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# User and Task Models Impact on an Adaptive User Interface for the Startup of a Power Plant

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***Abstract*: A number of different approaches to build adaptive user interfaces for web-based systems and office applications have been reported in the literature. However, for more demanding domains such as the operation of a power plant, little research has been conducted. To operate a power plant, the operator has to visualize information, analyze normal and failure situations, process changing data, and make decisions in a reduced time span. Since the all these activities have to be done by the operator through the user interface, the design of an adaptive user interface represents a challenge due to the decisiveness of the tasks for operating the plant. To deal with the above situation, we propose an adaptive user interface model that takes into account contextual information (process variables), and tasks to be performed at the current state process through the use of a task model, the user-system interaction history, and the preferences and experience of users are also considered through the integration of a user model. A partial prototype including both models: operator model and task model for an adaptive user interface applied to the electrical domain was evaluated. Evaluation was achieved with non-operators using a proprietary system to assist the operator in the startup of a power plant. This paper presents the partial evaluation of the task model and user model of the adaptive user interface. The initial results show that the combination of both models in the adaptive user interface have a positive impact particularly in gas consumptions reductions in a set of representative tasks of the startup of the power plant compared to the user interface lacking a user and task model.**
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***Keywords***: adaptive user interfaces, personalization, human computer interaction, power plant applications, user modeling**.**

## I. Introduction

Intelligent user interfaces (IUIs) is a specialized research field within the human-computer Interaction area (HCI) which pursues to overcome some of the limitations of traditional user interfaces. Current 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].

In a traditional graphic user interface (GUI) the designer establishes a priori the way each kind of data will be presented to the user and establishes a 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 GUI is not designed for abnormal situations, where information flow is higher and operators have to face new situations. Besides, these GUIs do not take into account any user data such as his/her experience, preferences, characteristics or domain knowledge; even though it is known empirically that these elements are important to operate a plant in a safety and optimal way [2].

## II. Previous work

Challenges faced by the IUI community are diverse and disciplines such as HCI, artificial intelligence (AI) and user modeling (UM) have reported different research lines with specific approaches for IUIs. Current research areas cover

IUIs based on models, knowledge, examples and demonstration, plan recognition, task recognition, agents as well as multi-modals interactions. 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. Mixed-initiative interaction models have been developed to deal with the interruptions challenge and its timing while presenting information to the user [4]. 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 him/her in the task at hand, or facilitate the use and learning of the user interface itself [5].

Research efforts in the electrical domain have focused on the development of systems to help operators in fault situations [6], 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 [7]. 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 humans.

## III. Motivation

We are convinced that in critical domains such as power generation plants, the use contextual information, the user navigation history and its selective use in an adaptive user interface will improve the performance of user-computer interaction by means of the personalizing of 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 shutdown stages of a power plant operation where a deviation in time from a pre-established sequence increases the fuel consumption and shortens the expected life span of the power plant equipment.

## IV. User-system interaction adaptive model

We propose a meta-model for an adaptive user interface that will improve the plant operation by personalizing information screens taking into account: context information of the power plant, the interaction history between operator and the user interface, as well as, the operator preferences and experience (operator model). The user-system interaction adaptive model privilege a novel integration of specific sub-models from AI, HCI and user modeling, coordinated in a mixed-initiative interaction approach. The components of our approach are shown in figure 1. The model addresses critical stages and infrequent tasks found in the startup of a power generation plant. Due to space restrictions, we will give a brief description of the model components. Adaptive model components were classified into two categories: support components and core components.

