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Strategic framework to maintenance decision support systems

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Abstract

In current global markets the maintenance can be considered key to assurance the required function of equipments and low life cycle costs of productive equipments. In this context, the Maintenance Decision Support Systems can be relevant as strategic framework. Accordingly, in this paper, the main objective is integrating the strategic functions with Balanced Score-Card, using the Analytic Hierarchy Process, where the Key Performance Indicators are associated to goals of company. The core of this purpose is to maximize the efficiency of the plant through maintenance. The decisional problem has been modelled with four production areas, as alternatives, that were pre-selected by experts. Commercial package Expert Choice has been used to model the problem and to analyse the results. A purely strategic approach has been followed to maintenance in the industrial business; results serve as input in tactical scope.

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Keywords: Maintenance; AHP; Balanced Score-Card; Key Performance Indicators; Decision Support System.

Nomenclature

AHP	Analytic Hierarchy Process
APi	vector collection for prioritizing areas
BSC	Balanced Score-Card
Ei	expert group
KPI	Key Performance Indicators

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$\bar{V}_{KPI}$	prioritization vector

1. Introduction

Currently, competition from companies under globalized market is characterized by a high rate of change in emerging technological innovation and changing market demands. In this scenario, the flexible models can help to decision-making [1]. When shorter product life cycles, the production equipments are put under stress. This variability leads to consider maintaining itself as key to ensuring the required function, low lifecycle costs and production operations teams. In this situation of stress, technical knowledge from equipment for a successful decision-making in maintenance becomes crucial, considering many variables and parameters, which in an industrial system is complex, devoting much analysis time for a proper decision-making.

This work is part of a broader development, in particular of an expert system to assist in decisions-making in the design of customized maintenance plans in a production plant. This system is based on the alignment of strategic business objectives, involving maintenance tactical decisions that conduce towards maintaining operational objectives. The result is a detailed maintenance program that meets the actual needs of the plant, according to their resources and aligned with business objectives. This should be implemented in the maintenance management system of the plant to control the execution. This system part of a is called hereinafter MDSS (Maintenance Decision Support Systems), integrating methodologies BSC (Balanced Scorecard) to align the goals of keeping with those strategic to company and RCM (Reliability Centered Maintenance) improving the operational performance of maintenance. By adding knowledge-based techniques KBS (Knowledge Based Systems) try to provide the system of assistance to the experts in maintenance decisions-making, assuming less time spent, in an optimum manner and subject to continuous improvement schemes. A modular system for decision support is proposed to achieve the overall objective, Fig. 1, as customized maintenance concept introduced by Waeyenbergh and Pintelon [2].

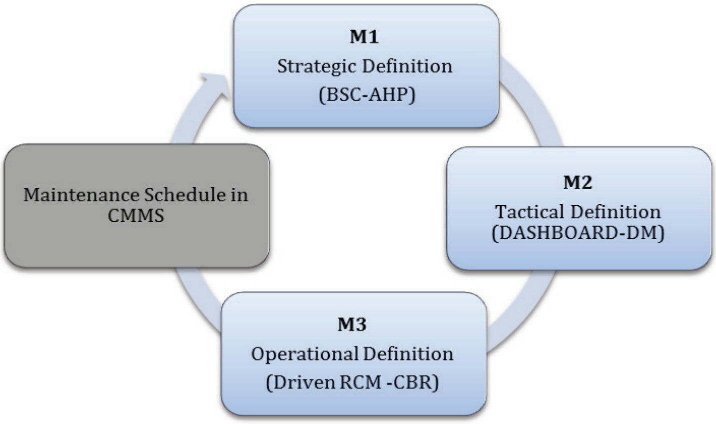

Fig. 1. Modular structure of the proposed system decision support framework MDSS

This approach indicates, for each module, a combination of methodologies and techniques used to build the system for maintenance decision support. The approach of this paper focuses exclusively on the Module I (M1 Definition Strategic) scheme of Fig. 1, integrating the strategic approach of the balanced scorecard (BSC) technique with decision support (AHP).

