Design and Evaluation of Ecological Interfaces

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1. Introduction

Electric power networks are representative of large-scale, multi-component, distributed and highly interactive systems, which are characterized by many interactions among a variety of agents: control room operators, field operators, network elements, control room equipment and instrumentation [1]. Furthermore, new technologically advanced control applications are continuously introduced, but they do not have the functionality required to meet the control requirements of the domain, exhibiting human factors design deficiencies. All these aspects of power system operations pose theoretical and pragmatic challenges, which can be met by *ecological interface design (EID)*. EID is a promising framework, which is appropriate for advanced interface design in complex safety critical systems, where unfamiliar and unanticipated events arise [12].

The current project applies EID to the electricity distribution domain. In Greece, distribution operations are under transition from traditional control man-machine interfaces (Wall Mimic Diagram, Transformer switches luminous Diagrams, Control Panel, Control Desk, etc) to a new control environment, where operators' interaction with the technological system will be performed by computer-based screen interfaces. We adopted the EID approach to develop an interface that could serve as a prototype for the requirements specification of the oncoming interface. The EID framework generates scientific knowledge, increasing the understanding of the relationship among human operators, technology and environment. In order to strengthen the efficiency and applicability of the developed ecological interface, and envision how future technologies would affect future work practices, we adopted a participatory design approach, performing iterative design and evaluation of prototypes by skilled work-domain practitioners.

2. Research Originality

EID has already been applied in process control, aviation, software engineering, medicine, command and control, and information retrieval systems [13]. However, most of these design attempts and evaluations concerned microworlds, while scaling up from generic process simulations to larger systems is difficult [2]. Therefore, applying EID in complex large-scale systems in order to solve real design problems, is a challenging issue both in terms of theory and practice.

In order to overcome the limitations of EID as regards real-world systems, and to consider in the design process the various aspects that affect effective operations, we proceeded to an extensive ethnographic and cognitive work analysis, giving emphasis also to the socio-organizational and collaborative aspects of the work system.

Furthermore we proceeded to a participatory-design process, through iterative design and evaluation of the developed prototypes by skilled domain operators, in order to assess not only the efficiency and suitability of the proposed design solutions, but also to identify the socio-organizational changes that the new control environment would bring about.

3. Significance of Research

The development of an ecological interface for the electricity distribution domain is significant in both theoretical as well as practical terms.

In theoretical terms, because it enriches and extends the results of prior studies, especially as regards the EID for real world large-scale industrial systems, which lacks integrated analysis and design case studies.

In practical terms, the developed ecological interface can be proposed as a requirements specification guide for the oncoming integrated computer-based management system that will be introduced soon in the electricity distribution operations domain, in Greece. Furthermore, due to the representativeness of the domain in terms of process control operations, the findings can be transferred and adapted to other network management domains.

4. Work System Analysis and Interface Requirements Specification

Work system analysis was performed in two stages. At a first stage, Ethnographic Analysis, helped to acquire a general view of the distribution operations, and to obtain the field data concerning the way human operators carry out their tasks. At a second stage, Cognitive Work Analysis helped in integrating the field data into a coherent and useful model of the joint-cognitive system and to set the design requirements [B].

4.1 Ethnographic Analysis

In this project, *ethnographic analysis* was useful in documenting and analysing the global physical and organizational characteristics of the system, the general properties of the information flow, the cognitive properties of the artefacts used, the social organization and culturally established practices, as well as to detect the interventions made by operators to overcome the limitations of the existing interface [8, 14].

4.2 Cognitive Work analysis

Cognitive Work analysis (CWA) is an analytical framework which adopts an ecological approach to system analysis, and gives precedence to the constraints, that the physical or social reality, outside the person or the technological system, imposes on dynamic goal- relevant actions, while it presents information in a form that is compatible with human cognition [9, 12]. CWA unfolded through five stages: a) *work domain analysis* was used to inventory the properties and relations that must be represented in the ecological interface, b) *task analysis* helped in detecting the information requirements that help operators to achieve anticipated task goals in a flexible situated manner, c) *strategies analysis* showed how the family of optional strategies that each control component affords for carrying out control tasks, influenced the structure of operations, d) *Socio-organizational analysis* helped to discern how the affordances of available control artefacts structured the tasks at hand, and to clarify where task allocation was guided by pure organizational reasons, and where it was guided by the capabilities of the control room artefacts [4] e) *worker competencies analysis* helped to identify the constraints related to the capabilities and limitations of the operators' cognition [7].

