A Multi-Criterion, Multi-Expert Fuzzy Approach to The Selection of A Software Tool

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Abstract. The technology part of business software applications development, represented by a variety of software tools, has improved significantly in recent years. This necessitates utilizing advanced selection techniques to reduce the chance of failure associated with acquiring a new tool. This paper presents a multi-criterion fuzzy approach capable of integrating evaluation results obtained from a number of experts to select an appropriate software tool. The proposed approach combines and extends the attractive features of both the analytic hierarchy process and fuzzy set theory. The approach is demonstrated by solving an application of software tool selection.
Key words: software tool selection, multi-criterion fuzzy decision making.

1. Introduction

Recently, the evolution of end user computing phenomenon has led to a wide range of software development tools usually referred to as productivity tools. Such tools are being used at every organizational level as a means to improve software development outcomes. The selected software tool impacts the development process through providing different capabilities to the user and the number of capabilities imbedded within the tool will have a significant impact on its usefulness and acceptance.

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important decision facing users on a continuous basis since the "fit" between the software tool and the task where it will be used is a major determinant of development outcomes quality [1]. Therefore, adequate selection procedures can offset the chance of failure associated with acquiring a new software tool [2]. But in the absence of clearly defined quantitative models, it is common that the selection process is based on some qualitative criteria that are subjectively evaluated.

The success of the selection process depends heavily on the knowledge pertaining to candidate software tools and selection criteria. The amount and richness of available knowledge can be improved by involving a number of experts in the field and integrating their opinions after ensuring that an acceptable level of agreement has been achieved. In fact, there are a number of advantages associated with involving a number of experts in a problem solving domain that include increasing validity, accuracy and relevance of the knowledge available [3].

In this study, a multi-criterion, multi-expert fuzzy approach is developed to the selection of a software tool. The presented approach combines and extends the advantages of both the analytical hierarchy process and fuzzy set theory. The analytic hierarchy process can be used to structure the selection process and enable the decision maker to consider objective selection criteria before arriving at a decision. This involves pairwise comparisons and uses a hierarchy of criteria and available alternatives from domain experts. Then, a fuzzy procedure is used to integrate the results obtained from experts to reach a final decision after using a statistical method to ensure that the level of agreement of experts' judgments is acceptable.

2. The Analytic Hierarchy Process (AHP)

The AHP was developed by Thomas Saaty [4], who described it as a general method for dealing with unstructured problems and it can be applied to a great variety of business, personal, domestic and public policy decisions. It provides a method of electing the decision maker's priorities and preferences and synthesizing this information to produce an overall evaluation of the alternatives. The general approach of the AHP is decomposing the problem and making pairwise comparisons of all elements on a given level with respect to the related elements in the level just above. The pairwise comparisons of each level elements of the hierarchy are done in terms of either:

Importance: when comparing criteria with respect to their relative importance.

Preference: when comparing the preference of alternatives with respect to their specific qualities to a criterion.

Likelihood: when comparing scenarios with respect to the probability of their occurrence.

When comparing a pair of criteria, a ratio of relative importance, preference or likelihood of criteria can be established. The AHP software allows the user to enter judgments in either a verbal or numerical mode. The numerical scale and its verbal equivalent are given below [4]:

1 : means equal importance of both elements.
3 : means moderate importance of one element over another.
5 : means very strong importance of one element over another.
7 : means very strong importance of one element over another.
9 : means extreme importance of one element over another.

Intermediate values are used between two adjacent judgments. A typical question asked to the problem solver would be: which option, element a or element b, is more important in aiding to achieve the desired goal?, and how important is it?. By answering such questions, the pairwise comparison matrices can be completed and AHP software responds to the problem solver with the ranking weights.

3. Problem Description

The general hierarchy proposed is presented in Figure (1) and consists of three levels. At the highest level is the ultimate objective of selecting a software tool. The second level consists of the criteria used to evaluate each candidate tool. Each major criteria was broken into several subcriteria as shown in the third level of the hierarchy. The criteria are the main components defined by a user when he/she has to make a decision on which software tool to use. Selecting a software tool requires considering and evaluating many different criteria. In this study, criteria are grouped into three different categories:

- Tool characteristics.
- Ease of introduction to the organization.
- Impact on development productivity.

3.1. Tool Characteristics

The main characteristics of a software tool are summarized in the following subcriteria:

I. Flexibility: This reflects the extent to which the software tool provides the developer with the ability to explore different design alternatives and modify the application in a reasonable amount of time in order respond to the continuous changes in user requirements during system development.

