ROLE OF AHP IN EVALUATION OF SOFTWARE MODELS CREATED FOR IMPROVEMENT ENVIRONMENTAL MANAGEMENT SYSTEM

Key words: AHP, Environmental Management System, software, evaluation

Abstract

In this paper, we have realized evaluation of four strategic management system models based on software system that includes ecological metrics which is created in order to improve environmental protection management inside the Pilot organization. The objective of this evaluation is to reduce the choice of solutions, and the choice is realized only after evaluation of quality in real working conditions. The evaluation of the model is realized by two teams using well–recognized MCDM methods such is Analytic Hierarchy Process (AHP) and respecting the relevant standards (ISO/IEC 9126 and ISO/IEC 14598), which points out the two best evaluated models. Following this approach, the significant improvement is achieved regarding the efficient choice of the best (from the offered) environmental protection model. The evaluation of the model presented in this paper is generally applicable regarding the choice and evaluation of the software systems models since it is based on MCDM method and using relevant standards which completely confirms the whole approach.

Introduction

The strategic management system represents the system of organizational performance measurement and improvement which is oriented to well–defined strategic objectives. Those objectives are cascadly transfer to all level of organization. Those systems are widely present in the world since they achieve significant results concerning organizational performance improvement through the good overview and monitoring of all relevant process characteristics. Therefore, we already examine in the papers\(^1\) and \(^2\) the possibility for environmental protection improvement using previously defined strategic management system which mobilizes all employees inside organization to be


oriented on clearly defined objectives. The very first activities in that field were related to the analysis of existing approaches including ecological objectives inside the strategic management system where we observed that the majority of organizations within this system define only a few ecological objectives, mainly those that are financially oriented\(^3\), \(^4\), \(^5\), \(^6\). In the paper\(^7\), three approaches are indicated concerning the integration of ecological objectives while there is no analysis concerning efficiency and effectiveness of environmental protection management using previously mentioned defined strategic management system. Therefore, this remark motivates us to analyze, inside the pilot organization which has developed strategic system management, all possibilities for environmental protection management improvement. Even if we start from the supposition that there are three approaches for ecological objectives integration inside the system of strategic management system, we develop four models for environmental protection management\(^8\). The basic two out of four created models are so-called ECO strategic management system (paper). This system represents the strategic management system which is completely oriented on environmental protection issues. Of course, it was necessary to connect this system with the basic strategic management system in order to avoid parallel managing systems inside the organization. This connection generates two models called Model 1 and Model 2, that both include ECO strategic management system, but the link with basic strategic management system is realized in different ways. In addition to these two models, we have created two more models that do not include ECO strategic management system, but the key ECO metrics is already implemented in strategic management system, also in two different ways. Hence, we created two more models Model 3 and Model 4.

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\(^4\) Bieker T., *Sustainability management with the Balanced Scorecard*, University of St Gallen, 2003.

\(^5\) Gminder C.U., *Environmental management with the Balanced Scorecard*, Institute for economy and the environment, Switzerland, 2005


In this way, we created 4 models that in different ways include the problem of environmental management system inside the strategic management system.

As a support for these models that accumulated significant number of data which are related to defined objectives and measures for objectives achievement at all levels inside the organization, we used commercial software. Hence, those models present the software system which is ready for implementation in realistic world.

Since we do not have the possibility to analyze all models in real working conditions, because of the quite long period that is necessary for the implementation of each model and for the evaluation of their quality, the choice of the most suitable model for implementation in pilot organization is realized based on expert evaluation using ISO standards and MCDM method. According to that, in this paper we define following hipotesis:

\[ H1: \text{Evaluating created software systems using Analytic Hierarchy Process (AHP) approach and relevant standard, the number of different solutions is decreased and the choosing of approach for final optimal implementation decision is more rapid.} \]

1. Decision making with the Analytic Hierarchy Process (AHP)

Methods of multi–criteria analysis and optimization are usually denominated by the acronym MCDM (“Multi Criteria Decision Making”) and they are used in all areas of decision–making. It has also been a practice to use several MCDM methods in solving one problem so as to compare results, because there is no absolutely the best method for all situations and usually it is not easy to verify validity of results. Certainly, methods that have a software support too are most commonly used nowadays.

This paper stresses the Analytic Hierarchy Process (AHP) well–known MCDM method of scientific analysis and decision–making by calibration of hierarchies whose elements are goals, criteria, sub–criteria and alternatives. Thomas Saaty represented conceptual and mathematical setting up of this model in 1980, and it has been enhanced through numerous scientific papers and doctoral thesis ever since \(^9\). AHP is reliable and easy to use for decision–making jobs and that is why it has been most commonly used and most popular among

experts and practitioners\textsuperscript{10}. It is a scientific qualitative and quantitative evaluation tool\textsuperscript{11}. \textit{Expert Choice} is a software for support of AHP that is entirely based on its mathematical basis and the most commonly used one.