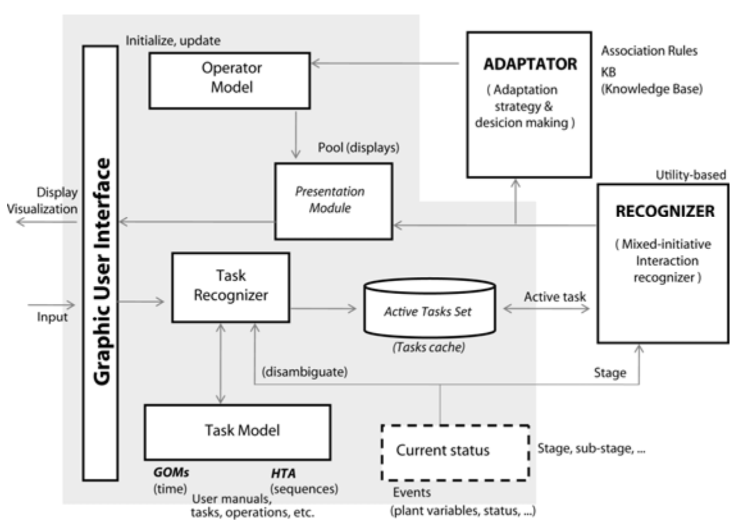


**Figure 1.** User model and task model for the adaptive user interface

### A. *Support components*

In order to provide the inputs to the decision making models (central models), a set of support components are required to provide the information related to the tasks under supervision (or control), the field variables of the power plant associated to the startup stages, the operator's preferences and knowledge and are briefly described in the following sections.

#### 1) *Task model*

In order to adapt contents and navigation in the user interface, an adaptive system needs to have a mechanism to figure out which task the user is trying to accomplish. Without this knowledge the system would have difficulties assisting the user to perform the task at hand. Two task related elements are fundamental to identify in order to provide an adaptive capacity. We proposed a hierarchical task analysis (HTA) to decompose the different elements to accomplish a general task and to identify its corresponding sequences. The second key element is to determine the time it takes an specific task to be accomplished in different situations (best, average an minimum). The main goal of our proposed task model is to represent the tasks performed within the system considering its duration, as well as, its sequences. This 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. The adaptive user interface prototype developed included a task model specifically designed for the startup stage of a power plant. The actions and goals for this stage are represented using the ACT formalism [2], a procedural knowledge representation for plans, operators and operating procedures supporting the smooth interoperation of planning and execution. The tasks in the operation of a power plant are grouped as follows: a "Procedure" is a set of "maneuvers" and is the largest. A maneuver is composed by a set of tasks and is represented as a node.

#### 2) *User model*

Most adaptation mechanisms applied in IUIs require the knowledge the system has about the user in order to direct the adaptations at the user interface level. User's knowledge about the domain application, display of type of preferences, knowledge of tasks and willingness to interact with the system are some of the elements that can be managed in a user model. Also the user model is in charge of maintaining the data associated to the operator characteristics, such as personal information, display type and navigation preferences, as well as his/her knowledge of the task to be performed. This model was developed with an overlay approach taking into account specified times for completing a task by a beginner, normal and expert operator during the startup of a power plant.

#### 3) *Task recognizer*

This model 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 knowledge it has 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 in a similar fashion as those proposed by Bunt [8]. The tasks are exchanged with the Active Set Tasks module as shown in figure 1.

#### 4) *Presentation module*

This module is commonly known by operators as the MMI (Man-Machine Interface) or HMI (Human-Computer Interface). In our prototype, this module was designed and implemented in such a way that it continuously logs the navigation traces during the interaction with the operator.

### B. *Central components*

The central components 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 way. To accomplish this goal these components apply AI techniques to the collected information by the support components.

#### 1) *RECOGNIZER*

It is a Mixed-Initiative interaction recognizer that takes into account the user-system interaction history and, based on this information and a utility-based algorithm, analyzes possible alternatives about controlling the interaction and takes the highest ranked option. This expected utility approach permits to establish the most convenient interaction mode to the current situation. Therefore, it determines who (the system or the user) has to keep the current interaction mode, change to another interaction mode or, ask the user for further data and interrupt 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 RECOGNIZER was developed following a utility based approach adapted from the research work presented by Fleming [9].

