METHOD FOR ANALYZING OPERATOR INTERACTIONS WITH COMPUTERIZED INTERFACES AND THEIR IMPACT ON PROCESS SAFETY

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The equipment of control rooms with computer-based human-system interfaces (HSIs) goes along with remarkable changes in the work of operators. However, while more detailed, publicly available methods of human reliability analysis (HRA) cover support of operators' actions with conventional interfaces, published methods for advanced interfaces are less detailed and require further development in order to be readily applicable in practice.

This paper presents a methodological approach supporting a systematic analysis of tasks specific for interactions with computerized interfaces applicable in control rooms of various domains. It provides generic categories of interface-specific cognitive tasks and actions, differentiating between tasks of process monitoring and control (primary tasks) and tasks necessary to enable and support the first kind of tasks (secondary tasks). These categories allow a detailed decomposition of activities with computer-based interfaces into sequences of actions and cognitive activities. Furthermore, criteria for the design of these interfaces were identified supporting a qualitative evaluation of cognitive workload and stress caused by the required interactions with the interface. Based on these categories and design criteria, the developed approach allows a systematic description of interactions with computer-based HSIs and the identification of error potentials related to unfavorable workload and stress.

I. INTRODUCTION

Main control rooms in various domains of process control are increasingly equipped with computer-based HSIs. These offer typically information on several computer monitors at operator workstations or on large screen displays instead on conventional layouts of control room panels. Interactions with computerized interfaces are largely performed via soft controls which are defined as "devices having connections with control and display systems that are mediated by software rather than physical connections" (Ref. 1, p.1-1) and less via conventional controls, such as knobs, buttons and keys. Control rooms characterized by computerized interfaces are often called advanced control rooms. Other typical features of such control rooms are higher levels of automation and computerized operator support systems or computer-based procedures.

Human factors design and evaluation of computerized control rooms and, more generally, computerized HSIs for safety relevant tasks have been an issue for decades. However, no widely accepted method for the analysis and assessment of reliable computer-based human-system interaction is available to the community of researchers and users (see Section III). In our opinion this situation can be traced back to the following major reasons:

- Due to the technical capabilities of hard- and software, a broad range of designs have been developed and implemented inside and outside the nuclear industry. It is therefore a big challenge to provide a method which is applicable to a broad range of conceivably quite differently designed computerized interfaces.
- Analysis and evaluation methods vary considerably with respect to the models of human cognitive performance on which the methods are based.
- Widely accepted methods for conventional interfaces (e.g. THERP, Ref. 2) are not applicable, because such methods do not adequately address digital HSIs as concluded in a work of Boring (Ref. 3).
- Progress towards a widely accepted method is handicapped by the limits of publicly available information about some methods applied in important nuclear industries.

Some authors differ between tasks of controlling a technical system (primary tasks) and tasks of using the interface (secondary tasks such as navigating through menus). Reliability of primary task-performance depends on secondary task-performance, because monitoring and control of the system may be delayed and (or) subject to errors to the extent that the interface does not adequately support quick, easy, and correct access to and use of required information and control devices.

This paper aims at presenting a method for the analysis of secondary tasks required by computerized HSIs and the contribution of secondary task-performance to primary task-performance in process control (see Section IV). In an ongoing R&D project, this method will be extended and enhanced by providing data and guidance for quantifying the reliability of secondary tasks and their contribution. Future projects will address the issue of allocating tasks of controlling technical systems to operators and automatic, computerized devices in such a way, that the best possible support of safe human-system interaction and, more generally, improvement of safety of the systems is provided. Results presented in this paper thus are one step of a more comprehensive approach to the development of a method for analyzing and evaluating computer-based human-system interaction.

The next three sections will present the goal, a summary of the relevant state-of-the-art, and the method for the analysis of human performance of secondary tasks and their contribution to the performance of primary tasks. The final section will discuss the method and give an outlook on its future development.

II. GOAL

The goal of this paper is to present the conceptual basis, scope and principal steps of a method which supports the

- identification of secondary tasks, personnel have to carry out in order to perform the primary tasks of monitoring and controlling systems and processes important to safety by means of a computerized HSI,
- analysis of these secondary asks and their contribution to primary task performance.

Although the scope of the method is a very broad one (see Section IV), the presentation will be focused on computerized main control rooms of nuclear power plants and other safety-critical process industries representing the main areas of application of the method.

III. SUMMARY OF THE STATE-OF-THE-ART

Since method development has to take into account the state-of-the-art achieved so far; the latter will briefly be summarized in the following.

