Prioritizing the usability criteria of adaptive user interfaces of information systems based on ISO/IEC 25040 standard

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ABSTRACT. *Usability is a major concern within adaptive user interfaces. It presents a combination of different attributes. The impact of each usability attribute may vary from one layer to another during the usability evaluation of adaptive user interfaces. On that basis, one question that arises is: "What are the priority levels of usability criteria that need to be assessed in individual layers and in the whole adaptive system?" This paper presents possible directions to address this question by identifying the priority level of usability criteria to be assessed in the adaptive user interfaces of information systems, considering the ISO/IEC 25040 standard. The priority level is calculated using a multi-criteria decision analysis method, namely the Analytic Hierarchy Process. The proposed approach provides guidance for evaluators to better evaluate adaptive user interfaces. An adaptive information system in the field of transport is presented in order to validate and illustrate our approach.*

RÉSUMÉ. *L'utilisabilité est un facteur de qualité important pour les interfaces utilisateur adaptatives. Il se focalise sur une combinaison des attributs. Le niveau d'importance de chaque critère peut varier d'une étape d'adaptation à une autre lors de l'évaluation de l'utilisabilité des interfaces utilisateur adaptatives. Une question qui se pose est : « Quel est le niveau de priorité des critères d'utilisabilité qui doivent être évalués dans les différentes étapes d'adaptation et dans l'ensemble du système adaptatif ? » Dans cet article, nous identifions les critères d'utilisabilité qui doivent être évalués dans les interfaces utilisateur adaptatives des systèmes d'information, en se basant sur la norme ISO/IEC 25040. Le niveau de priorité est déterminé à l'aide d'une méthode multicritère d'aide à la décision, à savoir le processus d'analyse hiérarchique. L'approche proposée sert à guider les évaluateurs pour*

mieux évaluer les interfaces utilisateur adaptatives. Un système d'information adaptatif dans le domaine du transport est étudié afin de valider l'approche proposée.

KEYWORDS: adaptive user interface, multi-criteria decision analysis method, ISO/IEC 25040 standard, usability criteria, layered evaluation.

MOTS-CLÉS : interface utilisateur adaptative, méthode multicritère d'aide à la décision, norme ISO/IEC 25040, critères d'utilisabilité, évaluation structurée.

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1. Introduction

The evaluation of the interactive part of Information Systems (IS) is of great importance during their development process (Vanderdonckt, 1994; Bastien and Scapin, 2001; Kolski *et al.,* 2012; Zen and Vanderdonckt, 2014). It consists in ensuring that the system fulfills its objectives. The present paper focuses essentially on the usability evaluation of the Adaptive User Interfaces (AUIs) of such systems. Many research activities related to the usability evaluation of AUIs have been performed in recent years. Different researchers have highlighted the importance of evaluating the usability of these interfaces (Benyon, 1993; Alshammari *et al.,* 2015; Alshammari *et al.,* 2016). For instance, conducting a usability evaluation is an essential task for developing usable adaptive systems. The usability concept is characterized by a combination of different criteria (Nielsen, 1993). The impact of each one may vary from a situation to another during the usability evaluation of AUIs. For an effective evaluation of adaptive user interfaces, many researchers have emphasized the importance of taking into account the layers of adaptation (Karagiannidis and Sampson, 2000; Brusilovsky *et al.*, 2001; Paramythis *et al.*, 2001; Paramythis *et al.*, 2010). This type of evaluation is called *layered evaluation*. The aim of this evaluation is to make an implicit logical division between the stages of the adaptive system, called *layers*, and to evaluate every layer separately where feasible (Paramythis *et al.,* 2010). Each layer is responsible for a specific step in the adaptation process (Brusilovsky *et al.*, 2001; Paramythis *et al.*, 2010). At each layer, a number of usability criteria are to be assessed (Paramythis *et al.*, 2001). Most of them are layer-specific. It should be mentioned that not all usability criteria are required in every evaluation situation and layer (Paramythis *et al.*, 2010). In fact, applying the same usability criteria to a specific layer or to the whole adaptive system at different evaluation contexts is impossible. Thus, before proceeding to the usability evaluation of AUIs, the usability criteria and their priority levels have to be determined in order to fully evaluate them in the individual layers and in the whole adaptive systems.

The level of priority of usability criteria depends essentially on the layers, the stages of the development process, and the available resources (Paramythis *et al.*, 2001). In this paper, the priority levels of the usability criteria that need to be assessed in adaptive user interfaces of IS are determined. When a conflict in the evaluation process arises, the obtained levels can assist evaluators in deciding which

usability criterion is more important than the other ones in particular context. The focus is on the main usability criteria of AUIs (e.g., breadth of experience, transparency, etc.) (Jameson, 2003).

