A Personalization Approach Based on Models Integration for a User Interface for Supervision in a Power Plant

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***Abstract*— In the operation of a power plant, the operator has to deal with a number of variables displayed in several windows, presented in different formats such as tabular, one-line diagrams, process diagrams, etc. Under these conditions, the operator needs to locate data relevant to the current status of the plant and efficiently navigate a large number of screens within the user interface. This situation becomes critical for infrequent tasks within the plant such as the start-up, shut-down or for abnormal operational conditions. In order to deal with the above situations, we propose a personalization mechanism based on models for adapting contents in a user interfaces for the operation of power plants. The model takes advantage of the integration of specific sub-models from artificial intelligence, user modeling and human-computer interaction. A personalization approach is applied into an adaptive user interface prototype that is expected to improve the user-system interaction by reducing the time to complete the startup of a power plant. For this purpose, contextual information of the power plant, user interaction logs, user's preferences and experience are considered. At this first stage, our prototype was evaluated in a simulated scenario with non power plant operators to investigate improvements of task performance for carrying out the procedure of the startup of a power plant process and to identify usability issues. Results from this initial evaluation show consistent time reductions and correct predictions of futures displayed variables for the adaptive user interface version despite the fact that participants in this evaluation had a lack of the domain knowledge. This results needs to be validated with further studies involving power plant operators, in order to compare the impact the domain knowledge plays in the time reductions.**

Keywords: personalization; user interface; user modeling; adaptive interaction; user interface evaluation.

I. Introduction

The area of Intelligent User Interfaces (IUIs) is a specialized research field within the Human-Computer Interaction discipline (HCI), which pursues to overcome some of the limitations of traditional user interfaces. Traditional user interfaces for process supervision in power plants are comprised of a large number of displays such as tabular data, one-line diagrams, sequential diagram, historic trends, process diagrams, critical events logs, etc. The user needs to visualize information, analyze normal and failure situations, process changing data, understand the underlying process dynamics and finally take all this information into account to make a decision in a reduced time span. This amount of information represents a high cognitive load that the operator has to deal with and becomes critical for abnormal, failure or infrequent operations within the plant [1]. Established design process involves a user interfaces designer who establishes *a priori* the way each kind of data must be presented to the user and establishes a corresponding mapping between the processed information and the way to be displayed to the user. This mapping is achieved based on user interfaces guidelines, ergonomics studies, usability rules or accepted HCI standards; however, this mapping is static and the Graphic User Interface (GUI) is not designed for abnormal situations, where information flow is higher and operators have to face new situations [2].

II. Previous work

Current research efforts attempting to use adaptive user interfaces for critical domains include IUIs based on models, knowledge, examples and demonstration, plan recognition, task recognition, agents as well as multi-modals interactions. The challenges faced by the IUI community are diverse and disciplines such as HCI, Artificial Intelligence

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(AI) and User Modeling (UM) have reported different research lines with specific approaches for IUIs.

Likewise, the generation, maintenance and use of user models as a core adaptation element has been another explored approach in recent years [3]. A search for novels ways to represent the knowledge a system has about its users, their skills, preferences and goals is another promising research line. Taking advantage of these user models, an IUI attempts to adapt its contents, layouts or navigation elements to suite the user experience or preferences [4]. Mixed-initiative interaction models have been developed to deal with the interruptions challenge and its timing while presenting information to the user [5]. Another approach followed in IUIs has been generating task models and use them as the central element of the adaptation strategy. The goal is to infer the next possible tasks and to anticipate actions the user is about to accomplish in order to find a way to assist her in the task at hand, or facilitate the use and learning of the user interface itself [6] [7].

