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A Decision Support Framework for the Layered Evaluation of Interactive Adaptive Systems

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Abstract. Many usability evaluation methods for interactive adaptive systems exist in literature. There is not yet an agreement in the adaptive system community about which method is more useful than another in specific evaluation situations. This raises the question, “What is (are) the suitable evaluation method(s) that need(s) to be used in specific evaluation constraints?” This paper presents possible directions to address this issue by proposing a multi-criteria decision support framework for selecting the appropriate methods for the layered evaluation. The proposed decision support framework is applied to determine the suitable usability evaluation methods for a specific adaptation layer of a given adaptive hypermedia system.

Keywords. Interactive adaptive system, Usability, Layered evaluation, Decision support framework.

1 Introduction

Interactive Adaptive Systems (IAS) can be defined as “interactive systems that adapt their behavior to users on the basis of processes of user model acquisition and application that involve some form of learning, inference, or decision making” [1]. The evaluation of interactive adaptive systems is an important part of their development process and it should be as comprehensive as possible. One of the peculiarities that differentiate the evaluation of interactive adaptive systems from that of the non-adaptive ones is layered evaluation [2], [3]. The aim of this evaluation is to decompose the adaptation process into different components (layers), and to evaluate them separately [4], [5]. A variety of Usability Evaluation Methods (UEMs) exist in literature [3], [6], [7], [8]. In each layer, different evaluation methods can be used. The diversity of UEMs engenders a difficulty of choosing the most suitable ones in particular evaluation constraints. In fact, a major problem which evaluators are confronted with is the choice of suitable usability evaluation methods [9]. The choice problem concerning UEMs is a challenging issue and it depends on many factors [9], [10]. For instance, huge efforts are needed in order to understand the suitability of each usability evaluation method in particular contexts [11]. The suitable evaluation methods to be used for specific situations dependent essentially on the characteristics of the layer under consideration and the available evaluation resources [2]. The aim of this work is to propose a multi-criteria decision support framework that guides evaluators in the choice of appropriate usability evaluation methods for a layered evaluation. In order to address the goal of this research, a multi-criteria decision making method, namely Analytic Hierarchy Process (AHP) is used to assist the decision making process. The present paper expands [12] by developing a decision support framework (it extends the state of the art, it enhances the proposed approach in order to guide layered evaluation of interactive adaptive systems, and it details the case study).

The outline of this paper is organized as follows. We introduce first a background of the evaluation of interactive adaptive systems. We also provide an overview of some existing works for IAS evaluation and their limitations, and we provide subsequently the motivation for our proposal (Section 2). In the following, we introduce the proposed decision support framework. We present AHP decision aid method and the steps of the

process of choosing the suitable evaluation methods (Section 3). Next, we present a case study related to an adaptive hypermedia system and we discuss the obtained results (Section 4). Finally, we conclude the paper by a summary and a look at perspective future works (Section 5).

2 State of the Art and Related Literature

2.1 The Evaluation of Interactive Adaptive Systems

One of the peculiarities that differentiate the evaluation of interactive adaptive systems and regular (non-adaptive) ones is the *layered evaluation*. The aim of this approach is to assess the success of adaptation by decomposing it into different layers and evaluating them separately [3], [13]. The different layers reflect the various stages of adaptation. Layered evaluation helps evaluators to identify the exact cause of the adaptation failure. Many studies identified several adaptation components in IAS literature [2], [13], [14]. In each layer, different evaluations have to be taken into account. The layered evaluation approach suggested by Karagiannidis and Sampson [13] discerns two layers that refer to the information processing steps within the adaptation process which should be investigated separately in IAS evaluation: (1) the interaction assessment layer where the assessment process is being evaluated, and (2) the adaptation decision making layer where the adaptation decision is evaluated. Similar layered evaluations but with a greater level of granularity have been proposed by Paramythis *et al.* [2]; the authors identify five layers, including: (1) collection of input data which refers to the collection of user interaction data, (2) interpretation of the collected data which refers to the parts of the system that interpret the information, (3) modelling the current state of the world which reflects the explicit or implicit representations of the users, (4) deciding upon adaptation which refers to the parts of the system that are responsible for deciding upon adaptations, and (5) applying adaptation which refers to the actual introduction of adaptations in the user-system interaction, on the basis of the related decisions. Recently, Manouselis *et al.* [14] proposed a layered evaluation for adaptive recommender systems, in which two layers are identified, namely: evaluation of user modelling and evaluation of adaptation decision making.