III.A. Effects of Interface-Management Tasks for Performing Critical Tasks

O`Hara and colleagues state in the report NUREG-6690 that “*the primary tasks performed by nuclear power plant operators are process monitoring and control. To perform these tasks in a computer-based system, operators must perform secondary tasks such as retrieving information and configuring workstation displays. These are called interface management tasks*" (Ref 4, p. iii). They distinguish between the following generic classes of interface management tasks:

- Configuring (setting up the HSIs in a desired arrangement);
- Navigating (accessing and retrieving of specific aspects of the HSI, such as a display);
- Arranging (adjusting the operator's view of the information);
- Interrogating (tasks associated with asking information provided by HSIs and help systems);
- Automating (setting up shortcuts to make interface management tasks easier).

Based on the results of an extensive research, NUREG-6690 (Ref. 4) provides a theoretical model of interface management effects on primary tasks: According to this model, limited cognitive resources have to be shared between these two groups of tasks because both use more or less extensively the same cognitive resources (e.g. attention and working memory) and of the same HSI elements (e.g. usage of a mouse to start a pump or to retrieve displays pages*)*. Furthermore, both types of tasks are dependent on each other because personnel must perform interface management tasks in order to retrieve the information and soft controls relevant to the ongoing activities. Allocation of resources to primary and secondary tasks may therefore have the following adverse effects on task performance, in particular in situations with high workload:

- Resource-limited effect: Primary tasks are delayed or otherwise degraded, because the bulk of the resources have to be allocated to secondary task performance. Resources for primary tasks performance may become too limited in order to support correct primary task execution. Personnel may e.g. miss important information, because attention is focused on secondary task performance.
- Data-limited effect: Primary task performance requires the lion's share of the available resources. Consequently, resources for secondary task performance become so limited, that the latter cannot be correctly performed. Since the proper execution of primary tasks needs an adequate support by the activities pertaining to the secondary tasks (e.g., retrieval of required information about systems and processes), primary task performance may degrade or be delayed

In addition, the following potential effects of interface management tasks on primary task performance have to be considered:

- The execution of secondary tasks could interrupt the task sequence of performing risk significant actions. This can promote failures of continuing the primary task with a wrong step or at least demands cognitive resources to memorize and recall the status of primary task sequence or of information for a later usage.
- A wrong conduction of secondary tasks (e.g. accessing a wrong display page) may promote failures in primary tasks such as the operation of a wrong control (on that wrong display page).
- Similarity of HSI features that are used for risk significant actions and interface management tasks can lead to errors such as accidental operation of plant equipment.

In summary, O`Hara and colleagues offer a useful theoretical framework to identify, describe and explain effects of interface management tasks on the performance of safety relevant tasks (Ref. 4). Their work emphasizes the importance of considering these effects because of their safety critical nature. However the proposed categories of interface management tasks are too broad to characterize effects of HSI design characteristics on the performance of these activities and the demands resulting from them on an adequate level of detail. In addition, no guidance on how to analyze interface management tasks and their effects on primary tasks is given.

III.B. Effects of HSI Characteristics on Interface Management Tasks

Interface management demands are strongly related to the design of the HSIs. In NUREG-6690 (Ref. 4) and NUREG-6947 (Ref. 6), US experts give overviews of design related issues with respect to interface management. For example, the limited size of screens is related to the "keyhole effect" (see e.g. Ref. 6) which means that some relevant information is hidden from view. As a consequence, the operator may have to carry out some serially demanding secondary tasks to get access to information or soft controls. HSI design may also affect the need for other activities than those belonging to interface management, like activities to communicate with other staff members. For example, if the access to some information is laborious and therefore demanding to the user or not possible at an operator`s workstation, this person may try to get the needed information by interrogating another crew member.

There is guidance for the evaluation of digital HSIs human factors engineering guidelines (see NUREG-0700, Ref. 7) as well as for analyzing aspects of usability which is defined in the international standard ISO 9241 (Ref. 8) as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context". According to Nielsen (Ref. 9) this broad concept is characterized by the following five attributes: Learnability, efficiency, memorability, low error rate or easy error recovery and satisfaction. These are important aspects with respect to errors and workload emerging in the course of human system interaction. That explains the existence of a large variety of evaluation methods aiming at discovering usability problems, such as the approach of heuristic evaluation (e.g. Nielsen`s Usability Heuristics, Ref. 10). However, there is no specific guide on how to analyze HSI characteristics with respect to their influence on interface management demands or other secondary tasks and their effects on primary task performance. Due to the strong links between HSI design and the demands for such activities, the authors see a need for a methodological approach taking these influences into account at an adequate level of detail.

