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Decision Support for Information Systems Management: Applying Analytic Hierarchy Process

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SOM theme A: Structure, Control and Organization of Primary Processes

Abstract : Decision-making in the field of information systems has become more complex due to a larger number of alternatives, multiple and sometimes conflicting goals, and an increasingly turbulent environment. In this paper we explore the appropriateness of Analytic Hierarchy Process to support I/S decision making. AHP can be applied if the decision problem includes multiple objectives, conflicting criteria, incommensurable units, and aims at selecting an alternative from a known set of alternatives. An AHP analysis is described by using the project selection decision as an example. The strengths and weaknesses of AHP are investigated based on a set of eight criteria for evaluating I/S decision support methods. This evaluation shows that AHP scores well on most criteria. Given this promising performance, other possible applications of AHP within the I/S function are listed.

Introduction

Information systems (I/S) managers are used to develop applications to support operations and decision-making in the non-I/S functions of an organisation, such as finance, production and marketing. Only recently, the possibility has been explored of using information systems to support I/S activities. Well-known examples are diagramming tools, screen generators, code generators, report generators, configuration management tools and other CASE tools (Fuggetta, 1993; Orlikowski, 1993; McComb, 1994). These systems mainly support operational activities in the I/S function. With the increasing complexity of I/S decision-making there is a need to extend information technology based support to I/S decision-making as well.

In the last decade, I/S decision-making has become more complex due to reasons related to (1) the alternatives, (2) the goals and (3) the environment in which I/S decisions are being made. First, for almost any I/S decision the number of alternatives has grown dramatically. Only about a decade ago, I/S departments built information systems on their own and dealt with only one vendor. Nowadays, the single vendor concept has been left, there are numerous alternatives for developing software (by I/S department, an external software house, end-users, or purchasing a canned package), and terms as outsourcing and facilities management refer to a range of I/S activities that can be supplied by external agencies (Lacity and Hirschheim, 1993; Ketler and Walstrom, 1993; Grover et al., 1994). Second, the number and the nature of the goals, criteria or constraints, have changed. When making I/S decisions, the goals are not limited to I/S related objectives anymore, such as compatibility of hardware and software, preventing data redundancy, and maintaining data integrity. Nowadays, user departments are involved in making I/S decisions and have added their own goals, including political considerations (Franz and Robey, 1984). Some goals are conflicting, many are not well-defined and hardly measurable. The third set of reasons for the increased complexity of I/S decisions refers to the environment I/S managers are faced with. I/S budgets are being cut, hardware and software technology is changing rapidly, and top-management wants to use Information Technology strategically but is considering outsourcing options simultaneously (Earl, 1989; Galliers, 1993). The changing alternatives, goals, and environment enlarge the complexity of I/S decisions and call for effective I/S decision support.

Decision-making involving multiple, sometimes conflicting, objectives and/or criteria is called Multi Criteria Decision-Making, MCDM (Hwang and Yoon, 1981). Often the criteria include both qualitative and quantitative factors, whereas the quantitative criteria may be measured in incomparable units (for example, the market share of a vendor and the price of a software package of that the vendor). MCDM is a broad and fertile field of research and applications aimed at more efficient and effective decision-making. One of the MCDM methods to which recently much attention is being paid, is Analytic Hierarchy Process (Saaty, 1977, 1980). The use of Analytic Hierarchy Process (AHP) is not restricted to a particular business function, in fact AHP has been applied to support decision-making in business functions such as accounting (Apostolou and Hassell, 1993), marketing (Dyer and Forman, 1992), production and logistics (Min, 1992; Mohanty and Venkataraman, 1993). Recently, a few papers have been published describing case studies in which AHP is applied to support a particular I/S decision (Finnie et al., 1993; Lee, 1993; Mitta, 1993; Yau and Davis, 1993).