2.2 The Existing Works for the Evaluation of Interactive Adaptive Systems

From 2000 onwards, some frameworks that can assist the evaluation of interactive adaptive systems have been proposed [2], [15], [16], [17]. Gupta and Grover [15] suggested a framework that treats evaluation as an integral part of the development process of adaptive hypermedia systems. It takes into consideration the environment in which adaptive hypermedia systems are used and the type of adaptation while evaluating individual modules in these systems. Another framework was presented by Tarpin-Bernard *et al.* [16], called AnAmeter. It provides the first steps towards the evaluation of the quality of a system's adaptation and it quantifies the adaptation degree of IAS. AnAmeter guides evaluators in the determination of the adaptation components in adaptive systems in a tabular form. In 2013, Mulwa and Wade [17] proposed a web-based framework, called EFEx. EFEx proposes the appropriate methods to be applied for the evaluation of adaptive e-learning systems considering different factors in the recommendation process. Examples of these factors are: the type of publications in which the evaluation methods have been proposed, the number of adaptive e-learning systems belonging to the same category that have been evaluated using the considered methods, etc.

The evaluation of interactive adaptive systems is an important task. However, important as it is, the research area is still open. This is due to some limitations in the existing evaluation works, including: (1) the difficulty of assisting automatically the choice of suitable evaluation methods to be applied for different layers, (2) the limited application domain of most of the existing works; the majority of them support only the evaluation of a unique type of interactive adaptive systems, (3) some of the existing works such as [15], [16] do not provide results in the form of reports or recommendations to evaluators. To address these limitations, this paper aims at proposing a decision support framework which helps evaluators in the selection of appropriate methods to be applied for the layered evaluation of IAS.

3 The Proposed Decision Support Framework

3.1 Concept of Analytical Hierarchy Process

The Analytic Hierarchy Process (AHP), proposed by Saaty [18], is a Multi-Criteria Decision Making (MCDM) method. It is applied to uncertain decision problems with multiple criteria in order to choose the best alternatives via a pair comparison process. One advantage of AHP is that it is simple to use since there is no need to build a complex expert system with the decision maker's knowledge embedded in it [19]. It allows us to make qualitative and quantitative analyses in the same decision-making methodology. The AHP method is based on five essential steps [20]:

1. Decomposing the problem into a hierarchy tree of different decision elements (i.e. goals, criteria, sub-criteria and alternatives).
2. Creating a pair-wise comparison matrix, at each level of the hierarchical structure; the elements are compared using a Saaty's nine-point scale [20], as displayed in Table 1. The pair-wise comparison matrix A is shown in Equation (1). In the comparison matrix A, a_{ij} refers to the degree of preference of i (row) criteria over j (column) criteria.

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & 1 & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix} = \begin{bmatrix} 1 & 1/a_{21} & \dots & 1/a_{n1} \\ 1/a_{12} & 1 & \dots & 1/a_{n2} \\ \dots & \dots & 1 & \dots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix}. \quad (1)$$

3. Determining the normalized weights, in which the eigenvector is derived from the matrix created in the last step measures of relative importance among the criteria and is used to determine the normalized priority weights for each criterion.
4. Determining the priority weights of alternatives with respect to decision criteria.
5. Analyzing the Consistency Ratio (CR) in order to validate and determine the acceptance of the weights. More details can be found in [20]. Based on Saaty's empirical suggestion [20] that a $CR \leq 0.1$ is acceptable, it is concluded that the foregoing pair-wise comparisons to obtain attribute weights are reasonably consistent. In contrast, if $CR > 0.1$, the matrix results are inconsistent and are exempted for the further analysis.