Copious research efforts in the electrical domain have focused on the development of systems to help operators in fault situations [2], the design of intelligent systems to assist operators in normal power plant operation, and even more efforts in the development of complex systems to detect, predict and correct faults in real-time in power systems [8]. However, there is a clear lack of research in the area of adaptive user interfaces and personalization for critical domains, such as those found in power plants where unfrequented tasks and fault situations need to be handled by operators. This work is relevant since is one of the initial efforts where researchers adventure at proposing and applying an adaptive user interface beyond the laboratory prototype scope to handle real critical operations for process control.

III. PROBLEM STATEMENT

Context domain knowledge information is a valuable assessment that traditional direct manipulation interfaces do not take into account. Same situation applies to user experience and preferences; even though it is known empirically that these elements are important to operate a plant in a safety and optimal way [2]. It is our belief that in critical domains such as power generation plants, the use of the abundant existent contextual information and the user navigation history is valuable and its selective use in an adaptive user interface will improve the performance of human-computer interaction by means of personalization the variables displayed for infrequent or critical tasks.

Contextual information includes operators' preferences and domain knowledge, the tasks performed at the user interface, as well as the process information such as monitored variables, plant operation status and process stage, information already stored for process analysis purposes. By improving the performances we mean the adaptive interface will allow the operator to achieve specific operational tasks within a pre-defined time frame by filtering out irrelevant information and personalizing contents and navigation. Infrequent tasks accomplished correctly in sequence and time have a relevant impact, particularly to the startup and shut-down stages of a power plant operation where a deviation in time from a pre-established sequence increases the gas consumption and shortens the expected life span of the power plant.

IV. PERZONALIZATION APPROACH

For personalization purposes, we propose the use and fusion of several sub-models integrated to create an adaptive user interface that will improve the plant operation by personalizing information screens taking into account 4 key elements: (1) context information of the power plant, (2) the user-system interaction history, (3) user preference, and (4) experience.

The meta-model is composed of two set of models: (1) central models and (2) support models.

A. Central Models

These are the intelligent components that provide the adaptive behavior to the system by receiving and processing the information from the support models to provide adaptive information displays and navigation in a timely manner. To accomplish this goal, these components apply AI techniques to the collected information from support components.

1) RECOGNIZER

The RECOGNIZER model decides *when* to proceed to change the current interaction mode. Possible interaction modes includes: directed, initiated or controlled by the system, directed by the user or a combination of both. The RECOGNIZER uses a mixed-initiative approach and takes into account the interaction history and, by applying a utility-based algorithm, analyze possible alternatives and take the highest ranked option available to keep, or change if required, the interaction mode. The expected utility approach permits to establish the most convenient interaction mode to the current situation. Therefore, it determines if it has to keep with the current interaction mode, change to another interaction mode or, ask the operator for further data and interrupts the interaction. This decision has to be made based on the evaluations of advantages and disadvantages when interrupting the operator, and the known history for handling similar situations in the past. The information to decide includes the willingness of the user to interact with the system in the past, the willingness to personalize in the beginning. Once an adaptation is detected and ready to be presented to the user, the RECOGNIZER decides if the cost is high enough to make it available to the user or if a switch in the interaction mode has a higher cost as a distraction or interruption for the user (ranked by the rule generator). The RECOGNIZER was developed following a utility-based approach adapted from the research presented by Fleming in his work [9].