5. Participatory Design Process and Evaluation of Interface Prototypes

The design requirements elicited by work system analysis were transformed to interface representations through *semantic mapping process*, by which goal-relevant structures and relations in the work domain are mapped to visual forms [10]. Various design guidelines [5], principles [15], concepts [16], and visualization techniques [6] were exploited to provide effective drivers for the nesting of information in display geometries and for the arrangement of information across the space, scale and time dimensions.

The final ecological interface was developed through a participatory-design process. *Participatory design* facilitates the construction, of a common space through which the designer and the operations team (i.e., operators and supervisor engineers) can communicate and formulate appropriate design solutions [3]. Through iterative design of prototypes, alternate future technological solutions are "worked up" in the present, helping to detect the implications of the design solutions in the organization of work.

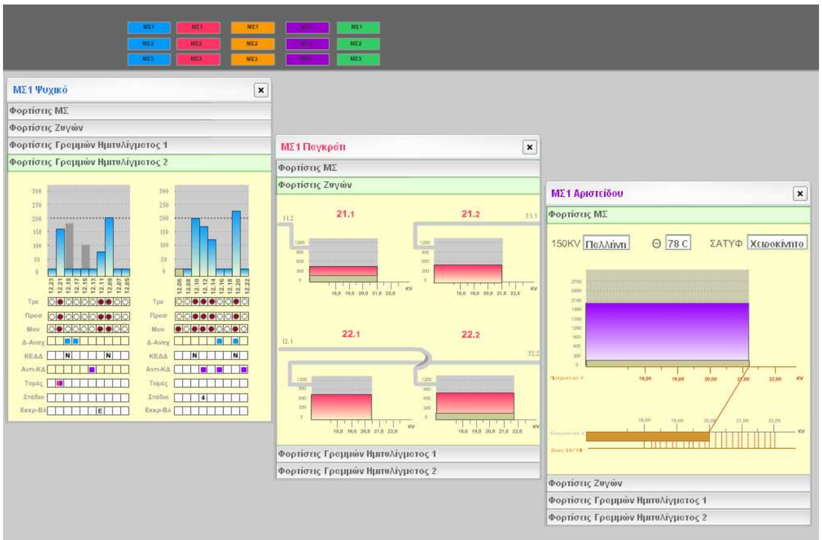

Figure 1. Supervision Screen –The three levels of Supervision Windows

5.1 First Phase

Based on the requirements specifications, which emerged from the extensive work system analysis, preliminary prototypes in low-fidelity media (i.e., paper and pencil prototypes) were first developed. These prototypes introduced the main representation concepts (e.g., codification of system elements and functions) [A]. Based on the feedback from our initial design process, we expanded the scope of the prototypes to more specific concepts such as information representation forms. Alternative design solutions were proposed to operators and engineers, and they were encouraged to argue about the functionality of each representation, and suggest changes that would facilitate monitoring. Considering all the factors that came up after the assessment of the prototypes, several revisions were made.

5.2 Second Phase

Once the prototype revisions were completed, a rapid prototyping tool (Macromedia Flash) was used to develop the primary supervision units for each transformer, in a dynamic format. Each Supervision Window (SW) presents each transformer in three discrete levels: lines level, bus bars level, and transformer level (Figure 1). Context-dependent representation of constraints, integrated representation of system variables (e.g., load-voltage graphs, Figure 1- central & right SW), and advanced ecological representations of previously scattered (e.g. Connectivity Matrix, Figure 1- left SW) or unmediated information (e.g., transforming trapezoid, Figure 1- right SW) were introduced to support effectively operators' cognitive tasks [D].

5.3 Third Phase

Once the Supervision Windows (SW) were completed, we proceeded to the design of the Supervision Screen (SS), where the SWs will be managed. In SS different SWs can be presented in parallel, move and overlap, and be activated at different levels, or deactivated, allowing operators to organize dynamically their workspace. Since the SS design was completed, typical scenario-based walkthroughs were performed, in order to identify and correct eventual operational difficulties, missing functionalities and navigational discontinuities.