Table 1. Fundamental scale for making judgments adapted from [20]

Definition	Description
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between two adjacent judgments

3.2 Choice Process of Appropriate Evaluation Methods for the Layered Evaluation

The choice of appropriate evaluation methods for a particular evaluation situation is an essential step in the evaluation process of any interactive system. In this paper, we present a decision support framework for choosing the suitable UEMs to be used for the layered evaluation. As shown in Fig 1, it consists of two main phases, namely: (1) the preparation of data phase, and (2) the selection of usability evaluation methods phase.

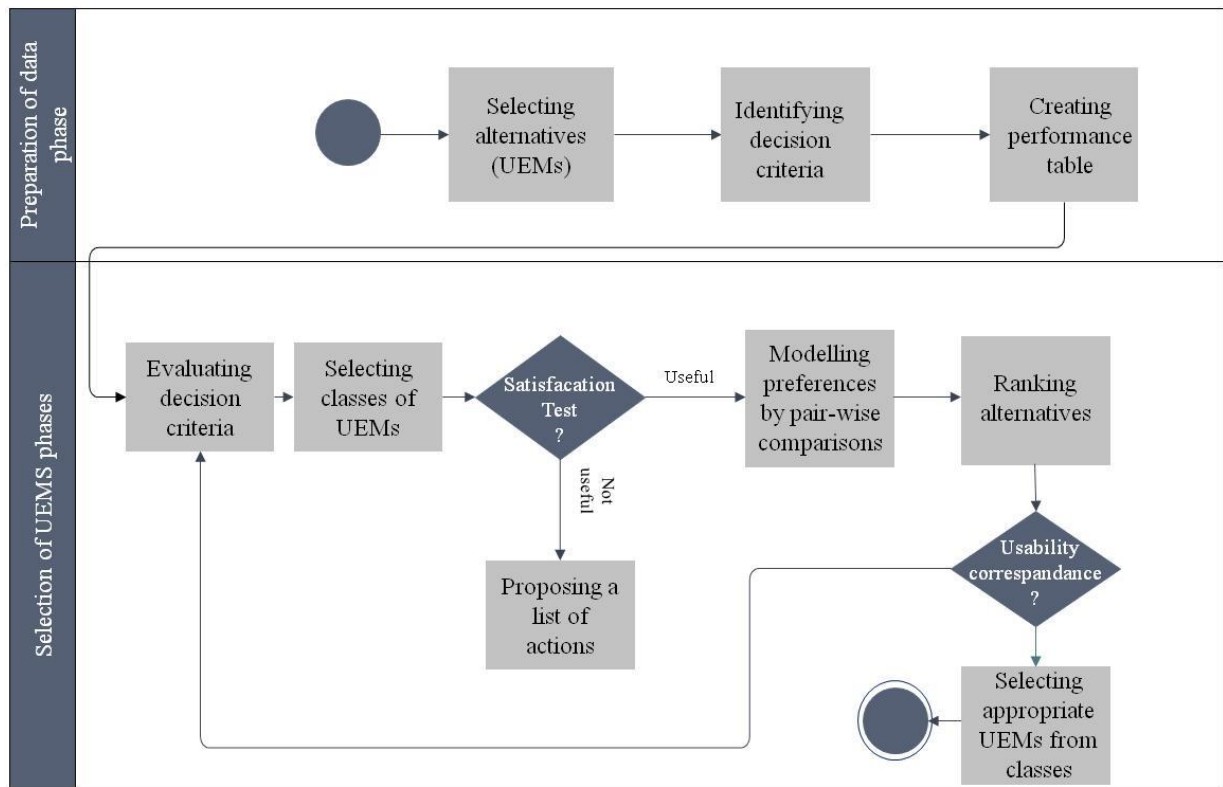


Fig. 1. The proposed decision support framework functioning flowchart

The process starts with the identification of the alternative usability evaluation methods, and the decision criteria influencing the choice of appropriate UEMs for the layered evaluation. From an overview of the IAS literature, it is clear that there are different criteria that can affect UEMs choice. In this paper, the considered criteria are those related to the specificities of layered evaluation and include: (1) the adaptation layer's input data that reflect the input data of the adaptive system's functionalities to be assessed by a layer. The input can be either given to the participants (e.g., users, experts) or decided by them [2]; (2) the layer's output data which reflect the data produced by the layers. Similarly to the input data, it can be either given or decided by the participants [2]; (3) the type of interactive adaptive system on which the evaluation methods may be applied [15]; (4) the system development phase that highlights the moment at which the evaluation can be used. According to [2], an adaptation layer may be evaluated in: the analysis, design, and implementation phases [2]; (5) the human resources which refer to the group of persons involved in the evaluation process [9]; (6) the temporal resources that underline the available time for conducting the evaluation of IAS [9]; and (7) the financial resources which reflect the available budget for conducting the evaluation of interactive adaptive systems [9].

Then, an evaluation of the performance of the alternative UEMs is provided in terms of the different decision criteria under consideration. A performance table is created then which consists of UEMs versus an array of decision criteria. This classification is based on previous works such as those of [2], [3], [8]. In the next step, the evaluator has to evaluate the decision criteria through questionnaires. The decision support framework retrieves then all the evaluation methods related to each factor. For instance, all the usability evaluation methods are grouped into classes of methods at this stage. Each class is classified according to the considered factors (e.g., class 1 includes the usability evaluation methods that can be applied in the implementation phase. This means that class 1 includes for instance all the UEMs that can be applied in the final evaluation phase such as user tests, simulated users, etc.). It should be noted here, that one UEM can belong to more than one class of methods.