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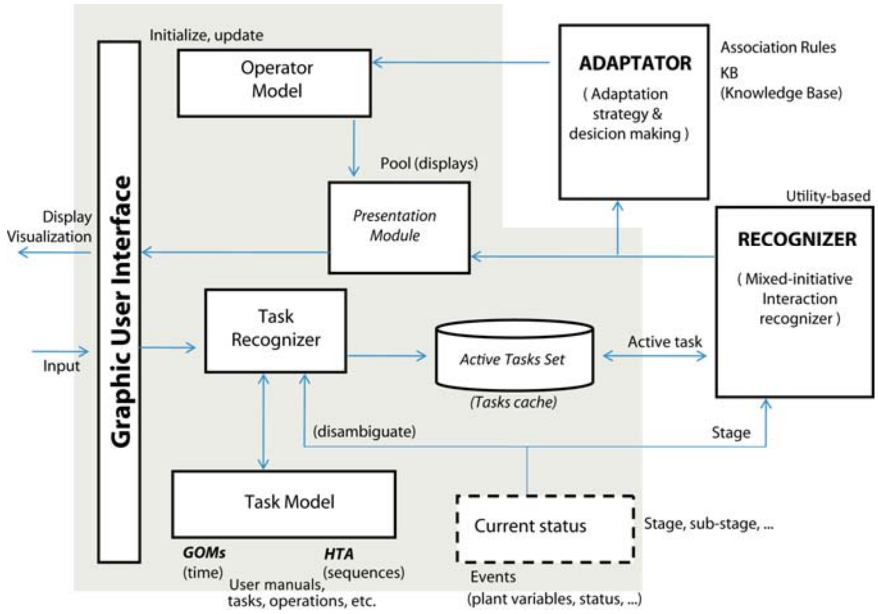

Figure 1. Central and support components for the proposed adaptive model

The costs of interruption computed in the RECOGNIZER are represented using a linear model, so the total cost is a weighted sum of any individual cost measures that have been identified for the application domain. For example, the identified factors for the startup of a power plant are: (1) user knowledge represented in the user model, (2) user willingness to interact determined by the initial personalization achieved by the user and the number of visited screens, (3) current context (current node for the task at hand), and (4) task performance expected due to interaction, provided by a domain expert. Each of these factors is normalized so that values range from 0 to 100. A cost of 0 indicates no cost for the interruption so the RECOGNIZER will allow to be presented the adapted content in the user interface. A cost of 100 is the maximum possible cost and in this situation the RECOGNIZER will not interfere to change the current presented content.

2) ADAPTATOR

This is a central component in charge of establishing the strategy for displaying contents and adapting the navigation to be presented to the operator. It determines what content will be presented as well as the way to be displayed. It also deals with data stored (history) for past interactions, contents and its presentation to the user along with the outcome of the prediction and the feedback received from the operator. We propose the use AI techniques, specifically applying Association Rules Mining (ARM) to generate a set of adaptation rules by borrowing some ideas from Bunt [7]. The ADAPTATOR was developed applying a modified AIS (*Agrawal*, *Ieminski*, *Suami*) algorithm using association rules mining techniques and extended the algorithm to support a meta-rule generator [10]. Rules are generated from process variables (i.e., pressure, temperature, gradient, dome level, etc.) correlated to previous interactions and the preferred variable presentations. A number of irrelevant and redundant rules are generated and in order to avoid its explosion we use domain expert knowledge to guide the meta-rule generation and to rank the generated association rules.

We describe a simple example to illustrate the application of our ADAPTATOR model regarding adapting contents to the user. The adaptive user interface has a set of default variables to be presented to the user for the current task. Data from support models such as user experience, display preferences, navigation traces, user willingness to interact and related plant process variables (i.e. temperature, dome pressure, temperature gradient, etc.) relevant to the current task are processed by the rule generator. Expert knowledge is used to eliminate redundant rules and also to guide the structure of the rules to be considered relevant. An example of a generated rule which includes experience level, visualization preference and process variable is presented in a simplified form as follows: IF Beginner AND Tabular AND Dome Temperature > 120 AND Dome Pressure Stable THEN Display = Set 3, where Set 3 is a predefined set of variables to be presented to the user. Note that the ADAPTATOR does not generate adaptive displays on-the-fly, but select one from a predefined pool of custom made sets. When this rule is generated, the specific set of variables (Set 3) is ready to be presented on the adapted area of the user interface.

B. Support Models

These components provide the information related to the tasks under supervision or control, the field variables of the power plant correlated to the startup stages, the operator's preferences and knowledge. These models are briefly described in the following sections.