III.C. HRA Methods with Respect to Interface Management Tasks

The review of the state-of-the-art considered available methods for HRA. This part of the review was carried out for the following reason: Design and implementation of advanced control rooms have been stimulating the development of HRA methods of the so-called second generation. In principle, these methods should consider primary as well as secondary tasks and, consequently, support the identification, analysis, and evaluation of secondary tasks and their contribution to primary-task performance. Second generation HRA methods could therefore be a source of useful information for the development of the method presented in this paper. In addition, the review was extended to first-generation HRA-methods, which are focused on conventional HSIs. This extension of the review was motivated by the fact, that some secondary tasks are quite similar in conventional and advanced control rooms: It does not make a great difference, if .e.g. the representation of a measurement on a display page or on a conventional panel has to be correctly distinguished from neighboring presented measurements. This review led to the conclusion that HRA-methods of the first and of the second generation do not provide sufficiently detailed information. Major reasons are the following ones:

- For some methods such as e.g. MERMOS (Méthode d'évaluation de la réalisation des missions opérateurs pour la sûreté, see e.g. Ref. 11), no sufficiently detailed documentation is available to the public (see Ref. 12).
- Methods can differ considerably with respect to the factors and processes of human performance the methods are based on. Consequently, there is no sufficiently unique conceptual basis which could be used as a starting point for modeling human performance of primary and (or) secondary tasks and of the underlying cognitive factors.
- In many methods, primary and secondary tasks are not or not clearly distinguished. There is thus no (sufficiently) clear guidance regarding the identification, analysis, and evaluation of secondary tasks and their contribution to human reliability.

Secondary tasks are explicitly taken into account in a few methods:

- Jang and colleagues describe a framework for evaluating soft control execution errors (see e.g. Ref. 13, 14). In line with the work of Lee and colleagues (Ref. 15), the following sequential steps related to the use of soft controls are discriminated in this framework: "Operation Selection", "Screen Selection", "Control Device Selection" and "Operation Execution". The second and third steps are secondary tasks. Eight types of soft control human errors modes are defined: "Operation selection omission", "Operation execution omission", "Wrong screen selection", "Wrong device selection", "Wrong operation", "Mode confusion", "Inadequate operation" and "Delayed operation". Guidance for determining the corresponding error and recovery probabilities is provided, but will not be presented in this paper which is focused on the identification and analysis, but not on the quantitative evaluation of secondary tasks.
- In the method HuRECA (Human Reliability Evaluator for Control Room Actions, see e.g. Ref. 16), extending the Korean standard HRA (K-HRA, see e.g. Ref. 17), effects of human-system interactions on human performance are taken into account. "Screen Selection" and "Control Device Selection" are considered as secondary tasks and a factor called "interface management complexity" is defined. This factor is supposed to reflect the influence of workload due to these interface management tasks. Its magnitude is determined "by the number of operations using soft-controls, the number of mixed uses of different kinds of soft controls, and the number of altering computer screens operations using soft-controls" (Ref. 16, p. 8). However, the method has not yet been practically applied (see Ref. 12) and its general application seems limited because it "was developed based on the features of the APR1400 MCR, and might be modified according to the features of each advanced main control room"(Ref. 16, p. 9).

In summary, HRA methods do not provide a unique and detailed breakdown of secondary tasks into individual activities or a clear basis for analyzing the cognitive performance related to secondary tasks.

IV. METHOD FOR THE ANALYSIS OF HUMAN PERFORMANCE OF SECONDARY TASKS AND THEIR CONTRIBUTION TO THE PERFORMANCE OF PRIMARY TASKS

In the following sections, the scope of the method, the relationship of the method to the overall methodology of human reliability assessment as well as the support of various steps of human performance analysis provided by the method and the conceptual framework the method development was based on are outlined.

IV.A. Scope of the Method

The scope of the method is a very broad one, because it is not restricted to a particular type of computerized HSI. In particular, the method is not subject to restrictions in terms of staffing, the number of workplaces, the number and type of display devices and (or) input devices (e.g. mouse or touch screen).

IV.B. Relationship to the Overall Methodology of Human Reliability Assessment

Human reliability assessment is a well-established methodology which includes the following phases and steps:

- Preparation (Phase 1):
  - Familiarization with the plant;
  - Selection of tasks;
- Qualitative Assessment (Phase 2):
  - Description of situational and personal characteristics;
  - Description of tasks;
  - Analysis of tasks;
  - Development of HRA event trees;
- Quantitative Assessment (Phase 3);
- Incorporation in the overall investigation, e.g. a probabilistic safety analysis (Phase 4).

The method presented in this paper was developed in order to support the application of this overall methodology to tasks personnel have to carry out by using computerized HSIs. Since the approach is completely in line with the overall methodology, the following sub-sections will be focused on the steps of task selection, description and analysis for which the method provides systematical and detailed guidance. For the remaining steps, the reader is referred to available literature (see e.g. Ref. 18 which provides a concise and highly practice-oriented introduction). As mentioned in the introduction, steps for quantifying the reliability of task performance (as well as the integration with results of e.g. technical analyses within PSA) are beyond the scope of this paper.

IV.C. Selection of Tasks for Analysis

In accordance with the overall methodology for human reliability assessment, only selected tasks will be analyzed. The Selection is based on the following criteria: A task has to be selected for analysis, if

- technical investigations (e.g., from system and event-analysis in a PSA) show, that the task is important to safety,
- according to personnel or other sources of information such as empirical studies performance of the task is difficult or otherwise highly demanding and/or
- analysis of the task is required by rules and regulations.