In the second sub-phase, a user interface of the decision support framework allows the evaluator to attribute his/her level of satisfaction with the proposed classes of UEMs. For instance, s/he has to allocate to each class of UEMs a score according to his/her level of satisfaction. This score can adopt the following values: (1) useful: the considered UEMs are useful and can be grouped into the same class, and (2) not useful: the proposed classes of UEMs do not meet the requirements for belonging to either of the constraints have been labeled as not useful in the total rating. In the case of no satisfaction with a specific class of methods, the decision support framework provides a list of actions (e.g., increasing the available budget, reducing the available time for the evaluation, etc.), which enable the evaluator to obtain a new class of UEMs until satisfaction.

In the following, we proceed to the choice of appropriate UEMs from the different classes of methods by means of an MCDM method, namely AHP. A user interface in the decision support framework allows the evaluator to compare each criterion with others according to his/her perception of the importance of each one. A score is given to a nine-point scale proposed by Saaty [20] (See Table 1). Then, our proposal calculates automatically the scores of the pair-wise comparison matrix once the scores are entered and the 'Calculate' button is clicked. All the entries along the diagonals are 1. After exposing the comparison matrixes of each criterion with the AHP method, appropriate UEMs from different classes of methods are determined. The last step corresponds to the validation of the obtained results. In this step, we propose to compare the usability criteria covered in the identified UEMs and the usability criteria of the adaptation layer under consideration. If the usability criteria to be assessed in each layer match the ones covered by the identified UEMs, then the process of choice is stopped and the identified usability evaluation methods are displayed as the most appropriate ones. Otherwise, the evaluator has to go back to the step called "evaluating decision criteria" in order to modify the input data. For instance, each usability evaluation method allows us to assess a number of usability criteria in each layer of IAS. Depending on the available evaluation constraints, a number of usability criteria must be evaluated at every layer. Finally, the most appropriate usability evaluation methods will be displayed in a list that represents their suitability for the considered adaptation layer in given evaluation constraints. Further information is provided about the final results of the appropriate usability evaluation methods to be used, including links to recommendations on how to use them.