The criteria weights are distinguished from the subjective weights of evaluator using the Analytic Hierarchy Process (AHP) method. AHP is considered as a powerful multi-criteria decision analysis method that allows decomposing all the problem elements into a hierarchy (Saaty, 2008). This method has been applied in different real life decision making situations, ranging from simple personal decisions to complex intensive decisions (Dagdeviren *et al.*, 2009; Jitendra and Nirjhar, 2011). In the human-computer interaction literature, AHP is a widely used decision aid method (Aydogan *et al.*, 2013; Hoo and Jaafar, 2013). Previous studies applied this method in user-interface design, namely to weigh the usability criteria (Mitta,1993; Park and Lim,1999) and to prioritize the usability problems during heuristics evaluation (Delice and Gungor, 2009). In (1999) for example, Park and Lim use AHP to weigh the usability criteria in order to select an interface among design alternatives. Other study proposed by (Delice and Gungor, 2009), involved the use of AHP in determining the severity ratings of usability problems detected by heuristic evaluation.

The planning of evaluation process of adaptive user interfaces is characterized by different steps (Totterdell and Boyle, 1990), which define (1) the objective of evaluation, (2) the adaptation layers that need to be assessed in adaptive user interfaces, (3) the usability criteria that need to be assessed across layers, (4) the priority level of usability criteria, (5) the metrics for evaluation, (6) the decision criteria for evaluation, (7) the appropriate usability evaluation methods for the considered usability criteria, and (8) the final evaluation report. Since adaptive systems are a special type of interactive systems, we propose in this research to adopt the evaluation process defined by ISO/IEC 25040. Our proposal adapts the steps of the evaluation process of AUIs and introduces them into the general evaluation process defined in ISO/IEC 25040. This standard defines the evaluation process for evaluating the quality of interactive systems and software products (ISO/IEC 25040, 2011). It replaces the ISO/IEC 14598-1 standard (1999) and it consists of five activities, namely (1) establishing the evaluation requirements (establishing the purpose of the evaluation, obtaining the software product quality requirements, identifying the product parts to be included in the evaluation, and defining the stringency of the evaluation. According to the ISO/IEC 25040 standard (2011), the stringency represents the degree to which the evaluation quality characteristics achieve the purpose of the evaluation), (2) specifying the evaluation (selecting quality measures, defining decision criteria for the quality measures, defining decision criteria for evaluation), (3) designing the evaluation (planning the evaluation activities), (4) executing the evaluation (making measurements, applying decision criteria for quality measures, applying decision criteria for evaluation), and (5) concluding the evaluation (reviewing the evaluation result, creating the evaluation report, reviewing the quality evaluation and providing feedback to the

organization) (ISO/IEC 25040, 2011). While all the steps of the evaluation process are very important, this paper focuses only on the first activity of the evaluation process in the case of the ISO/IEC 25040, namely "establishing the evaluation requirements". In this activity, details are given on the identification of the priority levels of usability criteria to be assessed in AUIs.

Accordingly, this paper is structured as follows. First, we introduce a background of the evaluation of adaptive user interfaces. We focus on the common evaluation approaches of adaptive user interfaces, the usability criteria of these interfaces, and the previous research studies in the field of the evaluation of AUIs (Section 2). In the following, we describe the used multi-criteria decision method, namely AHP (Section 3). After that, we detail the usability criteria measurement process adopted in this research (Section 4). Then, we illustrate the applicability of our proposal in the case of an adaptive transportation system and we discuss the results obtained (Section 5). Finally, we conclude the paper with a summary and possible future work (Section 6).

2. The evaluation of adaptive user interfaces

Adaptive user interfaces change their displays and behavior according to the user's preferences and needs (Jameson, 2003). In some cases, adaptivity changes might not meet users' needs, and this leads to a decrease in usability level. An important challenge is to show that the adaptive behavior improves the interaction with AUIs. The usability evaluation of such interfaces is therefore of great importance (Gena and Weibelzahl, 2007). It refers mainly to meeting usability criteria (e.g., transparency, controllability). The next section covers the evaluation approaches of adaptive user interfaces, the main usability criteria, and the previous research work that aims to identify the evaluation criteria for AUIs.

2.1. Evaluation approaches of adaptive user interfaces

During the last two decades, the layered evaluation has attracted AUI research attention with many approaches and frameworks (Karagiannidis and Sampson, 2000; Weibelzahl, 2001; Paramythis and Weibelzahl, 2005; Paramythis *et al.*, 2010). The purpose of the layered evaluation is to decompose an adaptive system into its layers and to evaluate each layer individually (Karagiannidis and Sampson, 2000; Paramythis *et al.*, 2010). In the adaptive system called GALE (Smits and De Bra, 2011), for example, two layers of adaptation exist, namely the *user model* and the *adaptation model* layers. The layered evaluation aims to identify the advantages of the provided adaptation and to improve the performance of each layer (Karagiannidis *et al.*, 2001; Paramythis *et al.*, 2010). A large number of layered evaluation frameworks have been proposed in AUI literature (Brusilovsky *et al.*, 2001; Weibelzahl, 2001; Paramythis and Weibelzahl, 2005; Brusilovsky *et al.*, 2006; Paramythis *et al.*, 2010; Manouselis *et al.*, 2014). These frameworks differ essentially in the number of identified layers. Karagiannidis and Sampson (2000)

proposed a layered evaluation approach in which they discern two layers, namely: (1) interaction assessment layer in which the user modelling process is evaluated, and (2) adaptation decision-making layer which tests the adaptation decision making. Weibelzahl (2001) identified three layers which include: (1) the evaluation of the input data that validates the acquisition process of the input data, (2) the evaluation of the inference mechanism responsible for the evaluation of the inference mechanism, and (3) the evaluation of the adaptation decision which assesses the validity of the adaptation decisions made.