In this paper we will explore the appropriateness of AHP to support I/S decisions in general. We will discuss the method itself, and its strengths and weaknesses with respect to I/S decision-making. The first section of this paper contains a brief overview of the various phases in AHP. By using the project selection decision as an example we will show how AHP supports decision-making. After this introduction into AHP, AHP is evaluated by means of a framework of eight criteria. These criteria refer to requirements that should be met by a method that is capable of supporting I/S decision-making. In the third section we will discuss which I/S decisions may benefit from support of AHP. Finally, we will present some conclusions upon the appropriateness of AHP to support I/S management decision-making

1 - Analytic Hierarchy Process: An I/S Example

This section describes Analytic Hierarchy Process as it has been developed by Thomas Saaty of the Wharton School of Business (Saaty, 1977, 1980). We will use the project selection decision as an example of a complex I/S decision. This decision is being made at the end of the information systems planning process. By using methods such as Information Engineering (Martin and Leben, 1989), Business Systems Planning (IBM, 1984) or Critical Success Factors (Rockart, 1979; Byers and Blume, 1994) management identifies a number of information systems that have to be developed. Then, it has to make the decision in which order these systems will be implemented. Determining the priority for each system is not easy because a large number of factors play a role (Agarwal et al., 1992; Parker et al., 1988; McFarlan, 1981). These factors do not only involve financial aspects, such as pay back period and the internal rate of return, but also qualitative factors, such as the extent to which the system supports organisational goals. The latter are hard to quantify, let alone to express in financial terms. Among the methods that have been applied to support the project selection decision are cost-benefit analysis (Hares and Royle, 1994), risk analysis (McFarlan, 1981), scoring models (Melone and Wharton, 1984), and ranking (Buss, 1983). Due to the characteristics of the project selection decision AHP might be applicable as well (Muralidhar et al., 1990). Analytic Hierarchy Process involves nine phases (see Figure 1). We will discuss each phase briefly.

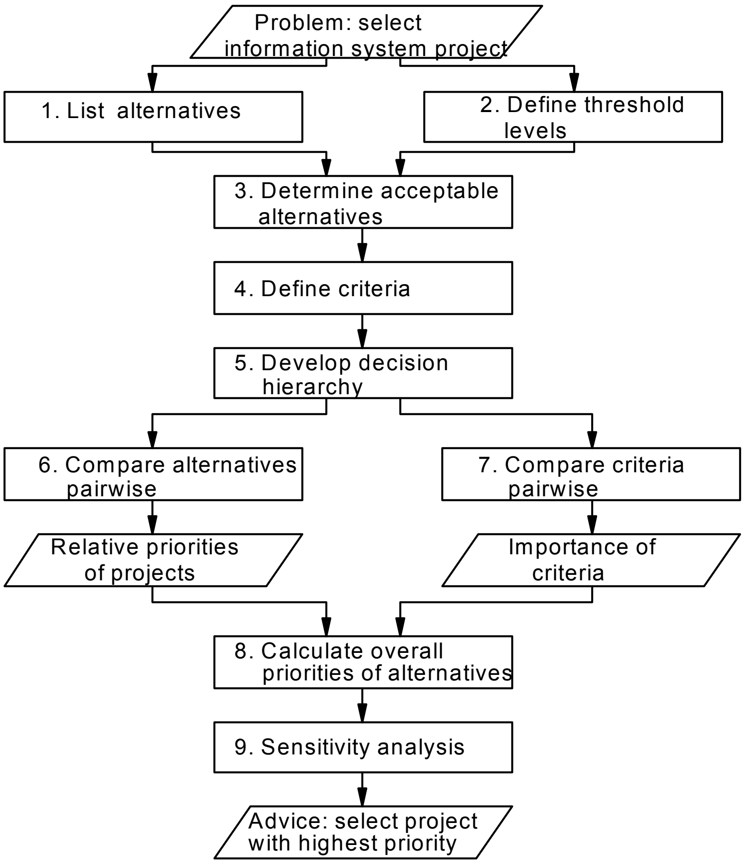

Figure 1: Nine phases of Analytic Hierarchy Process

1. List alternatives

In terms of Simon's (1960) model of the decision-making process (Intelligence, identifying the problem, Design, generating and evaluating alternatives, and Choice), AHP supports the choice-phase. The goal in this phase is to select one particular alternative from a set of known options. Therefore, the first step in AHP is to list all alternatives. In case of the project selection decision all proposed information systems are listed.

2. Define threshold levels

Next, the threshold levels are defined; these are the minimum requirements which an alternative has to fulfil. Possible requirements are a minimum level for the return on investment and the pay-back period. Sometimes there is a logical sequence between proposed systems: if one system needs data captured in another system, then obviously the latter has to be built first.

3. Determine acceptable alternatives

All alternatives listed in step 1 are reviewed with respect to the threshold levels. Alternatives which do not meet these requirements are dismissed. Suppose projects A, B, and C meet all threshold levels.