4 Application

To demonstrate the applicability of our proposal, a problem of selection of the most appropriate UEMs for an adaptive hypermedia system is presented. The considered system is intended to assist users in their information-seeking tasks by offering personalized access to news through a Web interface. In this study, we determine the appropriate UEMs for a layer-specific of the considered system, namely the *deciding upon adaptation* layer. According to [2], this layer reflects the decision taken in order to apply the suitable adaptation strategy on the adaptive system.

4.1 Procedure

Before proceeding to the different steps of the proposed decision support framework, the evaluator has to identify the different usability evaluation methods and the factors that have an impact on the UEMs' selection. In this study, thirteen methods commonly used for the evaluation of usability in interactive adaptive systems are considered; some of these methods are focus group [21], heuristic evaluation [22], cognitive walkthrough [23], user-as wizard [24], etc. Next, the evaluator has to define the different decision criteria that have an impact when deciding the suitable UEMs. As already mentioned in Section 3.2, seven criteria are considered in this study (i.e., layer's input data, layer's output data, type of interactive adaptive system, system development phase, stakeholders, temporal resources, and financial resources). These criteria are meant to assist in the decision of choice of suitable methods for the layered evaluation. A performance table is created, in which the different UEMs are classified according to the criteria. The evaluator has to identify the available constraints of the considered layer of the given system which is to be evaluated through a questionnaire. These questionnaires ensure the capture of the characteristics of the layer under evaluation. Once the different criteria are evaluated, the proposed framework retrieves all the evaluation methods related to each decision criterion.

The evaluation methods are classified in the next step into seven classes corresponding to the different decision criteria. Class 1 includes all the methods that require medium temporal resources. A score of satisfaction will be allocated to every class of methods according to the level of satisfaction of the evaluator. If so, s/he has to move on to the next step and no further analysis is required. In order to select the most appropriate usability evaluation methods from the identified classes, an MCDM method, namely AHP is applied. In this study, six UEMs are selected from the proposed classes of methods. The considered methods correspond to: simulated users, user-as-wizard, heuristic evaluation, focus group, user test, and cognitive walkthrough. The priority weights of each criterion and alternative in every level are determined by using the AHP method. The decision matrixes which are created by the developed decision support framework are shown below. The evaluator has to fill the matrix according to his/her evaluation by using Saaty's scale method [20].

