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Author(s): Ricardo M. Czekster, Henrique Jung De Carvalho, Gabriela Zucchetti Kessler, Liane Mahlmann Kipper, Thais Webber

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DECISOR: A SOFTWARE TOOL TO DRIVE COMPLEX DECISIONS WITH ANALYTIC HIERARCHY PROCESS

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Addressing consistent and reliable decision making are crucial activities when choosing seemingly related alternatives for a set of criteria. Models and methods for aiding decisions such as Analytic Hierarchy Process (AHP) were developed to handle quantified assessments of quality attributes, usually intangible and numerically hard to cope. We introduce the Decisor software tool to assist the use of AHP to drive complex decision modelling. We present a study of related tools describing advantages and drawbacks. The tool is user friendly, with intuitive data entry fields. Users may input alternatives and criteria, assigning weights from different judgment scales. Decisor's main characteristic is its simple interface where the tool computes priority vectors for all alternatives and its consistency rates. It is also possible to operate with negative weighting, inferring Benefits, Opportunities, Costs, and Risks. The tool implements Group Decisions, using the geometric mean to combine criteria comparisons from selected stakeholders.

Keywords: Analytic Hierarchy Process; decision making software; decision processes & methods.

1991 Mathematics Subject Classification: 68N99, 92-08, 65F99

1. Introduction

There are many advantages to model complex decision problems using multicriteria approaches. The literature on this subject is vast as researchers have defined, throughout the years, several ways to tackle decision making using numerical principles. Such methods are called *Multi-Criteria Decision Methods*, or MCDM[1], or *Multi-Criteria Decision Analysis* (MCDA), and examples are AHP (*Analytic Hierarchy Process*)[2,3,4] and ANP (*Analytic Network Process*)[5], MACBETH (*Measuring Attractiveness by a Categorical Based Evaluation Technique*)[6], PROMETHEE (*Preference Ranking Organization METHod for Enrichment of Evaluations*)[7], ELECTRE (*ELimination and Choice Expressing REality*) and variants[8], TOPSIS (*Technique for Order of Preference by Similarity to Ideal Solution*)[9], MAUT/MAVT (*Multi-Attribute Utility/Value Theory*), TRIZ (*Theory of Inventive Problem Solving*), Border methods, Condorcet, and VIKOR (*Multicriteria Optimization and Compromise Solution*). Each method has a set of specific modelling primitives for representing decision problems. MCDM is an active research subject and it may be combined with other interesting approaches such as Data Mining and Knowledge Discovery[10]. From all MCDM methods available, AHP and TOPSIS stands out mostly due to its simplicity.

This work focus exclusively on AHP and related software tools with emphasis on graphical user interfaces and numerical solution. The main challenge when modelling decisions are usually directed towards setting reasonable weight values when comparing criteria to criteria (in a pairwise fashion) and, for each criteria, weights among alternatives. These abovementioned decision theories and methodologies are currently employed by several companies, industries, and academia around the globe, where decision makers apply the techniques to estimate and choose the best alternative, i.e., the one that minimizes costs or raw materials while enhancing productivity. However, as it happens in other decision modelling approaches, AHP heavily relies on domain experts, i.e., managers with holistic vision, and decision makers in general for consistent and actionable results.

Challenges faced by decision makers and managers are rarely focused on modelling efforts or choosing the right method for a given analysis. On the one hand, the investigation resides on using specialized and reliable software tools where users could run and inspect models in a seamlessly fashion. On the other hand, software, in general, is prone to be delivered with defects, sometimes presenting unintuitive designs (e.g. not taking into account user needs), missing functionality or having too many features (confusing users), among other issues. The objective of this work is to bridge the gap between key decision features and ease of use and present a software tool for the AHP method. We have named the software *Decisor*, and we have equipped it with an intuitive graphical interface where users can easily model complex decision making scenarios setting their own criteria and alternatives. Decisor computes numerical results as some examples were thoroughly validated with AHP models present in the literature.

It is also our objective in this work to explain some of the tool's internal details, explaining how to use it and profit from its features. We present Decisor's major functionalities and discuss examples and tradeoffs. We also show the main screens behind the tool and its modelling aspects, demonstrating how users can explore it to achieve high performance and productivity while making complex decisions for different applications. Stakeholders from different backgrounds could use the software when making impactful decisions, considering key factors for enhancing profits, adjusting budget concerns, assigning skillful resources to key work posts, or selecting best machineries for acquisition, for instance.

The work is divided as follows: Section 2 will present the AHP method, discussing steps for numerical solution, related works and similar tools. Section 3 will describe our implementation choices and general aspects of Decisor, its features and some examples. Finally, in Section 4 we discuss final considerations and future work.

2. Analytic Hierarchy Process (AHP)

The method used by AHP is derived from the field of *Operational Research*, where it is applied to a broad spectrum of models ranging from military settings to logistics and supplier selection processes[11,12]. As an example, Ref. 13 has developed a decision support system applied to the automotive industry whereas Ref. 14 has combined it with real estate investment alternatives based on a consensus model for Group Decision Making. Early studies have discussed that one of the key issues driving AHP are how to combine models and associate numerical values into complex decision making. Another source of concern is the inherent aspects that usually emerge when assigning weights in practical applications. That became the theoretical basis for AHP, adopting ideas from seemingly distinct areas such as Linear Algebra, Operational Research, and even Psychology. Ref. 15 discussed how the method decomposes problems and performs synthesis in sets of criteria, aiming to provide a prioritization order, e.g., computing the actual decision or chosen alternative through the inspection of numerical indices.

AHP's practitioners must abide to specific assumptions prior any decision making process. For instance, one must select independent criteria, work with a reasonable amount of elements (e.g. criteria and alternatives), and consider fixed time limits for any particular study. AHP provides a convenient way to decide using available data that is usually intangible or based on quality properties. The idea of using a hierarchy aims to reduce any given system to a set of pairwise elements that are comparable against each other. For more information on pairwise comparison matrix, refer to Ref. 16 where authors have presented a comprehensive discussion on this subject. The human intellect is conditioned to break down and simplify problems into classes, reducing complexity and organizing characteristics when dealing with complex subjects.

AHP is used in daily business decisions. Ref. 17 discusses that companies around the globe are in fact huge risk taking mechanisms aiming to deal with different profit margins and provide high quality services and products to end customers. In terms of risk management, some considerations must be taken into account such as the need to discover the *perfect* client, i.e. those presenting less risk, or the ones that have the potential to yield significant financial returns according to the project under execution.

Ref. 18 has shown that the act of *administering* (in the context of businesses) is different from the act of *managing*. While the first is concerned with limited risk exposure, warranties and restrictive conditions in its day-to-day operations, the latter requires a clear risk division view and a strict vision on how to differentiate risk when establishing prices for labor products. Business process management, on the other hand, aims to address client satisfaction, trying to build relations to enhance customer loyalty while attracting other potential customers.