4. Define criteria

In the fourth phase, management defines the criteria that will be used to judge the alternatives (the projects). Dyer and Forman (1991, p. 27) suggest three methods to select criteria, a pro/con analysis of the alternatives, using 'off-the-shelf' norms, and the critical success factors technique. To avoid complexity, we will use Return On Investment (ROI), Risk, and Strategic Importance as the only three criteria in our example. AHP allows criteria to be decomposed into subcriteria, for example, in reality ROI may be a subcriterion of the criterion 'Financial Considerations', just like Pay-Back Period and Net Present Value.

5. Develop decision hierarchy

Now the alternatives and the criteria have been defined, the manager develops a decision hierarchy. This hierarchy consists of at least three levels, a goal, criteria and alternatives. These elements are represented in a tree structure (see Figure 2). The hierarchy represents the structure of the decision problem and forms the basis of the comparisons which have to be made in the following phases.

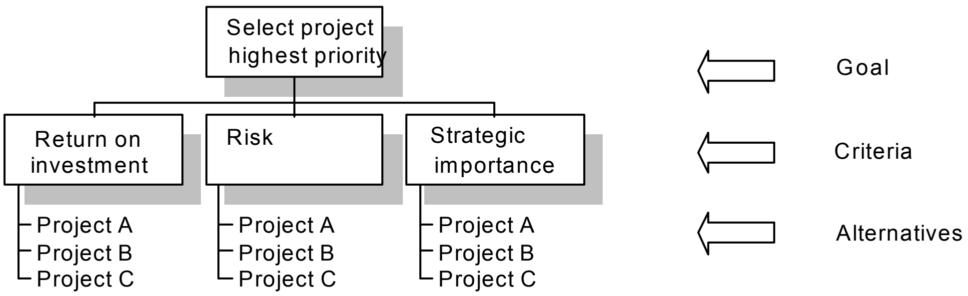

Figure 2. The decision hierarchy for the project selection decision.

6. Compare alternatives pairwise

For each criterion, the decision maker evaluates all alternatives pairwise. The manager answers questions such as: 'is project A better than project B with respect to the criterion ROI, and if so, to what extent'. For each criterion, every possible combination of two alternatives is judged in this way. The other criteria or characteristics of an alternative should not be considered in making the pairwise comparisons with respect to one particular criterion.

Managers can make numerical or verbal judgements. In the verbal mode, statements are selected varying from 'equally preferred' to 'extremely preferred' (see Table 1). In the numerical method, the decision maker selects a score from a scale of 1 to 9. A score of, for example, 2 indicates that one alternative is twice as preferable to the other alternative.

Table 1. Judgements scale for Pairwise Comparisons

Verbal judgments	Numerical Judgements
Equally preferred	1
Equally to moderately	2
Moderately preferred	3
Moderately to strongly	4
Strongly preferred	5
Strongly to very strongly	6
Very strongly preferred	7
Very strongly to extremely	8
Extremely preferred	9

The pairwise comparisons are the input of the AHP model that calculates the relative priority of each alternative. 'Relative' in this context means the priority with respect to a particular criterion. In calculating the relative priorities, AHP uses the eigenvalues and eigenvectors of the pairwise comparison matrix (Saaty, 1980). However, in this example we will apply an approximation approach which is much easier to understand.

First, the pairwise comparisons are represented in a matrix. Because each pair of alternatives is judged only once, this matrix is not full. The matrix is filled by deriving the remaining pairwise comparisons from the judgements the manager made (the comparisons are 'mirrored' on the diagonal, for example, if A is twice as preferable to B, then B is half as preferable to A). The diagonal is filled with 1's, because each alternative equals itself. The full pairwise comparison matrix is shown in Table 2.

Table 2: The full judgement matrix

ROI	Project A	Project B	Project C
Project A	1	2	8
Project B	1/2	1	6
Project C	1/8	1/6	1
Total	13/8	19/6	15

For each column the totals are calculated. Then the columns are normalised by dividing each value by its column total. The normalised pairwise comparison matrix is displayed in Table 3. Finally, the relative priority for each alternative is determined by calculating the mean of the values in a row (see Table 4).

Table 3. The normalised pairwise comparison matrix.