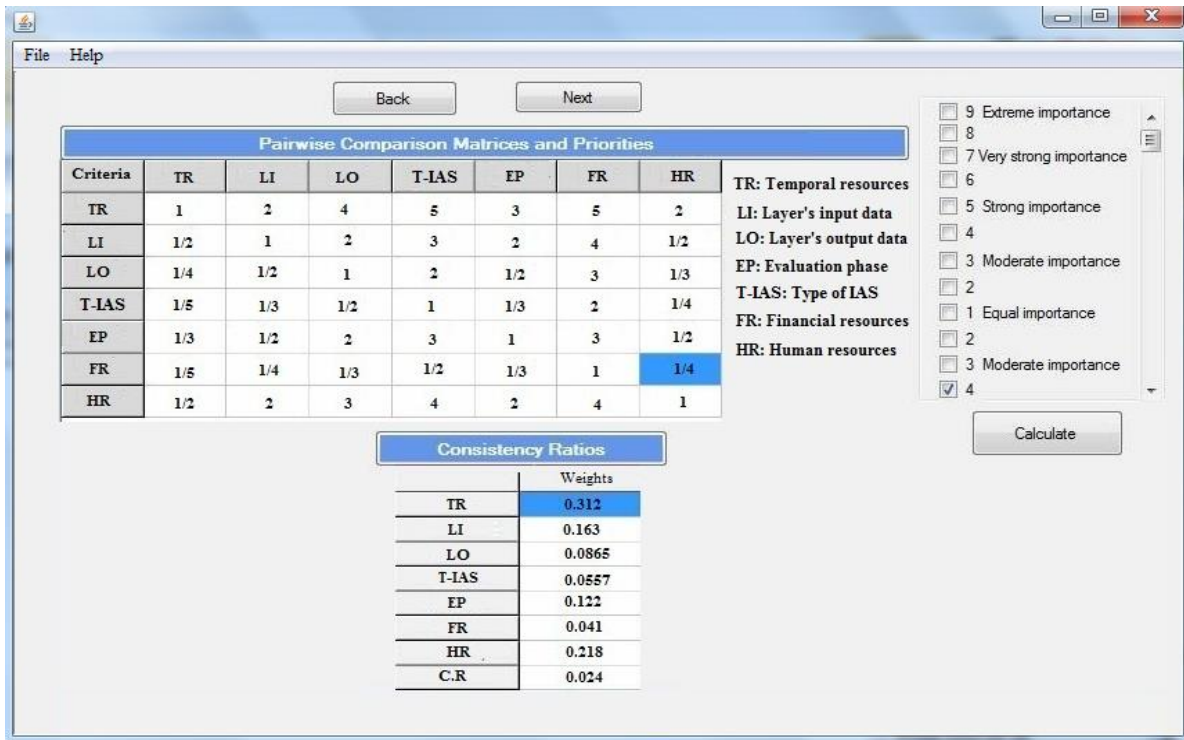


Fig. 2. The evaluation matrix of decision criteria

For instance, the criterion "human resources" is moderately stronger than the "financial resources", so we give the value 1/4 to the "financial resources" criterion compared to the "human resources" one and the evaluator has to click below the scale (shown by the value of 1/4). A screen shot of the proposed decision support framework at this stage is shown in Fig 2.