Companies are interested in knowing the set of actions that are most important to build up those relationships in competitive markets. AHP helps to model such scenarios, as discussed by some authors[19], which aims to select suppliers whereas other works aims to study sustainable strategic alliances among companies to strengthen cooperation efforts[20,21,22].

The canonical model for AHP is based on *Objective-Criteria-Alternatives*, as shown in Fig. 1. Once the model is formulated, it is subjected to a numerical procedure to discover the decision making that is best adjusted according the model inputs, e.g., weights and judgments among criteria/alternatives. When modelling, one *should* choose at least two and up to nine criterion or alternatives (a rule of thumb for this kind of analysis). However, for instance, if nine criterion and three alternatives are modelled, the analyst will have to perform 63 pairwise comparisons, which is rather cumbersome. Diversely, for the model presented in the figure having three criteria and two alternatives, only six comparisons would be necessary, which is a reasonable amount. Putting in perspective, in psychology, Ref. 23 has studied the *cognitive load* when learning, i.e. a measure of the amount of mental effort used in the working memory to perform tasks. When linking this concept in decision making with AHP, one should select at most seven criteria and up to five alternatives, easing the amount of required analysis.

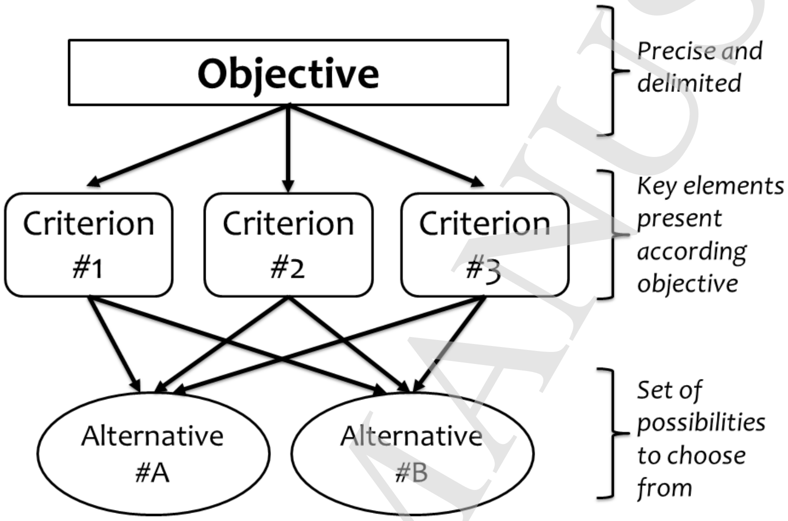

Fig. 1: Hierarchical AHP structure in its canonical form.

The method used in AHP requires a set of definite steps[15,4,24]:

- *Structure the problem into a hierarchy:* the starting point is a clear objective, listing key criteria closely addressing the issue and a list of alternatives to choose from;
- *Comparative judgment:* aims to measure the relative importance of elements among one another, weighing this difference numerically. The comparisons are made in pairs, analyzing not only the best option for the two, but how much its influence takes part;
- *Compute weights and global ranking:* from the model having Objective-Criteria-Alternatives and from the comparison matrices of previous steps, this phase aims to compute numerical indices into a vector that infers the influence of each element yielding a preferred selection order among the alternatives.

The three steps encompass the backbone of a comprehensive AHP analysis, consisting of choosing the criteria and alternatives, weights, and pairwise comparisons to establish priorities in the model. It also refers to the synthesis of the judgments where one obtains the set of overall weights for achieving the objective. Lastly, consistency is checked to evaluate the significance of the assigned judgments.

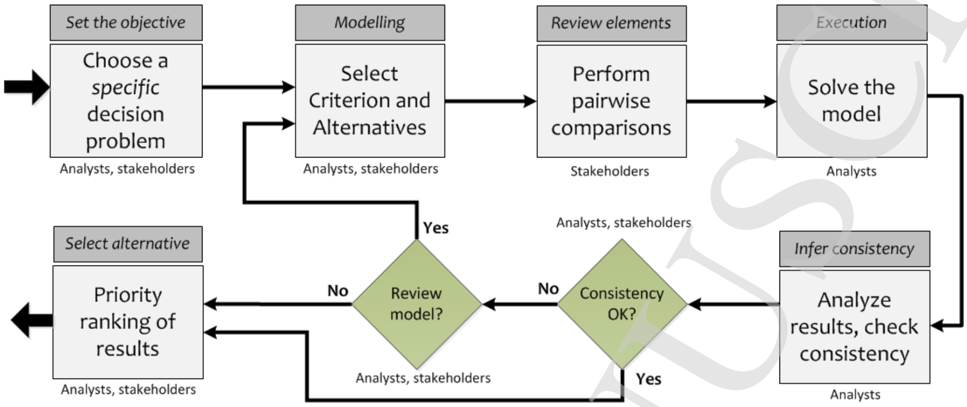

Fig. 2: AHP's decision making process, from modelling to refinement, and results.

The general process of AHP is represented by Fig. 2. It starts with a clear objective, decomposed by a set of criteria and alternatives belonging to the objective. Then, the analysts proceed to perform pairwise comparisons, where specialized software computes consistency indices. Through close inspection on the computed values, analysts/stakeholders decide whether or not to move on to the next phase. Once the indices are within predefined boundaries, the results are analyzed and a decision is made, observing the highest ranked alternative and its numerical proximity to others.

It is worth mentioning that the process of selecting criteria and alternatives, performing comparisons and compute indices is a *cyclical* procedure, i.e., it is repeated until analysts deem necessary. Some models may yield consistencies greater than the recommended threshold of 0.1 (or 10%) and, upon weighing chosen models parameters with stakeholders, may be considered valid as well. If not, experts and modelers should review the judgements and assign new parameters to the model.

The pairwise comparisons should adhere to the *Fundamental Scale* as proposed by Ref. 15. Despite the fact that other scales could be used, Saaty's seminal paper proposed a simplistic scale that varied from one (lowest value, or indifferent) to nine (highest, or important), where odd values are preferred over even values. Intermediate factors (e.g. even values) are possible for those cases where desired weights cannot be used (they are considered intermediate values). Table 1 discusses the Fundamental Scale in detail.

Table 1. Fundamental Scale of AHP as proposed by Ref. 15.

Scale	Definition	Explanation
1	Same importance, indifference.	Both elements contribute equally towards the objective.
3	Small importance one over another.	One element is slightly favored with respect to (W.R.T.) the other.
5	Considerable importance, essential.	One characteristic is highly important W.R.T. the other.
7	High importance.	One aspect is strongly more important W.R.T. the other in comparison, dominating the other.
9	Highest importance, absolute.	Highest importance between two elements, with high level of confidence of its relevance.
2,4,6,8	Intermediate values among the scale.	A good compromise between two characteristics acting as a reasonable balance.
Reciprocals	If a compared pair at position [i,j] has value over zero, then the pair at position [j,i] should have assigned 1/value, i.e., a reciprocal value.	The reciprocals values cause the model to have certain equilibrium W.R.T. the elements.
Rational	One could derive rational values as well.	Rational numbers are used when different scales are considered.