Regarding the state of the art for the M1 module, some studies can be found respect to the methodological approach combined BSC and AHP techniques. Thus, Theriou et al. [3] develop a framework, which defines quantitative links between the performance criteria and the strategic planning in the firms. Huang et al. [4] integrate financial measures with key indicators in a biopharmaceutical firm; while Lee at al. [5] construct an approach based on analytic hierarchy process and balanced scorecard for evaluating an information technology department in the manufacturing industry. Other example can be found in Wu et al. [6] that use both tools for banking performance evaluation, or in Yüksel and Dagdeviren [7] that analyze the performance level of a business on the basis of its vision and strategies through balanced scorecard and analytic network process. Also Cho and Lee [8] explain the applicability of fuzzy AHP and balanced scorecard concepts in business process evaluation and selection for business process management.

The purpose of the module M1 is to assist the design and construction of maintenance improvement programs, translating strategic objectives by integrating the strategic approach of balanced scorecard (BSC) technique with decision support (AHP). Therefore the aim of the module M1 is the strategic definition, allowing the decision maker to identify the most strategic business areas of the organization, following the approach of BSC, with a rational and informed choice. As a result of the module, a priority of productive areas should focus first set maintenance actions.

2. Methodology used in strategic definition BSC-AHP

To achieve the strategic objective, the Key Performance Indicators (hereinafter KPI's) will be linked with the goals and objectives of the organization. The AHP tool is used to set various KPI as criteria for measuring performance according to the BSC methodology. AHP transforms comparisons in a computer model, and therefore can be implemented in customer applications or dedicated software packages available as well Expert Choice© [9]. In Fig. 2, the BSC-AHP model proposed for the module M1 is detailed.

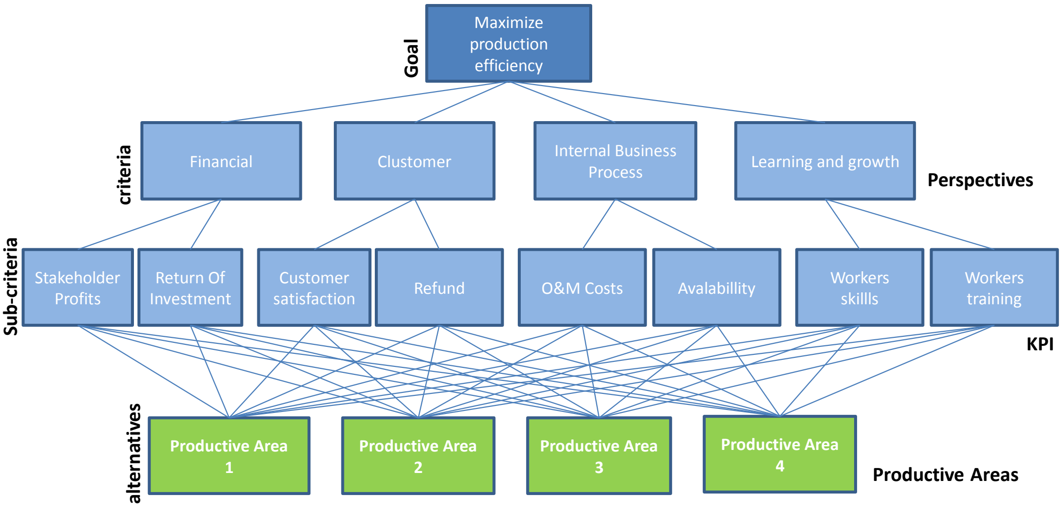

Fig. 2. Model BSC-AHP hierarchical decision proposed for the M1 module

The hierarchical structure constructed links to select the area to maximize the effectiveness of industrial business among alternatives as strategic areas; in this case, the structure shows four selected areas. It can be seen that the objective is to maximize the effectiveness understanding as industrial business performance; the criteria taken quantified as KPI's and are grouped into strategic objectives within the classical approach of the BSC perspective. The KPI's set is seen in Table 1.