#### 2) *ADAPTATOR*

It is a core component that establishes the strategy for displaying contents and adapting the navigation to be presented to the operator. Besides, it determines the way the contents to be displayed on the user interface, i.e., tabular, graphical or text. It also deals with data stored (history) for past user-system interactions, contents and its presentation to the user along with the outcome of the prediction or the feedback received from the user. The model uses AI techniques, specifically association rule mining to generate a set of adaptation rules from contextual data by borrowing some ideas from [3]. The Adaptator was developed applying an AIS (Agrawal, Ieminski, and Suami) algorithm using association rules mining techniques and modified to support a meta-rule generator.

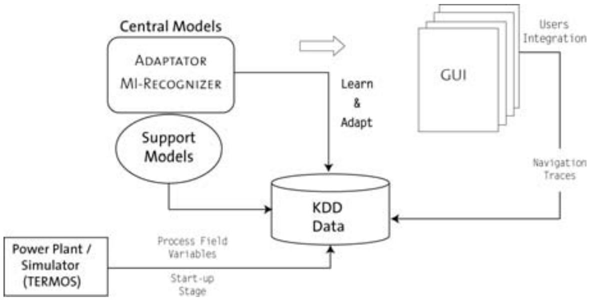


**Figure 2.** Adaptive user interface learning process and related components for the prototype

## V. Adaptive interface prototype

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. The current status of the user interface prototype includes the integration of the operator model, the task models, as well as the GUI module as shown in figure 2. In this evaluation the central modules are not included, so the learning algorithms and adaptation strategies of the ADAPTATOR are not considered in the presented evaluation.

The SUO system, a Plant Components Location System, called SUO (for its acronym in Spanish) integrates both models. SUO takes from the task model the specific set of tasks to be performed as well as their sequence. In figure 3, shows the two tasks that need to be completed. (1) Close of main gas valve trip (2) Turn-on level A pilots (igniters). A check mark provides visual aid to the task that has been successfully completed. Likewise, the SUO takes from the user model the recommendation according to the calculated level of experience. These preferences are stored and updated in the operator model as nodes of the startup process are completed.

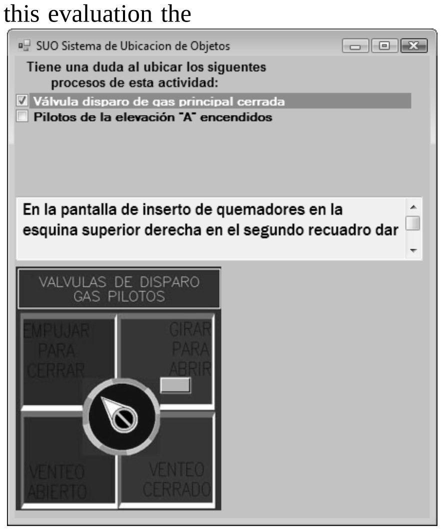


**Figure 3.** SUO system includes both data: (1) task to perform and their sequence (upper part) from the task model and (2) recommendations and graphic components (middle and lower part) from the user model.

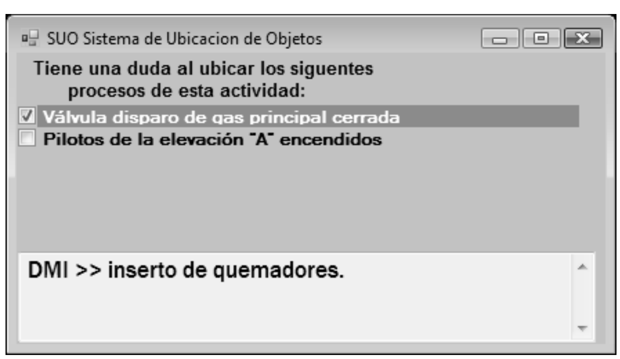


**Figure 4.** SUO system shows tasks to perform and limited recommendations for an expert user.

(Personalization) and user experience level but also according to the progression while using the user interface based on the interactions between the ASPO and the user and the operator's model is updated on every single node.