Once the modelling phase is complete and all pairwise comparisons are filled in the criterion-criterion table and the alternative-alternative per criteria table, the numerical method uses line sums, uniformizations and means to compute a priority vector which contains the alternative to be selected (ordered by the highest value). The AHP method is computing the *eigenvalue* of the combined matrices to estimate the one alternative that yields the highest value given the comparison weights for the decision problem[2,15].

Summarizing, AHP's major strength is the quantification of intangibles or quality factors that are inherent to many realities and very difficult not only to estimate a numerical value, but also to compare between quality properties. As a matter of fact, in AHP, it is sufficient to work only with criteria, alternatives and weights to develop a complex decision process. The key aspect of the decision making process is thus shifted towards experts, bringing their broad experience to drive the process. When modelers combine this expertise into textual models, interesting outcomes may potentially arise and shed light for better resource allocations, monetary investments, and other decisions.

2.1. *Discussion*

AHP have been withstanding scrutiny throughout the years as many researchers have sought to understand its applicability, intricacies, characteristics, and drawbacks. Ref. 25 has studied a large collection of applications where practitioners have used the AHP and ANP methods (more or less 600 noteworthy papers in four years' period). Ref. 26, for instance, criticizes the method mainly where the hierarchy is concerned because, from his point of view, the different modelled levels do interact among each other, having dependent relations. The author concludes that due to this, the hierarchical model is not suited for complex decisions possessing those characteristics. ANP, in contrast, was developed to take these concerns into account.

Ref. 27 comments that it is very easy to oversimplify complex problems in AHP, since it abstracts many behaviors into simplistic states referring to criteria and alternatives. The same author, however, pointed out the wide applicability of AHP in business and academia, where it can be used to hire professionals or determine suppliers with considerable confidence. Ref. 28 has applied AHP into agricultural studies whereas Ref. 29 has used AHP to estimate efficiency when managing research projects in universities.

Despite its broad use, the general technique for decision making behind AHP is not a widespread consensus among researchers. Despite the existence of many other MCDM available to date, where each claims to be superior in comparison to the other, AHP's strength is in fact its simplicity and broad applicability. Some authors have discussed the demerits of using AHP improperly[30] with interesting points of view and interesting remarks to be taken into account when choosing hierarchical approaches.

AHP is not immune to *Rank Reversal*[31] as well as many other multicriteria methods. This problem occurs when the insertion or removal of criteria or alternatives may produce different outcomes (in terms of ranking) each time the method is executed. The literature on Rank Reversal is vast and some authors[32,33] have addressed how to avoid it across AHP models with interesting discussions. AHP modelers are also biased towards the computation of only valid consistency rates, tweaking previously chosen weights to produce nice values (e.g. less than 0.1 or 10%). This process is achieved when users change weights and computing results until consistency levels are below some desired threshold. It is worth stressing that this backward solution is not recommended by the core AHP method, as it suggests meeting with the stakeholders and revising the whole comparisons (judgements) in its entirety.

In terms of modelling, inexperienced users sometimes confuse what is a criterion and what is an alternative, only learning the difference when addressing the pair comparison procedure. Usually, if criteria or alternatives are poorly chosen, the elements will not be comparable in pairs, however, the amount of time lost is significant. This is why it is important to design the AHP model carefully.

Another source of concern when using AHP as the preferred method for analysis is attributed to the assigned weights in the comparison tables (for criterion-criterion and for criterion-alternative as well). What happens is that for a number of cases, one criterion or alternative always gets small values, being not preferred in a case study. If one has selected a set of criteria and alternatives, it is important that it will be eventually preferred in comparison to other elements, a neglected consideration in some real world analysis.

2.2. *Steps for numerical solution*

Decision making encompasses at least four significant stages, i) choosing a decision problem worth of assessment, ii) modelling the problem using an MCDM technique and multiple scenarios considerations, iii) numerical solution, and iv) analysis and evaluations. We demonstrate a simple decision problem, enumerate and explain every step for generating the priority vector and consistency rates. After the user has created the model, with the list of criteria and alternatives, the following activities take place, as Table 2 summarizes the entire procedure in steps.

Table 2. Required steps for numerical solution using AHP.

#	Activity performed	Explanation
1	Criteria: column sum	Looking at the criterion-criterion matrix, one must sum the values per column.
2	Uniformize the matrix	Using the column sum performed at Step#1, the matrix is uniformized, i.e., all values are within [0,1].
3	Line average	The average for each line is computed, computing a weight vector (w), representing the '*force*' of each criterion.
4	Repeat steps#1 to #3 for each criterion, analyzing each alternative	The same principle is repeated for each criterion, looking at the alternatives matrices (A), yielding a weight vector for each. One could analyze the impact of each alternative W.R.T. the criterion.
5	Composition and synthesis	A matrix having the weight vector for the criteria in the columns, by the weight vector for the alternatives on the rows is built.
6	Multiplication of all weight vectors – synthesis matrix (SM)	The criteria and alternatives weight vectors are multiplied against each other, representing the effect of criteria judgments on the alternatives values.
7	Line average of the synthesis matrix	The line average of the SM is computed resulting in the final priority vector, i.e., the highest value corresponds to the final decision.
8	Consistency Rate (CR) computation	For each alternative matrix A, and corresponding weight vector w, one computes the matrix vector multiplication of A and w, divided by w, i.e. A.w/w
9	Lambda max (λ_{max}) calculation	The λ_{max} is the average of the A.w/w vector (one column), performed on Step#8.
10	Consistency Index (CI) computation	The CI is calculated looking at the value of λ_{max} and the order of the alternative matrix (n). Equation (1) below shows the formula for CI.
11	Consistency Rate (CR) calculation	The CR uses a matrix called Random Consistency Index (RI), explained in AHP literature[15], as showed in Equation (2). One CR is computer for each alternative matrix.
12	Analysis of CR	If the CR is higher than 0.1 (or 10%), the judgments should be reviewed by the modellers.

Steps #10 to #12 should be further explained, because they are important to the general method. The formula for CI is listed at Eq. (2.1), where n corresponds to the matrix order for the alternatives:

$$CI = \frac{\lambda_{\max} - n}{n-1}. \tag{2.1}$$

Next, one must compute the *Consistency Rate* (CR), as shown in Eq. (2.2), using the *Random Consistency Index* (RI) present in Table 3.

Table 3. Random Consistency Index (RI) matrix.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

$$CR = \frac{CI}{RI}. \tag{2.2}$$

The CR gives a ratio in respect with the CI and it should be a value less than 0.1 (or 10%), representing that the judgments are consistent. If the CR is greater than this, then modelers should re-evaluate the model and the comparisons.

2.3. *Related work*

When evaluating software tools, one must take into account user satisfaction and productivity while using the application. There are several tools built for AHP, with advantages and drawbacks. The main users of decision making software are often managers, accountants, financial consultants, or professionals not accustomed to use unintuitive tools having needless built-in features.