The system assembly decision AHP to the structure presented as the model is carried out in four steps: weighting of criteria (prospects), weighting the KPI's, weighing alternatives (areas) for each sub-criterion (KPI) and vector collection for prioritizing areas, (APi). Note that the vector for prioritizing areas will be direct, since the result is highest to lowest ratio of preferred areas to maximize their effectiveness.

Table 1. Strategic objectives and key performance indicators KPI

BSC perspectives	Strategic objectives	KPI
Financial	Stakeholder profits	EBITDA
	Return Of Investment	ROI
Customer	Satisfaction	Ratio Satisfied Customers/Total Customers
	Refunds	Ratio Refunds/Sales
Internal business process	O&M Costs	Ratio Operation Cost & Maintenance Costs/ Total Costs
	Availability	Variable A(t) as functions {MTBF, MTTR, UT}
Learning and growth	Workers skills	Measures {versatility, suitability to the job}
	Workers training	Certify and internal training

2.1. Expert Panel and consensus method (two stages Delphi)

AHP method is multiagent, so, it supports the assessment of an expert group that can be integrated into the decision-make. In the case under study, the group consists of four experts, covering the scope of the four perspectives seen in Table 2. This involves performing the same survey facilitating a form to each of the experts adding all the scores; an eigenvector formed as a geometric sum of the components of each of the experts is constructed. To manage any discrepancies scoring methods consensus among experts as the Delphi Method [10] are incorporated. It has been tested together with the AHP method in several studies [11, 12], it is an iterative process based on questionnaires to achieve consensus among the experts panel. In the present study, the Delphi Method is implemented in two stages [11]. While most orthodox method considers several successive stages (more than three) of sending questionnaires, this variant of the method provides that the method can be limited to two without affecting the quality of the results, assuming an advantage in saving time spent. The Delphi Method consists of two stages where the first stage are given questionnaires first panel of experts, a statistical treatment of the same, showing the central tendency (mean) and evaluate the dispersion. In second stage, easing back questionnaires, scoring the central value of the group and indicating whether they agree with it, only experts that do not conform to justify their position. This justified divergence serves to develop alternative scenarios that enrich the knowledge according to the quality and competence of the experts. The Delphi Method assumes at first that the dispersion among experts is decreased, facilitating consensus and secondly, analyzing points where there are differences, highlighting divergent judgments, but justified. Furthermore, since AHP uses a mathematical method of combining individual judgments of each expert (in this case the geometric mean) is not strictly necessary, although is considered ideal to decrease the dispersion.

Table 2. Panel, according to category and involvement in strategic decision

ID Expert	Category	Scope
E1	Factory Manager	Global industrial business and dialogue with shareholders
E2	Quality Manager	Focused on product and customer satisfaction
E3	Production Manager	Focused on exploitation and production process
E4	Maintenance Manager	Centered functionality of machines and process equipment

2.2. Strategic Model BSC-AHP

The prioritization vector is calculated by the product matrix and the productive areas matrix based on KPI, with the final weight vector $\bar{V}_{KPI}$. Dimensionally prioritization vector 4x1 size is obtained, where each component V_p (APi) corresponds to the total value of priority for each of the productive area APi . The highest value corresponds to the productive area chosen to apply maintenance actions aimed an increase in their productive efficiency. In fact, a priority area can be identified; this result and full BSC-AHP mathematical model shown in Fig. 3.

