Evaluating a Maintenance Department in a Service Company

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***Abstract*—** Maintenance has evolved from a tactical subject to being considered a strategic one due to its implications in availability, safety, quality and costs. Once maintenance policies have been set-up, different factors must be controlled so that the appearance and development of deficiencies in the maintenance department can be detected; for this purpose an evaluating maintenance process is developed in this paper by means of an additive model constructed by Hiview software. The audit is applied to a hospital where these areas are especially relevant as a result of their direct influence on the quality of the patients´ welfare service.

***Keywords*—**Continuous improvement, Hiview, Service company, Maintenance, Multicriteria technique.

I. Introduction

MAINTENANCE has ceased to be considered a tactical subject with relevant repercussions regarding company costs, but not profits, and started to be viewed as having a strategic dimension [1], due to its implications in quality [2], availability, safety and costs, making it just another requirement for doing business [3]; as a result maintenance performance has a direct influence on the fulfilling of the objectives established by an organization. Consequently, the maintenance function is an important element of modern business and must be managed effectively [4].

The implementation of advanced technologies in manufacturing plants with increased automation demands more efficiency on the part of the maintenance function because these new technologies make detection, diagnosis and correction of equipment problems more difficult [5]. The increase in the complexity of the assets already experienced by the manufacturing industries now extends to service industries. However, the number of contributions in relation to maintenance in service industries is almost non-existent (see [6]). These deficiencies are even more evident in hospitals, where maintenance efficiency not only has an influence on the machines but also on people, by influencing the quality of the patients´ welfare service directly.

The classic maintenance policies can be defined as follows:

a) Corrective maintenance. Maintenance activities are limited to repairing the equipment when a failure appears.
b) Preventive maintenance. Maintenance activities are developed with the intention of reducing the probability of failure of facilities or the degradation of a service. Maintenance activities are scheduled before the failure takes place. In order to determine the interval between inspections the maintenance history of the equipment has to be taken into account [7].
c) Predictive Maintenance. Its aim is to prevent component failure in a system, by controlling physical parameters; when these parameters exceed an established threshold, the maintenance activity is developed [8].

Once one or more maintenance policies have been set-up, different factors must be controlled so the state of the maintenance department can be established. Having established the state of the maintenance, a continuous improvement process can be developed whose aim is to correct the deficiencies and mistakes that commonly occur in a maintenance department. A tool able to detect the deficiencies and establish their importance should be applied. In this paper, an audit is proposed to detect the state of any maintenance department. The deficiencies detected and corrected can be checked again in the audit. The improvements developed can be quantitatively measured and translated into a qualitative value that provides a general state of the maintenance department.

Multicriteria techniques are widely applied in real applications. In [9] the analytic network process and zero-one goal programming are applied to select an information technology project. In [10] a decision-making method based on Quality Functions Development and an analytic network process are applied to improve decision planning and the evaluation of problems. As regards maintenance, multicriteria methods are applied to select the best maintenance strategy for an Italian refinery with an Integrated Gasification and Combined Cycle plant [11]. To justify the application of Total Productive maintenance (TPM) in Indian industries [12], and to identify the preferred maintenance policies for a specific weapon of the Norwegian Army [13].

The contributions related to measuring maintenance performance can be grouped into the categories: performance indicator systems and audit systems.

It should be pointed out that the audit system has been widely applied in the context of quality, principally as an ISO 9000 element; whereas, its application in a maintenance environment is more limited; [14] referred to the lack of development of maintenance audits, particularly for the

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control of more technological policies such as predictive maintenance. An audit should measure the effectiveness of normal practices and reveal whether improvements are required [15].

Amongst the contributions regarding the maintenance environment the following can be highlighted: Reference [16] tested, by means of an audit, production equipment effectiveness in a total productive maintenance (TPM) framework. Reference [17] describes a practical approach to carrying out maintenance performance analysis by means of a quality audit, using quantifiable performance indicators. Reference [18] describes the maintenance management audit process designed to identify the tasks of a facilities organization seeking to improve effectiveness and efficiency. Reference [19] developed a maintenance audit in a chemical process industry especially concerned with safety requirements; this was used to make benchmarking analysis. In [20] an audit approach is developed using performance indicators defined in terms of value. Reference [21] addresses the fundamental models, concepts, principles and practices of management system auditing, with the objective of improving the consistency and effectiveness of audits in maintenance between others areas. Reference [14] developed an audit applied to a TPM based on QS 9000 standards. In [22] a maintenance audit was developed in the Fuhais plant by means of a statistical method to determine the weak points in the existing maintenance system. In [23] an audit of the set up process of a Predictive Maintenance Program is developed.