Table 1. Comparison of the adaptation layers of three layered evaluation frameworks

<table>
<tr><th></th><th>Karagiannidis and Sampson (2000)</th><th>Weibelzahl et al. (2001)</th><th>Paramythis et al. (2010)</th></tr>
<tr><td rowspan="5">Layers</td><td rowspan="3">Interaction assessment</td><td>Evaluation of input data</td><td>Collection of input data</td></tr>
<tr><td rowspan="2">Evaluation of the interface mechanism</td><td>Interpretation of collected data</td></tr>
<tr><td>Modeling the current state of the world</td></tr>
<tr><td rowspan="2">Adaptation decision making</td><td rowspan="2">Evaluation of the adaptation decision</td><td>Deciding about adaptation</td></tr>
<tr><td>Applying adaptation</td></tr>
</table>

In 2010, Paramythis *et al.* (2010) proposed another layered evaluation framework, suggesting the decomposition of adaptation process into five layers including: (1) collection of input data in which data about user interaction are collected, (2) interpretation of the collected data which validate the collected information, (3) modelling the current state of the world in which an explicit or an implicit representation of the users is carried out, (4) deciding upon adaptation which refers to decisions about the adaptation strategy to be applied given the current user model, and (5) applying adaptation in which the adaptation decision is applied based on the related decisions. Table 1 illustrates the differences and relations of the decomposition layers proposed by the layered frameworks presented above.

In some cases, the evaluation of individual layers may not be feasible due to some unavailable resources (Paramythis *et al.*, 2010). For instance, certain constraints should be available in order to evaluate each layer separately such as the available time and the available budget for conducting an AUI evaluation, etc. In such cases, the evaluation of AUIs has to consider the whole adaptive system in which the adaptive system is considered as one block (Paramythis *et al.*, 2010). Thus, it is not possible to determine in which stage of adaptation the problem possibly exists. A number of usability criteria that can be assessed in the whole system as well as in any of the individual layers exist. In this research, we intend to

identify the priority levels of usability attributes using the AHP method. The proposed approach can then be used to guide evaluators to determine the relative importance of usability criteria and to improve the evaluation of the AUIs of information systems.

2.2. Usability criteria of adaptive user interfaces

Usability represents a combination of different criteria (Nielsen, 1993). There exists few models of usability that define the usability criteria to be measured in adaptive user interfaces. In each proposition, certain factors characterizing the usability of AUIs are defined (Höök, 2000; Jameson, 2005, 2009). Höök (2000) pointed out the following usability criteria for adaptive user interfaces (Table 2): controllability, predictability, transparency, trust and privacy. According to Jameson (Jameson, 2003, 2005), five usability challenges are to be considered in AUIs. Three of these challenges are generic for interactive systems, namely predictability, controllability, and unobtrusiveness; and two of them are especially relevant to adaptive user interfaces, these include privacy and trust on the one hand, and breadth of experience on the other one.

Table 2. Description of usability criteria for adaptive user interfaces

Usability criteria	Description
Predictability	The ability of users to understand the circumstances under which the adaptation takes place (Jameson, 2003, 2005)
Controllability	The degree to which users can control the adaptations (Höök, 2000; Jameson, 2003, 2005)
Breadth of experience	The behavior of the AUI that can prevent the users from experiencing the full range of available functionalities (Jameson, 2005, 2009)
Unobtrusiveness	The degree to which the adaptation can be applied with respect to the users' main interaction context (Jameson, 2005)
Privacy and trust	The degree to which the users' information is appropriately protected (Höök, 2000; Jameson, 2005)
Transparency	The capacity of users to understand adaptation (Höök, 2000)

Later, in 2009, Jameson (2009) extended the mentioned challenges into nine "usability side effects" of AUIs. Jameson's list includes predictability and comprehensibility, controllability, privacy, breadth of experience, timing, need to switch applications or devices, need to teach the system, need for learning by the user, and imperfect system performance (Jameson, 2009). A number of criteria are general and can be applied to the whole adaptive system, as well as to most or even

all layers such as privacy and trust, transparency, etc. (Paramythis *et al.*, 2010). Other criteria are more specific and can be applied only to particular layers. One example of such criteria is unobtrusiveness, which is expected to be applied only to *applying adaptation* layer proposed in (Paramythis *et al.*, 2010). In this research paper, the focus is on the common usability criteria specific to the adaptive user interface field. In Table 2, we present the considered usability criteria and their descriptions.