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1) Task Model

Its main function is to represent the tasks performed within the system considering its duration, as well as, its sequences. The operative knowledge about the tasks that are required to operate the plant through the user interface can be found in the plant manufacturer operation manual, operator's training manuals or can be extracted from observation of the user interface in action.

2) Operator Model

Based on an user *overlay* model, its main function is to manage and maintain the data associated to the operator characteristics, such as personal data, display and navigation information preferences, as well as her knowledge of the task to be performed. This model was developed with an overlay approach taking into account specified times for maximum, minimum and normal times for completing a task by a beginner, normal and expert operator during the startup of a power plant.

3) Task recognizer

It receives and integrates information regarding the task to be performed by the operator, and the possible available sequences. The task recognizer takes into account the operator's knowledge about the task available at this time and additionally integrates the operator's characteristics, which are retrieved from the operators sub-model. This module process the information to maintain a set of possible tasks similar to those proposed by Bunt [6]. These tasks are exchanged with the AST (Active Set Tasks) module as shown in Figure 1 above.

4) Presentation module

It is an isolated module separated from the central models that is constantly exchanging data with the central and support models. It is also perceived by the operator as the GUI (Graphical User Interface. A challenge for its design and implementation was the fact to be able to continuously logging navigation the traces during the interaction with the operator and save them to the knowledge database for its use by the rule generator.

V. ADAPTIVE USER INTERFACE PROTOTYPE

A prototype integrating the proposed models was developed. Due to the complexity of core components and the critical nature of supervision process of a power plant itself, the integration stage for this research project required unforeseen additional effort since different technologies and programming languages for different models were involved. Currently, we have finished the development of the ADAPTATOR and is also completed the testing of all the support models; however, the mixed-initiative RECOGNIZER is still under development, and its impact in the adaptive strategy is not researched in the evaluation presented in this paper.

Integration of all involved models was essential to proceed to the evaluation stage since its is required to collect the entire context information and navigation traces in order to feed the ADAPTATOR mining algorithms and correlate attribute-value pairs from the different models. The proposed meta-rule generator was also finished and is the key element to disambiguate and control the explosion in the number of association rules generated. The prototype for the Adaptive User Interface for Power Plant Startup (AUI-PPS) was the mean to implement the proposed mixed-initiative adaptive user model and is shown in Figure 2.

When operator uses the adaptive user interface prototype for the first time, it allows him to select his presentation preferences. Three GUI presentation modes are displayed for selection: minimalist, standard and graphical enhanced. These preferences are stored and updated in the operator model as nodes (tasks representation) of the startup process are completed.

Suggested presentations are displayed in a specific area (right side), which will be changing according to inferred data by the ADAPTATOR model, see Figure 2. User navigation traces are stored in order to integrate it with past interactions and user preferences and eventually decide whether to change the presentation or keep it until the expected utility function from the interaction RECOGNIZER reach specified trigger from the user model.

The selection of relevant variables to present, quantity and type of presentation for the task at hand are personalized constantly by the ADAPTATOR. These parameters are not changing all the time but when the RECOGNIZER algorithms evaluate to change the interaction mode as shown in Figure 3. The user can reject, at any given time, any of the suggested variables and its presentation, and his decisions are added into the navigation traces logger and feed backed to the mixed-initiative RECOGNIZER. By clicking on the red cross icon on the variable presentation space, the content is diminished and the user model is updated. For the RECOGNIZER and the ADAPTATOR this represents, an inaccurate prediction and is fed back to the central models for future content predictions in a similar situation.

VI. PROTOTYPE EVALUATION

For our evaluation, we selected a critical domain represented by the startup of a power plant, which is a complex process that takes hours (6-8 hours) and involves carefully operation of surrounding subsystems. For initial evaluations a proprietary simulator was used along with ASPPO (Aid System for a Power Plant Operation) that provided guidance to the operators during the startup of a power plant.