Additionally, in [24] a simulation model enables the visualization of trends in maintenance policies when a predictive maintenance policy is set-up. Once a maintenance policy has been set up, different factors must be controlled to enable deficiencies to be detected and diagnosed early.

In this paper a maintenance audit has been developed using an additive multicriteria technique; to implement the audit the software Hiview has been used as support.

As a result, the audit is able to establish the current state of the maintenance area in different areas and compare this current state with the highest and lowest possible states of the maintenance department in these areas. The detection and diagnosis of irregularities and deficiencies in the department is the reason for introducing an audit system.

The maintenance audit developed has the following characteristics:

1) Any maintenance department can be audited, independently of maintenance policies applied in the enterprise.
2) An objective evaluation system is used.
3) The evaluation is supported by a continuous improvement concept.
4) It permits the comparison between organizations and for the same company at different moments in time.
5) It increases the understanding of the maintenance systems and procedures and the nexus with other areas of the company.
6) It provides a detailed report of the problems and detected errors.
7) It is a baseline to develop the maintenance (in the long term).

The audit developed has been applied to a service company, although traditionally research in the field of maintenance has been limited to manufacturing companies. In this case, the audit has been applied to a hospital which is especially important as there are people who are influenced by the correct or incorrect operation of machinery and facilities and then by the availability, safety and quality of the service provided to the patients.

The layout of the paper is as follows. In section II the structuring process developed to construct the maintenance audit is presented. Section III presents the weighting process, the definition of alternatives or states of the audit and the limits between states. Section IV presents the results. Section V draws the conclusions and finally the references are given.

II. Structuring Process

The structuring process starts with the identification of a set of criteria. The audit is broken down into the following criteria:

1) Maintenance strategy. It analyses the existence of a defined maintenance strategy in accordance with the global strategy of the Hospital. The maintenance strategy and the level of application of each element must be established. The estimated influence of the maintenance area over the organization must also be established. Therefore, objectives from the maintenance department must be recorded.
2) Attitude. It evaluates the behaviour amongst the maintenance department personnel and between them and personnel of other areas of the Hospital, especially, medical assistance, safety and quality departments.
3) Resources/Facilities management. It evaluates the level of integration of the maintenance information system with the Computer Maintenance Management System (CMMS) or Enterprise Resource Planning (ERP). It evaluates other hardware required to transfer the maintenance data.
4) Human resources management. It includes the job roles, responsibilities, incentives, and training aspects. It evaluates the organisational structure.
5) Equipment records. It evaluates the quality of failures history, physical resources, etc.
6) Planning. It analyses the activities to be developed, the sequencing, the materials and skills required [25].
7) Scheduling. This may include details regarding various scheduled periods, maintenance procedures required, estimated job times and when the equipment is available for maintenance.
8) Work orders. A work order is a document authorizing the completion of a specific task.
9) Purchases. It analyses the purchasing policy, responsibilities, supplier qualification, etc.

10) Store/Stocks control. It analyses the efficiency of the layout, bar codes, localization of components, etc.
11) Procedures. It evaluates the level of use of standards, development of guidelines and procedures for the maintenance activities.
12) Calibration. The reliability of some the maintenance devices depends on the quality of the calibration program.
13) Technical skills. It evaluates the existence of analysis in technical issues such as threshold, etc.
14) System effectiveness. It analyses the level of fulfilment of the objectives established in the strategy and the degree of user satisfaction (medical assistance, quality and safety areas). It analyses the relationship between maintenance policies such as preventive or corrective.
15) Control. It analyses the existence of performance indicators, reporting, verification of the maintenance activities and diagnosis.

To obtain the information from the Hospital, a questionnaire was prepared. The questionnaire was drawn up from the literature [24]-[27]. This is a general questionnaire and can therefore be applied to any enterprise.

