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EvalCHOICE: A Decision Support Approach for the Usability Evaluation of Interactive Adaptive Systems

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Abstract

Successful usability evaluation of interactive adaptive systems requires the use of appropriate methods. Different usability evaluation methods exist in the literature. These methods can be applied in association with the individual layers and with the whole adaptive system. In each situation, it is essential to apply the appropriate evaluation methods. In this paper, we propose a novel decision support approach called EvalCHOICE. It guides evaluators in the choice of appropriate usability evaluation methods for individual layers and the adaptive system as a whole. Our proposal is applied to determine the suitable evaluation methods for a given Web-based adaptive system in the field of transport.

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1. Introduction

Interactive Adaptive Systems (IAS) are currently a hot topic of research due to their growing use in different application areas including tourism[1], education[2], transportation[3], etc. With this growing use comes a corresponding need to perform a comprehensive evaluation. For an effective evaluation of IAS, many researchers have emphasized the need for applying the *layered evaluation*[4,5,6,7]. The aim of this evaluation is to separate the adaptation process

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into different layers and to assess them individually where feasible[4,5,6]. The evaluation of IAS has to consider also the evaluation of the adaptation as a whole in which the adaptive system is considered as one block[4]. Different Usability Evaluation Methods (UEMs) can be applied to evaluate individual layers as well as the whole adaptive system[4,7,8]. It is essential to make the best choice with regard to the appropriate UEMs in each situation. One of the most important steps in the evaluation process of interactive systems is the choice of appropriate evaluation methods[8]. However, this step can be confusing due to the availability of a variety of UEMs[4,8]. For instance, many efforts are needed in order to understand the applicability of each UEM in a particular evaluation context[8,9]. The selection of appropriate methods is based essentially on the evaluators' expertise[9]. The choice of suitable UEMs to be applied for the individual layers and for the whole system needs the consideration of many criteria, which leads to two Multi-Criteria Decision Analysis (MCDA) problems. The aim of this paper is to propose a decision support approach, called *EvalCHOICE* (decision support approach for usability EVALuation methods CHOICE). The main goal is to propose the appropriate UEMs to be used for the whole adaptive system and for the individual layers, depending on the existent constraints. Two situations can then be solved through our proposal, namely (1) assigning the appropriate UEMs that can be used in association with layers, and (2) choosing the suitable UEMs for the whole adaptive system. These situations are considered as two different decision problems that can be solved using different MCDA methods. In this research, we have adopted ELECTRE TRI as an MCDA method for assigning the appropriate UEMs to the individual layers, and ELECTRE 1 as an MCDA method for the choice of suitable UEMs for the whole adaptive system.

The rest of this paper is organized as follows. Section 2 describes briefly the evaluation approaches and the usability evaluation methods for interactive adaptive systems. Section 3 presents the existing research works in IAS field. Section 4 explains the choice of the MCDA methods adopted in this study. Section 5 provides a brief description of these MCDA methods. Section 6 presents the proposed decision support approach. In Section 7, we report on the application of EvalCHOICE in a particular case study and we discuss the interpretation of the results. The presented case study is related to an adaptive Web-based system in the transport domain. Section 8 gives some conclusions and hints for future work.

2. Background

2.1. The evaluation of interactive adaptive systems

The layered evaluation and the traditional evaluation are considered as the common approaches in the IAS literature[4].

- The layered evaluation: Many researchers have emphasized the need for applying the layered evaluation approach for interactive adaptive systems[4,5,6]. The aim of this evaluation approach is to decompose the adaptation into different layers and to assess them individually[4]. In recent years, a series of layered approaches have been proposed in the IAS literature[4,5,6]. Those approaches argued that in each adaptation layer, different evaluations have to be taken into account. One of the advantages of the layered evaluation is that it helps evaluators to get information on the pros and cons of each step of adaptation separately thus leading to an improvement in the performance of each layer [5].
- The traditional evaluation: Its main goal is to compare the adaptive and the non-adaptive versions of the same system[10]. It consists of applying the evaluation methods to the whole adaptive system, without distinguishing between its layers[4]. Different methods can be applied for the evaluation of the whole interactive adaptive system. In this case, the selection of appropriate evaluation methods is domain and system-dependent [4].