This initial evaluation was achieved with six users (non plant operators) with computer knowledge and related to the electrical domain, but without prior knowledge regarding the operation of a power plant.

A. Participants

The evaluation was carried out with a group of six subjects with different experience levels. For the evaluation, the participants had to visualize information and interact simultaneously with two LCD monitors: (1) to display the process diagrams of the plant simulator, where the user carried out the actions instructed by the adaptive and (2) a second monitor to display the adaptive interface with the

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instructions to guide the participant in order to complete the current task.

Each participant had to evaluate both user interfaces (adaptive and non adaptive) with an assigned task of variable difficulty level.

B. Evaluation Procedures

A short introduction to the simulator and the startup process was given to the six participants. An introduction questionnaire was given to each participant in order to evaluate its domain knowledge and computational skills. At the end of the evaluation a final questionnaire was also applied to participants in order to capture the user's perception about the system and their general final thoughts.

All evaluation was achieved in an isolated room with two monitors: one for a simulator and another for the Adaptive User Interface Prototype for Power Plant Startup (AUI-PPS) in charge of displaying the recommended actions in order to achieve the task at hand required for completing the current procedure (node) of the startup stage.

Five of the most representative tasks for the pressurization stage and steam generator heating procedure were given to the participants. Taking into account the average time for completing each node for this stage, the 5 nodes should take 1 hour 43 minutes for an average user. Since this is a considerable time, it was harder than usual to find participants willing to spend so much time in an evaluation. The experiments followed an incremental approach (i.e., integrating additional models and evaluating its impact), so that the effectiveness and accuracy achieved by the adaptive user interface could be measured, isolated and attributed to specific models.

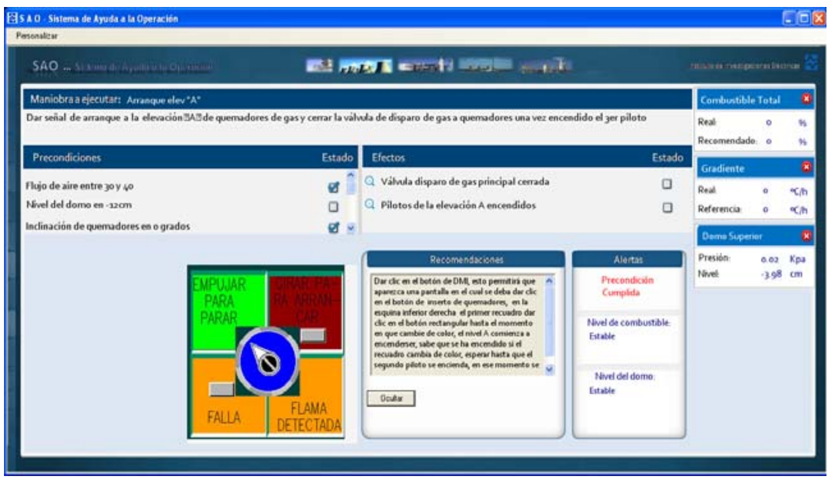

Figure 2. Adaptive user interface layout: adaptive content area on the right side and standard display area separated to minimize impact on user