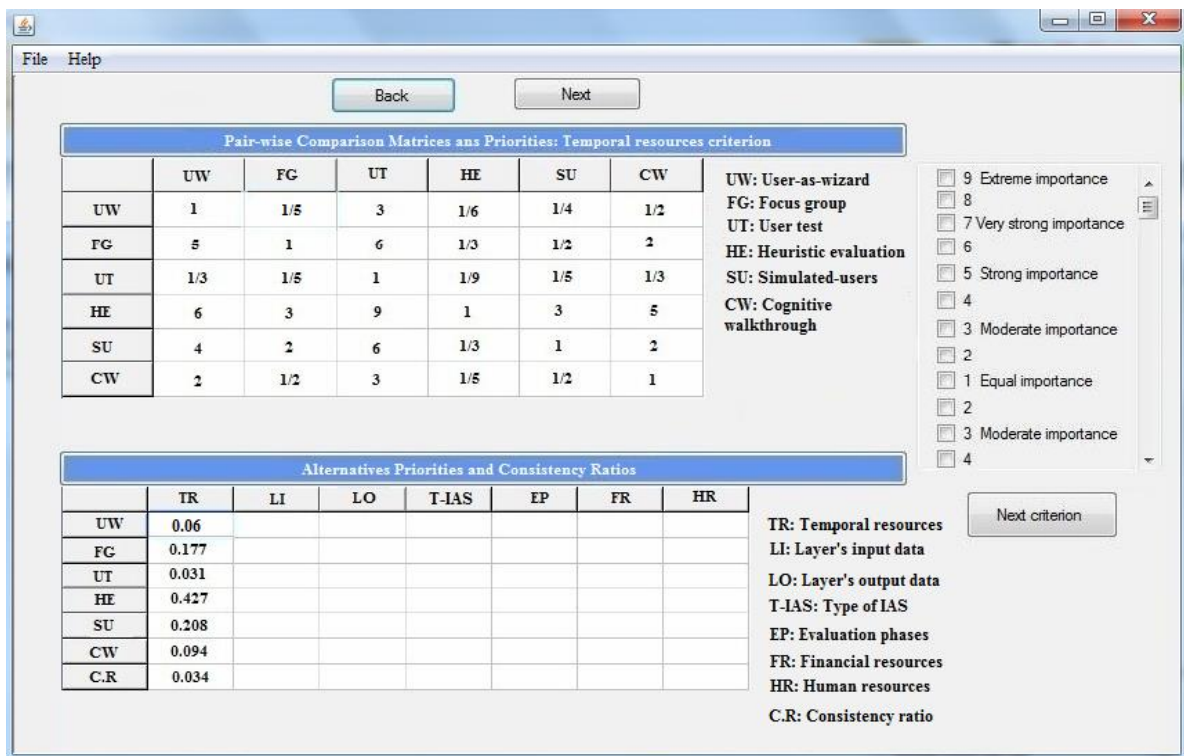


Fig. 3. Evaluation of alternatives with respect to temporal resources criterion

The consistency ratio for the comparison below is calculated to determine the acceptance of the priority weighting. The consistency test is one of the essential features of the AHP aid method. It aims to eliminate the possible inconsistency in the weights revealed through the computation of the consistency level of each matrix.

At this stage, the consistency ratio for the criteria is 0.034, which means that the pair-wise comparisons are consistent because the results are valid if this ratio is smaller than 0.1. Then, the evaluator has to fill the comparison matrix of each alternative in order to evaluate all the alternatives with respect to the different decision criteria. Fig 3 shows an example of evaluation of alternatives with respect to the temporal resource criterion. According to the temporal resource criterion, the most appropriate usability evaluation methods found are heuristic evaluation, and respectively, simulated users, focus group, cognitive walkthrough, user-as-wizard and user test. After evaluating the alternatives with respect to the temporal resources criterion, the evaluator has to enter the judgments for the rest of the decision criteria. For each criterion, every possible combination of two alternatives is judged in this way (Table 2).

Table 2. Priority weights of decision criteria

	Temporal resources	Layers' input data	Layers' output data	Type IAS	of Evaluation phases	Financial resources	Human resources
User-as-wizard	0.060	0.149	0.034	0.038	0.069	0.071	0.387
Focus group	0.177	0.055	0.039	0.382	0.412	0.246	0.146
User test	0.031	0.465	0.244	0.067	0.039	0.039	0.258
Heuristic evaluation	0.427	0.032	0.089	0.271	0.249	0.158	0.061
Simulated users	0.208	0.206	0.135	0.094	0.13	0.383	0.04
Cognitive walkthrough	0.094	0.090	0.059	0.145	0.098	0.1	0.105
C.R	0.034	0.075	0.038	0.036	0.026	0.025	0.036

4.2 Results and Discussion

Fig 4 gives a summary of the proposed appropriate evaluation methods using the AHP aid method. In this study, the heuristic evaluation method (21.2) was the most appropriate usability evaluation method for the deciding upon adaptation layer in the given evaluation constraints. Followed respectively by focus group (18.2), user-as-wizard (17.9), usability test (17.4), simulated users (15.7), and cognitive walkthrough (9.7). Further information is provided about each usability evaluation method, including links to recommendations on how to use them.

When the evaluators are confronted with the difficulty of choosing the suitable UEMs for interactive systems in general and adaptive systems in particular, the decision can often be very complex. In this paper, we have proposed a multi-criteria decision support framework based on the AHP method in order to select the appropriate usability evaluation methods for a layered evaluation. We presented a case study in which we applied AHP in order to determine the suitable UEMs for a specific layer. It should be noted that the choice of evaluation methods for different layers depends primarily on the system's development lifecycle and the characteristics of the layer under consideration. The proposed decision support framework offers a flexible guide for prioritizing the usability evaluation methods to be applied for the layered evaluation and for supporting the decision making in a coherent and transparent way.