In Germany for example, tasks belonging to the following categories have to be analyzed:

- Full power,
- start-up and shutdown,
- refueling,
- malfunction of plant components,
- maintenance, and
- design basis accidents (see KTA, Section A 3.4, Ref. 19).

Guidance presented in this paper is of course limited to those tasks or subtasks the performance of which is supported by computerized interfaces.

IV.D. Task Description: Conceptual Framework and Guidance Provided by the Method

Tasks selected for analysis have to be described. The description is an important step because the quality of the subsequent analysis depends on how precisely the task is described: Obviously, task aspects are more likely to be neglected in the analysis, if they were not addressed in the description.

The description has to be realized in the form of a so-called “model of task performance”. This model shows how personnel normally carry out the task to be analyzed. There may be systematic deviations from the course of action required by relevant procedures and (or) other rules of the plant. For the purpose of illustration, consider the following example: Personnel may prefer information which is readily available on the interface and skip the time-consuming or otherwise difficult navigation through many display pages of a complex display network in order to get those pieces of information which have to be used according to the procedure which is relevant to the task selected for analysis. Such shortcuts as well as other deviations have to be taken into account, because they can cause safety significant errors and can reveal design features of the interface (such as tedious access to particular pieces of information) which should be improved as far as possible.

For each task to be analyzed, a model of human performance has to be developed. The method presented here supports the development of human performance models by a systematic catalogue of personnel's activities and interface-related boundary conditions (or performance shaping factors, abbreviated as PSFs) which are related to these activities. This catalogue covers the areas of primary and secondary tasks. The catalogue provides the user with a means of investigating the task to be described with respect to important aspects which are relevant to human performance and which he might neglect without systematic guidance. Tables in the appendix present the catalogue. In the following, development, structure, main contents, and use of the catalogue will be described.

The development of the catalogue was driven by the goal of supporting task descriptions, which clearly distinguish between primary and secondary tasks and which are, as far as possible, systematic, exhaustive, and sufficiently generic in order to be applicable to interfaces with potentially very different designs (see scope of the method). Obviously, a clear distinction facilitates the identification and evaluation of the contribution of secondary tasks to primary task performance (e.g. rapidity and accuracy or, on the contrary, undue delay or error-proneness of access to information and soft-controls).

Input to the development of the catalogue was provided by relevant approaches which are well-documented in publicly available literature: O`Hara and colleagues (Ref. 4) presented a model of the effects of the secondary tasks of interface management on the primary, process-monitoring and control tasks, Lee and colleagues (Ref. 16) described an approach to take some of these effects into account as a PSF in a HRA method (see Section III). These works are subject to limitations (see Section III.B). Work reported in this paper therefore included a more detailed identification of activities and conditions of activity-performance by

- clarifying the precise interactions of primary and secondary tasks in the context of monitoring and controlling a technical process,
- performing a more detailed breakdown of activities and activity-performance conditions than the authors cited above.

Figure 1 shows the interactions between the overall task, secondary and primary tasks and the process to be monitored and controlled are networked.

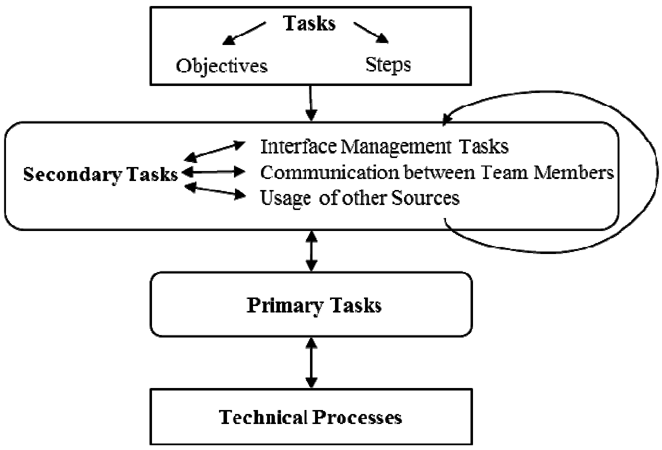

Figure 1. Interplay between primary and secondary tasks in the context of monitoring and control of technical processes

The reader should note:

- Secondary tasks are split of into the three groups of interface management tasks, task-related communications between staff members and use other sources of information like paper-based documents. “Communications” and “use of other sources” are included in order to take into account the possibility that particular pieces of information may only be available in paper-based documents or that team-members have to communicate with colleagues in order to obtain information from the addressee of the communication and (or) to initiate actions by the addressee of the communication. Such communications can be necessary, if, on the one hand, access to particular display pages, pieces of information and (or) controls is restricted to particular members of the team. On the other hand, task performance may be organized by the plant in such a way, that team-member A has to delegate particular steps of the task to team-member B, even though relevant information and controls are also available to A. Such an organization of task-performance can foster the cooperation between team-members. It also provides opportunities that B, getting involved in A`s task, recovers errors committed by A.

