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Human Factors Support in the Design and Evaluation of the Reactor Protection System Cabinet Operator Module

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1. Introduction

A Korean project group, KNICS, is developing a new digitalized reactor protection system (RPS) and the developed system will be packaged into a cabinet with several racks. The cabinet of the RPS is used for the RPS function testing and monitoring by maintenance operators and is equipped with a flat panel display (FPD) with a touch screen capability as a main user interface for the RPS operation. This paper describes the human factors activities involved in the development process of the RPS: conceptual design, design guidance, and evaluation. The activities include a functional requirements analysis and task analysis, user interface style guide for the RPS cabinet operator module (COM), and a human factors evaluation through an experiment and questionnaires.

2. Development Process and HF Activities

The system development process can be divided into three sequential phases – analysis, design, and evaluation. Human factors activities performed for the RPS COM and the cabinet are shown according to the phases in Figure 1.

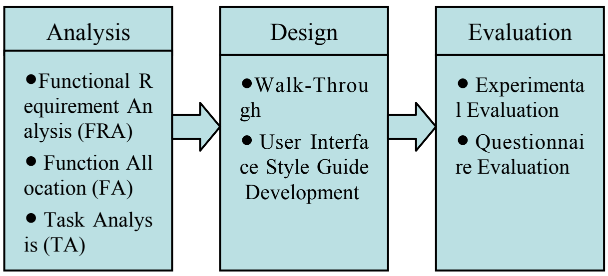

Figure 1. Human Factors Activities During the System's Development

2.1 Functional Requirement Analysis (FRA) and Function Allocation (FA)

The purpose of the FRA is to identify important functions that must be performed to achieve the system's objectives. Through a review of the design documents such as the design requirements, design descriptions, interface requirements, and function requirements, the RPS functions were identified, classified, and stratified so that a three-layered function hierarchy was developed.

Functions to be assigned were the third level functions in the function hierarchy and the allocation criteria were the performance demands, human capabilities/limitations, existing practices, operating experience, regulation requirements, and a technical feasibility. From the results of this FRA and FA, the functions related to the test and diagnosis of the system, system configuration, and the operational information provision were assigned to the maintenance personnel, however functions such as a signal and data acquisition, logic processing, information transmission were allocated to subsystems or modules of the RPS.

2.2 Task Analysis (TA)

From the results of the previous FA, the functions that maintenance personnel have to perform were deduced and a tasks analysis was executed to identify the task requirements for fulfilling the functions. Task grouping and a representative tasks deduction were accomplished to define the tasks to be analyzed. The defined task groups for the RPS COM were monitoring, testing, and bypass. In addition, most of the tasks which belonged to the testing task group were classified into representative tasks. Task description, preconditions for the task performance, task sequence, information requirements, and display requirements were analyzed for each representative task.

2.3 Walk-Through

To figure out the operational environment and the operation itself in the real situation, we visited a nuclear power plant in which a digitalized type of the RPS MTP similar to the RPS COM was installed. Through the investigation of the space and location in the real situation, the environmental and anthropometric characteristics could be defined. Useful information obtained from the walk-through was the behavioural characteristics of the local operators shown during a test task accomplishment.

Through this walk-through, basic information for the display design, such as the viewing distance and preferred display layout, and the maintenance personnel's comments on design improvements based on their operating experience were collected.

2.4 User Interface Style Guide Development

Insufficient understanding of the human factors design guidelines drives the designer to choose guideline items partly, arbitrarily and/or at his/her preference and to apply them to his/her design. The designed products derived via this way could be a partly satisfactory solution. Furthermore, there could be a considerable potential for a redesign of the products because the designer couldn't define the relative importance or priority of the guideline items correctly or didn't have the knowledge of the context to a certain extent.

The overall development procedure of the RPS COM user interface style guide was composed of an information acquisition, selection and screening, property determination and discussion, as well as a conversion and review.

2.5 Human Factors Evaluation

To ensure that the RPS COM drawn using the user interface style guide, supports the maintenance personnel tasks, a human factors experiment with task scenarios and a design review by human factors experts were designed. The task scenarios were prepared to cover every representative task defined in TA. As a result, seven task scenarios were defined as follows;

- Automatic periodic test
- Manually initiated automatic test
- Integrity and diagnosis test
    - a diagnostic error involved
    - a setpoint-related error involved
    - a bypass-related error involved
    - a processor output error involved
- Setpoint monitoring (a PLC error involved)

As the maintainability of the KNICS RPS cabinet from the aspects of the human factors was a major concern, two questionnaires were prepared to gather maintenance personnel's opinions on the existing cabinet they were in charge of and the design details of the KNICS RPS cabinet. One was composed of 29 question items related to the maintenance experience of the existing RPS cabinet, and another was prepared to verify the effectiveness of the design improvements applied to the KNICS RPS cabinet.

2.6 Evaluation Results

Subjects having experience in maintaining the RPS of a nuclear power plant participated in the human factors evaluation. They were trained in maintenance tasks on the KNICS RPS cabinet and COM before the scenario imposition. During the experiment, every subject behavior was recorded using a video camera.

Subject's performance was scored a success or a failure according to a task's completeness. As for the results of the performance analysis, most of the task scenarios were fully completed by the subjects, however just one scenario which required a subject to monitor setpoint information, to perceive an alarm occurrence, and to identify the root cause of the alarm, was not completed because a subject failed to catch the alarm within a predefined time limitation. Thus it was concluded that a more salient alarm presentation method was required for the RPS COM alarm display in order to capture the maintenance personnel's attention without a long delay. In addition, the video tape analysis showed that there was a need for an upgrade of the RPS COM hardware to get a higher touch acceptance rate than the reported 78%.

By means of the questionnaires analysis, issues on the existing RPS maintenance tasks were identified such as a narrow space for maintenance tasks, long test duration, and human error potentials during module substitutions. Contrary to the existing RPS, it was reported the KNICS RPS cabinet provided a sufficient space for the maintenance tasks, easy method for testing, and shortened test times. However the difficulty in reading labels on the slots of the rack was pointed out and information additions to the RPS COM were suggested.

Every opinion was examined and classified as a mandatory or a recommendation in order for system designers to decide quickly for a reflection of it.

3. Conclusion

To support the design of the KNICS RPS cabinet and COM, several human factors activities were carried out. In the conceptual design phase of the RPS, FRA, FA, and TA were performed to make the design concept concrete and to build a basis for a human system interface design. A user interface style guide was developed and produced to reduce the system designers' burden and to maintain a design consistency for the human system interface design phase. To verify and validate the designed human system interfaces, the RPS cabinet and the COM, a human factors experiment and a set of questionnaires were prepared and administrated. As for the results of the experiment and questionnaires analysis, many concerns with the RPS COM and cabinet design were deduced and classified into a mandatory or a recommendation according to the importance of the related tasks and the effects on the maintenance personnel.

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