2.3. Previous Studies

A number of researchers have attempted to evaluate adaptive user interfaces (Tobar, 2003; Tarpin-Bernard *et al.*, 2009; Paramythis *et al.*, 2010). In 2003, Tobar (2003) proposed the first tool to guide the identification of evaluation criteria, called the *Extended Abstract Categorization Map (E-ACM)*. E-ACM aims to determine the specific adaptation features that need to be assessed, to establish criteria for the assessment, and to generate evaluation plans on this basis. A Web-based tool, called *AnAmeter*, was presented by Tarpin-Bernard *et al.* (2009) to evaluate the quality of a system's adaptation. AnAmeter guides evaluators in the identification of the overall score for the adaptation degree of AUIs. Another framework was proposed by Paramythis *et al.* (2010); it guides the layered evaluation of adaptive user interfaces. This work presents a revised version of three previous layered evaluation frameworks of Weibelzahl and Lauer (2001), Paramythis *et al.* (2001), and Brusilovsky *et al.* (2004). The authors summarize the evaluation methods and criteria used in the layered evaluation, focusing on formative evaluation.

Table 3. A comparison of the mentioned evaluation frameworks for adaptive user interfaces

	E-ACM (Tobar, 2003)	AnAmeter (Tarpin-Bernard *et al.*, 2009)	Paramythis *et al.* (2010)
Orientation in the identification of adaptation features to be assessed in AUIs	×	×	×
Orientation in the identification of usability criteria to be assessed in AUIs			
Identifying the priority levels of usability criteria			×
Generation of evaluation plans	×	×	

The above-mentioned works do not provide the same level of guidance to AUI evaluators. The majority of them focus only on specific adaptation features that need to be assessed and not on the usability criteria to be considered across layers. AnAmeter for example (Tarpin-Bernard *et al.*, 2009), characterizes adaptivity in order to determine the adaptation aspects that need to be evaluated. A limitation that can be mentioned also is the lack of a methodology for identifying the priority levels of usability criteria that need to be assessed in the whole adaptive system and in individual layers. To the best of our knowledge, there does not exist any proposals in the AUI literature that address this topic. Those motivations have lead us to propose an approach which aims to identify the priority levels of usability quality sub-characteristics (usability criteria), considering the ISO/IEC 25040 standard and based on AHP. Assigning relative weights allows evaluators to determine the level of importance of usability criteria in specific evaluation contexts and to evaluate AUIs based on these criteria. Table 3 lists the above-mentioned evaluation works, and presents some features of each one.

3. The Analytical Hierarchy Process

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method proposed by Saaty (1980). It is used to make decisions, in order to choose the best alternatives when conflicting and multiple criteria are present. AHP is considered as an effective method to deal with complicated decision problems since it reduces complex decisions to a series of pair-wise comparisons. One advantage of AHP is that it is simple to use. For instance, it only requires the comparison of two elements to each other without building a complex expert system (Saaty, 1980). AHP allows decision makers to deal with both qualitative and quantitative criteria. The AHP method is based on six essential steps (Saaty, 2008):

– Structuring the decision problem elements into a hierarchy of goal, criteria, sub-criteria, and alternatives;

– Constructing a set of pair-wise comparison matrices, the elements are compared using Saaty's pair-wise comparison scale (1980), as shown in Table 4. The pair-wise comparison matrix (A) is illustrated in Equation (1);

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

– Calculating the eigenvector in order to determine the priority weights for the different criteria. In this step, the column entries are normalized by dividing each entry by the sum of the column. Then the overall row averages are considered;

– Determining the priority weights of alternatives with respect to criteria;

– Calculating the Consistency Index (CI), as in Equation (2). Where n represents the matrix size and λ_{max} is the biggest eigenvalue of matrix A.

$$CI= (\lambda_{max}-n)/(n-1) \quad (2)$$

– Verifying the Consistency Ratio (CR) in order to validate and determine the acceptance of the weights. If CR ≤ 0.1, then the obtained weights are acceptable. If CR is more than 0.1, then the results are inconsistent and the judgments must be repeated (Saaty, 1980). Consistency ratio is computed as in Equation (3).

Table 4. Fundamental scale of relative importance based on Saaty (1980)

Numerical rating	Description	Explanations
1	Equal importance	Two elements contribute to the objective with equal relevance.
3	Moderate importance	An element is slightly more important than one other
5	Strong importance	Judgment strongly favors one element over another
7	Very strong importance	An element is strongly important than another
9	Extreme importance	The compared element is favored over another
2,4,6,8	Intermediate values	Used to represent a compromise between the above-mentioned preferences

$$CR= CI/RI \quad (3)$$

Table 5 illustrates the Random Indexes (RI) with dimensions from 1 to 10.

Table 5. Random consistency index table

Size of matrix (n)	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

4. Proposal for determining the priority level of usability criteria

Due to the multiplicity of usability criteria to be assessed in each layer and in the whole adaptive system, it is essential to determine the usability criteria that are necessarily measurable in a specific situation in order to fully assess them. As already presented, the aim of this research is to propose an approach for prioritizing

the usability criteria to be evaluated in adaptive systems and their layers. The identification of usability criteria is embedded in a broader view treated in the evaluation process defined by ISO/IEC 25040 (2011).