The case of presentation of information that belongs to the supervisory authority of other control rooms, but is critical for planning long-term viable operations in the distribution control rooms, was also discussed in socio-organizational terms (e.g., confusion and diffusion of task allocation between cooperating control rooms) with system engineers.

Finally in order to explore the advantages and disadvantages of the developed ecological interface against the existing control room interface, simulations of typical incidents were performed by experienced operators and engineers with both interfaces [C].

5.4 Research Results

Simulations of representative incidents, showed that ecological interfaces lead to:

- Deeper understanding of the controlled process and more consistent control performance,
- Improved detection times of: close to limit parameters, parameters' inequalities and divergences of qualitative characteristics,
- More accurate disturbances diagnoses and localization of disturbances source,
- Better adaptation to tight operating constraints.

The effectiveness of the ecological interfaces against the traditional interfaces, can be addressed to the following characteristics:

- Availability of critical information in concentrated representation units and direct interaction with the units of interest, affords better detection and localization times of information and less navigational actions.
- Consistent codification of critical system properties and functions helps operators to develop and establish a common context of reference, which enhances mutual awareness.
- Integrated representations of critical parameters and goal-relevant properties help operators to consider the complex relations of the system, evaluate the consequences of a planned action, and proceed to efficient operations.
- Operators are facilitated in adopting the cognitive behaviour, which helps them cope effectively with the emerging needs of the task, with the least possible cognitive and physical effort.

6. Applications and Future Steps

The Supervision Screen designed in this project, has already been enriched with additional ecological representations and selective views of critical information, in order to further enhance operators' efficiency in critical operational conditions.

Designing ecologically discrete parts of an interface, presents explicit advantages in comparison to traditional interfaces, but it doesn't suffice. The capabilities of ecological interfaces can be exploited to the full, only in a complete, ecologically designed environment. Thus, based on the findings of work system analysis, three additional screens are now developed: Announcements & Pendencies Screen, Dynamic Mimic Diagram Screen, and Control Screen. Testing the efficiency of the complete -four screen- ecological interface remains an important area of future research.

EID cannot be expected to have its full impact unless corresponding changes are made to other system design elements. The content and structure of work system analysis that preceded the interface design in this project, gives rise to the extension of ecological design: a) in automation and instrumentation fault management [13] and b) in auditory alarms design [11], in order to create an integrated visual and auditory control environment. The decision support systems, training procedures, and team collaboration can also be designed in a coordinated manner using the ecological philosophy, as application of ecological approach aims not just to design a better human-machine interface, but to develop an integrated socio-technical system.

7. Research Team

- N. Marmaras, Project Intendant, Associate Professor in Ergonomics, School of Mechanical Engineering, National Technical University of Athens.
- S. Drivalou, Young Researcher, Industrial Engineer, PhD Candidate, School of Mechanical Engineering, National Technical University of Athens. S. Drivalou's doctoral thesis, entitled " Redesign of Human- Machine Interfaces for the support of breakdowns' restoration: the contribution of Cognitive Ergonomics", was funded by Thales project, for the section concerning the design of the Ecological Supervision Screen.

8. Publication of Research Results

A. Drivalou, S.,& Marmaras, N. (2005). "Designing Ecological Interfaces for the Supervision and Control of Electricity Distribution Networks", 1st Panhellenic Conference of Mechanical and Electrical Engineers, Athens, 28-30 March

B. Drivalou, S., & Marmaras, N. (2003). "Tracing Interface Design Solutions for an Electricity Distribution Network Control System using the Abstraction Hierarchy'', Proceedings International Ergonomics Association XVth Triennial Congress, August 24-29, Seoul, Korea

C. Drivalou, S. (2005). "Supporting Critical Operational Conditions in an Electricity Distribution Control Room through Ecological Interfaces", EACE 2005, 29 September- 1 October, Chania, Crete, Greece

D. Marmaras, N., & Drivalou, S. (2004). "Evaluation and Design of Ecological Interfaces", Final Report of "Thales" Basic Research Project, Pr. No. 65/1192, Athens, Greece

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