Each criterion included different subcriteria; each subcriterion has a descriptor associated constructed with levels that describe plausible impacts of alternatives with respect to each subcriterion. In the following section, the subcriteria included inside the criterion Human resources management are presented:

a) Are training courses provided and/or updating of technical knowledge of maintenance?
b) Has the director of the maintenance department been designated?
c) Has a supervisor of the maintenance activities been designated?
d) Have the responsibilities, functions, etc. of every working position in the maintenance department been described?
e) Are the human resources available adapted to their responsibilities?
f) Have incentives when the aims are reached been defined?
g) Is the organizational structure of the maintenance department in agreement with the strategy?
h) Is the continuity in the maintenance department assured if a human resource is removed/modified?
i) Has the work been organized in such a way to minimize the number of extra hours required?
j) Is the level of experience acquired by the maintenance department personnel controlled?
k) Is there a policy of rotation of the human resources?
l) Is there a plan of suggestions or continuous improvement groups?
m) Is there an evaluation system for the efficiency of the workers?
n) Have some global work conditions been defined?
o) Is the concept of ergonomics included in the normal work conditions?

Table I includes a descriptor belonging to a subcriterion of the Resources/Facilities management criterion with the different levels of impact.

Table I. Descriptor of a Resources/Facilities management subcriterion.

CODE F5	The utility of the Computerized Maintenance Management System (CMMS) available is considered:
Level	Description
L1	The CMMS is integrated with the hospital management system in complete yield/ Full production¨/operation.
L2	The CMMS is integrated with the hospital management system. The CMMS is not in full yield/operation!/production, some historical information is absent, but, it does not exceed 20 % of the information.
L3	The CMMS is not integrated with the hospital management system. The CMMS is not in full yield/operation/production, some historical information is absent, but, it does not exceed 20 % of the information.
L4	The CMMS is not integrated with the hospital management system. The CMMS is not in full yield/operation/production, some historical information is absent, but, it does not exceed 50 % of the information.
L5	There is no CMMS or it is not efficient because it is not in use.

III. Evaluating a Maintenance Department

The maintenance audit is developed by means of an additive model constructed by Hiview software. v_{ij} is associated with the value of alternative i on criterion j; w_j represents the weight assigned to criterion j, therefore, the overall value of alternative i is presented in (1) [28].

$$V_i = \Sigma_j \, w_j v_{ij} \tag{1}$$

Hiview allows constructing a hierarchical tree of objectives and criteria. Criteria are clustered under parent nodes and the alternatives are scored on all the criteria under the parent. Next, the criteria are weighted. Hiview normalises the weights established by dividing the weight on each criterion by the sum of the weights on all the criteria under that node. Those weights are used in the above equation to give a single, weighted average scale for the parent node [28].

This maintenance audit has been elaborated by means of Hiview software. The criteria and subcriteria are organized in a tree structure as is shown in Fig. 1.

