for three different plant types:

- The lift technological line (lift plants);
- Heat producing technological lines (thermal plants);
- Electrical distribution technological lines (electrical plants).

Figure 4: A view of the software management tool



By courtesy of Prof. Lorenzo Fedele

The system application was particularly effective when the plant system was significant in terms of the distribution among a larger area, the number of plants and the nature of the different types of plant. It makes it possible to guarantee the total availability of the plants and to show, through the IQ index, that the results guaranteed during the contractual phase have been respected.

The Tele-maintenance Intelligent System makes this possible because it is a tool which can gather information from each plant at a remote location and, in particular, forecast failures and decreased safety levels and send warnings to the management organization.

The system makes high levels of management efficiency possible, delivering guaranteed results with a progressive reduction in management costs through the optimization and rationalization of technical maintenance activity and of other associated resources.

Finally, it is a tool that shares transparent management data of the plant systems between the management organization and the contract provider, helping to maximise customer satisfaction and progressively and systematically improve performance.

2.5. Contact information

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2.6. Transferability

This methodology and the systems it creates can easily be transferred to any company that needs to manage complex maintenance services, particularly when these services are carried out by contractors. The highest cost of the system is in the sensors required to collect data remotely, but most modern machines already have sensors on-board. Companies providing maintenance activities for different customers at different plants over a wide geographical area can use the system to achieve many goals. They can optimise their management, improve their own performance, increase safety and create better customer satisfaction.

The most important benefits are fewer failures that result in an interruption of operation, fewer emergency interventions and higher safety levels for maintenance staff and machine users.

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