THE ROLE OF HUMAN-COMPUTER INTERACTION IN DESIGN OF NEW TRAIN TRAFFIC CONTROL SYSTEMS

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Summary
The rapid technical development of train traffic, and of the control systems, makes it necessary to study the interactions between the operators, e.g. the train dispatchers, and the technical information and control systems. Increasing train speed, and more dense traffic, means that more information must be transferred, and that higher demands concerning optimality in planning and control must be fulfilled. When new control systems are being developed, this must be based on detailed knowledge about the organisation and contents of the control tasks, and on knowledge concerning how skilled operators behave and perform in complex and dynamic work situations. Basic design questions that must be answered, concern e.g. how far the control systems should be automated, the use of different types of decision support systems, the organisation of the control activities and which information that should be presented to the operators and how. We present a theoretical and methodological background for how modern human-computer research can be applied to the modelling, analysis and design of future train traffic control systems, and especially to the design of operator interfaces.

Key Words
Train traffic control, human-computer interaction, cognitive load, user interface design.

Operators and train traffic control

Future systems for train traffic control must fulfil several new requirements compared to today's systems. The rapid technical development of train traffic, high demands concerning optimality in performance and economy, together with new technical possibilities for signalling systems and information exchange, make it both possible and necessary to redesign both the functionality and the interface of the control system. The operators have here a key role. It will be extremely important to have operators with the correct competencies and skills, working in an efficient work organisation. The operators must also be supported by very efficient control and support systems. The control systems must be efficient in both normal and disturbed work situations and must support all control goals that the operator are assigned to reach. In this respect the design and the implementation of the interface between the operators and the control system will be most important.

It is an experience from e.g. process control, that it is a difficult problem to design user interfaces to control systems, so that the utility and usability[1] of the system is optimised. In order to be efficient, the design of the interface must be based on a detailed analysis of the control tasks of the operators and of the control situations that the operators will face. This analysis is difficult to perform, since the operators are not always mentally aware of how they perform their tasks. Much of the knowledge and skills of the operators can be considered as tacit. However, if the design of the interface to the control system do not match important requirements, the result can be severe problems in efficiency and in the work environment.

In earlier research, cognitive aspects of interface design for train control systems have only been sparsely treated. In the European project ERTMS/ETCS [ETCS, 1996] one main focus has been on the ergonomical design of the train operators' work environment, and not on the dispatcher's support systems. Lenior [Lenior, 1993] has presented an approach to analysis of cognitive processes in the train dispatcher's work, with emphasis on the dispatcher's reasoning about control strategies. This has, however, not been applied to interface design.

The role of human-computer interaction

Interdisciplinary human-computer research has earlier been applied to other dynamic work situations, and the results from this research can to a large extent be directly applied to design of train traffic control systems. At CMD, Uppsala University, earlier research has concerned cognitive load, operator

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[1] Utility is related to the functionality of the system, i.e. that the control system is an appropriate tool. Usability is related to the interaction between the user and the system, i.e. that the control system can be operated efficiently and with a minimum of effort.

performance and interface design in different work environments [Sandblad, 1991].

Experiences show that, if the interfaces are not designed according to appropriate requirements, the result will be low user performance, higher error rates, increased safety risks, bad user acceptance, negative stress and even health problems.

The purpose of this paper is to present and discuss a theoretical and methodological background for how modern human-computer research can be applied to the modelling, analysis and design of future train traffic control systems, and especially to the design of operator interfaces.

Existing knowledge and research

The results presented in this paper has been obtained from a research co-operation between the Swedish National Rail Administration and CMD, Center for Human-Computer Studies, Uppsala University. As a first phase of this project, a rather comprehensive analysis of research relevant to design of operator systems for train traffic control has been made. Basic research areas that have been considered are e.g.:

• *Cognitive load and automated cognitive processes*

Human cognitive capacity is limited. On a very high level only one problem can be treated, i.e. no simultaneous processing is possible. Automated processes, on a low cognitive level, can however be performed efficiently and in parallel [Rasmussen, 1983]. Therefore, the design of the interfaces to the control and support systems should allow the handling to be as automated as possible, in order to allow the operator to be concentrated on the actual control tasks [Nygren et al, 1992].

• *Limitations in human memory performance.*

The human short term memory has a limited capacity, a fact that must be considered in the design of the interfaces. If several sets of information must be simultaneously stored in the short term memory during the work process, this can result in memory overload, causing low performance, high error rate and stress. It is of this reason important that the interface can show all decision relevant information in parallel.

• *Cognitive work environment problems*

Cognitive work environment problems are associated with hindrances, caused by e.g. badly designed interfaces, that prevent professionals from using their skills efficiently [Sandblad, 1991]. Such problems will result in low efficiency and negative stress. Also the work organisation can, if not adjusted to the work situation, cause these kind of problems. The conclusion is that it is important to consider the work situation as a whole, and to integrate the development of organisation, competencies and information systems.