## VI. Experimental Evaluation and Results

In order to test the user and the task model for the adaptive user interface presented in this paper, a critical domain represented by the startup of a power plant was selected. This application domain is actually a complex process which under normal conditions takes an optimal time of 7.5 hours approx. to be completed and involves a carefully coordination and operation of surrounding subsystems. A pilot testing to verify the evaluation setup was achieved in order to fine-tune the models as well as the specific designed experiments of our adaptive user interface prototype as shown in figure 5. This pilot testing was also important to generate initial data to feed the user model and to establish the approximate time to complete the experiments.

### *A. Users*

This phase of our evaluation was achieved with 6 users who have some computer knowledge and some sort of information related to the electrical domain. None of them had prior knowledge regarding the operation of a power plant or experience using a plant simulator.

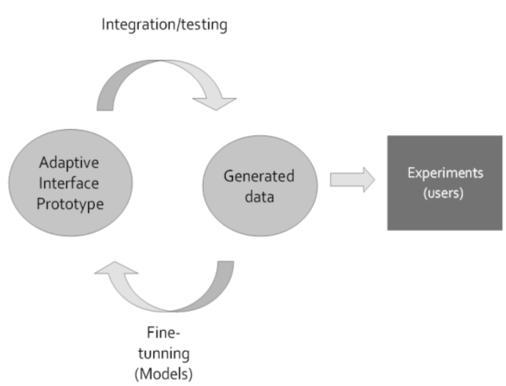


**Figure 5.** Fine-tuning for models (UM & TM) experimentation and datasets for navigation traces

### *B. Experimentation Environment*

For our initial evaluations a proprietary plant simulator denominated TERMOS was used along with an assistant computer for a Power Plant Operation, also known as SAO (for its acronym in Spanish) that provided guidance to the operators during the startup of a power plant.

The evaluation was conducted in an isolated room and with the aid of two monitors: one for simulator manipulation and another one for the SAO and the SUO. The SUO system integrates data coming from both, the user and task models and provides suitable recommendations to accomplish the task at hand, required for completing a specific procedure of the startup of a power plant.

Since to the aim of the experiments was to validate the user and task modules, the use of the SUO system provided the mean to accomplish two key functionalities: (1) Show recommendation to accomplish the assigned task and (2) assign a experience level to the user.

User model will evaluate each user performance for completing a specific task, and taking as reference the time he takes to complete it and the experience level assigned by the user model, the SUO will delivered the recommendations accordingly.

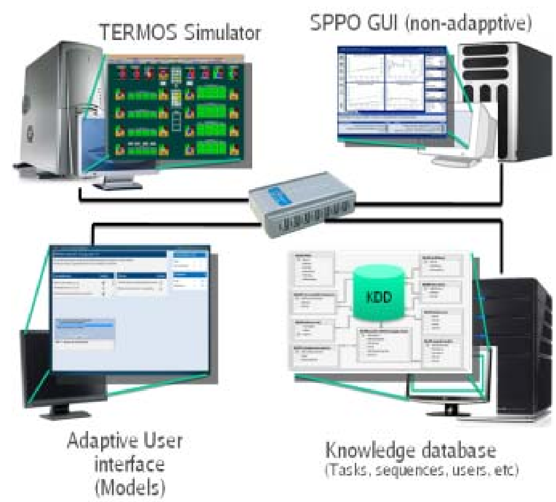


**Figure 6.** Hardware architecture for experimental evaluation of the adaptive user interface prototype

The interaction between (1) user-simulator and (2) user-SAO, and user-SUO were video recorded for each participant in every experiment. At the end of the experimental session both video recordings required to be synchronized for each session per participant. The sequence of actions was as follows: In each experiment a task was assigned to a user. Then she/he read the recommendation to achieve the task, review the first pre-conditions for the task and manipulate the require components in the simulator user interface in order to fulfill the first pre-condition. Then he/she proceeds with the following pre-condition and complete the same steps until the last pre-condition is fulfilled. When all pre-conditions are met, the SAO will automatically enter the next node (task) and the sequences is repeated again until the node pre-conditions are met.