- It may be necessary to perform a whole chain of secondary task activities in order to execute a particular primary task activity. Figure 1 represents this possibility by the arrow which indicates that a secondary task activity can lead to subsequent secondary task activities. Think of e.g. A's request, that B shall open a valve and B's subsequent interface management activities in order to select the display with required information and soft-controls for opening the valve.
- Figure 1 also represents input from the box "primary task" to the box "secondary task". This path can be exemplified by alerts which are automatically triggered by the technical process and which require additional information about the process to be retrieved manually.

The breakdown of primary and secondary tasks into more specific activities and conditions of activity performance was realized as follows:

- Since there is no unique or at least widely accepted taxonomy of primary and secondary tasks and related conditions of task-performance is currently available, the breakdown almost started from scratch making best-possible use of knowledge presented in available publications (see e.g. Ref. 4, 16).
- The breakdown was driven by a couple of questions. Imagine an operator in front of a computerized interface which presents information and soft controls, other information and control devices like conventional alarm annunciators and keyboards, and other sources of information such as printed documents and responses of the colleagues. This operator has been working on a particular task, the current configuration of information and controls on the computerized interface mirrors the results of the latest primary and secondary tasks he performed during the execution of this task. At a given moment, the operator is required to start a new task. It is to be expected that the operator has to cope with the following challenges:
  - Which information and (or) controls or information do I need to perform the new task?
  - Which information and (or) controls are already available on my interface?
  - Which sources do I have to use in order to get access to the information and (or) controls which are not already available on my interface?
  - How do I have to interact with the already available controls on the interface in order to carry out required primary or secondary tasks?
- Both physical and cognitive demands related to primary and secondary tasks were identified. For the purpose of illustration, consider some of the activities the operator has to perform in order to cope with the first challenge: He has to e.g. recognize and distinguish pieces of information and controls for interface management tasks from those pieces of information and controls which he needs in order to monitor and control technical systems or processes. He has to check, whether displayed information is correct and if he needs this information for his new tasks. If he has to control e.g. steam generator levels, he trivially has to check and recognize, whether these levels are already displayed on the screens of his interface. If not, he has to recognize the entry point of a menu which provides access to relevant displays, click on the corresponding push-button etc. Recognition, discrimination, verification, and understanding of the meaning of information are demands on human cognition. The click on a push-button requires physical actions and the psychomotor coordination of movements of the eyes, the hand etc. Obviously, these demands are more or less challenging, depending on ergonomic factors of the design of information and control devices.

  The systematic breakdown of primary and secondary tasks into more specific cognitive and physical activities and PSFs was guided mainly by a theoretical framework provided by Hacker (Ref. 20). This author developed a detailed and empirically well-grounded, general model of task performance in socio-technical systems. Since cognitive processes require operator's memory for retrieving, processing, and storing of task-related information, demands on memory were identified by using work by Baddeley as state-of-the-art frame of reference (Ref. 21). Figure 2 visualizes the framework underlying our work. In this illustration, boxes represent the task assigned to the operators, the interface available to them, the cognitive systems and the challenges operators have to cope with, whereas arrows between the boxes indicate input/output relationships. The box "cognition" shows the network of interacting cognitive functions relevant to task performance. The following explanations are limited to functions not self-explanatory:
  - Memory comprises working memory, with its function of processing and storing task-related information and knowledge during task performance, and long term memory providing knowledge from prior experience and learning which may have to be retrieved during task performance.
  - There can be differences between the goal set by an operator and the task objective, e.g. due to errors in understanding. The overall goal of an operator will normally comprise a set of sub goals.

- With respect to task objectives, there may be some degrees of freedom (e.g. due to instructions in a procedures which can be interpreted in different ways). In these cases, possible options have to be considered by the operators requiring processes of planning decision making.
- Actuation with the interface may change processes or states of systems which can lead to new tasks.
- Questions of the left box show that the cognitive systems have to cope with primary and secondary tasks and the interface has to provide proper support for both kinds of tasks.

- Additional insights into cognitive demands of human task-performance were provided by literature on cognitive task analysis (see e.g. Ref. 22, 23).