2.2. The usability evaluation methods for interactive adaptive systems

Various usability evaluation methods can be applied in association with the individual layers and with the whole interactive adaptive system. In this section, we present briefly some of these evaluation methods:

- User-as-wizard: In this method, participants perform the wizard's task without having a script to follow[11]. It consists of two steps, namely (1) the exploration stage in which the participants perform the task of IAS or of a specific layer, and (2) the consolidation stage in which the acceptability of the human performance is assessed[11].

- Heuristic evaluation: The evaluators examine a user-interface using a set of criteria[12]. Nielsen's heuristics[12] are considered as the most popular heuristics in usability testing. An integration of these heuristics with the layered evaluation of adaptive learning systems has been proposed by Magoulas and his collegues[13].
- User test: In this method, the participants use the adaptive system and record what happens[14]. The user test method is used in order to measure the user's opinions and performance.

3. Related Work

Few studies have been conducted to deal with the selection of the appropriate evaluation methods for IAS. Gena and Weibelzahl[7] presented an approach to evaluate adaptive hypermedia systems. They propose the evaluation methods for each phase of development. In 2013, Mulwa and Wade[15] proposed a framework for adaptive e-learning systems. It recommends the appropriate evaluation methods based on some criteria such as the type of publications in which the methods have been proposed, the number of publications in which the evaluation methods are applied, etc. A more recent decision support approach was presented by[16]; this one proposes the evaluation methods with regard to their suitability depending on specific evaluation contexts. One MCDA method, namely Analytic Hierarchy Process, was proposed for the selection process. The proposed approach was illustrated in the case of two different contexts to select the suitable evaluation methods for a specific layer and for the whole adaptive system.

Differently from previous studies, the aim of the present research is to propose a new decision support approach that guides the choice of the most suitable UEMs for the individual layers and for the whole adaptive system, using two MCDA methods in each case. These MCDA methods differ from one situation to another, unlike the case in our previous work[16] where the same MCDA method is used in each approach. With this novel proposal, it is possible to deal with the choice of the appropriate UEMs to be applied in each evaluation approach with more flexibility and efficiency. For instance, the choice of suitable UEMs for the layered and the traditional evaluation can be considered as two different decision problems. They can be solved using two different MCDA methods and considering some different criteria in each case. In the case of layered evaluation, the choice of suitable UEMs for individual layers corresponds to the assignment problem. Regarding the choice of suitable UEMs for the whole system, the decision problem corresponds to the choice problem. To the best of our knowledge, our proposal is the first work that solves the identification of suitable UEMs for IAS evaluation approaches by dealing with these situations as a sorting and choice problems.

4. The Adopted MCDA Methods

Various MCDA methods have been developed to facilitate the decision-making process. Each MCDA method has its advantages and disadvantages. Roy[17] distinguishes four types of MCDA problematic which represent different goals in relation to how a decision maker would like to solve a decision problem:

- Choice problematic P.α: aims to choose a subset of best alternatives or only one best alternative.
- Sorting or assigning problematic P.β: aims to assign alternatives to predefined categories.
- Ranking problematic P.γ: aims to rank alternatives with a partial order.
- Description problematic P.δ: aims to describe alternatives in a formalized way.

Two types of decision problems are to be solved in this research. In each one, a specific MCDA method is to be applied. For instance, we adopted two MCDA methods to handle each decision problematic, namely ELECTRE TRI and ELECTRE 1. The next sub-sections explain the choice of these MCDA methods.

