AN ANALYTICAL HIERARCHY PROCESS METHODOLOGY TO EVALUATE IT SOLUTIONS FOR ORGANIZATIONS

Spiros Vasilakos[(a)], Chrysostomos D. Stylios[(a),(b)], John Garofalakis[(c)]

[(a)]Dept. of Telematics Center, Computer Technology Institute & Press "Diophantus"
[(b)]Dept. of Informatics Engineering, Technological Educational Institute of Epirus, Arta, Greece

[(a)]vasilakos@westgate.gr, stylios@teiep.gr [(b)]stylios@westgate.gr, [(c)]garofala@cti.gr

ABSTRACT
Nowadays organizations continuously update, adopt or introduce new Information Technology Systems within their structure. This requires great resources in capital, staff and time. Selection and adoption of the proper information system and/or technologies must be performed in a way which will ensure that the system will meet the requirements and will fit in the organization's procedures and structure. This paper proposes a methodology for selecting the appropriate solution for an organization among the available options. It describes the requirement analysis phase where the selection criteria are defined and the available solutions are evaluated. For the evaluation of the different solutions, the Bipolar Analytic Hierarchical Process (BAHP) is proposed. The best solution is selected so as to fulfill the functional requirements and the requirements of the organization regarding the maintenance needs and the cost. The proposed approach is tested for the case of the Port Authority of Igoumenitsa, Greece.

Keywords: Information Systems, Modeling, Bipolar Analytical Hierarchical Process

1. INTRODUCTION

The ICT infrastructure of any organization has great importance. It supports the handling of any information and determines the effectiveness and performance of the organization. The adoption or update of a new IT System is an essential issue that may lead to higher efficiency both in customer services and in the organization's internal processes. But this selection is a complex process with great importance and any delay or failure to successfully adopt the new IT system within the organization's structure may lead to loss of critical amounts of resources. On the other hand, any failure to adapt to new technologies almost certainly means loss of competitiveness.

Thus, selection of new IT systems for any organization has to be done in a structured way. All the parameters that affect the choice of a new system must be taken into account. These parameters refer to the funds that the organization will invest, to the capabilities that the system must offer, to the technologies used as well as to how well the system can adapt to internal procedures and the philosophy of the organization and vice versa how some procedures of the organization can adapt to the capabilities of the system.

In this paper, we present a methodology to select the suitable IT technology that it is tested for the case of introducing an IT system at the port of Igoumenitsa, Greece. The first stage of the proposed methodology is the detailed domain analysis and requirements specification. Then, all the possible alternatives and the criteria that affect the decision are determined, regarding both the system requirements as well as criteria related to the organization's specificities. After the phase of alternatives and criteria recognition, there is the stage of eliminating alternatives that not fulfill some of the requirements and criteria required for the final choice. At the final stage, an updated version of the Analytical Hierarchy Process (AHP) (Saaty 1990) called Bipolar Analytical Hierarchy Process (BAHP) (Millet and Schoner 2005) is applied to prioritize the criteria and evaluate the different alternative solutions.

The rest of the paper is as follows: section 2 describes the problem of IT selection and the use of AHP in the specific area; section 3 describes the case study of the port of Igoumenitsa and its specificities. Then sections 4 and 5 describe the implementation of the proposed methodology and the results obtained, and finally section 6 concludes the paper.

2. IT SELECTION PROBLEM AND AHP

2.1. IT System Selection

The constant growth of demand for better services and/or products as well as cost reduction and better customer satisfaction, combined with the growth of complexity at all the operations of any organization makes the adoption of new technologies an absolute necessity. The adoption of a new IT system by an organization requires a high amount of resources both in capital investment as well as time for selection, installation and user training. The phase of adoption demands careful planning so that the influences to the business processes are as smooth as possible.

IT system selection is a Multi Criteria Decision Problem with many factors competing each other. First of all, one main factor is the capital investment. The cost of acquisition of any IT system is not the only factor that must be taken into account. Costs like maintenance, support and license must be considered as well. The capabilities of the product must be also examined in detail in order to verify if they fulfill both functional and non-functional requirements of the organization. Non-functional requirements demand special attention as in many cases they are qualitative and cannot be easily, or are impossible to, be quantified. Finally, the problem of IT system selection becomes even more complicated when the option to develop the system exists along with the option to select an 'of the shelf' commercially available product.