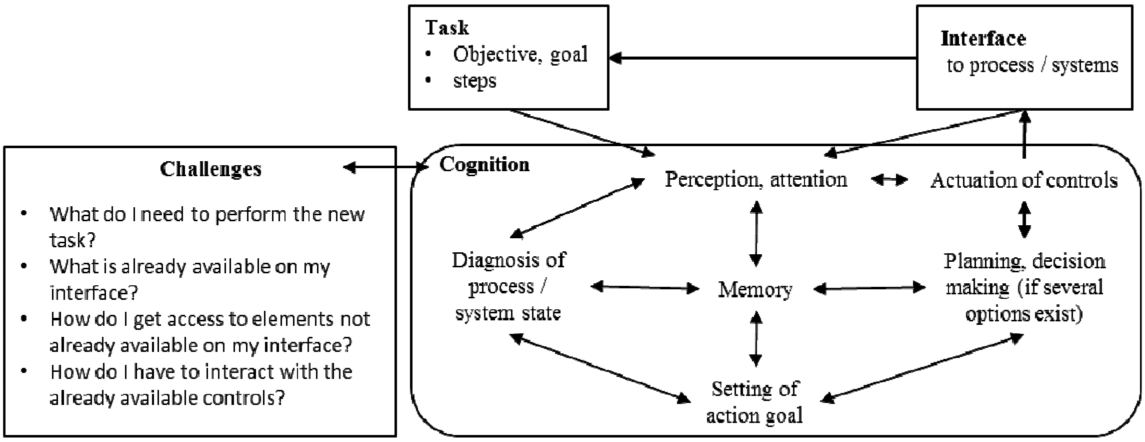

Figure 2. Theoretical framework

The detailed catalogue of activities and conditions of activity performance is presented in the appendix. It comprises a list of activities related to primary and secondary tasks and a list of boundary conditions with respect to HSI design. The catalogue can be used in two ways:

- Task descriptions have to be based on information about personnel's ways and means of actual task-performance. Such information is obtained by observing and interviewing personnel during so-called talk- and walk-throughs on site or in a simulator (see e.g. Ref. 2, pp. 4-5 for details about talk- and walk-throughs). Observers and interviewers should use the catalogue as guidance on the activities and performance conditions they should observe and address in interviews.
- The aforementioned models of human performance which represent personnel's normal way of performing the task in question shall also draw on the catalogue, because it provides a standard terminology which supports a clear description of computer-based man-system interaction and related PSFs.

Although the catalogue is very detailed and systematic, it is possible that some highly specific aspects of interfaces and human performance are not covered by its contents. In such cases, the user should expand the catalogue by suitable descriptors of activities or conditions of task performance.

IV.E. Task Analysis

In this paper, the term of task analysis is used to subsume the steps of identifying

- possible behaviors (i.e. action or inaction) of personnel with inacceptable effects on system- and process-safety ("human errors"),
- factors which bear on the likelihood of these errors,
- dependences between errors,
- possibilities of error recovery.

Human errors comprise omissions (i.e. the failure to perform an action) and commissions (i.e. incorrect performance of an action). Undue delays of actions required by system- and process-safety will be classified as commissions, because the action was carried out, but the timing of action performance was incorrect. An inacceptable deviation from the required sequencing of two or more actions will also be counted as an error of commission.

Task analyses are based on the models which are the end-products of the task-description process (see Section IV.D). These models represent the course, timing, and PSFs of the actions and activities personnel coping with the task will normally perform in the areas of primary and secondary tasks. The analysis has to be carried out for each individual task which was selected for analysis according to the criteria listed in Section IV.C.

Since task analysis in general is a well-established methodology, the following remarks will highlight only those aspects of task analysis for which specific guidance was prepared as part of the method presented in this paper.

- The clear distinction of primary and secondary tasks allows the distinction of four classes of dependent errors:
  - An error in the area of primary tasks leads to at least one other error in this area.
  - An error in the secondary-task domain entails at least one error in the same domain.
  - An error of secondary task performance degrades the performance of primary task, and, the counterpart of this dependence
  - performance degradations in the sector of secondary tasks which are due to errors in executing a primary task.
- The detailed cataloguing of actions, activities, and factors related to the design of the computerized HSI (see Appendix) supports a detailed analysis of errors, the four types of dependence between errors, error recovery possibilities and error causes in terms of design factors which are not in line with needs or capabilities of personnel. Consider the following examples for the purpose of illustration:
  - Interfaces require the operator to distinguish information and controls which support secondary tasks from information and controls for primary tasks. The likeliness of errors is expected to increase to the extent that the interface design does not support the quick and correct identification of the task domain a particular piece of information or control belongs to. For evaluating “good” or “bad” interface design and the corresponding error-potentials, the method presented here strongly recommends to use relevant ergonomic norms and recommendations as guidance.
  - The monitoring of a particular process parameter may be required to be performed with a particular meter, because this meter provides highly reliable information. But the menu could be designed in such a way, that it costs much time and effort to “click” one’s way through the menu (secondary task-actions) in order to get this information. Operators could therefore prefer to use less reliable, but easily accessible information.
  - Errors to perform a manual input in time can be recovered, if the operator is automatically alerted that his action is required. A chance to recover erroneous inputs is provided by alerting the operator to grave consequences and by the requirement to acknowledge the action in question. The designer may also implement measures for preventing possible errors or for reducing error-potentials, e.g. automatic actions which override incorrect human actions or the use of computerized procedures which “tell” the operator step by step which actions he has to execute.