4.1. MCDA method Used for the choice of appropriate UEMs for the layered evaluation

As already stated, the layered evaluation consists in decomposing an adaptive system into its layers and evaluating them separately[4,5]. In each layer, different usability evaluation methods are to be applied[4]. Assigning the appropriate UEMs to one or more layers corresponds to one of the problem statements proposed by Roy[17], namely the assignment problematic (P.β). For instance, the aim of this decision problem is to assign each alternative evaluation method to predefined ordered or not ordered categories (in our case layers)[17]. The semantics of categories may imply an ordered structure of the categories and may not. In the case of ordered categories, the problem is

called ordinal sorting. In each case (ordered or not ordered categories), different MCDA sorting methods can be used. Due to the implicit dependencies of layers, the undetected problems of higher layers may influence and have a cascading effect on the other layers. In fact, undetected problems identified in a higher layer may be the causes of the problems in the lower layers[4]. This implies that the layered evaluation should give priority to the different steps of the adaptation process. We can consider then, that the structures of layers are ordered. Given this situation, we put forward the arguments for adopting an MCDA method that assigns alternatives to ordered categories. Given the heterogeneous nature of decision criteria and the presence of qualitative data, ELECTRE TRI seems to be a suitable method for the given decision problem. One advantage of ELECTRE TRI method compared to other MCDA sorting methods is that it does not require to compare every pair of alternatives. For instance, when ELECTRE TRI method is used, the alternatives are compared to (C-1) profiles delimiting the C categories. This has a great importance in terms of saving computing time when large sets of alternatives are considered[18].

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4.2. MCDA method used for the choice of appropriate UEMs for the evaluation as a whole

The choice of suitable UEMs for the evaluation as a whole does not distinguish between the different layers. Such situation typically corresponds to the choice problem proposed by Roy[17]. The major purpose of this decision problem is to select a subset of potential alternatives or one alternative[17]. In this paper, ELECTRE 1 is adopted as an MCDA method for the choice of suitable UEMs for the whole IAS. In practice, ELECTRE 1 is adopted to treat the choice problematic (P.α). It is considered as the MCDA method most commonly used to resolve the choice decision problem.

The choice of these two MCDA methods takes into account the fact that they are complementary in their conditions of use and in their ability to model different data. The next sub-section describes the adopted MCDA methods.

5. The Basic Structure of ELECTRE TRI and ELECTRE 1

In this study, two versions of ELECTRE (ELEction Choix Traduisant la REalite) methods are used to solve the appropriate UEMs choice problem.

5.1. ELECTRE TRI

ELECTRE TRI is a multi-criteria assignment method (i.e., it assigns the set of alternatives A to predefined ordered categories C)[19]. It uses an outranking relation S that validates or invalidates the assertion aSb_h, whose meaning is: "a is at least as good as b_h". ELECTRE TRI builds an index $\sigma(a,b_h) \in [0,1]$ that represents the degree of credibility of the assertion aSb_h. In order to determine this index, the following steps should be calculated: the partial concordance indices, the global concordance index, the discordance indices, the credibility index $\sigma(a,b_h)$ of the outranking relation[19]. Then, a cut-off level λ should be introduced in order to obtain a crisp outranking relation. The statement aSb_h is considered valid if $\sigma(a,b_h) \geq \lambda$, where $\lambda \in [0.5,1]$[19]. Two assignment procedures can be evaluated using ELECTRE TRI[20], namely pessimistic procedure, and optimistic procedure. More details about the ELECTRE TRI method can be found in[18,19,20].

5.2. ELECTRE 1

ELECTRE 1 is a multiple-criteria method which is principally devoted to the choice problem[19]. It consists of computing two matrices:

- The concordance matrix: computes the concordance index C(a,b) for each pair of alternatives (a,b) as shown in Equation 1, where p_i is the weight of importance.

$$C(a,b) = \sum_{i:a_i+\beta_i \geq Bi} p_i \quad (1)$$

- The discordance matrix: computes the discordance index D (a,b) as shown in Equation 2

$$D(a,b)= 1 \text{ if } £i,\ bi > a_i+v_i, \text{ Otherwise } D(a,b)=0 \quad (2)$$

A detailed description of ELECTRE 1 method can be found in[19].