Many methodologies have been proposed for the selection of the appropriate IT system. Jadhav and Sonar (2009) reviewed a large number of methodologies for software selection, evaluation techniques and criteria; among others AHP, Feature Analysis, Weighted Average Sum (WAS) and Fuzzy-based approaches have been proposed. A general selection approach consists of six steps, beginning from the domain analysis and proceeding to gradually decomposing the criteria until quantifiable measures are used (Franch and Carvallo 2002). A set of actions that include the determination of alternatives and steps for their qualification was proposed by Jadhav and Sonar (2011). Stamelos and Tsoukias (2003) proposed the categorization of the software selection problem in seven categories.

2.2. The Analytic Hierarchy Process (AHP) and the Bipolar AHP (BAHP)

AHP introduced in the '70s (Saaty 1980, Saaty 1990) and since then it has found a wide adoption and use (Saaty 2008, Saaty and Vargas 2012). Especially at the domain of IT system selection AHP has been widely applied (Cebeci 2009; Lai, Wong, and Cheung 2002; Wei, Chien, and Wang 2005). AHP is a Multi Criteria Decision Methodology (MCDM) that uses a hierarchy to formulate the problem. At the top of the hierarchy the goal of the decision is placed. The second level includes the criteria that are used for comparison. Each criterion may have sub-criteria that are placed at the consequent levels. At the final level, all the alternative choices are placed.

A 1-9 scale is used to determine the relative importance between the criteria. Their meaning is shown in Table 1.

Table 1: The Range from 1 to 9 used in AHP to Determine Relative Importance among Criteria

Relative Importance	Value
equal	1
moderate	3
strong	5
very strong	7
extreme	9
intermediate values	2,4,6,8

For *n* criteria a comparison matrix $\mathbf{A}_{(n\,\mathrm{x}n)}$ is formed. In the a_{ij} position of the matrix the relative importance of the i_{th} criterion compared to the j_{th} criterion is placed and consequently in the a_{ji} position the $1/a_{ij}$ value is placed. So, a reciprocal square matrix is formed where value 1 is placed in the diagonal a_{ii}

$$A = \begin{pmatrix} 1 & a_{12} & a_{13} & \dots & a_{1n} \\ 1/a_{12} & 1 & a_{23} & \dots & \\ 1/a_{13} & 1/a_{23} & 1 & \dots & \\ \dots & & & \dots & a_{(n-1)n} \\ 1/a_{1n} & & & 1/a_{(n-1)n} & 1 \end{pmatrix}$$

The relative weights of the criteria are the normalized eigenvector v_n of comparison matrix $\mathbf{A}$. The same procedure is followed with the alternatives. So, for *m* alternatives that are compared to *n* criteria a $\mathbf{W}_{(mxn)}$ matrix is formed where $w_{n,m}$ is the ranking of alternative *m* in relation to criterion *n*. The final ranking of each alternative $r_i^{(i=1:m)}$ is calculated with equation (1):

$$r_i = \sum_{j=1}^{n} w_{i,j} v_j \qquad (1)$$

When numerical values are available, then they are used instead of the 1-9 scale. AHP have the ability to combine both qualitative and quantitative criteria. Due to the nature of IT system selection, both kinds of criteria have to be used, so AHP is used in many cases (Jadhav and Sonar 2009).

In many multicriteria problems, along with factors that contribute positively to the decision; there may exist factors that have negative impact. Common factors of this category can be cost, time, and required effort. The strictly positive additive values of equation (1) in the final ranking of AHP make handling of such negative factors problematic. The standard procedure is to use inversion of these values. But inversion of a positive number also leads to a positive number, in this way factors with great negative contribution are treated as factors with very small, but still positive, contribution, which may lead to incorrect ranking. For these reasons, it is preferable the use of BAHP (Millet and Schoner 2005). BAHP is an extension of AHP that allows the incorporation of negative factors into the AHP calculations. Factors that have negative contribution to the decision are treated as negatives in the final ranking calculations and are not inverted.

3. METHODOLOGY DESCRIPTION

For any IT system selection there are two main options either to choose among available commercial systems or to develop an IT system from scratch when there are not available commercial systems that fulfill all requirements. Thus, here we include both of these options.

The proposed methodology is analytical and precise, but also flexible enough so that it is able to adapt to a variety of scenarios (Figure 1).