The computation behind AHP is straightforward and one could use spreadsheets for simple models using templates[34]. The problem of spreadsheets is that it only provides static analysis, i.e., they are useful for a fixed amount of criteria or alternatives. For more advanced studies, one must select specialized software to handle more complex decision making possibilities such as varying scales, sensitivity, or Benefits-Opportunities-Costs-Risks (B.O.C.R.) analysis. Due to the simplicity of the solution, several Internet websites have implemented on-line solutions for AHP.

Due to several possibilities in terms of features, prices, licenses, and platforms, Ref. 35 have compiled an extensive list of software devoted to MCDM analysis for supporting environmental planning processes. We focus solely on AHP tools and their specific functionalities. The *Priority Estimation Tool* (PriEsT)[36] is a decision analysis tool that offers graphical means for complex analysis using AHP as the main decision making method. The tool is free and open source (under license GPLv3).

SuperDecisions[37,38] was created by the same researchers that presented the AHP methodology and it is also equipped with ANP solution mechanisms. The software requires a registration for the evaluation version, providing a limited set of functionalities for assessment. There are costs associated with the releases, making it a proprietary tool with inaccessible source code. The software tool runs on MS-Windows, GNU/Linux and MacOS platforms, and the website contains documentations and other materials such as tutorials, and sample models. There are some known issues and bugs for each platform, however, those problems does not impact the execution of models and the extraction of interesting analysis. Table 4 presents a comparative analysis among selected software.

Table 4. Comparative table of selected AHP software tools ordered by name.

Software tool	***License***	***Architectural details***	***Comments***
Decisor	Free to use, only binaries are supplied	Windows based platforms, written in Qt's framework	Very intuitive, simple to use tool, providing timely results for users.
Expert Choice	Proprietary, web based	Runs on the cloud; requires Internet for operation	Lots of useful tools for solving AHP models, however, it is proprietary.
On-line web based tools for AHP	Depends; use of web based programming languages	Internet applications; requires Internet	The model is submitted on-line; there are no guarantees as to privacy or security issues. There are no guarantees of maintenance and long term support.
– *AHP Online Calculator:* https://bpmsg.com/ahp-online-calculator/ – *AHP Calculation software by CGI:* http://www.isc.senshu-u.ac.jp/~thc0456/EAHP/AHPweb.html – *123 AHP (My choice, my decision):* http://www.123ahp.com/Default.aspx – *MCDM Online Calculator:* http://people.revoledu.com/kardi/tutorial/AHP/MCDM_Calculator.html			
Priority Estimation Tool (PriEsT)	Free, open source (GPLv3)	Built in the Java Programming Language; requires *Java Runtime*	Graphical tool, requires *Java Virtual Machine* for operation. Performance issues (due to Java), however it is also a multiplatform solution.
Spreadsheet templates	Free	Depends heavily on *Operating System* versions	Used for static models, flexibility issues, used for simple models.
SuperDecisions	Proprietary	Windows, Mac, GNU/Linux platforms	Sensitivity analysis and offers solution of ANP models.

Expert Choice[34] is also a proprietary solution used by several customers around the globe for decision making. It promises advanced decision making analytics through a set of companion tools that aid modelers to achieve high productivity. The solutions provided by the company offer broad ranges of analysis, focusing mainly in AHP to accomplish those results. For instance, it offers opportunities for users to plan resource allocation, reduce risk, prioritize objectives in strategic planning, and advanced scenarios analysis. Their decision making methodology is thoroughly explained and aids users to perform structured decision making and weighing of subjective data. The company also offers webinars, tutorials, training, and consulting for customers that adopt the tool to profit from their technologies.

The main problem of some highlighted tools is due to the high licensing costs for broad use. Despite the fact that they are stable and provide a reasonable amount of useful functionalities, the prices usually are too expensive for adoption. Users resort then to free or open source solutions, however, the level of help (e-mail support or documentation with examples and tutorials) is quite low in comparison with its proprietary counterparts.

In terms of costs and licensing, the tool choice varies a lot, except for PriEsT, some on-line tools, the spreadsheet templates (some are available for download). Since the our solution is a desktop application implemented in a robust language (C/C++) it runs quicker than web based or Java applications (the closeness between compiled code and processing unit is known as *bare* metal execution, i.e., the code runs without redirections, for instance, from a virtual machine). If simplicity is important for modelers, only a few tools provide these requirements, since the vast majority of known software offers a considerable amount of features that may or may not be used by decision makers.

3. Implementation details of *Decisor* software, modeling and evaluation

The key proposition when designing our software was *simplicity*, following the ideas of the AHP method itself. Our idea was to provide user friendliness and intuitive operation while accessing features. We are using tabs, inviting users to complete forms using the *wizard* GUI (*Graphical User Interface*) design approach, e.g., sequences of screens allowing users to continue or return to other tabs. The tabs follow the AHP model (Objective-Criteria-Alternatives) followed by the pairwise comparisons, synthesis, and analysis/reporting.

The tool was implemented using Qt[40], a cross-platform application framework used for developing visual applications. Decisor also uses the C/C++ (combined with Qt primitives) language underneath the visual interfaces for calculating the results. The current software version is compiled for the Windows platform, however, it could be easily ported to other platforms without any major concerns. There are no specific requirements for execution, for instance, a machine with sufficient RAM memory would run Decisor software effortlessly. Considering all Qt's shared DLLs (*Dynamic Link Library*), executable file, and examples, the final tool size sums to 20 Mb, considered of small size in relation to other tools.

Fig. 3 below shows the main screen of Decisor. It has a top menu consisting of user options such as "File" (enabling options to Open/Save files, and to exit the tool), "Analysis" (allowing users to perform advanced analysis), "Settings" (where users sets up scales, and other options), and "Help" (showing the "About" screen, where modelers can access on-line documentation). The mid screen shows panels where users can input parameters, and the bottom has a visual component that is used for displaying computations and output for users.