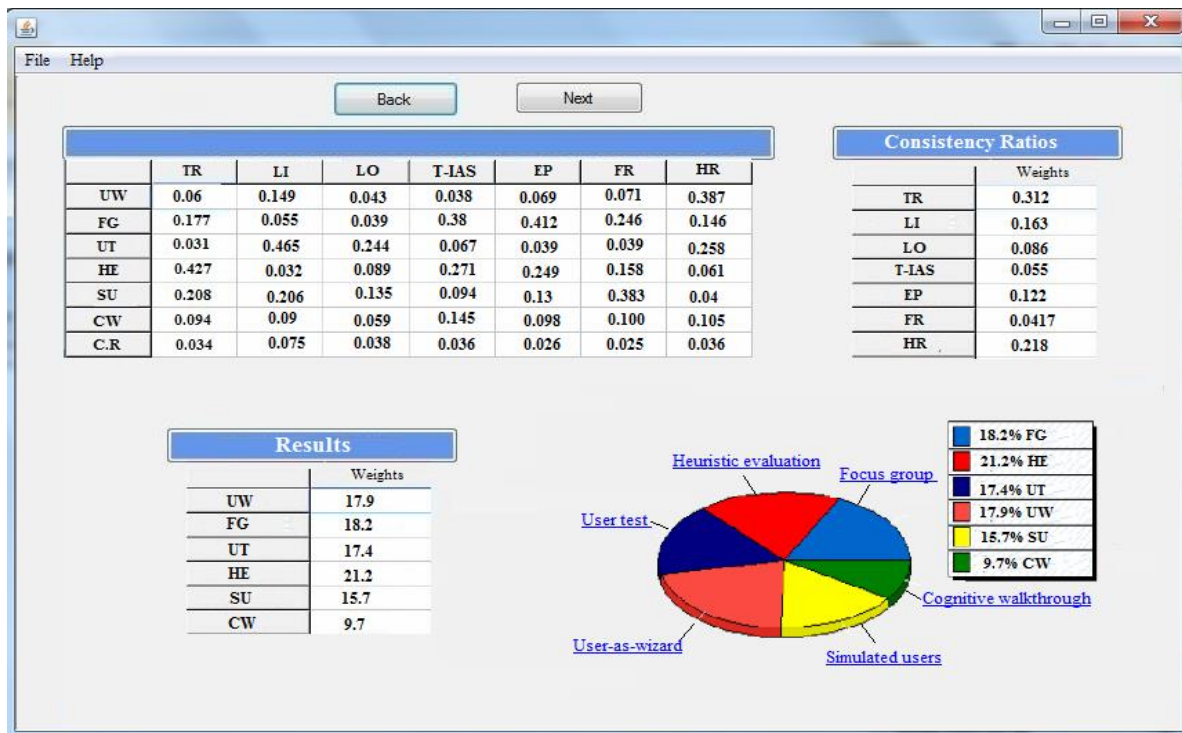


Fig. 4. Obtained final results of the proposed decision support framework

5 Conclusion and Future Work

The choice of the best evaluation methods is a key part of the process of evaluation of interactive adaptive systems. Different evaluation methods exist which differ along many dimensions such as the resource requirements, the system's development lifecycle, etc. The diversity of these methods engenders a difficulty in choosing the most suitable ones in particular constraints. This paper addresses these challenges by proposing a multi-criteria decision support framework that aims to help evaluators in the selection of best usability evaluation methods for a layered evaluation. A case study concerning an adaptive hypermedia system was presented, in which we determined the suitable methods to be applied for a specific adaptation layer.

As a perspective for future research, we intend to conduct a usability evaluation of the overall decision support framework. We intend also to test the proposed decision support framework in other fields of adaptive systems.

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