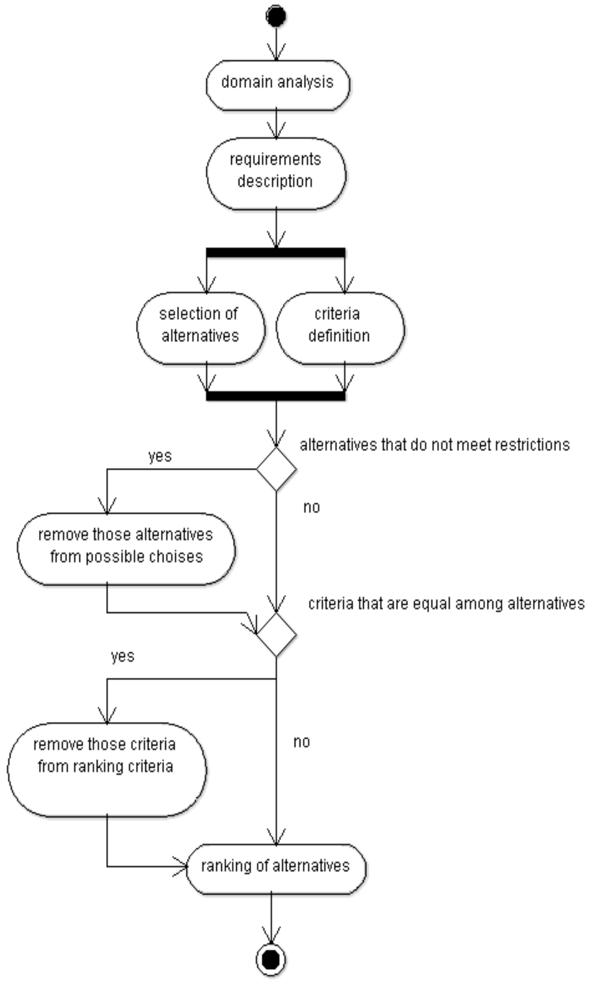


Figure 1: UML Activity Diagram describing the Sequence for IT system Selection Methodology

The first step for every IT system selection is to perform a detailed domain analysis. Sometimes, this is an overlooked step, but it is of high importance. The domain of interest must be analyzed so that to describe in detail all the procedures that the system has to support. The analysis must be done in many perspectives, covering all the spectrum of user categories. Overlooking this step and considering the procedures description and analysis as trivial can lead to unpredicted situations and to the selection of an IT system that does not fulfill all the requirements and procedures within the organization.

Next step is the description of the requirements, both functional and non-functional. The term "functional requirements" describes specific tasks that the IT system has to perform. There are includes the intended behavior of the system that is expressed as tasks and/or behaviors. Non-functional requirements are used to describe criteria and goals of the system rather than certain behavior and can be qualitative attributes.

The next two steps can be performed in parallel. The first one is the selection of alternatives and the second one is the determination of comparison criteria. There are two main alternatives either to select existing commercial IT system or to develop of a new IT system. In the second case, there are some more subcategorized alternatives regarding the technologies to be used. .

In addition to this, the different criteria for the comparison of the alternatives have to include all aspects of the system's implementation, usage and functionality. These criteria can be divided into four categories: i) managerial, ii) user-related, iii) technology-related and iv) vendor-related.

Managerial criteria are mostly related to cost and to required implementation time of the project. User-related criteria refer to the capabilities of the system (whether it satisfies the functional and nonfunctional requirements) as well as the ease of use and learning cycle of the IT system. Technology-related criteria refer to technologies used by the system, both software- and hardware-related. Finally, vendor-related criteria refer to the vendor's reputation, expertise and stability.

After the selection of alternatives and criteria, the phase of elimination follows. Firstly, the existing alternatives are compared to an initial set of criteria. These criteria do not regard the functionality of the system, since all the alternatives must fulfill the system requirements. The initial set of criteria is usually related to management, and we name them "hard criteria", they are mostly constraints that are used to eliminate alternatives from the set of choices and not to compare them. Such criteria can be cost or time of deliverance and any other criteria that impose certain restrictions to a particular project. For example, all alternatives up to a certain cost are among the candidates for selection and the cost will be calculated as a criterion in the final decision, but alternatives exceeding a certain cost are unacceptable and are eliminated from the selection procedure.