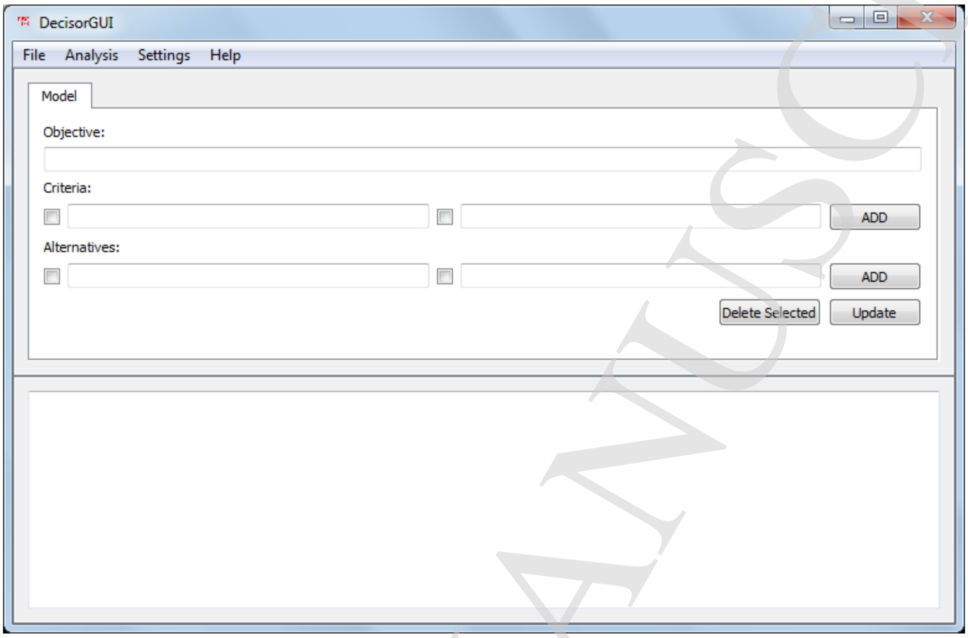

Fig. 3: Main screen of Decisor showing the menu, the mid panels with just one tab for the main model (called 'Model'), buttons, and the bottom output component.

The main screen asks users to provide the objective of the study, in an input text field. Then, at the same tab, the modeler enters the criteria (where pressing the "ADD" button another criterion is appended to the model) and the list of alternatives (the "ADD" possibility is present as well). It is possible to review the set of criteria and alternatives, edit the textual description at will and select one to many (using near checkboxes) items for removal (selecting and then pressing the button "Delete Selected"). Once the model is deemed ready, the user must press the "Update" button to compute the necessary number of pair comparisons given the number of criteria and alternatives. If the user wants to review the model, he/she could opt not to continue, staying at the same tab, and editing the items until the model is considered fit, repeating this process. Once the users agree to continue, the tool creates as many tabs as the number of criterion were input, renaming them with the same criterion name to help users locating item easily.

Fig. 4 shows an example model where a modeler has chosen to study a decision problem of "Hire a manager for the Philadelphia branch" (Objective), having four criteria ("Experience", "Education", "Charisma", and "Age") and three alternatives to select from ("Tom", "Dick", or "Harry"), yielding a total of 18 required comparisons. The tool asks users whether to continue (where a total of four new tabs will be added to system, having the criteria as names), or to remain in this screen and edit the items, adding or removing criteria or alternatives. This model is adapted from a different set of examples available in the literature[41,15,17].

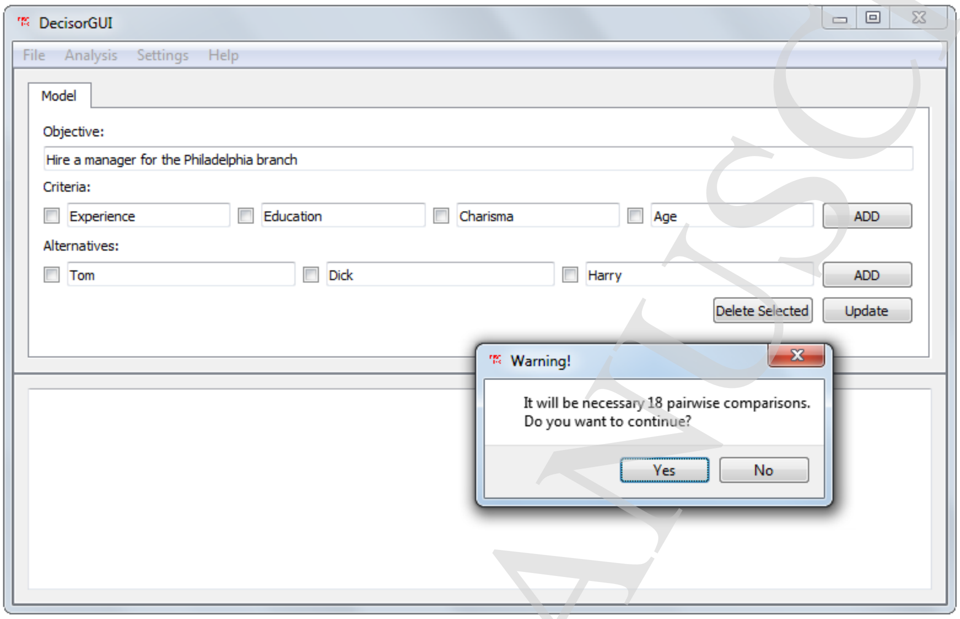

Fig. 4: A new model is under consideration for a decision making having four criteria and three alternatives, requiring a total of 18 pairwise comparisons.

If the user chooses to continue, the system add new tabs and, for each tab, it asks the modeler to perform the pairwise comparisons (criterion-criterion) and per criterion, alternative-alternative comparisons. Fig. 5 shows the set of added tabs for this model.

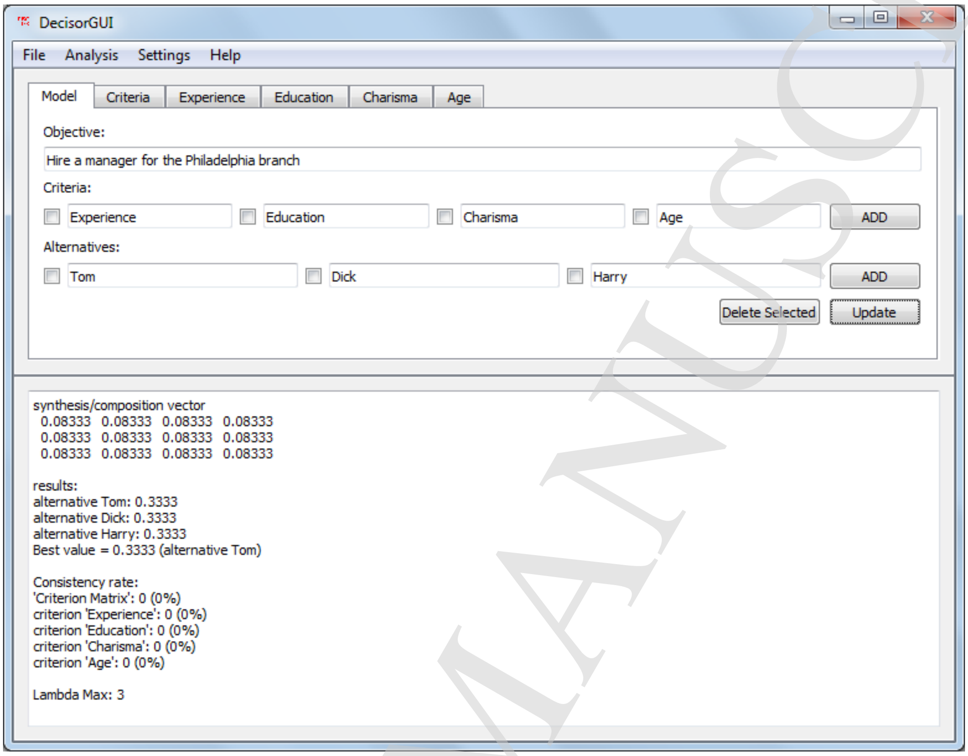

Fig. 5: According to the example model, new tabs were added in execution time, and the Decisor tool runs the model using identity matrices just to enable valid computations. For this particular case, the results have the same weight.

