Improving interface usability for train dispatchers in future traffic control systems
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Abstract

The operator's interface to train traffic control systems must support high efficiency and a good work environment. Modern research on human-computer interaction in complex and dynamic work situations gives a framework for requirement specifications. Important aspects concern cognitive workload, limitations in memory capacity, dynamic decision processes and work environment problems. Operators should be able to prevent disturbances rather than react on alarms. The train dispatchers' work has been studied through observations and interviews. Based on this, we have identified requirements for interfaces to tomorrow’s traffic control systems. Prototypes of new operator interfaces have been implemented and tested.

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, e.g. concerning train speed and traffic density, 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. Very efficient control and support systems must support the operators.
The control systems must be efficient in both normal and disturbed work situations and must support control goals of different nature. 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 functionality and usability of the system is optimised. 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 normally not mentally aware of how they perform their tasks. Much of the knowledge and skills of the operators can be considered as tacit and based on long time experience. However, if the design of the interface to the control system do not match important requirements, the result can be severe problems in safety, 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[1] one main focus has been on the ergonomically design of the train driver's work environment, and not on the dispatcher's support systems. Lenior[2] 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 performance and interface design in different work environments, e.g. Sandblad 1991[3].

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 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, e.g. Sandblad 1997[4]. Basic research areas that have been considered as background knowledge are e.g.:
• **Cognitive load and automated cognitive processes**
  High level human cognitive capacity is limited. Automated processes, on a low cognitive level, can however be performed efficiently and in parallel, e.g. Rasmussen[5].

• **Limitations in human memory performance.**
  The human short-term memory has a limited capacity. 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.

• **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, e.g. Sandblad 1991[3]. This will be discussed further below.

• **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, guidelines, style guides and design principles from similar work environments can be tested and used here, e.g. Nygren[6].

• **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, e.g. Brehmer[7].

• **Operators in process control.**
  Modern control systems are often designed to efficiently support the operator’s 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.

**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 observation interviews of the operators work situation, environment, control work tasks and their use of today's information systems. 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 were:
• The operator's possibilities to efficiently build up mental models of the train traffic process is not adequately supported.

• 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 goals for the control tasks are time related, while the information supplied to the operators is not.

• 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.

• 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 and contain conflicting parts.

• The communication between the operators and their environment is frequent and technically not efficient.

• 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.

• Important information is often delayed. A time delay can result in that the operators are uncertain about the present state of the traffic process or that the operator have difficulties in relating the result of a control action to the action itself.

• Today's interfaces to the control system are divided into several different parts, each with it's own technology and user interface. If a more integrated presentation were used, this would allow the operator to "perceive" the situation rather than to read it with effort.

**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.

Some basic cognitive work environment problems that can be caused by badly designed user interfaces, and that must be minimised, are:

- **Interruptions in operator's cognitive processes.**
  The operators are not allowed to be continuously concentrated on the control problems, but are interrupted by e.g. operating the interface.

- **Orientation and navigation problems.**
  In large information spaces it is difficult to relate the presented details to the whole, to identify the presently displayed part and to navigate between the different parts of the total information system.

- **Cognitive "tunnel view"**
  The operator tends to over-estimate the visible information and to under-estimate the hidden parts of the information.

- **Working memory over-load.**
  Information must be stored in the short-term (working) memory during the decision processes.

- **Unnecessary cognitive load.**
  Cognitive load not related to the control problem as such, but rather to the understanding and operation of the interface to the control system.

- **Spatial confusion.**
  Information sets are not stationary with respect to their location and form.

- **Problems in time-co-ordination.**
  Different sets of information are not presented together with information about when they were obtained.

- **Problems in identification of process status.**
  If the status of the controlled processes is not presented in an obvious way, it is difficult to consider this in the decision processes.

**Basic design principles**

In order to minimise such cognitive work environment problems, and to design the operator's interface in an efficient way, the design must fulfil some basic requirements:

- Clear formulation of the control goals to be achieved by the operators (dispatchers). When different and conflicting goals exist there must be explicit rules for interpretation.
• Support the development of cognitive models of the train traffic system. This is especially important for the operators’ models of the automated parts of the control system.

• Possibilities for the operators to plan their own and the group's work. Avoid built-in limitations.

• Show decision relevant parts of the present status of all involved processes.

• Allow the handling of the control system to be automated, so that all cognitive capacity can be concentrated on the control tasks.

• Simultaneous presentation of all information needed for one decision process, in order to avoid working memory overload.