6. EvalCHOICE: The Proposed Decision Support Approach

Various methods are to be used for the usability evaluation of interactive adaptive systems[4,7,8]. Some of these methods can be applied to evaluate a specific layer as well as the whole adaptive system. It is essential to make the best choice with regard to the appropriate methods to use in each situation[8,16]. In this research, we propose a decision support approach that guides IAS evaluators in the choice of appropriate UEMs to be used in individual layers and in the whole adaptive system. The application of such approach would greatly reduce the complexity of the process of selection of UEMs. As shown in Fig. 1, our proposal consists of two main steps, namely (1) structuring the problem, and (2) determining the appropriate UEMs.

6.1. Structuring the problem

As already mentioned, two decision problems are to be solved by our proposal, namely assigning the appropriate UEMs for individual layers, and choosing the suitable methods for the whole adaptive system. In each case, we use a specific MCDA method. Every MCDA method needs the determination of alternatives and criteria that refer to the tool constructed for the comparison of these alternatives. In this research, alternatives represent the usability evaluation methods for IAS. Different criteria can influence the choice of usability evaluation methods. The considered criteria in this study include: (1) layer's input data which can be shown or produced by the participants[4], (2) layer's output data which it can be either given or decided by the participants[4], (3) system development phase that highlights the moment at which the evaluation can be applied[4], (4) location, evaluation can be carried out either in usability laboratories or in a natural environment[21], (5) number of evaluators which highlight the number of available evaluators included in the evaluation process[22], (6) number of users which refer to the number of users involved in the evaluation process[22], (7) presence of representative users, IAS evaluation can be applied in the presence of representative or real users[23]. Then, data are collected in order to create the performance matrix in which each alternative UEM is related to the identified decision criteria. In this step of evaluation, we are based on different studies such as those of [4,7,8].

6.2. Determining the appropriate usability evaluation methods

The next step continues with the determination of the decision criterion values for each specific evaluation context. To establish the values of criteria, a questionnaire is proposed to the evaluators. They give their answers to ascertain the context of use factors. For instance, the questionnaires ensure an automatic analysis phase to support evaluators in the identification of available constraints. Based on evaluators' answers, it is possible to define the usability criteria that should be assessed in IAS and its layers. A mapping is made between each participant's response of context of use factors and the usability criteria based on the studies of[24,25]. Table 1 illustrates some examples of this mapping.