The criteria elimination procedure is the following: criteria that have the same value among different alternatives are eliminated. The elimination of alternatives and criteria is important as it reduces the amount of required calculations and furthermore it eliminates the potential to choose an unacceptable alternative.

The final step is the ranking of alternatives using a Multi Criteria Decision Methodology (MCDM). As aforementioned, we use the Bipolar Analytic Hierarchical Process (BAHP). BAHP has the main advantage to use negative values in the ranking calculation for criteria that have negative impact on the final decision. The BAHP that has described above forms a hierarchy, with the four criteria and their subcriteria at lower levels of the hierarchy and it is shown at Figure 2.

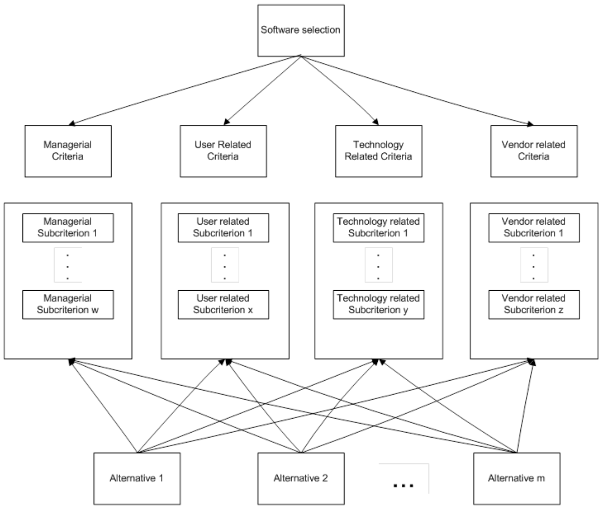


Figure 2: The Hierarchy formed for IT system Selection

4. CASE STUDY

4.1. Problem Description

The port of Igoumenitsa is a very important transport hub of Northwestern Greece. It connects Greece to Italy and mainly provides ship docking, passenger and vehicle traffic services. It focuses on passenger traffic through ferry connections to domestic and foreign destinations, while goods are transported mainly by trucks. It serves a high amount of vehicle and passengers in relation to its size. In 2012, it served a total of 1.436.239 passengers, 338.355 private vehicles and 79.814 trucks for domestic destination and 79.814 passengers, 120.409 private vehicles and 68.702 trucks for abroad destinations (OLIG S.A. 2013).

Our team collaborates with Igoumenitsa Port Authority (OLIG) within the Generalized Automatic Exchange of Port Information Area project (GAIA). We provide OLIG with consulting services by describing the functionality and organization for an Integrated Information System which will supply the Port Authority with the desired functionality for passenger, vehicle and authorized personnel trafficking in the port areas and also the itineraries to and from the port. Every passenger, in order to enter the port facilities, is supplied with a boarding card. These cards will be edited by the shipping agents to the customers and they will contain all the necessary information allowing the passengers to pass any security checks. Similar procedure will be followed for vehicles. The authorized personnel and their vehicles will make use of security cards in order to access the port area. In addition, the different IT systems of the shipping agents, responsible for the tickets/boarding passes editing, will communicate with the overall port's system in order to provide the required data.

The Integrated Information System will be able to process and store data regarding all procedures of the port operations related to the itineraries and passenger and vehicle traffic. Also a Database Management System (DBMS) will be included in the system that will provide the required scalability for the storage and processing of large amount of data and the tools to monitor and tune the database.

4.2. Approach and Criteria Selected

4.2.1. Methodology Used

For the selection of the appropriate technology, a detailed domain analysis was initially performed. This phase involved interviews with the interested parties/Stakeholders that are somehow influencing the system, such as staff of Port Authority, of Shipping Companies, of Customs Office and of the Coast Guard.

After this domain analysis, the user main categories were identified. Regarding, Port Authority, two categories exist: one from a managerial perspective and one from users perspective. The first category is interested more in factors regarding the cost of the system and its value as a long-term investment. The second category was mainly concerned about the user-friendliness of the system and its capabilities regarding its everyday usage and administration. The Shipping companies, in order to provide the necessary data, will connect to the system through their operational IT systems. Their main concern was about the compatibility of the system and the ease of the interconnection implementation. Passengers are the final beneficiaries as they will use the system to enter the port area and during their boarding procedure. Their main concerns were about the speed and the user friendliness of the system.