### *C. The experimental tasks*

The startup stage of a power plant under normal conditions takes considerable time, so it poses a problem to be fully evaluated with users (8 hours). For evaluation purposes of the task and user model, the use of small portion of the whole process, (i.e., one of the several stages) of the startup of the power plant was appropriate. The selected operation procedure was the "Heating and Pressurization of the Steam Generator" (see figure 7) due to its flexibility to provide challenges to the different users to interact with and the different difficulty levels found in it to successfully complete the tasks.

For each node there are a number of *pre-conditions* that need to be met in order to proceed to accomplish the *effects*.

Five of the most representative tasks for the pressurization of the steam generator stage were given for completion to each one of the participants. The selected tasks are shown below:

- Task 1: Turning on of pilots in level A and closing of main gas valve.
- Task 2: Take values to reach maximum gradient temperature.
- Task 3: Vents closings of SH4 for Dome and SH3 drain.
- Task 4: Controlling pressure and temperature for main steam
- Task 5: Starting heating of main steam pipes, starter ejector and deareator.

Taking into account the average time for completing each node for this stage, all five tasks should take 1 hour 43 minutes for an average user.

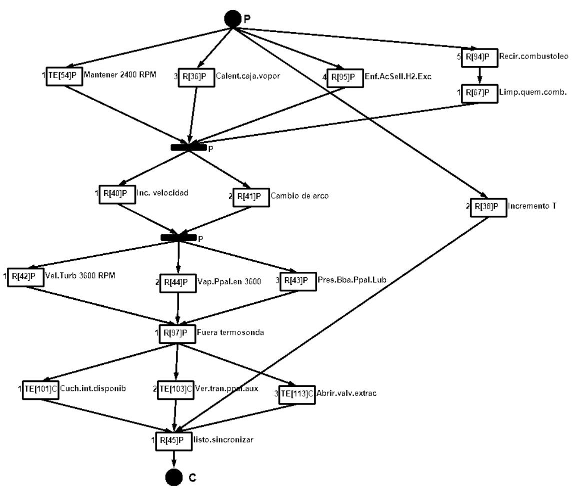


**Figure 7.** Nodes to be completed by users for the Heating and Pressurization of the Steam Generator Stage.

The evaluation reported in this paper was achieved integrating only the operator model and the task model into a limited feature version of the ADAPTATOR. Final ADAPTATOR version will include the mining algorithms for the generation of correlation rules, the plant process variables and the user interface navigation traces. Likewise, future evaluations will include the processing of data provided by the mixed-initiative RECOGNIZER, which will be gradually integrated into the adaptive user interface model. The idea behind this approach is to research the operator's behaviors and interactions improvements gained as each component is added into the adaptive user interface model.

Experimental evaluation was conducted in a 3 day scheme as follows:

Day 1, experiment 1: Since all subjects were neophytes at using the SAO and the plant simulator, a 40 minutes introduction to both systems was given. A fundamental action to be performed in the five selected tasks is the turn-on and shut-off of the burner pilots (igniters). Since there is no recommendation on how to accomplished this action in the SAO, a training session to perform it was provided. After this training, the subject was asked to perform the five defined tasks.

Day 2, experiment 2: The participant was asked to immediately (no prior training) perform the five tasks. If the participant has not used the SUO yet, at the end of the test was asked to answer an exit questionnaire and informed that in the next day experiment he will use it.

Day 3, experiment 3: Subjects are asked to perform the five tasks already accomplished in the prior day's experiments. At the end of this activity, subjects that used the SUO were asked to answer an exit questionnaire. This questionnaire was a different one from that who was answered on day 2 by participants who did not use the SUO.

We use post-experiment questionnaires-based techniques to evaluate the user perception of the user interface usability [10]. The evaluation with five representative tasks of a specific procedure from the startup stage, provided us the base parameters in terms of efficiency, effectiveness as well as the operator's perception for both interfaces: (1) Non-adaptive user interface, evaluated through the use of the SAO and the POG guidebook and (2) Adaptive User Interface, evaluated through the use of the SAO with the SUO user interface. A video recording and logging of interactions at the user interfaces level was achieved and analyzed.