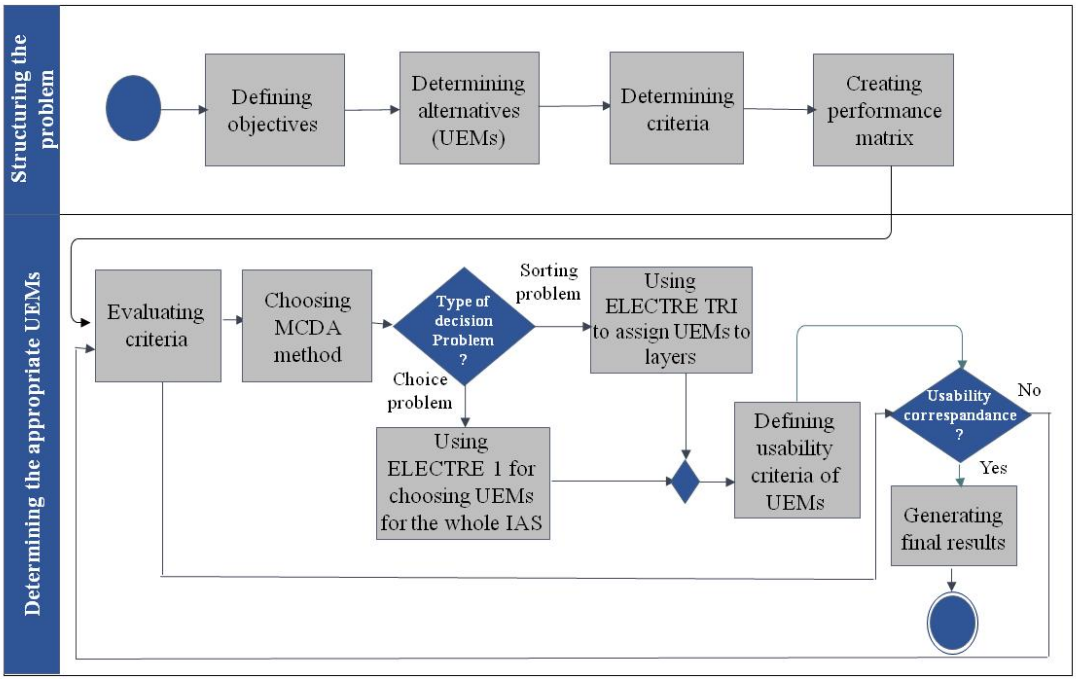


Fig. 1. The functioning flowchart of EvalCHOICE.

Table 1. Examples of mapping between usability criteria and context of use factors based on [24,25]

Usability criteria	Context of use factors
Predictability	Complexity of tasks
Controllability	Error correction
Transparency	Self-descriptiveness

According to the preferences of the evaluator, appropriate UEMs are to be identified either for the layered evaluation or for the system as a whole. Once the evaluation approach is selected, the next step is to perform the evaluation of the input values, using the corresponding MCDA method. As already mentioned, in the case of assigning UEMs to layers, ELECTRE TRI method is applied. In this situation, certain technical parameters are to be identified, such as the veto thresholds, the boundaries between categories, etc. For instance, the veto thresholds help to give an assignment to a category if an alternative is not strong enough according to one or more important criteria[13]. In order to choose the appropriate methods for the usability evaluation as a whole, we apply ELECTRE 1 method.

Before proposing the final results, we propose to compare the usability criteria that should be evaluated in the IAS under consideration and the usability criteria covered in each UEM. For instance, each usability evaluation method allows assessing a number of usability criteria in the different layers and in the whole IAS. Depending on the context of use, certain usability criteria must be evaluated in IAS and their layers such as predictability, transparency, etc.[4,18]. If the usability criteria of IAS matches the ones covered by the usability evaluation methods to be proposed, then the result is validated and our proposal proposes these UEMs as the final result; otherwise, the evaluator has to go back to "evaluating criteria" step in order to modify the input data. The next section presents a case study related to an adaptive Web-based system used in the field transport.

7. Case Study

In this section, we present a case study related to an adaptive transportation system. The aim is to illustrate the applicability of the proposed decision support approach.

7.1. Goal

In this case study, an adaptive system called *MyintelliTransport* is presented. It tailors the presentation and the content of user interfaces to the needs and the preferences of travelers. *MyIntelliTransport* adapts the user interfaces in such a way as to present only the relevant information about the itinerary. It takes into account the diversity of devices (i.e., PC, Smartphone). Such systems appear progressively in transport domain[3]. Fig. 2(a) illustrates a partial screen of the adaptive transportation system. Fig. 2 (b) shows the same user interface after the process of adaptation to a Smartphone.

7.2. Procedure

The first step corresponds to the identification of the alternative evaluation methods and the decision criteria that affect the usability evaluation of the interactive adaptive system. Twelve usability evaluation methods are considered, as shown in Table 2. These methods are classified according to the considered decision criteria (e.g., system development phase, number of evaluators and users, etc.) and the usability criteria that need to be assessed in each layer. In this study, evaluator prefers to choose the appropriate UEMs for layered evaluation of the given adaptive transportation system. ELECTRE TRI method is applied then to handle the considered situation.