At the next stage, the functional and non-functional requirements were described. In addition to this, the architectural description of the system was described, including the system's functionality, the actors of the system, the components and their interactions. After this phase, the main criteria regarding all the aspects of the system's implementation, usage and functionality and the available alternatives were determined.

Then, there is the first phase of the selection, where we followed the elimination procedure, i.e. any choice that did not cover certain criteria was eliminated. Also criteria whose values were the same among the alternatives were eliminated. In the second phase of the selection procedure the alternatives were ranked according to the remaining criteria based to the BAHP.

4.2.2. Evaluation Criteria

The evaluation criteria are divided into four main categories: i) Managerial, ii) User-related, iii) technology-related, iv) vendor-related.

The managerial criteria include mostly cost-related criteria and the implementation time of the project. The selected criteria are: cost of the project which includes development cost, maintenance cost, support cost, hardware cost, usage of already existing equipment and delivery time of the system.

User-related criteria mainly regard the capabilities of the system (whether it would satisfy the functional and nonfunctional requirements) as well as ease of use and learning curve of the system. The actors related to these criteria are the back end users that monitor the traffic in the port, retrieve data and reports and perform administrative tasks. The criteria for this category are: fulfillment of requirements, user-friendliness for operators, user-friendliness for passengers, learning curve for operators, and accessibility from different devices.

Technology-related criteria refer to the technologies that will be used to implement the system or that the commercially available system uses, both software- and hardware-related. The main actors concerned with these criteria are the company that will develop the system, the shipping companies whose IT systems will interact with the system, and both the management and users of the Port Authorities regarding software/hardware support and warranties. The criteria for this category are: reliability, speed, database capabilities, security, ease of upgrade and maintenance, hardware compatibility, ease of integration with other systems and support and warranty.

Finally, vendor-related criteria concern the choice of the candidate vendors and include vendor expertise, experience and stability. The criteria for every category are shown in table 1.

Table 1: Selection Criteria for each category

Category	Criteria	Sub-criteria
Managerial	Cost	development cost; maintenance cost; support cost; hardware cost; software (DBMS) cost; use of existing equipment
	Delivery time	
User-related	Fulfillment of requirements	
	User-friendliness	user-friendliness for operators; user-friendliness for passengers; learning curve for operators
	Accessibility from different devises	
Technology-related	Capabilities	Reliability; Speed;, database capabilities; security; ease of upgrade and maintenance; hardware compatibility; ease of integration with other systems
	Support and Warranty	
Vendor-related	Expertise	
	Experience	
	Stability	

4.2.3. Alternatives

Four main alternatives were considered: i) acquisition of an existing commercial system ii) updating the existing IT system that does not meet the functional and non-functional requirements iii) design and develop the system from scratch using proprietary technologies and software and iv) develop an new system using free/open source technologies and software.

4.2.4. Elimination of Alternatives and Criteria

In this phase, the different alternatives were examined. The acquisition of an existing system was excluded, as none of the available systems fully covered the requirements and the acquisition cost was significantly higher than the cost of the other three alternatives. Also difficulties would arise in using existing hardware equipment consisted of barcode/RFID readers, license plate recognition cameras and the acquisition of new would further increase the cost. This choice would be delivered in a quite short period of time, but this advantage by itself is not so important to consider this alternative as a choice.

Regarding the criteria, the fulfillment of requirements was eliminated as it is a prerequisite, since the requirements of the system were described and the final developed system will cover all the requirements. Also user-friendliness for the passengers was removed from the list since in all cases, the passengers will interact with the system in the same way regardless the used technologies. Both the programming language and the DBMS in the three cases are compatible with the majority of hardware, so the criterion of compatibility was removed. Finally, in our case-study, the vendor-related criteria were also removed, as only one vendor was final candidate. Table 2 shows the criteria after the elimination phase.

Table 2: Criteria used after the Elimination of the Criteria that would not affect the selection

Category	Criteria	Sub-criteria
Managerial	Cost	development cost; maintenance cost; support cost; hardware cost; software (DBMS) cost; use of existing equipment
	Delivery time	
User-related	User-friendliness	user-friendliness for operators; learning curve for operators
Technology-related	Capabilities	Reliability; Speed;, database capabilities; security; ease of upgrade and maintenance; ease of integration with other systems
	Support and Warranty	

Figure 3 illustrates a diagram with the remaining, after the elimination, criteria and their hierarchy.