ROI	Project A	Project B	Project C
Project A	8/13	12/19	8/15
Project B	4/13	6/19	6/15
Project C	1/13	1/19	1/15
Total	1	1	1

Table 4. The relative priorities for the criterion ROI.

ROI	Project A + Project B + Project C	Row average
Project A	$\frac{8/13 + 12/19 + 8/15}{3}$	= 0.593
Project B	$\frac{4/13 + 6/19 + 6/15}{3}$	= 0.341
Project C	$\frac{1/13 + 1/19 + 1/15}{3}$	= 0.066
Total		= 1

The decision maker compares all alternatives pairwise for each criterion. In this way, the relative priorities of alternatives can be calculated for each criterion (see Table 5).

Table 5. Relative priorities of project A, B, and C for each of the three criteria.

Relative priority	ROI	Risk	Strategic Importance
Project A	0.593	0.123	0.087
Project B	0.341	0.320	0.274
Project C	0.066	0.557	0.639
Total	1.000	1.000	1.000

Because the decision maker judges every possible pair of alternatives, a measure of consistency can be calculated. If A is twice as preferable to B, and B is twice as preferable to C, then, in case of perfect consistency, the decision maker should prefer A four times to C. Deviations in these judgements are represented by the consistency ratio (Saaty, 1980).

7. Compare criteria pairwise

Next, AHP determines the relative importance of each criterion. This is done by means of the same process which was used in the previous step to derive the relative priorities of the alternatives. The decision maker compares all criteria pairwise. The manager indicates which criterion is more important, and to what extent. Based on these judgements, the importance of each criterion is calculated by applying similar computational rules as used in calculating the relative priorities (see Table 6).

Table 6. The relative importance of the three criteria.

Criterion	Importance
ROI	0.548
Risk	0.211
Strategic Importance	0.241
Total	1.000

8. Calculate the overall priorities for the alternatives

The overall priorities are determined by means of a linear additive function, in which the relative priorities for an alternative are multiplied by the importance of the corresponding criteria and summed over all criteria. For project A, the priority is (see Tables 7 and 8):

$$0.593 * 0.548 + 0.123 * 0.211 + 0.087 * 0.241 = 0.372.$$

For projects B and C, the priorities are 0.320 and 0.308 respectively. The AHP analysis shows that project A has the highest priority.

9. Sensitivity analysis

Before the I/S manager chooses the project with the highest overall priority, a sensitivity analysis can show the robustness of the overall priority rating. Sensitivity analysis shows, for example, to what extent the overall priorities are sensitive to changes in the importance of criteria. The more stable the ranking of the alternatives, the more confident the manager will be in the proposed choice. By using an AHP software package, such as Expert Choice, HIPRE 3+ or Criterium (Buede, 1992), sensitivity and what-if analyses are easily performed. Such analyses enlarge both the understanding of and the confidence in the outcome of the AHP analysis.

2 - Evaluation of Analytic Hierarchy Process

Analytic Hierarchy Process, like every method, has some strengths and weaknesses. This section discusses the extent to which AHP meets requirements for I/S decision support methods. Several criteria to evaluate I/S decision methods have been proposed. Sowder (1972) and Santhanam et al. (1989) discuss the following criteria, a method should be able to provide a realistic description of the selection problem, to analyse alternatives and should be easy to comprehend and apply. Muralidhar et al. (1990) add the incorporation of both quantitative and qualitative factors, and the relative importance of factors.

Huizingh and Vrolijk (1994) add the criteria of supporting group decision-making and structuring the decision process. In practice, I/S decisions involve many people from different departments with different needs and goals. Therefore a method should be able to support group decision-making. The complexity of the I/S decisions requires a phased solution of the problem and therefore a method should structure the decision-making process. The resulting eight criteria are listed in table 7. AHP will be evaluated according to these criteria.

Table 7: Criteria for evaluating I/S decision making.

	Criteria
1	Providing a realistic description of the problem
2	Supporting group decision-making
3	Structuring the decision-making process
4	Incorporating both quantitative and qualitative factors
5	Expressing the relative importance of factors
6	Analysing alternatives
7	Comprehensibility of the method
8	Applicability of the method

1. Providing a realistic description of the problem. Many I/S problems are characterised by multiple goals, constraints and risks. AHP provides the opportunity to deal with all of these aspects by incorporating them in the decision hierarchy. AHP assumes that all criteria are independent, which precludes interactions between the criteria. AHP assumes that an I/S manager is able to compare two projects on a criterion without considering the other criteria. Sometimes this may be difficult to accomplish. For example, I/S managers may think it is likely that strategically important projects also have a high risk. Then both criteria are not independent anymore.