• The operator should not need to take any design decisions during operation of the control system. This means that the interface must be completely designed to fulfil the needs of each possible work situation.

• Show the whole and the details in parallel.

• Allow easy switching between tasks.

• Give the information a clear and obvious form, to support quick and automated interpretation.

• Efficient use of colours. Colours must have a meaning and not be used as cosmetics.

• In many situations: avoid scrolling of information and use a "turning of page" metaphor. Scrolling will change the spatial relations and hinder automated perception of information patterns.

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**Design principles specific for the train traffic control system**

*The operators want to be "in control" of the situation*

The operators do not want to wait for warnings from the control system, which would be the case if they are forced to work according to a "management by exception" principle. They want to be fully aware of what is going on, and detect which disturbances that can be expected in a near future. By continuously being active, expected disturbances can be prevented. We call this control principle "management by awareness". In this way the operators can reach a more optimal control and at the same time control their own workload. However, this requires a very good over-view over the dynamic development of the controlled traffic process.
• **Design for professional users**
  The efficiency for the skilled, professional users is here far more important then the efficiency for the novice user. The skilled operators normally require simultaneous presentation of all decision relevant information. They do not want to switch between different presentations. It is our experience that a skilled user can use very information dense presentations without difficulties if the presentation is efficient. The problem of "information over-load" is probably not a question of the amount of information, but rather of the design of the presentation.

• **Support understanding of the train traffic process**
  The interface must supply the train dispatchers with information that supports their development of mental, dynamic models of the traffic system. This is needed in order to allow the operators to sort their experiences in categories that can be retrieved whenever needed.
  Especially important is the understanding of the functionality of the automated parts of the control system. If the dispatcher do not fully understand the actions of the automated system it is not possible to "co-operate" with it. The dispatcher must be able to plan and evaluate control activities in relation to what can be expected from the automated "partner". In other cases the result will be "automation surprises" and a tendency to take over the control from the automation in situations where this is not efficient.

• **Allow automated handling of the control system**
  This can be achieved by e.g.:
  
  • show dynamic information rather then static,
  • show all information needed simultaneously,
  • do not hide information or functionality, all must be clearly visible,
  • use colours for information coding and use colours that support readability,
  • group information sets that belong together,
  • provide direct and consistent feedback on all control actions.
Prototypes of new interfaces for the train dispatchers

As a part of this project, a set of different preliminary prototypes has been developed. These can, however, not be presented in detail here but will be published separately.

The design of the prototypes is mainly based on the present Swedish train traffic control systems. These are, however, not designed according to the principles discussed above and are often rather fragmented and technically distributed on different hardware. Therefore, one important design goal has been to integrate the functionality into one single system.

Another main design goal has been to include all decision relevant information into the prototype system, also such information that is not technically feasible today.

The analysis has shown that the design requirements depend strongly on the type of train traffic that is being controlled, e.g. its intensity and if the traffic is mixed or not, and on if the traffic runs on single-track systems or not. These differences are so important that the corresponding prototypes often must be designed differently.

Today the interfaces to the control systems normally separate the timetable from the static information of the track system and from the dynamic information concerning the controlled train processes. In our prototypes we are trying to integrate these main information sets into one presentation where the operator simultaneously and without navigational problems can see e.g.: the actual and updated traffic plan, the track system, relevant train and passenger information, the dynamic development of the traffic etc.

Another question that has been addressed is how decision support systems can be incorporated into the control systems, and the implications with regard to the operators' interface, e.g. Hellström[8].

Evaluation of the user interfaces

The prototypes are being designed and evaluated in close co-operation between human factor experts and train dispatchers. The skills of the operators can only be fully utilised and incorporated into the design process if the dispatchers are part of the analysis and design team.
So far, the interface prototypes have been tested in evaluation sessions together with train dispatchers. The functionalities and presentations of the interface have been analysed following scenarios of different train control situations. The subjective comments from the dispatchers have been recorded and analysed.

As a part of the project, we will later use full-scale simulator systems, where prototypes of future control systems together with their interfaces can be tested and evaluated.

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 understand the actual work situations of the train dispatchers, we must base all analysis and design 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 has been preliminary presented elsewhere, e.g. Andersson[9].

In the future, also other principles and techniques then those used today may be considered, e.g. Neerincx[10]. Preliminary investigations have been made concerning how e.g. three-dimensional presentations could enhance the efficiency of the interface for the users.

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 is an important part of the research. The scenarios 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.

References