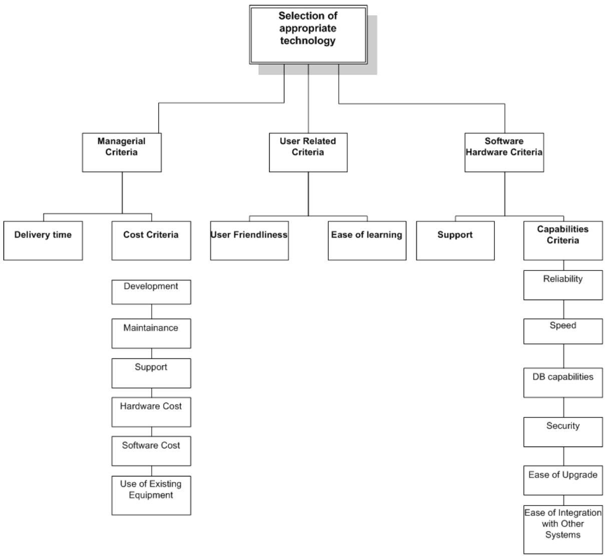


Figure 3: The hierarchy of the criteria after the elimination phase

5. CALCULATIONS AND RESULTS

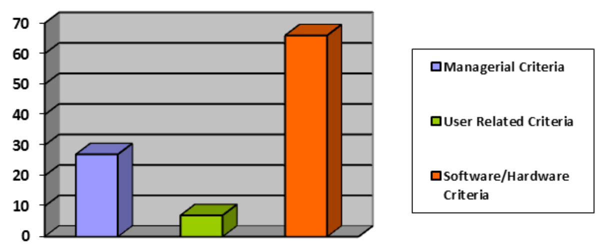
5.1. Calculations

The values and priorities regarding the criteria were acquired by the Port Authority staff that acted as the domain experts. They explained the importance of all criteria and, after a brief explanation of the BAHP methodology, they suggested their estimations about the relative weights for each factor. In this case, mostly qualitative criteria were used. In table 3 the comparison matrix between the main criteria is shown and figure 4 illustrates a chart with the calculated importance of each criterion.

Table 3: Values among Main Criteria

	Managerial	User-related	Technology-related
Managerial	1	5	0,333
User-related	0,2	1	0,125
Technology-related	3,000	8	1

Figure 4: The percentage weight of each of the three main factors



Due to space restrictions, we cannot present all the tables that have been formed and the calculations performed for each of the sub-criteria. The final weights of all sub-criteria are presented in Table 4, as well as whether the contribution to the decision has positive or negative affect.

Table 4: The Weights of the Criteria and Sub-criteria in Percentage Values and Positive or Negative Contribution of the Criteria

Managerial Criteria	Contribution	%
delivery time	negative	9
development	negative	6,65
maintenance	negative	1,80
support	negative	1,44
hardware cost	negative	3,78
software cost	negative	2,16
use of existing equipment	positive	2,16
Total Cost percentage		17,98
Total percentage of managerial criteria		27

User-Related Criteria	Contribution	%
User-friendliness for operators	positive	4,66
learning curve for operators	positive	2,33
Total percentage of user-related criteria		7

Technology-related Criteria	Contribution	%
support	positive	21,98
reliability	Positive	16,70
speed	Positive	2,07
DB capabilities	Positive	7,91
security	Positive	7,91
ease of upgrade and maintenance	Positive	3,52
ease of integration with other systems	Positive	5,85
Total capabilities criteria		43,96
Total percentage of technology related criteria		66

Moreover, there were asked experts from vendors to estimate the time of development and experts from Computer Technology Institute & Press estimated the software and hardware capabilities of the specific technologies. In addition, the costs and actual prices of DBMS licenses and support, as well as the maintenance cost were estimated.

After the estimation of the corresponding criteria, the calculation of the alternatives ranking was performed. Table 5 presents the scores of the three alternatives regarding the available support for each solution.

Table 5: The scores of the alternatives regarding the support criterion

Update of existing system	**27%**
Development with proprietary technologies	**60%**
Development with open-source technologies	**13%**

The final calculations were performed using the BAHP and Table 6 presents the score for each alternative.