The method presented here requires the user to carry out a detailed analysis of the nature and causes of potential errors, dependences, and recoveries. This level of detail is necessary for two reasons:

- Computerized interfaces can be designed in very different ways. Consequently, there may be many and quite different possibilities of causing, preventing and (or) recovering human errors. Proper identification of these potentials requires correspondingly deep, detailed analyses. The catalogue in the appendix shows which performances and factors shaping performance should be considered.
- Many errors may be recovered quickly, e.g. selecting a wrong path in a menu. The operator will quickly recognize and recover his error, if the information and controls presented on the screen are not those he wanted. But each of these errors costs a bit of time and the total amount of time lost due to these errors could create time pressure and add to the failure to complete the entire task correctly in time. This potential for error must not be neglected.

Only safety significant errors will be considered in the HRA tree (see e.g. Ref. 18). The method requires the user

- to fully start with the safety significant errors in the domain of the primary task,
- to attach to each of these errors a concise evaluation of the support (or lack of support) which is provided by the interface and which explains why the action affected by the error was omitted or performed erroneously,
- to attach, as in standard HRA, to each of these errors the PSFs which are not covered by the evaluation of support by the interface (e.g. personnel’s qualification). Figure 3 represents the resulting structure.

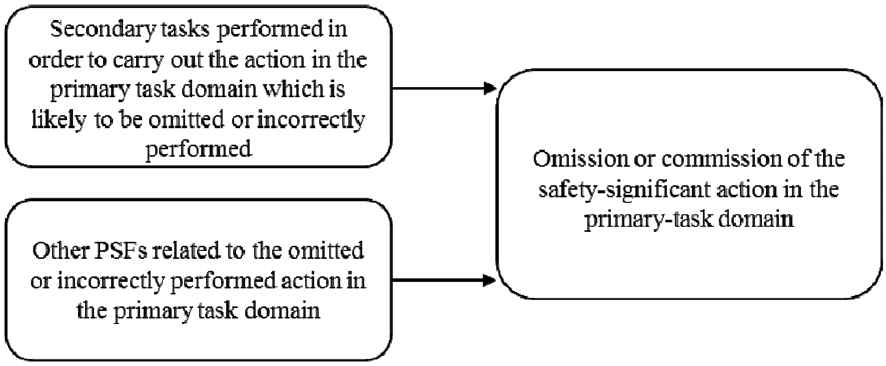

Figure 3. Relationship between secondary task, other PSF, and error in the area of primary tasks

The evaluation of the support by the interface may be quite different for the various actions which belong to one and the same overall task because e.g. soft-control A is easy to access and identify, whereas operators have to invest much more time and effort in order to reach and use soft-control B on the interface. Therefore, the evaluation of the support by the interface has to be broken down to the evaluations of the support for each action which could be omitted or erroneously performed with adverse effects on safety. This evaluation has to address

- potential errors of the secondary task on which the safety significant (primary task) error in question depends (if applicable),
- cognitive burden caused by performing the secondary task,
- stress caused by time pressure (if applicable).

The error in question may occur, even if the PSFs and the support by the interface are optimal or at least not likely to cause errors. This is similar to the potential of errors which might occur with a small, but non-zero probability in conventional control rooms. Stress due to time pressure can arise, if the small losses of time caused by performing and recovering access to wrong information or soft-controls amount to considerable delays.

Cognitive burden caused by performing secondary tasks is qualitatively assessed in terms of Rasmussen's distinction of skill-, rule- and knowledge based behavior (Ref. 24). Ideally, interfaces provide support of primary-task performance in such a way that secondary tasks are very easy to execute and personnel can acquire a high level of routine in using the interfaces. In other word, the "ideal" interfaces guide the user step by step and without causing uncertainties and hesitation to the information and soft-controls he needs for primary-task-performance. The worse or even worst case is given, if the interface poses the problem of how to get the information and controls which are needed for tasks performance. In such cases, the operator has to turn much or all of his attention away from the primary task, which can add to the risk of safety-significant errors and (or) delays of primary tasks. The method presented here captures this feature by the binary distinction between interfaces which require secondary tasks on the skill- and rule-based level and interfaces which can only be managed by recourse to knowledge-based behavior.

Although the analysis is a very detailed one with respect to actions, activities, and factors shaping their performance, the results of the analysis will in principle be quite straightforward and easy-to process.

V. DISCUSSION AND CONCLUSION

This paper presents an approach which supports the analysis of particular tasks pertaining to the monitoring and control of processes by means of computerized HSIs. The method addresses the domain so-called "interface management" or, more generally, "secondary tasks". The term "interface management" applies to the task of interacting with the interface (e.g. using menus and input devices such as e.g. touch screens) in order to have access to the information and control devices (e.g. digital displays, soft controls) which are needing for the primary tasks of process monitoring and control tasks. The more general term of "secondary tasks" is broader than "interface management", because it covers all other sources of relevant information about plant, systems, and processes as well as the coordination of process monitoring and control actions which are performed by the different members of the operator team. Obviously, interface management and other secondary tasks related to one and the same primary task can be very different depending on the particular design features of the interface (number of screens per workplace, structures of the menus, ways and means of presenting information on screens etc.).