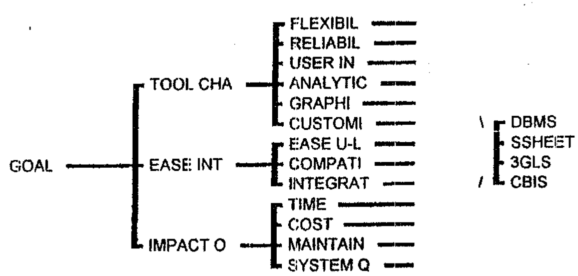
II. Reliability: This covers the capability of the software tool to store and retrieve information with minimal degree of risk, the capability of the tool to initiate a backup routine at a predetermined interval specified by the user, the mechanism provided by the tool to prevent unauthorized access to the application and interruption capabilities to notify the user that a problem has occurred.

III. User Interface: This covers consistency of the user interface, clarity of diagnostics, inputs methods, screen layout quality and reverse action capabilities.

IV. Analytical Capabilities: This covers the ability of the software tool to represent and analyze relationships between variables, activate mathematical functions when asked by the user and perform "if-then" sensitivity analysis needed to evaluate different alternatives to solve the problem.

V. Graphical capabilities: This covers the ability of the tool to produce and represent information in a graphical form, the ability to navigate between within the same diagram, support of zoom displays to adjust the size of the graph and the ability to display many graph objects on the same screen.

Figure 1. Hierarchy Structure of the selection Criteria



Abbreviation	Definition
GOAL	
3GLS	Third Generation Languages
ANALYTIC	Analatical Capability
CBIS	Computerized Business Information Systems
COMPATI	Compatibility of The Software Tool
COST	Development Cost
CUSTOMI	Customization
DBMS	Database Management Systems
EASE INT	Ease of Introduction to The Organization
EASE U-L	Ease of Use and Learn of the Software Tool
FLEXIBIL	Tool Flexibility
GRAPHI	Graphical Capability
IMPACT O	Impact on Development Productivity
INTEGRAT	Integratability of The Software Tool
MAINTAIN	Maintainability of The Developed System
RELIABIL	Tool Reliability
SSHEET	Electronic Spreadsheets
SYSTEM Q	Developed System Quality
TIME	Time to Develop The System
TOOL CHA	Tool Characteristics
USER IN	User Interface

VI. Customization: This reflects the ability to respond to a particular set of user's needs by tailoring the software tool to fit these needs rather than adjusting the problem according the capabilities of the tool.

3.2. Ease of introduction to the organization

This category includes the following subcriteria:

I. Ease of Use and Learn: This includes easiness of search and navigation through the tool, prompts and menu structure, clarity of massages produced by the tool, errors handling and organization of tool documentation availability of tutorial, help facilities, accessibility of explanations for commands and the amount of time required to learn the tool.

II. Compatibility: This covers the extent to which the software tool is compatible with existing hardware and software and with software development practices and guidelines.

III. Integratability: This reflects the ability of the software tool to interoperate with and/or directly exchange data with other software systems available.

3.3. Impact on Development Productivity

The software tool impacts development productivity in several areas that include:

I. Time: The time needed to develop the software application using the tool.

II. Cost: The cost of developing the software application using the tool.

III. Maintainability of the developed software application.

IV. Overall quality of the developed software application.

The lowest level (fourth) of the hierarchy consists of the alternatives, which are the software tools, to be evaluated. Four highly popular software tools, which are database management systems (DBMS), computerized business information systems (CBIS), electronic spreadsheets (SSHEET) and third generation languages (3GLs), were evaluated using the approach presented in this paper.

4. Checking Level of Agreement of Experts' Judgments

Before integrating experts' judgments, we need to test the statistical significance of the rankings of software tools based on their relative weights obtained from the AHP. Statistical methods enable us to determine the significance of the level of agreement of experts' opinions and the meaningfulness of the results obtained based on their inputs to the selection problem [5]. To do so, let us define the following equation:

$$R_i = \sum_{j=1}^{N} R_{ij} \qquad (1)$$

where N is the number of experts evaluating a total of n software tools, R_{ij} is the rank given by expert i to tool j and R_i is the sum of the ranks assigned to tool j. In this study, all the experts gave different opinions. By modifying equation (1), we obtain the following:

$$\sum_{i=1}^{n} R_i = \sum_{i=1}^{n}\sum_{j=1}^{N} R_{ij} = \sum_{j=1}^{N}\left(\sum_{i=1}^{n} R_{ij}\right) \qquad (2)$$