2. Supporting group decision-making. Project selection, like many other I/S problems, is a problem that involves a large number of people from both the I/S department and the user departments. A method is able to support group decision-making if differences in opinion among members can be stated and evaluated explicitly. AHP provides this ability in several ways. First, a group of managers can reach consensus on each pairwise comparison. Then these collective judgements are used by AHP to compute priorities. In the second method each manager makes his or her judgments and subsequently these judgements are combined. Different weights can be assigned to different managers by adding the managers as an additional layer to the decision hierarchy. Finally, it is possible to determine a range of the individual judgements and to calculate the overall priorities based on these intervals. This method is called interval-AHP (Hämäläinen et al., 1992).

3. Structuring the decision-making process. A method should structure the decision-making process by prescribing which steps should be taken to reach a solution. Structuring can refer to the construction of the model as well as to the use of the model. AHP clearly structures the process of establishing priorities (Figure 1). Although AHP presumes that the phases are executed sequentially, the decision maker can return to a previous phase in order to make some changes. Because of the flexibility of the method it is not necessary to repeat all judgements when a change is made. Changes in the model, such as the addition of an alternative or criterion, have only a limited impact on other parts of the model.

4. Incorporating both quantitative and qualitative factors. When selecting projects, some criteria are quantitative (such as the costs of the system), and others are qualitative (such as the risk of a system). In AHP, the criteria are specified in the decision hierarchy and are not restricted in any way. A criterion can also be divided into subcriteria. The requirement to construct a decision hierarchy provides the additional advantage of diminishing the chance that an important criterion will be forgotten.

5. Expressing the relative importance of factors. I/S decisions involve many factors, therefore, decision makers should be able to state differences in the relative importance of the criteria. AHP includes criteria as one or more levels in the decision hierarchy. All elements in a certain level have to be compared pairwise in order to calculate the importance of the criteria. In this way it is very easy to assign different values to the importance of different criteria.

6. Analysing alternatives. A method for I/S decision making should provide I/S managers with the opportunity to perform a number of analyses. Sensitivity analyses and what-if analyses show the consequences of changes in, for example, the importance of factors. Confidence in the outcome of the analysis will increase if small changes in the relative importance of factors do not have much impact on the overall priority rating. When the AHP analysis has been completed it is rather easy to determine the consequences of changes in the judgments on the overall priorities. Because of the complexity of the calculations, an AHP software package is required to perform these analyses.

7. Comprehensibility of the method. A method is only a useful support tool if it is easy to understand. I/S managers have to understand how the method derives the overall priorities. This does not necessarily imply that a method is easy to use. Comparing the costs and benefits of a system is easy to understand, quantifying these costs and benefits can be hard. The comprehensibility of AHP is increased by both the construction of the decision hierarchy and the subsequent pairwise comparisons. The understandability is, however, somewhat limited by the complex calculations based on the eigenvectors and eigenvalues of the pairwise comparison matrices.

8. Applicability of the method. This criterion refers to the costs of developing and using the model. A method should be easy to use without elaborate training. AHP analysis can be divided into three parts: developing the decision hierarchy, making the pairwise comparisons and using the model. The first part requires I/S managers to think in a structured way. They have to define the problem in terms of goals, criteria (subcriteria) and alternatives. In the second part, AHP requires the I/S managers to make every possible pairwise comparison on a certain level. This enables the computation of the consistency ratio. A disadvantage is, however, that the number of pairwise comparisons becomes quite extensive in a larger decision model. Finally, using an AHP model is quite easy provided that an AHP software package is available.