AHP is multi–criteria method which is based on disaggregation of more complex problem on several levels of hierarchy with established objective on the top as the first level. The following level is criteria and sub–criteria and the final level represents alternatives. Actually, the basics of AHP hierarchy consists of three levels (objective, criteria and alternatives), but it is possible to further disaggregate this structure. This approach of disaggregation can be realized when necessary level of details is achieved. (Fig. 1) represents four levels of AHP hierarchy. However, it should be considered that it could be the case that (Fig. 1) does not present the complete possibility. In other words, it is possible that one criterion is not in common to all alternatives (k1, A1, A2) which divides the hierarchy into the sub–hierarchy with same objectives (Fig. 1). In AHP approach, the Objective is defined firstly and then criteria, sub–criteria and lastly the alternatives. Hence, the approach for defining problems is from top to bottom (UP BOTTOM). AHP allows evaluation of levels in both directions (UP BOTTOM) and (BOTTOM UP), but in the practices the evaluation from top, i.e. evaluation of criteria related to objectives, sub–criteria related to criteria, alternatives related to sub–criteria.


Final result of AHP method is a list of relevant alternatives significance related to objective. The comparison in pairs is realized by Saaty scale which is presented in (Table. 1) which is considered as a base for AHP implementation.

Table 1. Saaty scale of comparison

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<tr>
<td>1</td>
<td>The same meaning</td>
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<tr>
<td>3</td>
<td>Low dominance</td>
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<tr>
<td>5</td>
<td>Strong dominance</td>
</tr>
<tr>
<td>7</td>
<td>Very strong dominance</td>
</tr>
<tr>
<td>9</td>
<td>Absolute dominance</td>
</tr>
<tr>
<td>2,4,6,8</td>
<td>Inter–values that are used for presenting balance between notes</td>
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Source: 12, 13, 14.

In (Fig. 2) we present, through six steps by an algorithm, the overview of the decision approach using AHP method for problem defined hierarchical structure from “n” level.

![Fig. 2. AHP approach for decision making](image)

AHP is based on the following 4 principles:

1. **Decomposition** – complex problem is being decomposed into hierarchy where every level comprises many elements that are further decomposed
2. **Priority** – implies comparison and evaluation of paired elements from the same level in relation to the element of a higher level
3. **Synthesis** – Integration of evaluations per all levels in order to eventually get a list of priority elements of the last level (alternatives)
4. **Sensitivity analysis** – Stability of the final result is being additionally verified by testing the best choice by question “what – if” through hierarchical levels

AHP procedure itself is based on 6 basic steps:

1) definition of the problem and clearly set goal and possible alternatives (solutions) of the problem,
2) decomposition of the problem into hierarchical structure with defined criteria, sub–criteria and alternatives,
3) comparison of paired elements from the same level in relation to the element of a higher level,
4) determination of relative weight coefficients of hierarchical elements,
5) testing of evaluation consistency,
6) synthesis of relative weights of decision–making elements in order to get a complete evaluation of significance of alternatives (solutions).

The main advantage of AHP approach is regarding the possibility that apart from individual decision making, it allows group decision making which is more and more presented. Previously described procedures which are related to individual decision making represent the basics of group evaluation where we have more decision makers with fundamental differences concerning the summary of final results.

2. Model of evaluation using ISO standards

The utilization of relevant standards and approaches for quality software product evaluation, computer programs as well as data set inside organization give possibility to support their development and acceptance since they offer the evaluation of their quality in the phase when the software is not yet implemented. Having in mind specificity of models created for improving Environmental Management System using strategic management system, even if there are great number of standards for software products in this research we propose ISO IEC 9126 and ISO 14598 standards.

The purpose of quality software evaluation is to propose development support and accept software products to reach customer needs.

ISO 9126 standard requirement is used as a guideline for quality software testing and includes 4 following entities:


Concerning the first part of the ISO 9126 standard – Model 1 Software Quality, we should underline that it includes two models that are used for software quality evaluation:
- Internal and external quality model,
- Quality in use metrics.

3. Internal and external quality model

First part (internal and external quality models) is defined with 6 basic criteria that are further divided into 27 sub-criteria as it is presented in (Fig. 3).

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Model of internal and external quality evaluation is completely adopted for all types of software, computer programs as well as databases inside the

organisation. So, each criterion is defined through 4–5 sub-criteria that describe better their main purpose.

In series ISO 9126 standard, there are two technical standards ISO 9126–2 for external measures and ISO 9126–3 for internal measures that propose description of external and internal measures, more precisely description of attributes for each quality sub-criterion.