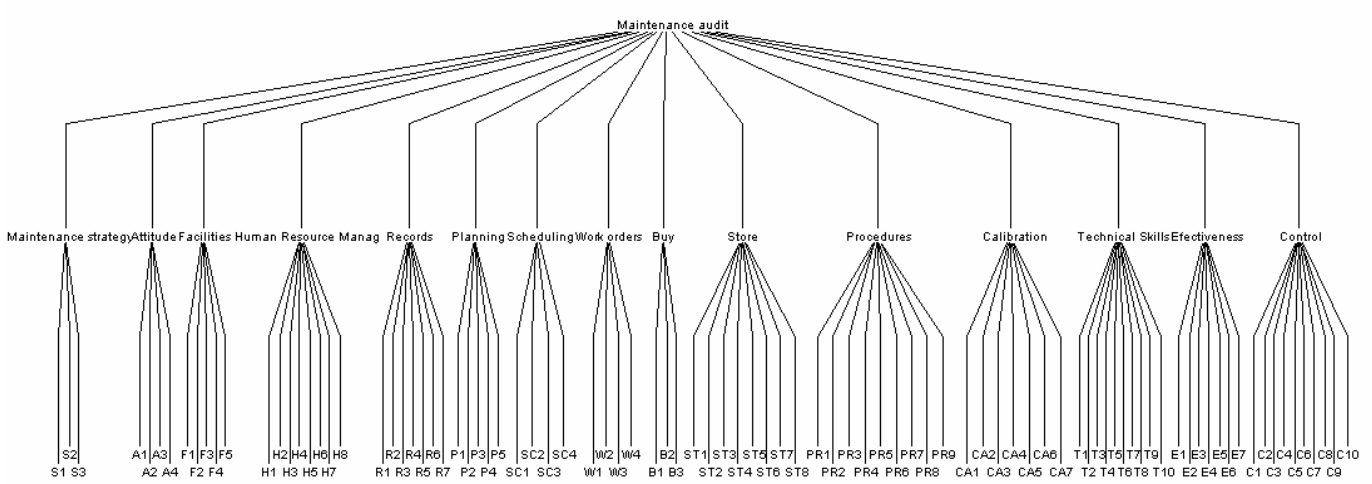


Fig. 1. Hierarchical tree.

The model is composed of 15 criteria and 94 subcriteria, codified as shown in Fig. 1; each subcriterion has a discrete value function associated with a maximum value of 100 and minimum value of 0. Each level of the descriptor has a value in the scale as a result of applying the MACBETH [29] tools included in the Hiview software (see Fig. 2).

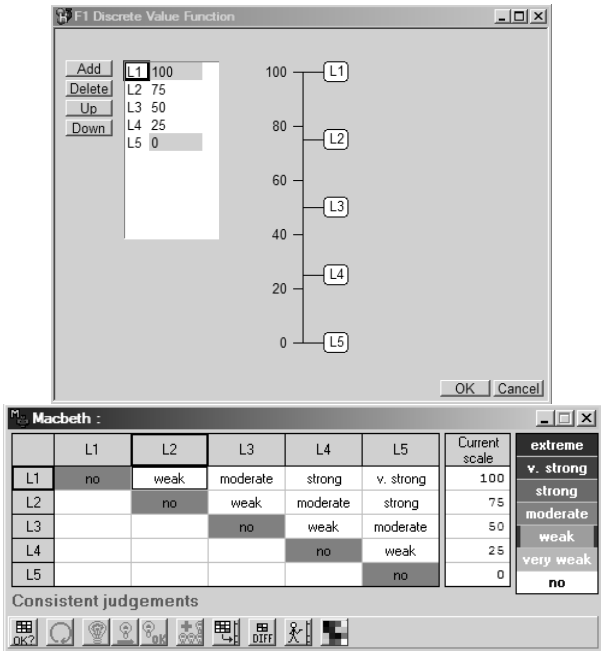


Fig. 2. MACBETH scale from the judgement matrix corresponding to the subcriterion available work space form Resources/Facilities management criterion.

A. *Weighting process*

There are some subcriteria with only two levels in the scale (results of a yes/no question). In these cases, only two values of scale have been considered; when the weighing process by means of MACBETH has been applied, the lineal scale shown in Fig. 3 is obtained.

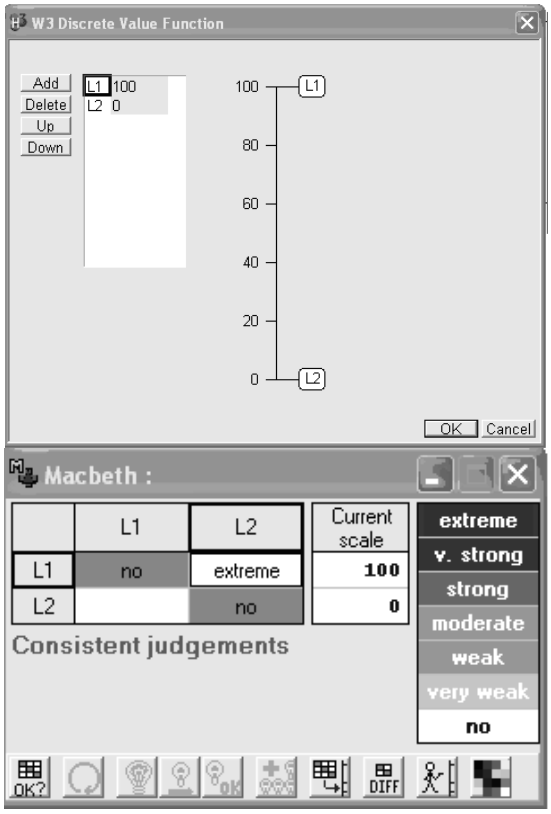


Fig. 3. Weighting with MACBETH of a subcriterion with two levels.