As shown in Figure 1, this standard demands that the evaluation process follows five activities. The process begins with "establishing the evaluation requirement". In this activity, the purpose of AUI evaluation is clarified. Then, the different layers are identified. It should be noted that not all adaptive systems have the same number of adaptation layers and that not all layers can be evaluated individually in all evaluation contexts (Paramythis *et al.*, 2010). Then, the usability quality sub-characteristics (criteria) of AUIs and their priority levels are identified. According to ISO/IEC 25040 standard (2011), this task involves also the selection of characteristics to consider in the identification of criteria and the stakeholders involved in the evaluation process. For instance, the determination of usability criteria should be based on different constraints such as evaluation budget, and purpose of the evaluation, etc. (ISO/IEC 25040, 2011). In the present study, the aim is to determine the usability criteria that need to be evaluated in each layer and in the whole adaptive system along with their priority levels. For this reason, the AHP method is used to prioritize and weigh the usability attributes based on the feedback from the evaluator on the context of use factors and the available constraints.

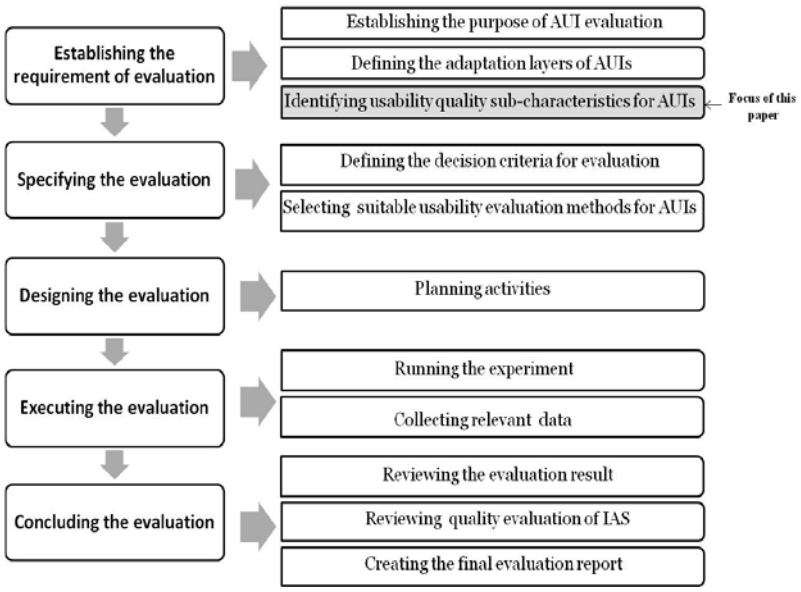


Figure 1. Process to evaluate the usability of adaptive user interfaces inspired from ISO/IEC 25040 standard (2011)

The choice of AHP was motivated by its simplicity of use and its ability to prevent subjective judgment errors, allowing to provide a measure of the consistency in judgments. Another reason for choosing AHP is that it makes it possible to sort out the elements according to their contribution to achieve the main objective. The results gathered from the last activity and the considered evaluation constraints are used as input for the "specifying the evaluation" activity.

In the third activity, called "designing the evaluation", the usability evaluation methods are chosen and the evaluation activities are planned. Next, the evaluator has to identify the AUI's requirements that have been implemented and to execute the functional test case in order to check if the results are as expected.

Finally, in the "concluding the evaluation" activity, the results of the evaluation are checked and an evaluation report is produced. As already mentioned, the focus of this research is on one acticity of the usability evaluation process of adaptive user interfaces, namely "establishing the evaluation requirements"; the tasks deployed in this activity of the evaluation process are presented in the next section.

4.1. Establishing the objective of the evaluation

The usability evaluation of adaptive user interfaces depends essentially on the context within which it is used. Before an adaptive user interface is evaluated, the evaluator needs to identify the aspects related to the contexts of use having an impact on the usability evaluation. In this task, the objective and the planning of AUI evaluation are determined. The evaluator has to answer a questionnaire to ascertain the constraints of the usability evaluation of the interactive adaptive systems.

4.2. Defining the adaptation layers of adaptive user interfaces

In this task, the different layers to be included in the evaluation have to be identified. It should be noted that not all adaptive systems have the same adaptation layers and not all layers can be evaluated individually at the various stages of the development process and in all the evaluation contexts (Paramythis *et al.*, 2001). For example, the *collection of input data* layer proposed by Paramythis *et al.* (2010) has not been addressed in the evaluation studies of certain adaptive systems.

4.3. Identifying the priority level of usability criteria to be evaluated

It is a challenging task to identify the usability factors to be evaluated in the interactive adaptive system. Depending on the context in which the user interfaces are used, a usability attribute may be more important than the other ones (Bevan, 1995). The priority levels of usability criteria to be evaluated in the AUIs depends essentially on the adaptive system, the context of use, and the purpose for which

usability is described. The main contribution of this task is to select and determine the level of priority of usability factors. A multi-criteria decision analysis method is suitable for this aim since it resolves a multi-criteria decision problem. We, therefore, perform an analysis of the context of use factors against usability criteria. It should be noted that this mapping is not always a straightforward task since the AUI literature provides few guidelines that can assist towards this end. Table 6 shows examples of the mapping of some context of use factors with the usability criteria of AUIs.