• *HCI and interface design.*
Within the science of HCI (Human-computer interaction) we find a broad theoretical base for specification of design principles for train traffic control. Rules, guide-lines, style guides and design principles from similar work environments can be tested and used here.
In order to specify necessary requirements for the design of the interfaces, we must use efficient methods for capturing important aspects of the operators' work and how they utilise different sets of information. Our methods here are based on a combination of observations and interviews, where important cognitive aspects can be (at least partially) captured [Gulliksen et al, 1997].

• *Dynamic decision processes.*
Knowledge here concerns how mental models are being created, how this can be facilitated by the interfaces and how time critical decision processes can be efficiently supported - or hindered [Brehmer, 1992]. An important conclusion is that it is necessary to support the operators with dynamic information in order to support the creation of dynamic mental models of the process.

• *Operators in process control.*
Much knowledge exist from studies of how operators perform when using different types of support systems. Generalised knowledge can partially be applied here. Modern control systems are often designed to efficiently support the operators possibilities to react on alarms and to solve problems that occur. This can be considered as a "management by exception" approach to control. However, in order to perform efficiently, operators often consider their task to be to prevent disturbances and alarms in the process. This can be called a "management by awareness" approach. It is obvious that the different approaches to process control will result in radically different design of the control system and of the user interface.

Some results from observation interviews

In order to get more knowledge about the human-computer problems that today are related to the operator's work, especially the train dispatchers in the train control centres, we have performed some observation interviews concerning the operators work situation, environment, control work tasks and their use of today's information systems. During these observation interviews, a lot of important information was collected. After an analysis of the findings, a number of important problem areas for future research were identified. Some of the more important problem areas identified (without priority) were:

- The operator's possibilities to efficiently build up mental models of the train traffic process is not adequately supported. Our analysis has shown that very detailed information is needed for this, and that the needed information is normally not presented in today's control systems. The design of future interfaces should support this better.
- There is evidence that "automated" decisions play an important role if a mental model is to be used in time critical situations. The operator does not have the "time to think". The information must be presented so that the situation can easily and without mental effort be identified in enough detail.
- The goals for the control tasks are time related, while the information supplied to the operators is not. This means that the operators will have difficulties to relate the information to the timeliness of the control decisions and actions.
- In many work situations the decision relevant information is not available simultaneously. This can cause memory overload.
- The position and the speed of the trains are not known at the precision needed. New technical systems for position and speed detection, and for signalling, are needed in the future.
- The control goals on different levels, and the rules for giving priority to different types of traffic, are not known in detail to the operators. Another problem can be that different goals are conflicting or that the goals are not operational, i.e. they are not related to the control tasks of the operator or not formulated so that an evaluation is possible.
- The communication between the operators and their environment, e.g. with other operators, to and fro the trains, technical staff etc. is frequent and technically not so efficient. Much time is spend on getting connected. In time critical situations this is not acceptable.
- Much of the operator's work is focused on identifying and solving disturbances. Therefore information about the disturbances must be presented to the operators clear and in time.
- There are several reasons for information delays. Several different difficulties are associated with time delays. A time delay can result in that the operators are uncertain about the present state of the traffic process or if an action has had effect or not. Another important effect is that the operator have difficulties in relating the result of a control action to the action itself. The effect of this is that the possibilities to create adequate mental models will be reduced.
- Today's interfaces to the control system are divided into several different parts, each with it's own technology and design principles. The problems are accentuated by the above mentioned lack of details. The cognitive interpretation and integration of the different sets of information, the identification of necessary but missing information etc. puts a heavy mental load on

the operator. If a more integrated presentation was used, this would allow the operator to "perceive" the situation rather than to read it with effort. This would then allow the operator to concentrate on the control goals and on initiating efficient control actions.

Design of operator interfaces - some key problem areas

Basic questions that must be asked when new control systems are being developed are e.g. how far the control systems should be automated, the use of different types of decision support functions, the organisation of the control activities, which information should be presented to the operators, how should the information be presented, time co-ordination between information presentation, decisions and actions, how should the interactions between user and system be designed etc. When more knowledge has been gained, it can be manifested in form of rules and style-guides that can improve the efficiency and quality of interface design in this field.

As a part of the project, we will develop simulator systems, where prototypes of future control systems together with their interfaces can be tested and evaluated. The design of these prototypes will be based on the knowledge described above, on a more detailed analysis of the actual control tasks and on scenarios describing the technology, organisation and control principles for tomorrow's train traffic.

Discussion

When future operator systems for train traffic control are being designed, developed and evaluated, knowledge of the nature described above will be indispensable. In order to analyse the actual work situations, the analysis must be based on a model describing the components of the studied system and how these components are related to each other. Such a model is under development and a preliminary version will be presented elsewhere [Andersson et. al., 1997].

When prototypes of new control systems are being developed, this must be based on rather detailed scenarios of future traffic and control systems. The formulation of such scenarios will be an important part of the future research. These will serve both as a base for requirement specifications and for evaluation of prototypes.

Finally, it is necessary that the analysis, design and development of the functionality and of the user interface to the control system, are performed according to a user centred method. This will enable operator skills, that can not be explicitly modelled, to be incorporated in the design work. Also for evaluation of prototypes, e.g. in simulator systems, the participation of skilled professionals is a necessity.

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