To compare the subcriteria from different criteria a normalization process of the scales between the criteria is necessary. To achieve this, the subcriterion with the greatest weight within each criterion is selected and relative weights for only those dimensions are determined using the MACBETH weighing process for the respective swings. Next, the greatest weight within each criterion is considered a re-scaled factor (see Table II) and is multiplied by the original weights of the rest of the subcriteria of the criteria. Thus, the weights of all of the subcriteria are then proportionally re-

scaled and added up within each component (see Table II). Finally, a normalized weight for each subcriterion is calculated. The criteria weights are shown in the last column of Table II. Excel has been used for the re-scaling and normalization processes from the results obtained with MACBETH.

Table II. Aggregated re-scaled scores.

Criteria	Re-scaled factor	Aggregated subcriteria score	Criteria weight
Strategy	0.75	74.95	7.69
Attitude	1.00	100.00	10.26
Facilities	0.75	74.95	7.69
Human resource management	0.62	62.48	6.41
Records	1.00	100.00	10.26
Planning	0.87	87.43	8.97
Scheduling	0.50	50.00	5.13
Work orders	0.62	62.48	6.41
Buy	0.38	37.52	3.85
Stocks control/store	0.25	24.95	2.56
Procedures	0.75	74.95	7.69
Calibration	0.50	50.00	5.13
Technical skills	0.75	74.95	7.69
Effectiveness	0.50	50.00	5.13
Control	0.50	50.00	5.13
Total		974.67	100.00

B. States

The alternatives considered in this model are totally excellent state, excellent/satisfactory limit, satisfactory/acceptable limit, acceptable/alert limit, alert/catastrophic limit and totally catastrophic state. An alternative called current status has been included to evaluate the state of the maintenance department of the Hospital.

C. Limits between states

The limits between state values are obtained by analysing the level in which each subcriterion should be considered once that the criterion is in a specific state. For example, in the case of record criterion:

a) The totally excellent limit is obtained with all the subcriteria at the optimum level.
b) The excellent/satisfactory limit is obtained when subcriteria R1, R2, R4 and R5 are at the second best level and the subcriteria R3, R6 and R7 are at the best level.
c) The satisfactory/acceptable limit is calculated considering the subcriteria R1, R2, R6 and R7 at the second best level, the subcriteria R3 at the best level and the subcriteria R4 and R5 at the third best level.
d) The acceptable/alert limit corresponds with the subcriterion R3 at the second best level, the subcriteria R1, R6 and R7 at the third best level and the subcriteria R2, R4 and R5 at the fourth best level.
e) The alert catastrophic limit is obtained with the subcriterion R3 at the second best level and the rest of subcriteria at the fourth best level.
f) The totally catastrophic limit is obtained with all the subcriteria at the worst level.

Therefore, the limits between states are presented in Table III. Similar procedures have been applied considering all the criteria simultaneously, (see Table IV) to obtain the limit between states in a global audit. The limits between the resulting states are exposed in Table V.

To evaluate any enterprise, in our case in the Hospital, a level of the descriptor should be associated to each subcriterion. Partial results from the Human resource management criteria provided by the model are in Fig. 4.

Table III. Limit values between states in each criterion.

Limits	Value
Maintenance Strategy	
Excellent/Satisfactory limit	75
Satisfactory/Acceptable limit	60
Acceptable/Alert limit	44
Alert/Catastrophic limit	25
Attitude	
Excellent/Satisfactory limit	75
Satisfactory/Acceptable limit	63
Acceptable/Alert limit	44
Alert/Catastrophic limit	25
Facilities	
Excellent/Satisfactory limit	80
Satisfactory/Acceptable limit	72
Acceptable/Alert limit	47
Alert/Catastrophic limit	25
Human Resource Management	
Excellent/Satisfactory limit	78
Satisfactory/Acceptable limit	68
Acceptable/Alert limit	39
Alert/Catastrophic limit	28
Records	
Excellent/Satisfactory limit	87
Satisfactory/Acceptable limit	75
Acceptable/Alert limit	46
Alert/Catastrophic limit	31
Planning	
Excellent/Satisfactory limit	80
Satisfactory/Acceptable limit	65
Acceptable/Alert limit	45
Alert/Catastrophic limit	30
Scheduling	
Excellent/Satisfactory limit	69
Satisfactory/Acceptable limit	58
Acceptable/Alert limit	33
Alert/Catastrophic limit	19

Table III (cont). Limit values between states in each criterion.