The sum of the ranks given by each expert (i.e., the expression in parentheses in equation (1)) equals to $Nn(n+1)/2$. Due to this,

$$\sum_{i=1}^{n} R_i = Nn(n+1)/2. \qquad (3)$$

The mean rank is calculated as follows:

$$R_{im} = \sum_{i=1}^{n} R_i / n = N(n+1)/2, \qquad (4)$$

The degree of agreement of opinions is the sum of the squared deviations R_i from the mean R_{im}. A degree of agreement at the absence of equal ranks is defined by a concordance coefficient W which is defined as follows:

$$W = \frac{12\sum_{i=1}^{n}[R_i - \frac{1}{2}N(n+1)]^2}{N^2(n^3 - n)} \qquad (5)$$

The statistic $N(n-1)W$ follows a χ^2 distribution with $(n-1)$ degrees of freedom. The value of $N(n-1)W$ is compared with W_{error} obtained from the χ^2 tables and if $N(n-1)W > W_{error}$ then the rankings obtained are statistically significance and a reasonable amount of agreement of experts' opinions was achieved (see [5] for more details).

5. A Fuzzy Approach for Aggregating Experts' Judgments

Imprecision and vagueness should be considered in situations where human judgement is a major part. The software tool evaluation and selection problem is vague in nature. Fuzzy set theory, which is an extension of the crisp set theory, has the ability to model inexactness resulting from human judgement [6]. We applied fuzzy set theory to the software tool selection problem and proposed a method to overcome this vague phenomenon.

5.1. Fuzzy Set Theory

A fuzzy set A is characterized by a generalized characteristic function $\mu_A(x) \rightarrow [0, 1]$, called membership function of A and defined over a universe of discourse U. This universe of discourse in a concrete case has to be chosen according to the specific situation of this case.

The most elementary operations for usual sets are the union as well as the intersection of any two sets and the complement of any set with respect to some superset of it. For the basic set algebraic operations, Zadeh [7] has already given such extensions. The union operation of two fuzzy sets A and B is a fuzzy set $A \cup B$ such that

$$\mu_{A \cup B}(x) = \max \{\mu_A(x), \mu_B(x)\} \text{ for all } x \in U,$$

The intersection of fuzzy sets A and B is a fuzzy set $A \cap B$ such that

$$\mu_{A \cap B}(x) = \min\{\mu_A(x),\ \mu_B(x)\} \text{ for all } x \in U,$$

and the complement of a fuzzy set A is denoted by Ā and defined by

$$\mu_{\bar{A}}(x) = \{1 - \mu A(x)\} \text{ for all } x \in U,$$

All these operations on fuzzy sets are straightforward generalizations of the corresponding operations on ordinary sets [7,8].

5.2. The Fuzzy Approach Procedure

In real life problems, one type of decisions consists of a situation where a set of criteria are given in terms of requirements where the decision process is to select the "best" alternative, which satisfies all the set of criteria. As Zadeh [7] and Bellman and Zadeh [8] suggest, using the rule of implied conjunction, these criteria are stated as

$$C_1 \text{ and } C2 \text{ and } C_3 \text{ ....} \qquad (6)$$

If we associate with each criterion a fuzzy subset over the set of alternatives, then, in terms of fuzzy subsets the decision D becomes:

$$D = C_1 \cap C_2 \cap C_3 \text{ ....} \qquad (7)$$

The decision D, is a fuzzy subset of the set of potential alternatives whose membership function $\mu_D(x)$ indicates how well each of the alternatives satisfies the set of evaluation criteria. Then, the alternative which has the highest degree of membership in D is selected as the best alternative.

In some cases objectives have varying degrees of importance to the decision maker, Yager [9] proposed an approach for handling this situation based on the idea of assigning to each objective C_i a number $\alpha_i >= 0$, as an indicative of its importance. In this case, the decision D will be

In this study, the above procedure was modified to aggregate different estimates of some experts during the selection of a software development tool

$$D = C_1^{\alpha 1} \cap C_2^{\alpha 2} \cap C_3^{\alpha 3} \text{ ....} \qquad (8)$$

from a set of specific tools. The modified approach is based on the assumption that the expert estimates is uncertain because of some reasons such as:

1) The expert estimates may be inaccurate because he does not know exactly the degree to which an alternative satisfies a criteria.
2) The questions in the questionnaire may not be clear or the expressions are vague and consequently the estimates will be imprecise.
3) The inability of AHP to treat uncertainty in the final estimation of ranking to get more accurate ranking.

judgments can be summarized as follows:

Step 1: Define the relative weights of alternatives obtained from the AHP for each expert i, i=1,2,....N and represent these weights as a fuzzy set as follows:

$$(EX_i)=\{w_{i1}/\text{alternative}_1,\ w_{i2}/\text{alternative}_2, \ldots\ldots\ldots\}$$

Step 2: Check the level of agreement of experts' judgements derived from the AHP model by following the statistical analysis of section 4. If it is statistically significant go to step 3, otherwise, reconsult with the experts about their judgements and go to step 1.