The tool initially fills all matrices with the value for one (1's), enabling a quick execution with results (even though meaningless, because no weights were input). Choosing this particular value in the Judgment Scale (Table 1) means indifference, so it could be used for any starting model. In Fig. 6 it is possible to verify that the results for the alternatives are the same, because the pairwise comparisons have not been completed yet. It is now the modeler's job to compare the criteria and the alternatives using the Fundamental Scale (or other scale, as it will be explained later).

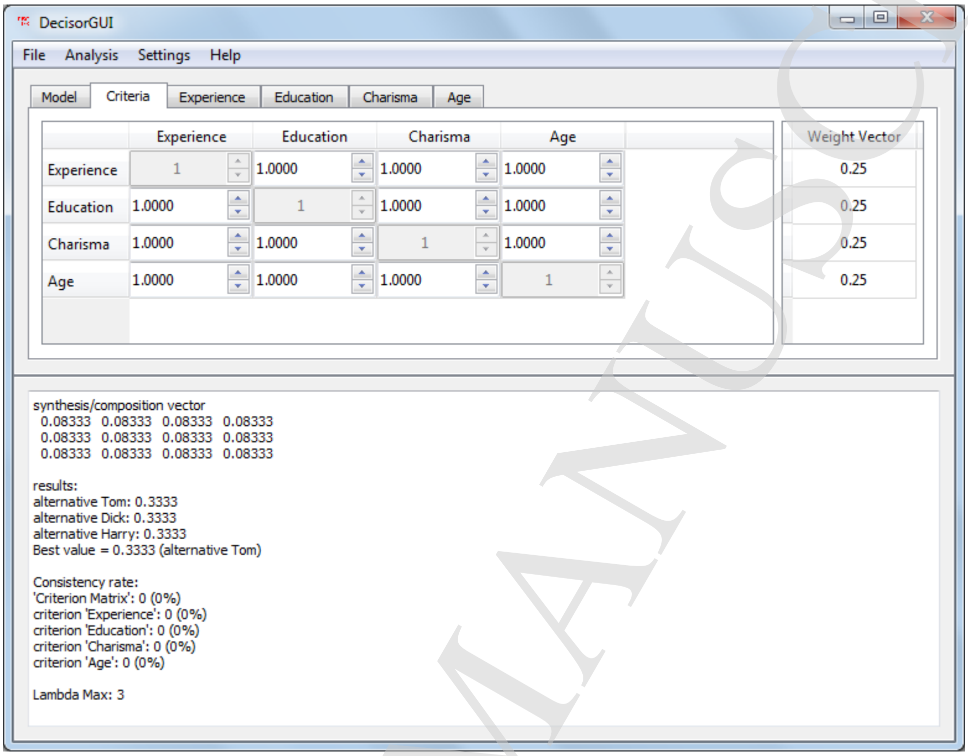

Fig. 6: The tool allows users to do criterion-criterion comparisons. The comparison matrices are created in execution time and increment/decrement components are presented.

As the tool is executed, it lets users select values and input them in the text fields or use the increment/decrement component (text field components with arrows on the side, called *spinners*), or even the mouse wheel (if the mouse is pointed on top of a given text field). As the values are entered, the tool computes the weight vector (e.g. the priorities calculation), presenting the synthesis/composition matrix and the results preview, indicating the highest ranked alternative (the one with the highest priority vector value). It is possible to turn off these real time calculations if the user desires so (there is an option in the menu called "Settings > Automatic Calculation"). It is worth noticing that for this dummy example, all the pairwise matrices are initially set with one's as weights, causing the weight vector to be equiprobable (a vector containing – for this case – the value 0.25 for all positions), and indicating the best alternative to be the first one, in this case, "Tom".

Fig. 7 shows real values for the pairwise comparisons and the resulting weight vector (on the right side) for the criterion-criterion evaluation. The diagonals cells are blocked, so users cannot edit them, and every time a comparison is entered at matrix index `[i,j]`, the reciprocal (one over the value) is automatically set at matrix index `[j,i]`.

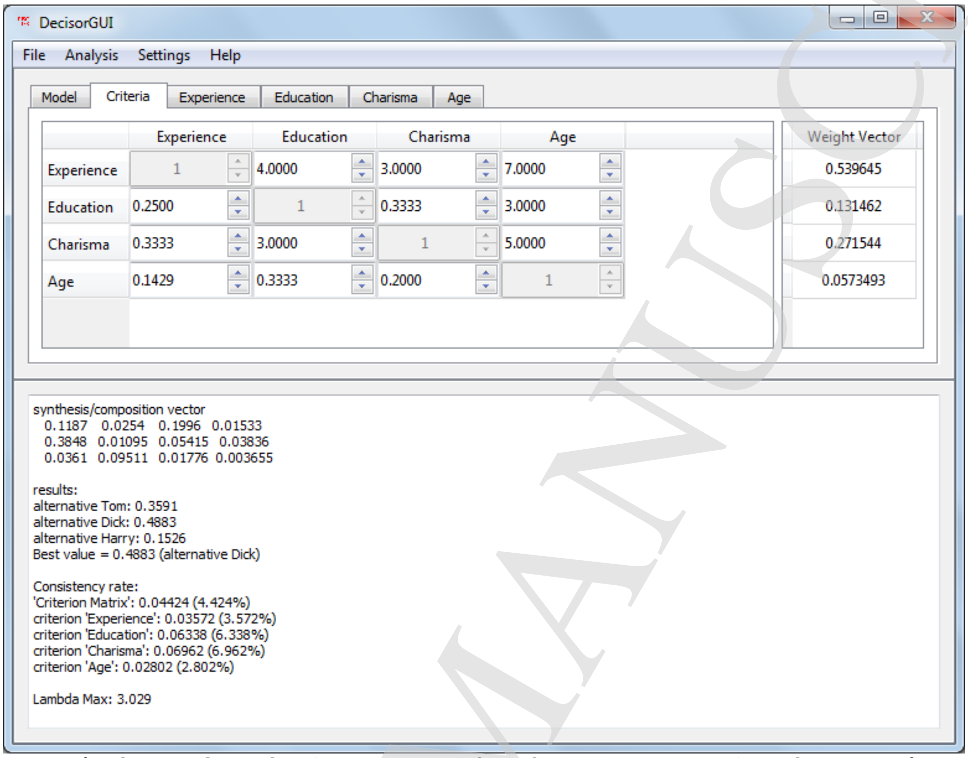

Fig. 7: After the user selects values (integers or ratios) for each pairwise comparison (e.g. values ranging from 0 to 9 in this case), the weight vector is computed.