The development of such a method was necessary, because neither publicly available HRA methods nor published classifications of interface management tasks, their effects on primary task performance, and relevant influences of HSI design characteristics provide sufficiently detailed support of the systematic identification, description, and in-depth analysis of interface management and other secondary tasks and their effects on the correct performance of primary tasks. Method development drew on the available knowledge and provided additional guidance, which is focused on the proper consideration of interface management tasks in the overall process of Human Reliability Assessment. The resulting method supports important steps of HRA:

- Selection of tasks for analysis;
- Collection of information about personnel's performance of the selected tasks during observations and (or) talk- and walk-throughs;
- Description of task performance by personnel;
- Analysis of human performance by identifying nature, causes, dependences, and recovery possibilities of potential human errors which would have adverse effects on process safety.

More precisely, support is provided by defining

- criteria for selecting tasks;
- for information collection and task description: systematic and detailed catalogue of (1) human activities related to the performance of primary and secondary tasks and (2) features of interface design which affect the performance of these tasks;
- a criterion for qualitatively assessing the positive or negative effect of secondary task performance on primary task performance. This criterion summarizes the many detailed pieces of information about interface management tasks and factors related to the performance of these tasks in a comprehensive way. It amounts to a distinction of interface management tasks which can be performed routinely on the level of skill and rule based behavior from interface management tasks which require knowledge behavior because personnel have to solve problems of finding and (or) using information and control devices they need for task performance. Routine behavior is a barrier against errors and undue delays, whereas the solution of problems caused by the interface design is expected to increase the likeliness of errors and inacceptable losses of time.

In an ongoing project this analysis method will be developed further to a full-fledged method for the analysis and the quantitative evaluation of human-system interactions which are supported by computerized interfaces.

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APPENDIX

In the following, "HSI elements" is used as a summary term for elements presented on surfaces of HSIs, such as information, icons, displays, soft controls and input fields.

List of Activities Related to Primary and Secondary Tasks

Cognitive Activities

Primary and Secondary Tasks

- Find out how to access or locate needed HSI elements
- Recognize presented HSI elements
- Distinguish presented HSI elements related to secondary tasks and such related to primary tasks
- Determine the relevance of presented HSI elements
- Determine the correctness of presented HSI elements
- Memorize presented information for subsequent usage
- Recall memorized information when required
- Perform rule- or knowledge-based activities (e.g., diagnosis of current process status, selection of required procedures or development of action plan)
- Keep track of goals, activities (already finished, ongoing, to be done), and links between activities (e.g. to be able to continue correctly a sequence of tasks after interruption)
- Coordinate the performance of tasks which have to be performed in parallel

Actions

Primary Tasks

- Perform the required actions to influence technical processes or system states

Interface Management

- Actions to get access to not presented HSI elements (e.g. clicking on icons in menus or on a display)
- Remove HSI elements not or no longer needed for task from screen
- Change the arrangement of presented HSI elements in a task-oriented way
- Change the format of presented HSI elements in a task-oriented way
- Save presented information for later usage

Communication

- Request information / instruct
- Answer / give feedback

Usage of other Sources

- Actions to get access to other sources of information
- Consult the source of information

List of Boundary Conditions with Respect to HSI Design

Conditions of Cognitive Activities

Primary and Secondary Tasks

- HSI elements are visible (e.g. not hidden)
- HSI elements are easy to recognize
- HSI elements for secondary tasks are easy to distinguish form those for primary tasks
- HSI elements are easy to understand (meaning, function or state)
- HSI elements are clearly arranged
- HSI elements are grouped in such a way that best-possible support of workflow is provided
- Salience of information corresponds to its importance
- Information is directly usable for tasks (without the need for additional cognitive tasks, such as mental calculations to convert it)

Secondary Tasks

- Adequate guidance on accessing and locating HSI elements needed for the task
- Adequate navigation concept (e.g. organization of screens is logical)

Conditions of Actions

Primary and Secondary Tasks

- Automatic reminder if required input has not been supplied within a specified time-window
- Protection against unintentional erroneous inputs
- Automatic preview which inputs are admissible
- Automatic request for confirmation for inputs with severe consequences
- Automatic control for wrong or erroneous inputs
- Enable as far as possible to correct erroneous inputs
- Consistency of inputs with user expectations
- Feedback that input processing is in progress
- Feedback about the results and consequences of inputs

Secondary Tasks

- Interface management activities are easy to perform
- Number of actions necessary to access task-relevant HSI elements is acceptable