A part of ISO 9126 standard, ISO organisation has delivered series of ISO 14598 standard for Software Product evaluation as well as guideline for ISO 9126 standard utilization.

So, standard ISO/IEC 9126 defines general aim of quality model, quality criterion and gives examples of measures for ISO/IEC 14598. It gives directions and assignment of activities inside software products process evaluation.

Series of ISO/IEC 14598 standard propose directions and requests that should be realised inside evaluation process for three different situations:

- development
- adoption
- independent evaluation

Correlation between standards ISO IEC 9126 and ISO IEC 14598 is best described with (Fig. 4).

Fig. 4. Relations between ISO IEC 9126 and ISO IEC 14598 standards.

Source: 24


We can notice from the (Fig. 4) that ISO 14598–1 standard covers whole evaluation software product process in sense of evaluation approach, but it is supported by quality model which is defined by ISO 9126–1 standard concerning criterion that should be evaluated.

Evaluation software approach is presented by ISO 14598–1 standard and it underlines that software quality evaluation needs after all defined request for evaluation, specificity, design and that evaluation should be realised as it is presented in the (Fig. 5).

![Fig. 5. Evaluation process](source)

Evaluation process is presented through four key phases as it shown in (Fig. 5). Each sub-phase or activity is developed in detail as well as standards that improve their realisation.

Previously described evaluation model process is compatible with MCDM methods of decision making in which we have evaluated elements of one level relating elements of superior levels. This methods propose messages for level definition of certain measures and final mark of all proposed alternatives. It is realised by solutions synthesis with obligatory mark of consistency.

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Hence, with MCDM method choice which is compatible with software product evaluation process (ISO 14598) with defined model criterion and sub–criterion in way it is described by ISO 9126, organisation could successfully realise quality evaluation for any product software type.

Reference for standard used for evaluation created models in this research is ISO IEC 9126 which includes software product evaluation through assessment of internal and external quality model and quality model in use metrics.

ISO 9126 Standard allows dispensation of certain criterion and sub–criterion in evaluation process with justified explanation. However, to realise more precise sub–criterion definition it is necessary to realise technical analysis of ISO 9126–2 and ISO 9126–3 standards that recommend relative external and internal measures. In fact ISO 9126–2 and ISO 9126–3 standards propose for each quality sub–criterium internal and external measures that additionally explain their importance and signification but do not oblige for the utilisation of ISO 9126–1 standard, since each software product is specified by design and functioning conditions.

**Internal measures** apply software products which are not utilised during their development phase, while it enables customers to measure quality during the phase of software development as well as to forecast final product quality.

**External measures** could be used for software product quality measurement valuation of their behaviour inside the system. Utilisation of those measurements is possible only if measurement is realised in environment where software is utilised.

Literature analysis underlines that evaluation and software products choice are supported by certain MCDM methods that support approach evaluation of ISO 14598–1 standard description.

In fact, articles\(^{26}\), \(^{27}\), \(^{28}\) used AHP (MCDM method) for software product evaluation principles. Furthermore, each evaluation criterion is based on ISO 9126–1 standard suggestions. Some authors base evaluation on 6 basic criteria while others also use other 27 sub–criteria in choice of software product.

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4. Group AHP in evaluation models for improving Environmental Management Systems

The process of assessing software models is not feasible in their real working conditions, because a rather long period for the implementation of each model is needed, and a rather long period for the evaluation of their values in practice, and thus, the assessment of the models will be conducted from theoretical and empirical aspects of the experts from all areas of functioning. Namely, in the assessment of the models, the available standards for these issues will be analyzed and through their implementation in certain areas the usable value of each model will be defined according to the literature considered.

The reference standard for the assessment of strategic management system models created in this work is certainly the ISO IEC 9126 – Software engineering–Product quality–Quality Model, which considers the assessment of software products through the assessment of internal and external quality of the model and the quality of the model in use.

The evaluation of four strategic management system models is conducted only by the implementation of internal and external quality model, i.e. based on six criteria and their 27 sub criteria, while the evaluation of the “quality model in use” is provided for further researches after the implementation of the chosen model.

The ISO 9126–1 standard enables the exception of certain criteria and sub–criteria in the evaluation process, with the justified explanations. Nevertheless, in order to define the meaning of the sub–criteria more precisely, it is necessary to apply the technical standards ISO IEC 9126–2 and ISO IEC 9126–3, which recommend the relevant external and internal measures and explain the importance and meaning of each criterion and sub criterion.

The model evaluation process is conducted in two parallel sessions, by two teams:\n
- Team 1, whose members are the experts from the areas of environmental management system, but who are not employed in the pilot organization;
- Team 2, whose members are competent personnel from the top management of the pilot organization (including the EMS manager).