The pairwise comparisons of each criterion for all alternatives are presented on Fig. 8. The figure shows the weight vector for the criterion "Experience" where the user selects the importance among all alternatives.

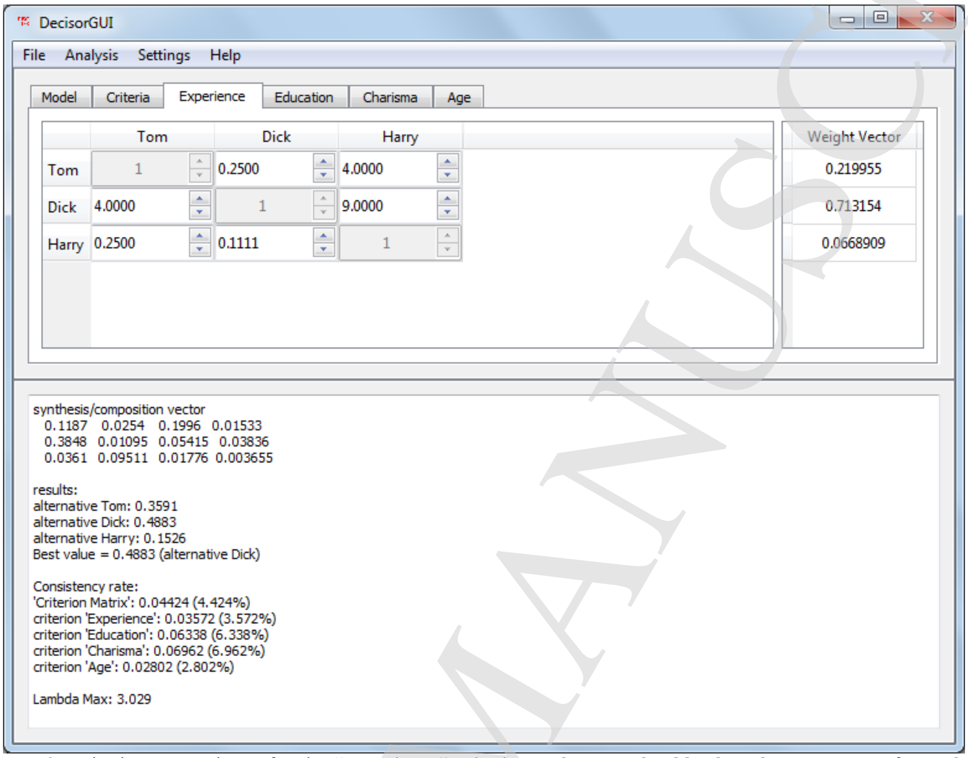

Fig. 8: Pairwise comparisons for the "Experience" criterion – the user should select the importance for each alternative and the tool computes the weights.

It is also important to mention that the Decisor tool computes and shows the consistency rates for the model, its actual value and its percentage, so the users can decide whether the chosen judgments are reliable. The consistency is computed not only for the alternatives but also for the selected judgments according the set of criteria. It also presents users with the computed Lambda max (λ_{max}) value, a parameter that is used in the AHP core solution to derive the right weight vector.

The Decisor tool also offers to users the possibility to perform a full B.O.C.R. analysis, using the menu item named "Analysis > B.O.C.R.". This kind of evaluation is used when the resulting weight vectors are slightly close and other factors strongly influence the decision outcomes, such as costs, or risks. The user could select to "Open" or to start a "New" analysis. For the "New" analysis, the tool presents users with a matrix where they enter the values they deem important in terms of benefits, opportunities, costs, or risks. The users also select a method to calculate the final results, based on three formulas: "Multiplicative", or M, "Additive (reciprocal)", or A^1, and "Additive (negative)" or A^2. Table 5 shows the formulas used for each method (where w is the weight vector for each B.O.C.R.).

Table 5: Standard formulas used for B.O.C.R. analysis.

Multiplicative	$M = (B^{w_b} \times O^{w_o})/(C^{w_c} \times R^{w_r})$

Additive (reciprocal)	$A^1 = w_b \times B_p + w_o \times O_p + w_c \times 1/C_p + w_r \times 1/R_p$
Additive (negative)	$A^2 = w_b \times B_p + w_o \times O_p - w_c \times C_p - w_r \times R_p$

Those formulas and methods for actual B.O.C.R. analysis are thoroughly explained in discussions of AHP[42]. We direct readers to the work of Ref. 43 for a broad point-of-view on B.O.C.R. analysis, discussion, and its limitations. The main screen for B.O.C.R. is demonstrated on Fig. 9.

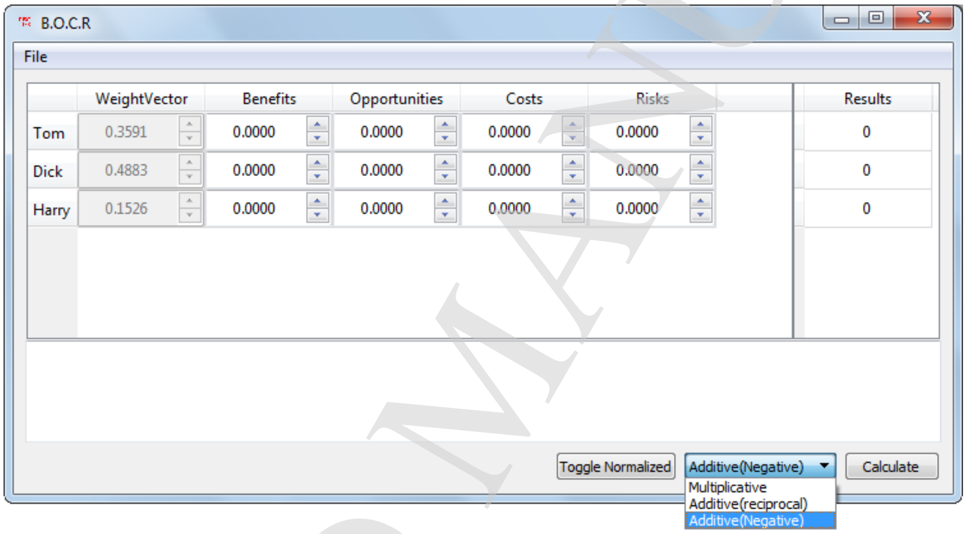

Fig. 9: B.O.C.R. analysis for the example, showing the alternatives and textual inputs where users select the formula and compute the results.

The B.O.C.R. screen starts with all zeroed values. For the working model where one must select the leader for the company, we could consider probable monthly stipends for each, considering their last salary or income. These values will be entered on the "Costs" column of the B.O.C.R. matrix. Fig. 10 shows these analyses, where Tom supposedly earns $5,000, Dick $9,000, and Harry has a monthly stipend of $6,000 (those are random values). We have used the "Additive (reciprocal)" method, and the figure also yields the final results.