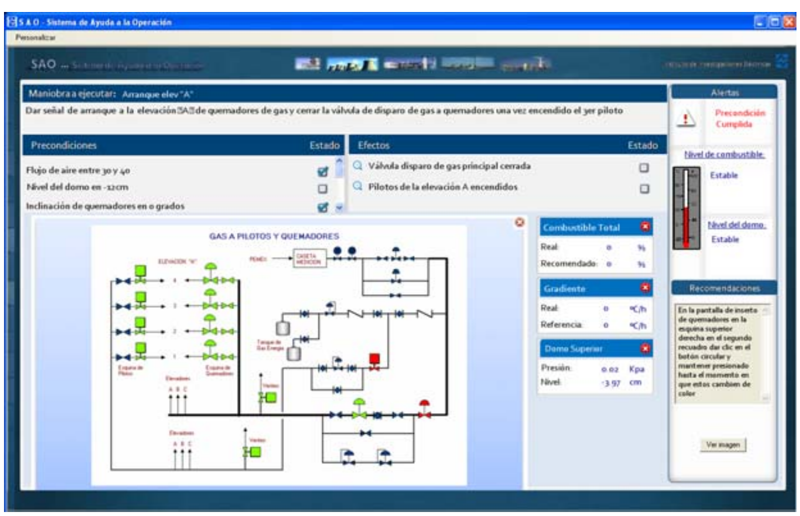

Figure 3. Adaptive user interface with recommendations presented in the lower right corner.

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C. *Experimental Evaluation*

The experimental evaluation reported in this paper was achieved with six users using a prototype that integrated the operator model, the task model and the ADAPTATOR model. The Mixed-Initiative RECOGNIZER model was not included in this initial evaluation. The next step in this research work will include a greater number of participants, the inclusion of the RECOGNIZER and an evaluation with actual operators in a power plant in order to contrast and validate the initial results.

This experiment also included data provided by the task model in charge of detecting the currents task to accomplish (node) and its associated variables to be processed by the ADAPTATOR. The idea behind this incremental approach is to research the operator's behaviors and interactions improvements gained as each component is integrated into the adaptive model.

We use usability techniques to evaluate the adaptive prototype of the user interface [11]. This assessment provided us the base parameters in terms of efficiency, effectiveness as well as the operator's perception of the current non-adaptive user interface. A video recording and logging of interactions at the user interfaces level was achieved and analyzed.

VII. Results

Results presented here are grouped in three key areas: efficiency (time, consumption), task completed and user's perception. It is important to note that this evaluation was carried out with participants with knowledge about computers but a lack of knowledge about the operation of a power plant. The rationale behind this approach is to study and measure the degree of impact the domain knowledge has (if any) in the completion of the tasks and its contribution to the overall time reduction in order to isolate it from the contribution of the adaptive user interface model itself. Our final goal will be, when finished the next evaluation stage with operators, to study the impact of the 2 different participants: (1) users with computational knowledge, associated with their ability and familiarity for handling a user interface and following the adaptive interface guidance to complete the task, regardless of their lack of domain knowledge and (2) participants (operators) with domain knowledge, associated with an in-depth knowledge of the start-up process and operation of a power plant.

Results of the evaluation of the operator model provided information regarding the user preferences and knowledge (or lack of) about the processes required for the startup of the power plant. This knowledge is used to adapt the presentation of the elements to achieve the operations recommended by the AUI-PPS. The user follows these recommendations and she needs to explore and find those components by navigating the different screens of the simulator user interface.

Figure 4 shows the times (in minutes) to complete the task assigned to the six participants, using the normal user interface, the adaptive user interface and the third bar shows the values predicted by the ADAPTATOR.

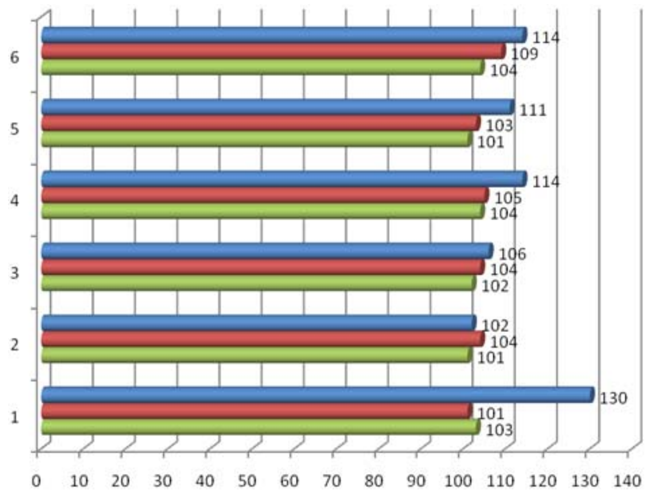

Figure 4. Time to complete the assigned tasks.