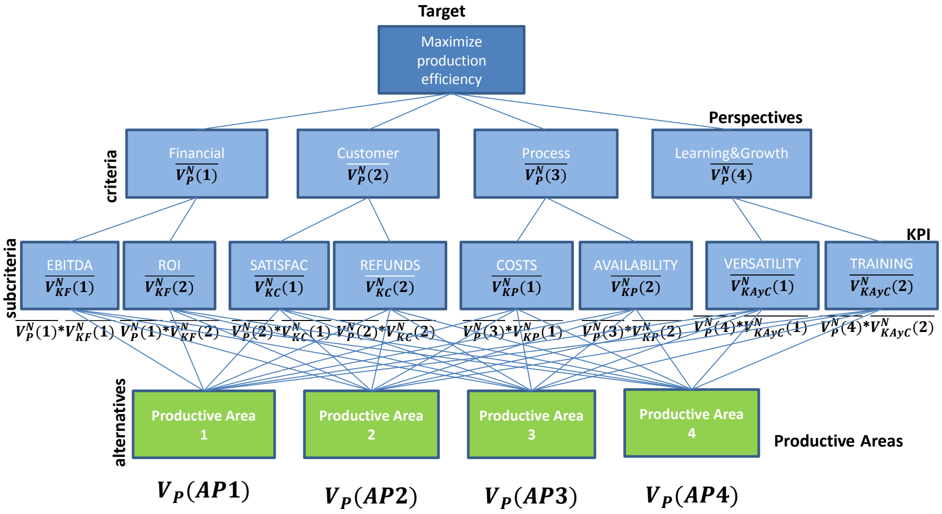

Fig. 3. Model BSC-AHP Module I for 4 production areas APi and prioritization vectors $\overline{V}_p$ (APi)

3. Strategic definition BSC-AHP: Results

In the scoring process and the strategic decision Expert Choice software package was used as application dedicated to the AHP methodology, following the pattern seen in the previous section. Moreover, Expert Choice subsequent analysis or post-processing the input information (expert judgment) allows a sensitivity analysis, identifying the more sensitive variables.

3.1. BSC-AHP modeling scheme in Expert Choice

The problem modeling aims to select the productive area in order to improve their production efficiency, according to a strategic level for the industrial business, represented by the expert group {*E1, E2, E3, E4*}. According to Table 2, study areas has been restricted to four, called respectively {*AP1, AP2, AP3, AP4},* as a result of a consensus between a group of experts to limit the number of them. The result of higher score will set a priority on the group of areas to evaluate. The appropriate action is implemented in the maintenance plan designed by customer and based on the history of failures and pathologies presented. The AHP-BSC model, seen in Fig. 3, is introduced in the Expert Choice environment, Fig. 4.

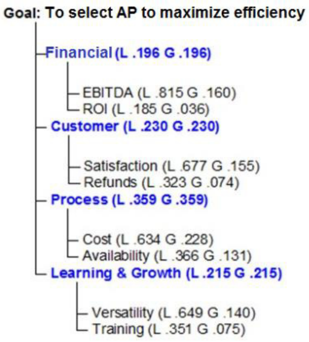
Goal: To select AP to maximize efficiency
- Financial (L .196 G .196)
  - EBITDA (L .815 G .160)
  - ROI (L .185 G .036)
- Customer (L .230 G .230)
  - Satisfaction (L .677 G .155)
  - Refunds (L .323 G .074)
- Process (L .359 G .359)
  - Cost (L .634 G .228)
  - Availability (L .366 G .131)
- Learning & Growth (L .215 G .215)
  - Versatility (L .649 G .140)
  - Training (L .351 G .075)

Fig. 4. BSC-AHP Model EC environment, equivalent to model Fig. 3.