Next, the evaluator has to perform pair-wise comparisons of criteria and alternatives, based on his/her preferences and experience. The pair-wise comparisons are conducted using the scale proposed by Saaty (2008). As a result, the level of importance of each usability attribute is obtained. This can assist evaluators in deciding which usability attributes meet the most important usability characteristics of the adaptive system. The next section presents an application of our proposal in order to illustrate its feasibility.

Table 6. Association between some usability criteria and context of use factors

Usability criteria		(Jameson, 2003)	(Jameson, 2009)	(ISO 9241-110, 2006)
Controllability	Speed of dialog	×	×	
	Suitability for individualization			×
	Error correction	×	×	×
Predictability	Conformity with user expectations			×
	Success at specific sub-tasks	×	×	×
Transparency	Self-descriptiveness			×
	Number of users able to access to unavailable data	×	×	

5. Case study

An application of the proposed approach is presented in this section. It concerns an adaptive Web-based information system in the field of transport. The aim of this research is to identify the priority level of usability criteria in a specific layer of the considered system.

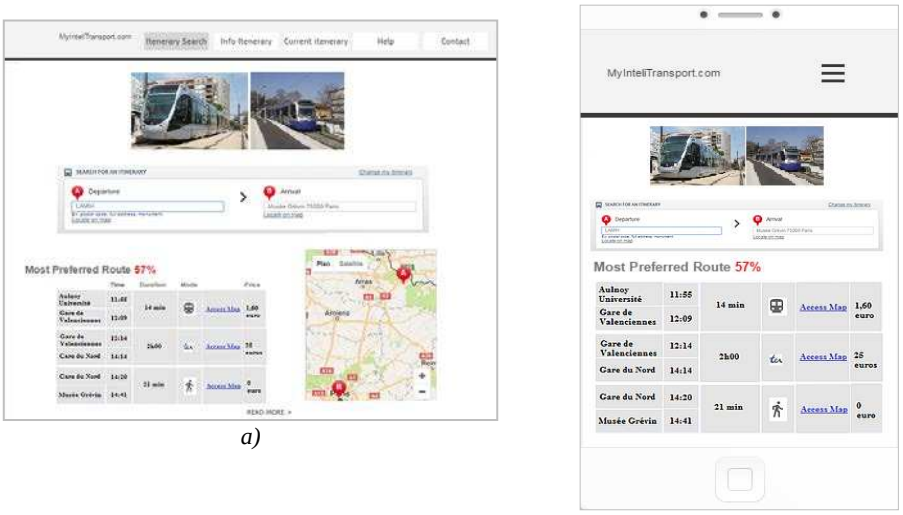
5.1. Procedure based on the ISO/IEC 25040 Standard

In this section, we describe the procedure followed in the experiment during the "establishing the evaluation requirement" activity using the proposed approach. A characterization of this activity is performed in three tasks, based on the ISO/IEC 25040 standard (2011).

5.1.1. Establishing the objective of evaluation

A detailed analysis is conducted to determine the contexts of use of the adaptive information system (e.g., users, tasks, and environmental characteristics). In this case study, an adaptive system called *MyinteliTransport* is considered. The given adaptive system tailors the interfaces in such a way as to present only the relevant information about the itinerary. It allows travelers to choose the itinerary that best fits their preferences based on different criteria. Examples of those criteria are: low cost, most comfort, low trip duration, etc. *MyinteliTransport* adapts also the presentation of interfaces according to the used devices (i.e., PC, Smartphone). Such systems appear progressively in the field of transport (Brossard *et al.*, 2007; Ezzedine *et al.*, 2008; Kolski, 2011; Soui *et al.*, 2012).

Figure 2a illustrates a partial screen of an interface of the adaptive transportation system. Figure 2b shows the same interface after the process of adaptation on a Smartphone.



a) *b)*

Figure 2. Partial screen of the adaptive information system a) in transport domain b) after an adaptation on a Smartphone

5.1.2. Defining the adaptation layers of adaptive user interfaces

In the following, the layers of the adaptive system under consideration should be determined. The adaptation process of the considered adaptive information system is centered on the decomposition model of Paramythis *et al.* (2010). In this case study, we determine the priority levels of usability criteria of a specific adaptation layer, namely *deciding upon adaptation*. According to Paramythis *et al.* (2010), the *deciding upon adaptation* layer refers to the decision taken in order to apply the suitable adaptation strategy on the adaptive system.

5.1.3. Identifying the priority level of usability criteria to be evaluated

After the determination of the adaptation layers of the adaptive system, what is needed is to identify the usability criteria to be evaluated in the selected layer. The process starts with modeling the hierarchy tree based on the decision problem. The hierarchy refers to a relation between elements on one level with those of the level immediately below. As illustrated in Figure 3, a three-level hierarchical structure is built, based on the overall goal of the problem, namely the "identifying the priority level of usability quality sub-characteristics". The first level of the hierarchy contains this goal. The middle level explains a group of decision criteria that achieve the goal. These criteria are related to the specificities of the considered adaptation layer. The last level of the hierarchy's decision shows the alternatives. In this research, the alternatives represent the usability criteria for adaptive user interfaces based on (Höök, 2000; Jameson, 2003, 2005, 2009).