For participants 1, 3 and 5 the non-adaptive user interface was first evaluated. Participants 2, 4 and 6 first evaluated the adapted version of the user interface. In eache one of the evaluations consistently the user with the adapted version took less time to complete the tasks. The maximum difference was 29 minutes, however this was an isolated case, since the global average was 5.8 minutes.

Depending on his experience and knowledge so it is the time he takes to achieve the recommended task in the expected time. If the subject under evaluation follows the displayed recommendations and knows how to accomplish them on the simulator, he/she can finish the task on time, earlier, take longer or even abort the task by lack of knowledge or by misunderstanding the recommendations.

The time to complete the task to startup the power plant (pre-heat and pressurization of the steam generator) had a direct impact in the gas required to operate the plant as it is summarized in table 1.

TABLE I. Gas Comsumption for both user interfaces

Subject	Non-adaptive User Interface	Adaptive User Interface	Predicted
1	9681.75 Kg.	7653.5 Kg.	7907.2 Kg.
2	7536.75 Kg.	7615.25 Kg.	7371 Kg.
3	7614.75 Kg.	8053 Kg.	7419.75 Kg.
4	8424.75 Kg.	7624.45 Kg.	6864 Kg.
5	8297.25 Kg.	7673.25 Kg.	7646 Kg.
6	7946.25 Kg.	7829.25 Kg.	7624.5 Kg.

The results from the post-test questionnaire show the user perception while interacting with both interfaces. Usability issues included 3 questions to capture perception for ease of use and learn for each user interface.

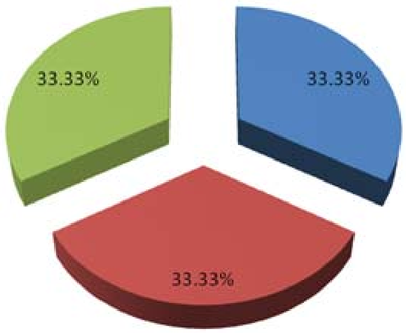

Figure 5. Balanced usability overall user perception for standard user interface: 33% easy, 33% neutral, 33% hard.

The adaptive user interface version is perceived more user friendly and easy to learn in general, however for some participants the user interfaces in both versions was perceived as "not easy" to learn. This perception was associated with the participant with less experience in both interfaces.

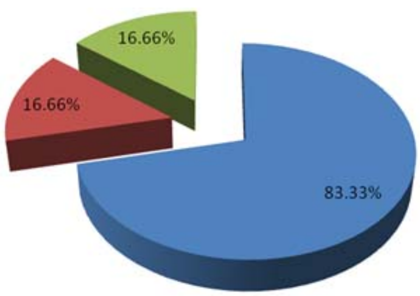

Figure 6. Usability overall user perception for adaptive user interface: 83% (easy to use and learn) and 16.66% for neutral and hard

VIII. CONCLUSIONS

Current results shows a consistent advantage of the adaptive user interface, by presenting personalized contents (variables and recommendations) over the traditional user interface for the startup of a power plant. A reduction in time of an average of 5.8 minutes for a reduced portion of the test of just 1 hour and 44 minutes that took the evaluated nodes is a significant reduction. If we keep the same linear proportion in the time reductions it is reasonably to forecast a reduction of 27 minutes for the whole process for the startup of a power plant, taking into account that this process normally takes 8-9 hours approximately. Likewise, this advantage shown in raw data is also present in the user perception about the usability of the adaptive interface.

These results seem to be promising for the adaptive user interface version versus the non adaptive version from the point of view of time reductions for this domain. However future work is required to include a greater number of participants in the next experiments and to carry out the evaluation with actual operators, so we expect that the difference in performance for both interfaces in the startup of a power plant might present different behavior.

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