3.2. Questionnaires for evaluation of the expert panel

The modeled hierarchy has been punctuated with the criteria and from the point of view of each expert *Ei* {1/2/3/4}, for each strategic approach BSC {Financial / Customer / Process / Learning & Growth}, prioritizing the importance of each variable KPI. Following the AHP methodology, questionnaires were established to collect the information, where first is weighted for paired comparison perspectives and then for each perspective, the KPI variables are weighed. Two-step Delphi Method was used; once the first questionnaires rated by each expert, the average is calculated, being returned to each expert and incorporating the average score of the group, and asked them if they are according to the average; if there is not conformity, a justification must be given. These questionnaires were answered by each of the four experts, combining their individual judgments, the weighting of the AHP-BSC hierarchy modeled, Fig. 4, where L represents the local weights and G represents the overall relative weight of each perspective and variable. For each rated questionnaire, the degree of inconsistency was assessed and compared with the maximum value set (0.1). A new assessment should be made by the expert in those judgments that have greater inconsistency (> 0.1). To limit the consistency, the maximum permissible, the degree of overall consistency (0.03) has been evaluated and this has been observed as tolerable (<0.1), and if it is inconsistent, a new iteration is necessary. Most of the experts were satisfied with the average response of the submitted form, even an expert nuance some differences. The combined weight and prioritization results following perspectives and variables are represented in Fig. 5. The process is the perspective of higher weight (35.9%), followed by customer (23%), learning (21.5%) and financial (19.6%).

3.3. Analysis of results

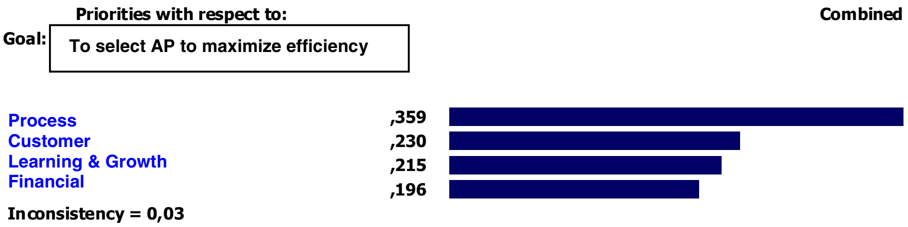

Fig. 5. Prioritization of perspectives and variables, combined judgment of experts

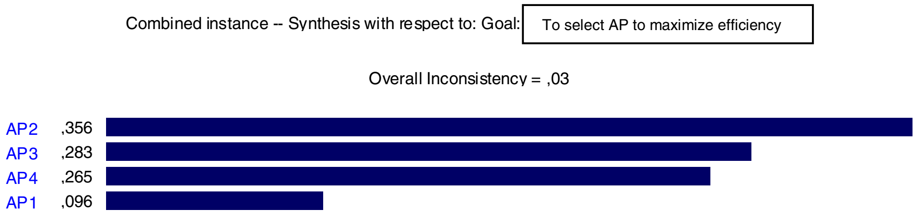

Fig. 6. Results of model selection AHP-BSC

As a result, the scores of the four production areas are shown, being the highest scoring preferred to maximize the effectiveness and thus to apply the maintenance action plan and to measure the performance. Fig. 6 shows the results sorted from production areas, Productive Area 2 is selected to maximize efficiency. The obtained overall inconsistency (0.03) is less than the maximum permissible tolerance (0.1).

A sensitivity analysis was performed to demonstrate the variables that most affect the choice of alternatives. That is, what are the most sensitive variables, whose small changes in their values, cause changes of results in the final selection of the alternative to maximize. This allows evaluating different simulation scenarios.

3.4. Sensitivity analysis

The representation of a sensitivity analysis allows observing how varying priorities criteria (prospects) changes in the priorities of the alternatives would be caused. From the point of view of the prospects, the most influential perspectives are customer decision process. From the point of view of the alternatives, *AP1* and *AP3* shown (less sensitive) variations, but not so with the *AP4* alternative, very sensitive to the perspective client and the *AP2* alternative, very sensitive to stable values process perspective. The representation of the sensitivity analysis shows how the various alternatives were prioritized or relatively weighted against each criterion (perspective) and the overall decision. Fig. 7 shows the production area *AP2* was mainly prioritized by prospects and learning process. However, the client perspective presents great influence on the production area *AP4*, that is, an increase in the above perspective identifies the area to maximize rather than *AP2 AP4*. Decisional remarkable fact is that the alternative *AP1* would not be chosen for any variation of prospects, as is seen in Fig. 7.