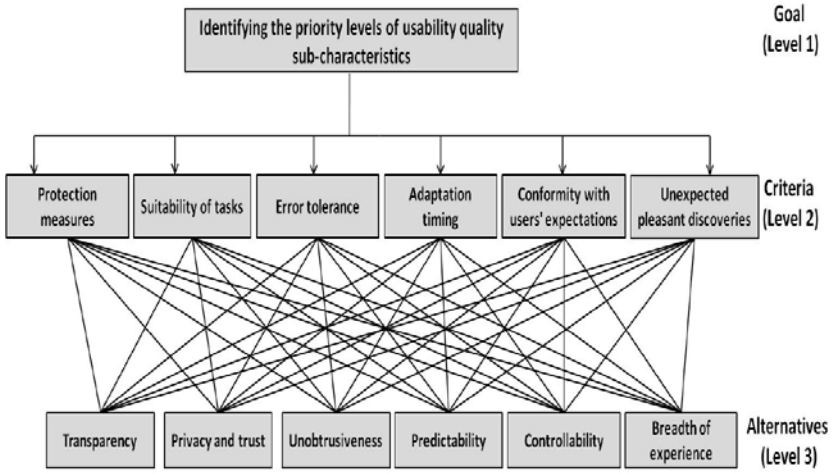


Figure 3. Hierarchical structure of the identification of the priority levels of usability criteria

For the *deciding upon adaptation* layer, a number of usability criteria can be considered (e.g., predictability, privacy, transparency, breadth of experience, controllability, unobtrusiveness) (see Table 2). Each usability criterion can have some different perspective than the same one adopted in another layer. For example, *predictability* refers to the user' ability to predict what the effect of his/her actions will be on the system's decisions (Höök, 2000). *Privacy and trust* reflects whether the adaptation may potentially disclose information about the user to other users. *Controllability* refers to the user's ability to control which decision is taken (Paramythis *et al.*, 2010). *Breadth of experience* refers to the ability of the system to allow users to make unexpected pleasant discoveries (Höök, 2000). *Transparency* is related to the awareness of users about why a specific adaptation has been chosen (Jameson, 2005). *Unobtrusiveness* is related to the user's approval of system actions that are not really needed (Höök, 2000).

Following the construction of an AHP hierarchy, the relative weights of each criterion and each alternative are to be determined by using AHP. The evaluator is asked to perform pair-wise comparisons among the criteria such as "How much more important is a row criterion than the column criterion in ranking the usability criteria?". Table 7 shows the comparisons of scale ranking for the pair-wise comparison of the decision criteria obtained on the basis of Saaty's scale (2008).

Table 7. Pair-wise comparison matrix of decision criteria and their relative weights

	Unexpected pleasant discoveries	Suitability of tasks	Adaptation awareness	Error tolerance	Conformity with user expectation	Adaptation timing	Protection measures	Weights
Unexpected pleasant discoveries	1	3	4	5	3	5	2	0.325
Suitability of tasks	1/2	1	2	3	3	4	1/2	0.161
Adaptation awareness	1/4	1/2	1	2	1/2	3	1/3	0.086
Error tolerance	1/5	1/3	1/2	1	1/3	2	1/4	0.085
Conformity with user expectation	1/3	1/2	2	3	1	3	1/2	0.089
Adaptation timing	1/5	1/4	1/3	1/2	1/3	1	1/4	0.039
Protection measures	1/2	2	3	4	2	4	1	0.215

The pair-wise comparisons are performed in order to justify the importance of the decision criteria and alternatives. For each set of pair-wise comparisons, a

consistency ratio is calculated. In this case study, the consistency ratio for the criteria is 0.074, which is smaller than 0.1. It can be inferred that the pair-wise comparison done by the evaluator is consistent, so the results are accepted. Next, all the alternatives are compared with respect to each decision criterion. Each matrix compares each criterion with the different alternatives. Table 8 shows an example of evaluation of the alternatives with respect to the "unexpected pleasant discoveries" criterion. We explain the choice of some numerical rate presented in Table 8. Considering breadth of experience and predictability alternatives; we give 5 as a value to the breadth of experience compared to the predictability, which means that breadth of experience is much more important than predictability for the decision criterion "unexpected pleasant discoveries". The main diagonal elements of the pair-wise comparisons matrix are equal to 1.

5.2. result and discussion

In the final task of "establishing the evaluation requirement", the overall ranking is obtained. This is achieved by multiplying the factor weight for each decision criterion by the alternatives. The usability criterion receiving the highest weight score have to be evaluated in the first position. After evaluating all alternatives with respect to the rest criteria, the comparative analysis resulting from AHP in terms of weights is obtained (Table 8).