Limits	Value
Work order	
Excellent/Satisfactory limit	98
Satisfactory/Acceptable limit	83
Acceptable/Alert limit	22
Alert/Catastrophic limit	13
Buy	
Excellent/Satisfactory limit	75
Satisfactory/Acceptable limit	61
Acceptable/Alert limit	44
Alert/Catastrophic limit	25
Store	
Excellent/Satisfactory limit	76
Satisfactory/Acceptable limit	64
Acceptable/Alert limit	43
Alert/Catastrophic limit	25
Procedures	
Excellent/Satisfactory limit	79
Satisfactory/Acceptable limit	55
Acceptable/Alert limit	37
Alert/Catastrophic limit	28
Calibration	
Excellent/Satisfactory limit	82
Satisfactory/Acceptable limit	68
Acceptable/Alert limit	47
Alert/Catastrophic limit	30
Technical skills	
Excellent/Satisfactory limit	86
Satisfactory/Acceptable limit	76
Acceptable/Alert limit	50
Alert/Catastrophic limit	32
Effectiveness system	
Excellent/Satisfactory limit	75
Satisfactory/Acceptable limit	61
Acceptable/Alert limit	44
Alert/Catastrophic limit	33
Control	
Excellent/Satisfactory limit	75
Satisfactory/Acceptable limit	60
Acceptable/Alert Limit	42
Alert/Catastrophic limit	29

IV. Results

The questionnaire with the information about the current state of the hospital was completed in February 2009 by an independent person to the organization.

Therefore, from the previous semantic values the current state of the hospital is 75 (Acceptable) and very near to a satisfactory state, (see Fig. 5 and Fig. 6) in a [0, 100] scale.

Table IV. Values assignees to establish the global excellent/satisfactory limit.

Criterion	Excellent	Satisfactory
Predictive Maintenance Strategy	X	
Attitude		X
Resources/Facilities management		X
Human resources management	X	
Equipments records	X	
Planning	X	
Scheduling	X	
Work orders		X
Buys		X
Store/Stocks control	X	
Procedures	X	
Calibration		X
Technical skills	X	
System effectiveness	X	
Control	X	

Table V. Limit values between states considering the global audit.

Alternatives	Limits between states
Totally Excellent state	100
Excellent/Satisfactory limit	80
Satisfactory/Acceptable limit	67
Acceptable/Alert limit	42
Alert/Catastrophic limit	27
Totally Catastrophic state	0

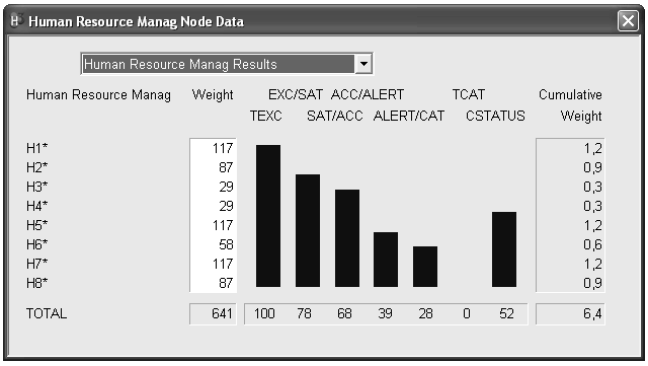
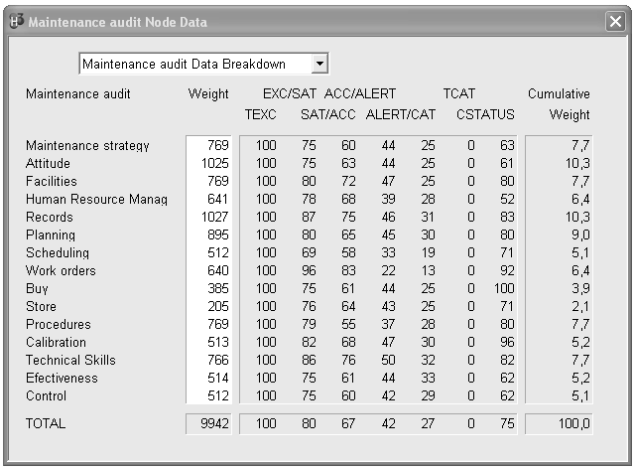


Fig. 4. Audit results in Human resource management criterion.