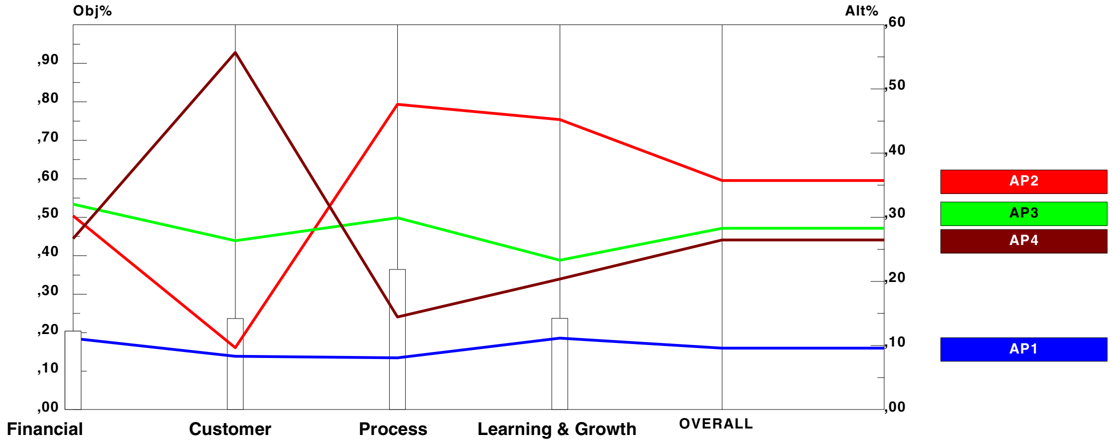

Fig. 7. Representation sensitivity analysis model based on AHP-BSC perspectives

3.5. Analysis of the robustness of the decision of experts

A sensitivity analysis gradient perspective, evidence for each perspective what variations alter the final decision to maximize the productive area, depending on the weight against the overall objective. In short, the financial perspective adopted (20%) situation is far from 84%, where an investment occurs, then this perspective is not sensitive to uncertainties. The same occur in the customer perspective, (23%) is far from the 35%, and the perspective process, (36%) vs 12% and the learning and growth perspective shows that there are not breakpoints and any adopted weighting produces the same result in the selection of alternative. Concluding that the decision of the panel is robust.

4. Conclusions

This paper has described the AHP process using the BSC approach in an industrial plant, describing customized maintenance concept, based on a purely strategic approach that serves as input to the tactical scope. This modular vision allows following a top-down scheme, starting in the early stages, more strategic of high level of abstraction.

In successive modular stages details of failures, malfunctions and/or particular conditions presented in the various item of equipment, facilities and machines can be detailed. The application of the first module, strategic level, in an industrial plant, has stood its use as a tool to decide by a group of experts formed by strategic responsible for different areas, of all productive areas, which area will be chosen to implement the maintenance actions, so that their production efficiency is increased. As productive area is understood as a section or productive unit clearly separated from the plant. For this we have modeled the decisional problem by using the AHP technique approach scorecard BSC, with the alternatives, in this case 4 productive areas that were pre-selected by experts. The calculation scheme AHP-BSC has been presented showing their variables: criteria and sub-perspectives-KPI. Expert Choice commercial package was used to model the problem and analyze the results. As a result, a combined decision has chosen a productive area and has analyzed the decision sensitivity, ensuring that it is robust. It can be concluded that the AHP-BSC model has the following advantages: Used as a first step to attend the first strategic-level decision allows evaluating individual consistency and re-consider the weights until a specified level of individual consistency. As multi-agent model, the combination of individual trials, gives more robust scheme while incorporating expert knowledge model, recording their individual preferences and combining them. Being a multi-criteria, the model is advantageous in data processing, data from the industrial process can be incorporated as quantitative, qualitative variables, or a mixture of both. This flexibility allows the AHP-BSC model can be used in other industrial plants with poor information, either through ignorance of certain data or because of restricted access. A final advantage is to evaluate the model sensitivity, allowing to observe the sensitivity to uncertainties in the data and the robustness of the group decision, allowing reformulate the judgments of experts in those little robust perspectives or variables.

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