Evaluation involved 6 participants using both, the adaptive user interface (SAO + SUO) and the non adaptive user interface (SAO + POG) performing the five selected tasks from the Heating and Pressurization of the Steam Generator stage.

On experiment 1 and 2, subjects 4, 5 and 6 used the non adaptive user interface (SAO) and received help to complete the tasks by consulting a Plant Operator guidebook (POG for its acronym in Spanish). support for completing the task by on Day 1 and day 2adaptive user interface (SAO + SUO) only on experiment 3 (day 3). Subject 1, 2 and 3 always used the adaptive user interface (SAO+SUO).

User model was in charge of evaluating and updating the experience level for each user while performing the assigned tasks. User model assigned experience levels included: beginner (B), intermediate (I) and experts (E). Results for each participant are shown in the following table 1:

*Table1*: User model experience for experiments

Subject 1

| | SAO+SUO | SAO+SUO | SAO+SUO |
|---|---|---|---|
| Node | Experience day 1 | Experience day 2 | Experience day 3 |
| 11 | B | I | I |
| 12 | B | B | I |
| 13 | B | I | I |
| 14 | B | B | B |
| 15 | B | I | I |
| Level | Beginner | Intermediate | Intermediate |

Subject 2

| Node | SAO+SUO Experience day 1 | SAO+SUO Experience day 2 | SAO+SUO Experience day 3 |
|---|---|---|---|
| 11 | I | E | E |
| 12 | I | I | I |
| 13 | I | I | I |
| 14 | B | B | I |
| 20 | I | I | I |
| Level | Intermediate | Intermediate | Intermediate |

Subject 3

| Node | SAO+SUO Experience day 1 | SAO+SUO Experience day 2 | SAO+SUO Experience day 3 |
|---|---|---|---|
| 11 | E | E | I |
| 12 | E | I | I |
| 13 | I | I | I |
| 14 | N | N | I |
| 20 | N | E | E |
| Level | Beginner | Intermediate | Intermediate |

Subject 4

| Node | SAO+POG Experience day 1 | SAO+POG Experience day 2 | SAO+SUO Experience day 3 |
|---|---|---|---|
| 11 | E | I | E |
| 12 | B | I | I |
| 13 | B | I | I |
| 14 | B | N | N |
| 20 | B | I | E |
| Level | Beginner | Intermediate | Intermediate |

Subject 5

| Node | SAO+POG Experience day 1 | SAO+POG Experience day 2 | SAO+SUO Experience day 3 |
|---|---|---|---|
| 11 | I | E | I |
| 12 | I | B | E |
| 13 | I | B | I |
| 14 | B | B | B |
| 20 | I | B | E |
| Level | Intermediate | Beginner | Intermediate |

Subject 6

| Node | SAO+POG Experience day 1 | SAO+POG Experience day 2 | SAO+SUO Experience day 3 |
|---|---|---|---|
| 11 | I | E | I |
| 12 | B | I | I |
| 13 | I | I | I |
| 14 | B | B | B |
| 20 | I | E | E |
| Level | Intermediate | Beginner | Intermediate |

Times for completing the five assigned tasks for each subject in the three days experiments are shown in table 2.

*Table2*: Task completion times for experiments

| | **Day 1** | **Day 2** | **Day 3** |
|---|---|---|---|
| | H:m | H:m | H:m |
| **Subject 1** | 2:10 | 01:41 | 01:43 |
| **Subject 2** | 01:42 | 01:44 | 01:41 |
| **Subject 3** | 01:46 | 01:44 | 01:42 |
| **Subject 4** | 01:54 | 01:45 | 01:44 |
| **Subject 5** | 01:51 | 01:43 | 01:41 |
| **Subject 6** | 01:54 | 01:49 | 01:44 |

Results from the initial experiments for completing a task, shows differences in time to accomplish the pressurization stage for the startup of the power plant. Times differences varies from 103.1 to 130.4 minutes between the best and worst time accomplished by users when using the adapted interface. Similar rate differences were also found for the amount of gas consumption.