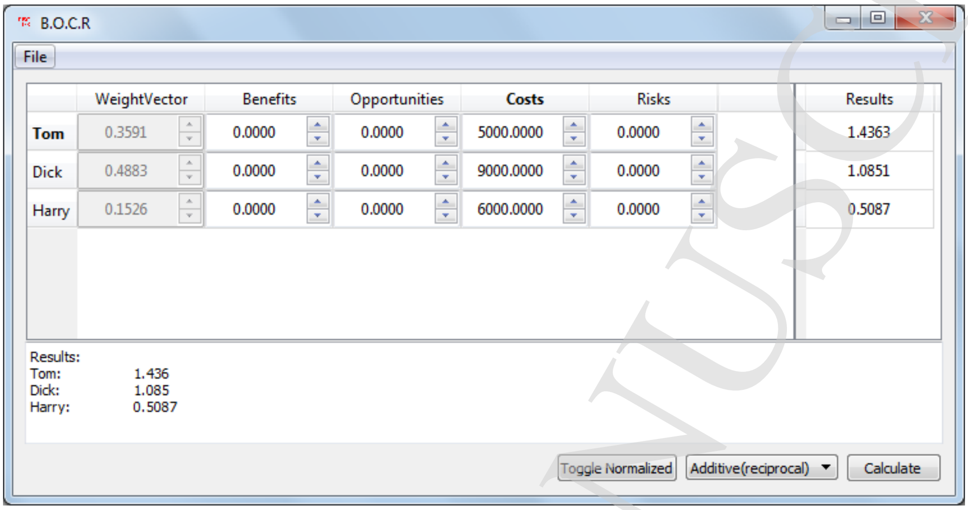

Fig. 10: The tool allows the stipulation of a monthly income for each alternative. For this analysis, the user has chosen the Additive (reciprocal) method according to the formula present in Table 5.

It is worth mentioning that without B.O.C.R. analysis, the decision was Dick (0.4883, or ~48%), Tom (0.3591, or ~36%), and Harry (0.1526, roughly 15%), in this order. However, it would be normal to assume that they could have different associated costs. In B.O.C.R. one could investigate such scenarios, yielding another ranking order for the actual choice, or Tom (1.436), followed by Dick (1.085), and Harry (0.5087). The numeric values are viewed as weights, where the largest value is deemed the desired choice to be made by the decisor. It is noticeable that the model disregarded costs completely, because one could address these issues in B.O.C.R. analysis. And, for this example, we used only the "Cost" dimension, i.e., one could use still Opportunities, Benefits, and Risks for a broader investigation.

It is possible to select different scales for the judgments, based on the literature on AHP. Using the menu item "Settings > Set Scale", the system allow the users to select one of many scales to be used in the analysis, according to Fig. 11.

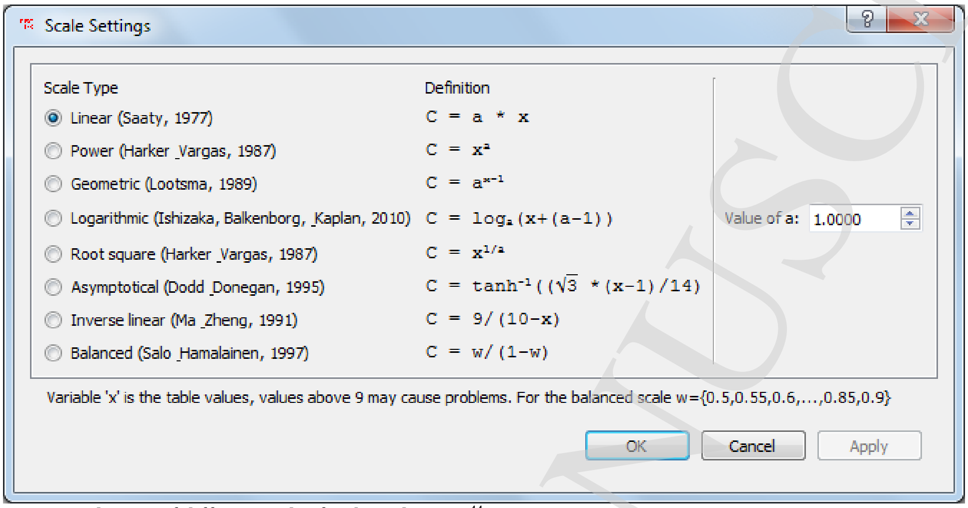

Fig. 11: Selection of different scales for the judgments[44].

The tool also has some other interesting features such as: it opens and saves textual files (users could edit the files and then open in the Decisor tool). The file format is straightforward, using matrices and floating point numerical values. This also allows users to create automatic models, since the format is easy to understand. The tool also allows *Group Decision Making*, where the users open the same model with different inputs (judgements) by accessing the menu item called "File > Open Several". The software will actually compute the *Geometric Mean* among all input files and then assess the priority vectors and consistencies accordingly.

Finally, the tool exports the model and the main results to a spreadsheet friendly version (which can be used in MS-Excel or similar spreadsheet system). The menu item is called "File > Save Report" and creates a *Comma Separated Values* (CSV) file that can be processed, since it comprises all judgments, synthesis, and consistencies for the model under analysis.

4. Final considerations

Decision making software should be implemented as user-friendly as possible because end users are usually non-technological oriented professionals. They do not have time to waste time learning different tools and specific particularities to help them do their work. They require effective, intuitive, simple to use, clean (in terms of GUI), friendly, reliable, robust, and adequate tools that allows them to be productive and conduct complex decisions with confidence. We offer a software tool designed to compute the best alternative to choose given a set of preferences among criteria using the method proposed by AHP. The tool presents a set of functionalities that allows the modelling and execution for fast decision making. Since the tool was built using a multi-platform implementation framework (Qt), it can be easily adapted for other targets and platforms such as GNU/Linux, Android, or MacOS, reaching out larger audiences.

Our results show that the tool is simple to use, reliable and robust. It allows users to quickly input criteria, alternative, and weights. It was shown that the software readily presents the computations and, more important, the alternatives in perspective to its ranking. It is our hope that users from different backgrounds could profit from the tool and use it to build models for complex decisions, where numerical values could be used to convince management towards effective decisions. One of the key qualities of the approach proposed by AHP consists in deriving values for intangible attributes, and the Decisor tool offers a reasonable way to model decision problems.

Our intention is to address other advanced aspects and integrate them into the Decisor software framework. We are considering the integration of TOPSIS in Decisor, as it has a simple (yet powerful) numerical solution. Another idea will be to develop a module responsible for computing *Analytic Network Process* (ANP). We may also combine fuzzy analysis with AHP[45,46], and addressing mechanisms on how to incorporate more levels (e.g. sub-criteria) into the model, including other visual components into the tool (i.e. a visual tree-like structure). We also aim to implement a feature for automatic execution of models , and another module for automated analysis producing visual reports for quantitative metrics used in decision making. Finally, we would also like to evaluate the tool under the analysts' point-of-view in contrast with the stakeholders', adapting the tool for each user profile through a detailed usability test.

The tool binaries are available on-line at https://github.com/czekster/Decisor/releases

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