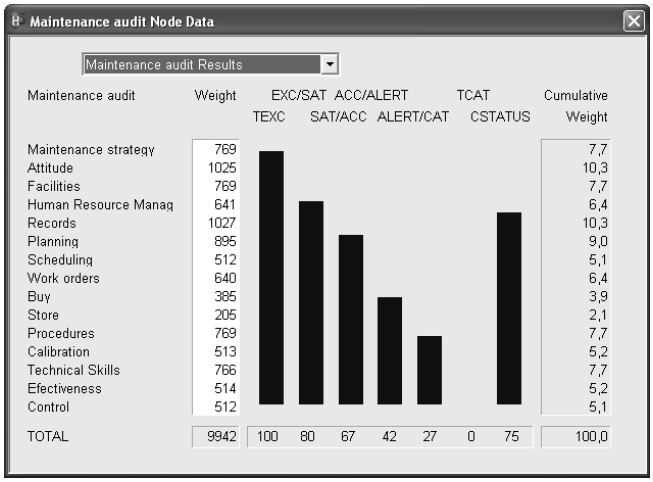
In the areas scheduling, work orders, buy and calibration the state is excellent. The areas maintenance strategy, records, store, Technical skills, effectiveness, and control, the performance is satisfactory. In the areas facilities and planning, the performance of the hospital is in the limit between satisfactory and excellent states. In the areas attitude and human resource management the performance of the hospital is only in an acceptable state; this can be due to the special long life contracts established to the human resources

in public administration centres.



Maintenance audit	Weight	EXC/SAT	ACC/ALERT		TCAT		Cumulative
		TEXC	SAT/ACC	ALERT/CAT	CSTATUS		Weight
Maintenance strategy	769	100	75	60	44	25	0	63	7,7
Attitude	1025	100	75	63	44	25	0	61	10,3
Facilities	769	100	80	72	47	25	0	80	7,7
Human Resource Manag	641	100	78	68	39	28	0	52	6,4
Records	1027	100	87	75	46	31	0	83	10,3
Planning	895	100	80	65	45	30	0	80	9,0
Scheduling	512	100	69	58	33	19	0	71	5,1
Work orders	640	100	96	83	22	13	0	92	6,4
Buy	385	100	75	61	44	25	0	100	3,9
Store	205	100	76	64	43	25	0	71	2,1
Procedures	769	100	79	55	37	28	0	80	7,7
Calibration	513	100	82	68	47	30	0	96	5,2
Technical Skills	766	100	86	76	50	32	0	82	7,7
Efectiveness	514	100	75	61	44	33	0	62	5,2
Control	512	100	75	60	42	29	0	62	5,1
TOTAL	9942	100	80	67	42	27	0	75	100,0

Fig. 5. Maintenance audit results.



Maintenance audit	Weight	EXC/SAT	ACC/ALERT		TCAT		Cumulative
		TEXC	SAT/ACC	ALERT/CAT	CSTATUS		Weight
Maintenance strategy	769						7,7
Attitude	1025						10,3
Facilities	769						7,7
Human Resource Manag	641						6,4
Records	1027						10,3
Planning	895						9,0
Scheduling	512						5,1
Work orders	640						6,4
Buy	385						3,9
Store	205						2,1
Procedures	769						7,7
Calibration	513						5,2
Technical Skills	766						7,7
Efectiveness	514						5,2
Control	512						5,1
TOTAL	9942	100	80	67	42	27	0	75	100,0

Fig. 6. Hospital current status.

V. Conclusions

An additive multicriteria technique has been applied, with the support of Hiview software, to construct a maintenance audit, selecting as criteria different areas for evaluation in a maintenance department. This maintenance audit is objective and can be distinguished for any enterprise by means of establishing the specific limits between states and weights.

This maintenance audit can be used to apply a continuous improvement process.

The maintenance audit shown has been applied to a service company, specifically in a Hospital, where the number of contributions related to maintenance is almost non-existent but, the activities of this department have an important influence on the correct working of the machines and facilities and therefore on the quality of the patients´ welfare service.

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