Average times for the same user when using the normal user interface and the adaptive version reported differences of 11.3 minutes for the more skilled participant, with the best time for the adaptive version.

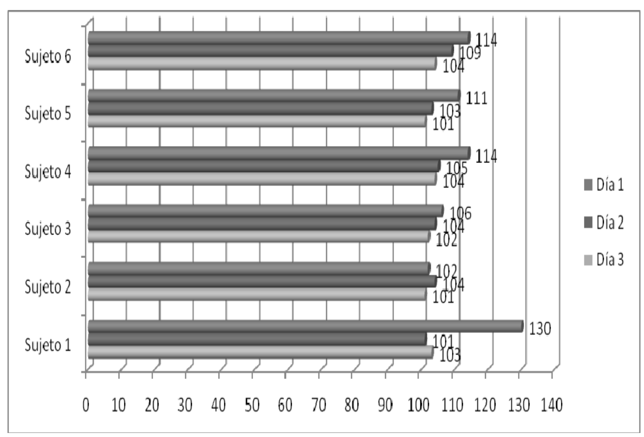


**Figure 7.** Times to complete the tasks for the 3 day evaluation experiments

*Table 3*: Gas consumption in kilograms for subjects using both user interfaces in day 2 and day 3

| | day 1 | day 2 | day 3 |
|---|---|---|---|
| Subject 1 | 9681.75 | 7653.5 | 7907.2 |
| Subject 2 | 7536.75 | 7615.25 | 7371 |
| Subject 3 | 7614.75 | 8053 | 7419.75 |
| Subject 4 | 8424.75 | 7624.45 | 6864 |
| Subject 5 | 8297.25 | 7673.25 | 7646 |
| Subject 6 | 7946.25 | 7829.25 | 7624.5 |

However in the standard user interface, the user required to use a sheet of paper printed with instructions in order to follow the startup process.

## VII. Conclusions

The work reported in this paper shows the results of the evaluation of the task and operator model for an adaptive user interface. Our evaluation was performed with six participants performing five representative tasks for the startup of a power plant in a simulated scenario. Participants performed the assigned tasks and evaluated both user interfaces: (1) Adaptive user interface version, including task and user model (SAO+SUO) and (2) non-adaptive user interface version, including the SAO and the POG guidebook.

The user model under evaluation provides information regarding the user preferences and knowledge about the processes required for the startup of the power plant. Task model under evaluation provided the details to complete the task. Information provided by both models is used to personalize the recommendation presentation style (i.e., text or graphic), and the detail level of the recommendation (i.e., succinct or extended) to guide the user to locate the plant components and achieve the operations required to complete the task. To perform the startup of a power plant, the operator followed the recommendations provided by the SAO and guided either by the POG guidebook or by the SUO, located those components in the simulator by navigating a number of screens.

Depending on his/her experience level and familiarity with the simulator, so is the time it takes to achieve the task. If he is able to follows the displayed recommendation, and it provides instruction accordingly to his knowledge on how to accomplish the task on the simulator, he can finish the task on time, earlier, take longer or even abort the task due to lack of knowledge or by misunderstanding the provided recommendations. Recommendations are personalized according to user knowledge, so if a user fails at completing a task or takes longer at following the recommendations and locating the plant components on the simulator, it can be due to an inaccurate assignment in the user level experience provided by the operator model.

Current evaluation results shows a time reduction as well as savings in gas consumption in the startup task for participants using the user interface version that includes the support models; however, we need to extend these experiments and take them as partial results, since as we experiment with operators and integrates the interaction RECOGNIZER and the ADAPTATOR model, they might have a greater impact in reduction of time and gas consumption when interacting with operators with domain knowledge.

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