3 - AHP support for I/S decision-making

The previous section showed the strengths and weaknesses of AHP with respect to I/S decision making in general. From this evaluation we conclude that AHP scores well on most criteria. This section turns to other I/S decisions besides the project selection decision that may benefit from AHP-based decision support. The changes that increased the complexity of I/S decision making, as described in the introduction, also affected the I/S function itself (McNurlin and Sprague, 1989). The traditional role of the I/S department was peripheral to the main business of an organisation, e.g., building, operating and maintaining information systems (Angell and Smithson, 1991). King (1983) distinguished the functions of application systems development, operations, technical services, and administration. Angell and Smithson (1991, p. 62) argue that nowadays the I/S role is much broader and more complex, comprising three main functions: the provision and maintenance of the information systems infrastructure; the support of end-user computing; and a long term research and planning function. These three functions include a broad range of I/S decisions (Angell and Smithson, 1991, p. 62-64):

- The infrastructure function requires I/S managers to make decisions concerning the use of networks, both internal and external, central databases, and central (mainframe) computers to ensure that the infrastructure can cope with fluctuating levels of traffic.
- The user support function involves defining organisational standards in terms of hardware, software, development methods, and data handling; evaluating new products; developing and selecting internal and/or external training courses; and co-ordinating end-user application development.
- The long term planning function includes I/S strategy and policy formulation, for example investigating the consequences and feasibility of large-scale technological changes in terms of business implications, such as profitability, structure, and human resource development.

These decisions may benefit from AHP support if they include multiple objectives, conflict among criteria, and/or incommensurable units, meaning that the objectives have a different unit of measurement (Hwang and Yoon, 1981). In addition, the decision problem should be to select the best alternative among a previously specified finite set of alternatives. AHP is not aimed at designing alternatives. In situations where these requirements are met and I/S management is unsatisfied with the current decision-making process, or the quality of its outcome, it should consider the application of AHP.

There are many I/S decisions that meet the four AHP requirements. AHP applications in the field of I/S decision-making include the selection of user interfaces (Mitta, 1993), the selection of a database management system (Zahedi, 1985), the prediction of software development efforts (Lee, 1993), the judgement of factors affecting the software development productivity (Finnie et al., 1993), the selection of software (Min, 1992) and the prioritisation of auditing tasks for large scale software systems (Yau en Davis, 1993). According to Dyer and Forman (1991) AHP can be applied to any decision involving allocation of resources, making choice-determination decisions, and making evaluations or performance assessing (Table 7 contains some examples of I/S decisions that belong to these three categories).

Table 7: Some I/S decisions that may benefit from AHP support.

Selection of information system projects
Outsourcing of system development
Selection of hardware
Decisions involving down and rightsizing
Choice between canned package or tailor made
Choice of a programming language
Choice of an information system development method
Selection of conversion method (direct, phased or parallel)
Determining the extend of integration between systems
Selection of a user interface
Selection of a Data Base Management System
Predicting the software development effort
Judging software development productivity factors
Selection of software
Prioritising auditing tasks
Choice of a supplier
Selecting new I/S employees

4 - Conclusions

Many decisions that I/S managers have to make have become more complex in the last decade. The number of alternatives has grown dramatically, I/S managers have to deal with more (conflicting) goals including political considerations of user departments, and at the same time the environment imposes I/S managers with more severe constraints. The increased complexity calls for effective decision support. Many I/S decisions belong to the class of Multi Criteria Decision-Making. Recently, much research effort in this field has been devoted to the method Analytic Hierarchy Process. In this paper we have explored the appropriateness of AHP to support I/S decision-making. Using the project selection decision as an example, we have shown how I/S managers can make decisions using AHP. The example reveals that an AHP analysis establishes priorities for each alternative in a number of clearly defined and understandable phases.

A framework of eight criteria was used to evaluate AHP. Important characteristics of AHP are its ability to incorporate both quantitative and qualitative factors, and to deal with criteria that are not equally important. AHP structures the decision-making process, supports group decision-making, and provides analysing capabilities (e.g., sensitivity analysis, and what-if analysis). On the other hand, AHP has some weaknesses. The method includes rather complex mathematical calculations, using eigenvalues and eigenvectors. However, these calculations are performed easily when using one of the available AHP programs. The number of pairwise comparisons an I/S manager has to make may increase quickly when a large number of (sub)criteria and alternatives are considered. Finally, the assumption of independence of criteria might cause problems in practice. Reviewing all of these aspects we conclude that AHP is a promising method for I/S management decision-making. The appropriateness of AHP is not limited to the selection of information system projects. If I/S management feels a need to improve the effectiveness and/or efficiency of its decision-making, AHP should be considered in case the decision problem includes multiple objectives, conflicting criteria, incommensurable units, and aims at selecting an alternative from a known set of alternatives. This makes AHP a decision support method which deserves the attention of I/S managers.

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