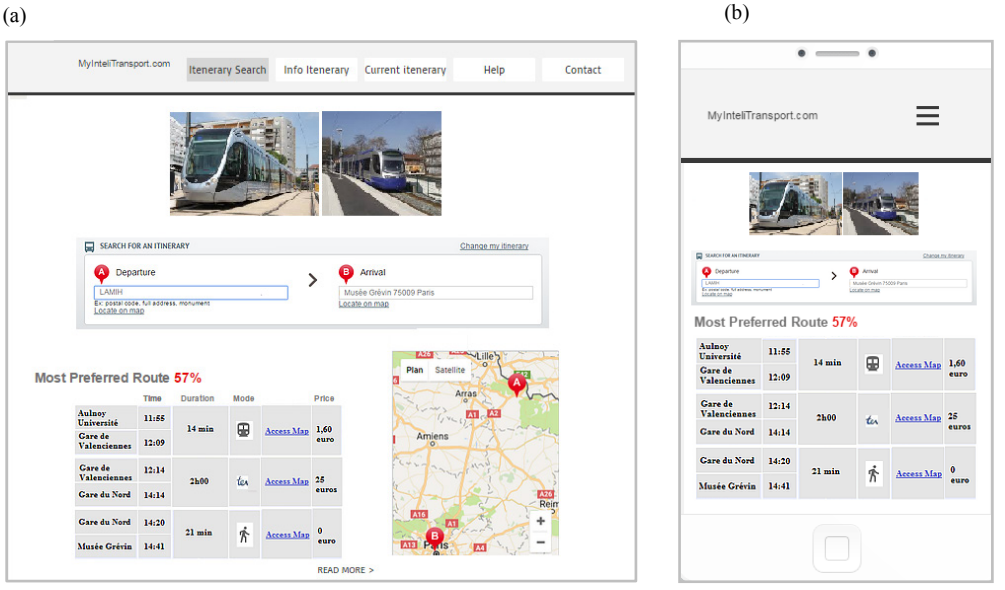


Fig. 2. (a) Partial screen shot of the adaptive transportation system on PC; (b) Partial screen shot of the adaptive transportation system on a Smartphone.

Table 2. The considered usability evaluation methods.

Focus group	User test	Heuristic evaluation	Cognitive walkthrough	User-as-wizard	Questionnaires	Interviews	Play with layer	Co-discovery	Think-aloud protocol	Simulated user	Cross-validation
a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12

To apply the ELECTRE TRI, a number of technical parameters have to be identified such as the importance weights of decision criteria. The construction of these weights is carried out through an analysis by an expert done before our study. The expert has more than two years of research experience in evaluating IAS. A group of evaluators was surveyed and 34 answers were received. The expert calculated the frequency of answers of evaluators to questions. The sum of the frequencies is used in order to provide the weight of criteria. Table 3 presents these criteria and their relative weights.

Table 3. Criteria and relative weights.

Criteria	System development phase	Location	Number of evaluators	Layer's input data	Presence of representative users	Number of users	Layer's output data	Total
Number	C1	C2	C3	C4	C5	C6	C7	--
Total answers	8	4	4	5	4	4	5	34
Weights	8/34	4/34	4/34	5/34	4/34	4/34	5/34	1

The next step was to determine the veto thresholds. The main question which was put at this stage consisted in judging if for a criterion C_i the possibility of imposing the power of veto is convenient, taking into account the outranking in all of the other criteria. Table 4 shows the values determined for the veto thresholds.

Table 4. Values for veto thresholds of each criterion.

Criteria	C1	C2	C3	C4	C5	C6	C7
Veto thresholds	2	4	4	3	5	4	3

The following step continues with an elicitation of the characteristics needed for the categories. In our context, these categories represent the adaptation layers. The adaptation process of the considered adaptive system is centered on five distinct layers of Paramythis *et al.*[4], including collection of input data (CID) which refers to the collection of interaction context data, interpretation of the collected data (ID) in which the input data are interpreted, modelling the current state of the world (MW) which reflects the introduction of data about the interaction context in IAS models, deciding upon adaptation (DA) which refers to the parts of the system that are responsible for deciding upon adaptations, and applying adaptation (AA) in which the adaptations are introduced in the user-system interaction. These layers of adaptation have respectively the following priorities: very high, high, moderate, low and very low. In this way, four borders (or limit profiles) b_i are defined in order to separate these categories. Border b2, for example, determines the limit between the interpretation of the collected data and the modelling the current state of the world layers.