Table 8. Pair-wise comparison matrix of alternatives with respect to unexpected pleasant discoveries criterion and their relative weights

	Transparency	Controllability	Unobtrusiveness	Breadth of experience	Privacy and trust	Predictability	Weights
Transparency	1	1/5	3	1/6	1/4	1/2	0.058
Controllability	5	1	6	1/3	1/2	2	0.176
Unobtrusiveness	1/3	1/5	1	1/9	1/5	1/3	0.032
Breadth of experience	6	3	9	1	3	5	0.433
Privacy and trust	4	2	3	1/3	1	2	0.207
Predictability	2	1/2	6	1/5	1/2	1	0.094

From this study, it is deduced that among the usability criteria, the most important one is the breadth of experience which has a rating of 0.218. This means that breadth of experience has to be assessed firstly in order to verify if the system's

adaptive behavior can prevent the travelers from experiencing the full range of available functionalities of the adaptive transportation system. The second most important usability criteria to be assessed is controllability, with a priority level of 0.18. This can be explained by the importance to assess the users' ability to control the decision taken. The results put transparency (0.175) in the third position. It can be explained by the importance to verify the users' trust in the transportation system's adaptive behavior. Unobtrusiveness (0.172), privacy and trust (0.157) are in the fourth and fifth positions, respectively. Predictability has the least priority level (0.098) (Table 9)[1]. The prioritization results will help evaluators to decide which usability attribute is more important than the others. This leads to having a clear goal in mind while evaluating the identified layer. For instance, evaluators can use the obtained weights to focus on the usability criteria that have to be evaluated in priority.

As already mentioned, when a conflict in the evaluation process arises, the prioritization results will assist evaluators to decide which usability criterion is more important than the others in a particular context and will guide the evaluation of adaptive user interfaces and their layers, based on these weights.

Table 9. The weighting coefficient of alternatives

	Unexpected pleasant discoveries	Suitability of tasks	Adaptation awareness	Error tolerance	Conformity with user expectation	Adaptation timing	Protection measures	Weights
Transparency	0.058	0.149	0.43	0.038	0.069	0.071	0.387	0.175
Controllability	0.176	0.055	0.039	0.382	0.412	0.246	0.146	0.180
Unobtrusiveness	0.032	0.465	0.244	0.067	0.039	0.039	0.258	0.172
Breadth of experience	0.433	0.032	0.089	0.271	0.249	0.158	0,061	0.218
Privacy and trust	0.207	0.206	0.135	0.094	0.130	0.383	0.040	0.157
Predictability	0.094	0.093	0.063	0.148	0.101	0.103	0.108	**0.098**

Once decisions have been made regarding the usability criteria of the considered layer, the next challenge to tackle in the evaluation process is "specifying the evaluation". In this activity, it is important to choose the appropriate usability evaluation methods. A variety of usability evaluation methods can be applied to evaluate the adaptation layers and the whole adaptive user interfaces (Gena, 2005;

1. The experiment was done with the assistance of the software package *Expert Choice* (http://www.expertchoice.com/)

Gena and Weibelzahl, 2007; Van Velsen *et al.*, 2008; Mulwa *et al*., 2011; Dhouib *et al.,* 2016a). Each one has its advantages and disadvantages and may be more appropriate for the considered evaluation settings (Dhouib *et al.,* 2016a). The choice of the best evaluation methods depends on the system development phase, the evaluation criteria to be assessed, and the characteristics of the layer under consideration.

6. Conclusion and future work

The usability of the adaptive user interfaces of information systems is of great importance since it aims to ensure that the AUIs' adaptive behavior improves the interaction with the users. It consists of a combination of criteria. The impact of each one may vary from one layer to another during the usability evaluation of the AUIs. The identification of the usability criteria for individual layers and for the whole adaptive system is a challenging task. This paper presents possible directions to address this issue by identifying the usability criteria and their priority levels, considering the ISO/IEC 25040 standard. The AHP aid method is used to prioritize and weigh the usability criteria to consider in specific evaluation contexts. This research illustrates the use of the AHP method in determining the priority levels of the criteria to assess in a specific layer of an adaptive Web-based IS in the field of transport. It corresponds to *deciding upon adaptation* layer.

Future work will investigate the use of the AHP method to identify the priority levels of usability criteria of the rest of the adaptation layers since we have focused only on the determination of the usability criteria of the *deciding upon adaptation* layer. It should be mentioned that the choice of usability measures depends on the contexts of use that may influence the usability and the adaptation layers under consideration. We intend also to include the opinions of field experts in order to validate the final results.

In this research, we have focused only on the common usability criteria for adaptive user interfaces. It should be noted that the evaluation of adaptive user interfaces should take into account both the usability criteria of the interface and the correctness of the adaptive solutions. Further work should then be pursued in order to focus on the adaptation-specific criteria (e.g., appropriateness of adaptation).

Future work will concentrate on using the final results in order to exploit them in the next activity of the evaluation process, considering the ISO/IEC 25040 standard. We intend also to turn our attention to the next task of the AUI evaluation process, namely "selecting the suitable usability evaluation methods for adaptive user interfaces". In this task, we intend to identify the appropriate UEMs that can be used for the evaluation of the identified usability criteria. In our previous works (Dhouib *et al.,* 2016a, 2017), some guidance towards this end has been proposed. We intend to improve those works by integrating the priority levels of usability criteria in the evaluation of adaptive user interfaces.

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