Step 3: For each expert, define the expert weight which represents the acceptance degree of his judgment. Let this degree is α_i , $i = 1,2,\ldots,N$.

Step 4: Apply the following relation to determine the final ranking:

$$D = (EX_1)^{\alpha 1} \cap (EX_2)^{\alpha 2} \cap \ldots\ldots \cap (EX_N)^{\alpha N} \qquad (9)$$

Step 5: Stop

The procedure presented so far is under the condition that information about the competence of the experts are available.

6. Example of an Application

To illustrate the use of the proposed approach, four software tools widely used in building business applications were selected. They are database management systems (DBMS), computerized business information systems (CBIS), electronic spreadsheets (SSHEET) and third generation languages (3GLs). The criteria are compared with each other on a pairwise comparison and the relative weights are obtained. Then, the alternatives were compared on each criterion in order to obtain the final weights for these alternatives.

A questionnaire was developed with respect to the study problem. A total of six experts in the field who are knowledgeable in the four software tools and in developing business applications using these tools were asked to respond to this questionnaire for selection of appropriate software tool and the responses were used as an input to the AHP model. The Expert Choice software package [10] has been used for developing pairwise comparisons of the criteria as well as for the alternatives and for analyzing input data. The input data was processed for each user response in order to obtain relative weights and rankings of alternatives. Then, the final results were aggregated using the fuzzy approach.

The experts' responses to the questionnaires were used as inputs to the AHP model. Figure (2) shows the relative weights of the four software tools obtained from the AHP model using pairwise comparisons given by the first expert ($expert_1$) and using comparison criteria shown in Figure (1). Table 1 shows the resultant relative weights of alternatives for all expert. The numbers between parentheses are the ranks (R_{ij}) determined by the relative weights.

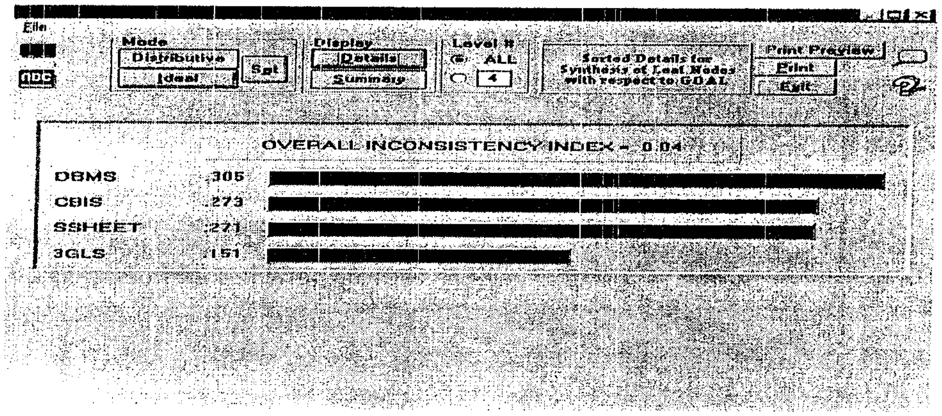


Figure 2: relative weights of alternatives obtained from the AHP for $expert_1$

Table 1. Experts' Judgments of the Alternatives

	DBMS	CBIS	SHEETS	3GLs
$Expert_1$	0.305 (1)	0.273 (2)	0.271 (3)	0.151 (4)
$Expert_2$	0.247 (3)	0.250 (2)	0.309 (1)	0.194 (4)
$Expert_3$	0.364 (1)	0.258 (2)	0.190 (3)	0.187 (4)
$Expert_4$	0.367 (1)	0.253 (2)	0.191 (3)	0.189 (4)
$Expert_5$	0.349 (1)	0.190 (3)	0.298 (2)	0.163 (4)
$Expert_6$	0.555 (1)	0.067 (4)	0.250 (2)	0.128 (3)

From equation (5), W=0.63,
Degree of freedom =4-1=3,
$N(n\text{-}1)w$=7(4-1)*4.0531=11.4.

From the statistical table of χ^2 distribution, we find that $W_{0.05}$=7.8147. It is clear that the calculated value of $N(n\text{-}1)W$ is greater than W. Hence, the result ranking is statistically significant.