Table 6: Scores of each of the alternatives

Alternative	Score
Update of existing system	**0,05141**
Development with proprietary technologies	**0,32606**
Development with open source technologies	**0,15386**

5.2. Result Analysis

The alternative of improving the existing system received the lowest ranking. The main advantage of this solution was the utilization of the existing equipment. But it would require updating the existing programming code produced by a non-up-to-date programming language. Moreover, the existing system did not met the requirements so it would require more development time that introduce further risk for the final system not to meet the functional requirements.

Poor project planning is recognized as one of the main reasons for software projects failure (Han and Huang 2007, Whittaker 1999). Incorrect or incomplete system requirements are another one of the top five reasons for software projects failure (Baccarini, Salm, and Love 2004, Han and Huang 2007). Since the existing system did not fulfill the requirements, attempt to use code that has not been properly developed and was poorly designed in the first time is likely to require more development time or even to project failure. Also, since the used programing language is not-up-to-date, it lacked from the two other solutions in quality characteristics.

The development with proprietary technologies scored highest and was recommended as the appropriate solution. Development with open source solution had lower cost, mainly related to the lack of license costs. Also regarding some quality characteristics, it is equal and better than the proprietary solution. However, the development with proprietary technologies has the advantage of support and guaranties that come along with the use of proprietary solutions. The lack of standard support in the case of using open source technologies could potentially lead to greater cost when an update of the system would be required or in case of system malfunction. This is very critical for the case under study, because OLIG has not qualified and experienced IT team to support and maintain the system.

Our results come in accordance with other researches results; actually, the success of open source technologies adoption from an organization greatly depends on the organization's IT capabilities and its experience in using open source software (Lin 2008; Goode 2005; Spinellis and Giannikas 2012). Also, the lack of reliable technical support is recognised as one of the reasons that Open Source Software is rejected (Goode 2005).

6. CONCLUSION

This paper describes a procedure for the selection of appropriate technologies for the development of an IT system regarding the passenger, vehicle and authorized personnel in a Greek port. After the determination of the functionality requirements, the possible solutions and the corresponding criteria were identified. A two-stage procedure was followed. At first stage, solutions that did not meet certain requirements and criteria that would not affect the selection (having the same characteristics among the remaining solutions) were eliminated.

Commercial available system was removed from the candidate solutions, because its price exceeded the available budget of the project and in addition to this not all the requirements were met. For the selection of the appropriate solution, the Bipolar Analytic Hierarchical Process (BAHP) was implemneted so that criteria with negative impact would be incorporated. From the examined solutions, the further development of an earlier non-functional system received the lowest score. The solutions with the higher scores were the development of the system from the beginning with proprietary or with open source technologies. Although the capabilities and characteristics of the technologies had a high impact on the final results, characteristics related to the software guaranties and support played a fundamental role in the final selection of the proprietary solution. Our results are similar to other studies and point out that lack of experienced IT teams is one of the factors for which organizations prefer proprietary solutions, even if open source solutions with similar capabilities are available.

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AUTHORS BIOGRAPHY

Spiros Vasilakos is research collaborator at Computer Technology Institute & Press “Diophantus”. He received his diploma from the Department of Computer Engineering & Informatics, University of Patras. His scientific interests include: System Modeling and Analysis, Decision Support Systems and Multicriteria Decision Methodologies.

Chrysostomos D. Stylios is an Associate Professor at Dept. of Informatics Engineering, TEI of Epirus; he is a senior researcher at Telematics Center Department of Computer Technology Institute & Press. He received his Ph.D from the Dept. of Electrical & Computer Engineering University of Patras (1999) and diploma in Electrical & Computer Engineering from the Aristotle University of Thessaloniki (1992). He has published over 100 journal and conference papers and book chapters. His main scientific interests include: Fuzzy Cognitive Maps, Soft Computing, Computational Intelligence Techniques, Neural Networks, Knowledge Hierarchical Systems and Decision Support Systems

John Garofalakis, born in 1959, obtained his Ph.D. from the Department of Computer Engineering and Informatics (CEID), University of Patras, Greece, in 1990, and his Diploma on Electrical Engineering from the National Technical University of Athens, Greece, in 1983. He is currently Professor in CEID and manager of the Telematics Center Department at the Research and Academic Computer Technology Institute of Greece. His research interests include performance evaluation, distributed systems and algorithms, Internet technologies and applications. He has published over 100 papers in various journals and refereed conferences and is author of several books and lecture notes in the Greek language.