Team 1 conducts the evaluation of quality criteria (total of 6) and sub–criteria (27), based on the internal measures according standard ISO IEC 9126–3 with a view to evaluating the capabilities of the software product, to satisfy the

requirements and needs of the organization from the aspect of strategic management of the organization and environmental management system.

Team 2 conducts the evaluation of quality criteria (total of 6) and sub–criteria (27), based on the external measures according to the standard ISO IEC 9126–2 with a view to evaluating the degree in which the software product can, in real conditions, satisfy the requirements and needs of the organization from the aspect of strategic management of the organization and environmental management system. Apart from the series of ISO 9126 standards, the ISO organization has issued a series of ISO 14598 standard – Software product evaluation more as the instruction for conducting the evaluation process. The process of model evaluation described with the ISO 14598 standard is compatible with MCDM (multi–criteria decision making methods) methods, in which the evaluation of elements from one level is performed in relation to the element of a higher level. As it is previously said that the AHP model has, in purpose like this, used the MCDM method most often, and it is used for the needs of this evaluation, too.

Result of these methods represent list of ranking elements on the last hierarchy level called alternatives. The team members have performed the evaluation on the basis of all 6 criteria and 27 sub criteria (ISO 9126–1), so it can said that those are the AHP models of a group synthesis with complete information. The evaluation was conducted according to the principle of individual assessment of each team member, after which the integration of the evaluations was conducted. In that manner, group results of evaluations for Team 1 and Team 2 were achieved. This work will not provide separate evaluations of each team members, but only the group models achieved through the synthesis of the evaluations of team members. The results achieved by the evaluation of Team 1 (experts who are not employed in the pilot organization) are illustrated in the (Fig. 6).
The result of model evaluation done by Team 1 show high degree of consistency. Namely, the non–consistency of 0.02 is very good, bearing in mind that its maximum allowed value is 0.1. The solution of the Team 1 points to the best ranked Model 2.

The results gained through the evaluation of the models of Team 2 (managers from the pilot organization) are illustrated in the (Fig. 7).
The results of the evaluation conducted by Team 2 also point to a very good solution consistency (0.05). The best ranked model is also Model 2, as with the Team 1 evaluations. It is also illustrated here that the Model 2 has significant advantage in respect to other models. It is also obvious that the Team 2 favored the solutions with specially created Eco strategic management system, thus Models 1 and 2, while they estimated Models 3 and 4 with almost same evaluations and severely lower than those given to the models 1 and 2. With a view to gaining a final rank–list of the recommended models, another AHP evaluation was realized (Fig. 8), within which the results from Team 1 and Team 2 evaluations were incorporated.

Through the analysis provided by evaluation using AHP, illustrated in (Fig. 8), it can be noted that models which encompass the specially created ECO strategic management system (Models 1 and 2), through which they most broadly included the area of environmental management system in the organization, were the better ranked model. The first is Model 2.

The model which gained the lowest possible rank was Model 3, which is the least oriented on the environmental management system.
This evaluation decrease of the number of different solutions that are needed to be implemented inside the organization in order to value the quality of the model used according ISO/IEC 9126. More precisely, two models out of four are chosen which include Eco strategic management system and are also compatible what significantly facilitates evaluation of the quality in real work conditions and also are necessary for final decision concerning the choice of the best solution.

Consequently, the established hypothesis is confirmed.

**Conclusion**

Even that the environmental protection is actual subject in business world; still the majority of organizations treat the ecological objectives as less important than those that impose the survivor and development of the organization. Consequently, considering it as a challenge, the authors developed in the pilot organization 4 models that inside the well developed strategic management system includes also ecological objectives what permits improvement of environmental protection. Since, the test of all four models in real world was not technically possible in short period of time, what is necessary to determine the final decision, the experimental approach is used to evaluate effectively and efficiently model by respecting relevant standards and methods for supporting decision making.

The objective of this evaluation is to decrease the number of proposed solutions what induces the simplification of the quality testing of chosen models in real work conditions. Applying experimental evaluation by two teams using an AHP method and respecting the relevant standards (ISO/IEC 9126 and ISO/IEC 14598), the number of possible solutions decreases from four to two. Both of these
models includes Eco strategic management system what induces that are mainly oriented to environmental protection. Additionally, those two models are compatible what simplifies their implementation as well as the quality evaluation in real work conditions.

This approach of evaluation based on recognized MCDM method such as AHP, by respecting relevant standards such as ISO 9126 and ISO 14598, presents objective and reliable evaluation of the offered software programs what reduces the time necessary to choose the best solution for environmental protection management. The evaluation presented in this paper is applicable for evaluation and choice of all software models since it is based on MCDM method and using relevant standards what completely confirm the whole approach.

References

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