From Table (1), the weights corresponding to each expert can be written as follows:

(EX_1) = { 0.305/DBMS, 0.273/CBIS, 0.271/SHEETS, 0.151/3GLS}
(EX_2) = { 0.247/DBMS, 0.250/CBIS, 0.309/SHEETS, 0.194/3GLS}
(EX_3) = { 0.364/DBMS, 0.258/CBIS, 0.190/SHEETS, 0.187/3GLS}
(EX_4) = { 0.367/DBMS, 0.253/CBIS, 0.191/SHEETS, 0.189/3GLS}
(EX_5) = { 0.349/DBMS, 0.190/CBIS, 0.298/SHEETS, 0.163/3GLS}
(EX_6) = { 0.555/DBMS, 0.067/CBIS, 0.250/SHEETS, 0.128/3GLS}

Based on our experiences, the experts' weights are {0.85, 1.12, 0.86, 1.17, 1.15, 0.65} respectively. To determine the final relative weights of each applied to each expert. As a result, the equations are rewritten as follows:

$$(EX_1)^{0.85} = \{ 0.365/DBMS,\ 0.332/CBIS,\ 0.329/SHEETS,\ 0.200/3GLS\}$$
$$(EX_2)^{1.12} = \{ 0.209/DBMS,\ 0.212/CBIS,\ 0.268/SHEETS,\ 0.159/3GLS\}$$
$$(EX_3)^{0.86} = \{ 0.419/DBMS,\ 0.312/CBIS,\ 0.239/SHEETS,\ 0.237/3GLS\}$$
$$(EX_4)^{1.71} = \{ 0.309/DBMS,\ 0.201/CBIS,\ 0.144/SHEETS,\ 0.142/3GLS\}$$
$$(EX_5)^{1.15} = \{ 0.298/DBMS,\ 0.148/CBIS,\ 0.249/SHEETS,\ 0.124/3GLS\}$$
$$(EX_6)^{0.65} = \{ 0.682/DBMS,\ 0.173/CBIS,\ 0.406/SHEETS,\ 0.263/3GLS\}$$

The final ranking of the alternatives, corresponding to the proposed procedure, is as follows:

$$D = \{0.209/DBMS, 0.148/CBIS, 0.144/SHEETS, 0.124/3GLS\}.$$

The decision D is a fuzzy subset of software development tools whose membership function $\mu_D(x)$ shows the weight for each tool as indicated by the experts. The tool that has the highest grade of membership in D is selected as the best alternative which is the DBMS in our case.

7. Conclusion

Evaluating and selecting a software tool is a complex problem because of the number of criteria that have to be considered. The task becomes more complicated when there are a number of experts involved in the selection process because of the need to integrate their evaluation results based on their own relative weights. This study outlined an approach derived from different fields of knowledge to software tool selection when there are a number of experts involved.

The approach consists of a number of steps. First, a set of criteria was used to develop pairwise comparison matrices to extract relative weights of candidate tools for each expert. Second, statistical methods were applied to ensure that an acceptable level of agreement has been achieved since the same objects are being compared. Third, a fuzzy approach was used to integrate experts' opinions to reach final evaluation weights of alternatives. Although the study was illustrated using four popular software tools, the approach itself can be generalized to any software system selection problem.

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أسلوب فازي متعدد المعايير والخبراء لإختيار أحد أدوات تطوير نظم البرامج

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ملخص. لقد تطورت نظم برامج تطبيقات الأعمال تطورا كبيرا في السنوات القليلة الماضية ونتج عن هذا التطور العديد من هذه النظم و هذا التطور يحتاج إلى إستخدام أساليب متقدمة لتقييم هذه النظم بناءا على مجموعه من المعايير لإختيار الأنسب منها وذلك لتقليل إحتمالات الفشل عند الإستخدام. ويهدف هذا البحث إلى تقديم أسلوبا جديدا لتقييم أدوات تطوير نظم برامج التطبيقات يعتمد على تكامل نتائج التقييم التي يتم الحصول عليها من مجموعه من الخبراء. ويعتمد هذا الأسلوب على إجراء التحليل الهرمي ونظرية الفئات الفازية (المشوشة) بهدف تقليل الفوارق في الآراء بين الخبراء ومعالجة المعلومات الغير مؤكدة التي قد تظهر عند التقييم. وقد قدم مثال تطبيقي لتوضيح كيفية تطبيق الأسلوب المقترح وبيان مدى ملائمته لهذا المجال.