Concerning the cut-off level λ, we use the default value, 0.76, which means that in order to suppose that an alternative a is at least as good as a limit profile, at least 76% of the criteria must be concordant with this affirmation. Then, the binary relations defined by a_iHb_i (where a_i represents the alternatives and b_i represents the border) are identified. Table 5 shows the binary relations between alternatives and the four borders in which the outranking relations (S), the indifference (I), or the incomparability (R) are defined.

Table 5. The binary relations between alternatives (a_i) and the four borders (b_i).

a_iSb_1	a_iSb_2	a_iSb_3	a_iSb_4
a1Ib1	a1Ib2	a1Sb3	a1Sb4
a2Ib1	a2Ib2	a2Ib3	a2Sb4
a3Sb1	a3Sb2	a3Sb3	a3Sb4
a4Ib1	a4Ib2	a4Ib3	a4Sb4
a5Ib1	a5Ib2	a5Sb3	a5Sb4
a6Ib1	a6Ib2	a6Ib3	a6Sb4
a7Ib1	a7Ib2	a7Sb3	a7Sb4
a8Sb1	a8Sb2	a8Sb3	a8Sb4
a9Ib1	a9Ib2	a9Ib3	a9Sb4
a10Ib1	a10Ib2	a10Ib3	a10Sb4
a11Sb1	a11Sb2	a11Sb3	a11Rb4
a12Sb1	a12Sb2	a12Ib3	a12Ib4

7.3. Results and discussion

The last stage of exploration of the ELECTRE TRI method consists in allocating the usability evaluation methods to the previously defined layers. This process aims essentially to analyze the way in which each UEM compares with the limit profiles which bind the layers. A comparison between the usability criteria of each layer and the ones covered in the UEMs was made. Based on the information given about the context of use factors, the usability criteria to be covered in the IAS could be determined. It should be mentioned that the obtained results are dependent on the given evaluation context. After applying the ELECTRE TRI, our proposal shows the appropriate UEMs for every layer according to two assignment procedures (pessimistic or optimistic). In this study, we adopted the pessimistic version of ELECTRE TRI as this version proposes the most suitable UEMs that assess the different usability criteria in each layer. Table 6 presents the final results obtained in relation to the appropriate UEMs for the layered evaluation of the adaptive transportation system. Considering these results, we can note that in each layer, different UEMs are proposed. These methods were considered as the most appropriate ones for the given evaluation context. It should be mentioned that the choice of appropriate UEMs depends essentially on the layers of adaptation, the life-cycle of the system development phase, and the usability criteria that need to be assessed in each layer. For instance, in each layer, different usability criteria are to be assessed. These usability criteria may differ from one layer to another. Every UEM is assigned to one layer according to which this method might be appropriate to assess the considered usability criteria of the considered layer.

Table 6. Final proposed results.

Layers of adaptation	Usability evaluation methods
CID	Cross-validation, simulated-users
ID	Heuristic evaluation
MW	Play with layer, focus group, user-as-wizard
DA	Cognitive walkthrough, interviews, thinking-aloud protocol
AA	User test, questionnaires, co-discovery

8. Conclusion and Future Work

This paper proposes a novel decision support approach called EvalCHOICE, which guides evaluators in the selection of the most suitable usability evaluation methods for the whole IAS and for individual layers, depending on the evaluation context. Future directions of this research consist of identifying the appropriate UEMs for the adaptive system as a whole since we have focused only on the identification of UEMs for the individual layers of the adaptive transportation system. We intend also to test our proposal in other fields of adaptive systems.

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