

## **A SYSTEMS ANALYSIS APPROACH TO MODELLING TRAIN TRAFFIC CONTROL**

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### **Summary**

The rapid technical development of train traffic systems, together with increasing control demands, makes it necessary to develop new support systems for the train dispatchers. The dispatchers' support systems must have an appropriate functionality and a high usability.

In order to design such control systems, we need a model of the complete train traffic system. This model must fulfil a set of different requirements. Main requirements concern descriptions of the relations between the goals for the planning and control of the train traffic system, i.e. the control objectives, and the strategies and performance of the operators. The model must also describe the technical support systems, the information systems and the dispatchers' use of these.

A set of observation interviews have been performed, documented and analysed according to the described model structure. The analysis has resulted in a number of important conclusions for the design of a new generation of control support systems and of the operators' interfaces to these systems.

### **Key words**

Train traffic control, systems analysis, user interface design, decision support

**Train traffic control**

Planning and control of train traffic systems must in the future be based on partially new organisations and principles. Increasing demands, with regard to train speed and more optimal control, also makes it necessary to develop new support systems for the train dispatchers. Especially important in this respect is the functionality and the usability of the interface between the operators and the control systems. When new control systems are being developed this must be based on detailed knowledge about the involved work tasks and the requirements imposed by future organisation and technical support systems. Experiences from process control show the importance of designing the control systems to comply with human skills and capabilities and to be well adapted to the control tasks of the operators.

In earlier research we find few studies covering this problem area. Lenior [Lenior, 1993] has presented an approach to analysis of cognitive processes in the train dispatchers' work, with emphasis on the dispatchers' reasoning about control strategies. This is, however, not applied to design of control systems. In the European project ERTMS/ETCS [ETCS, 1996] the main focus is on the signalling to and from the trains and the technical and ergonomical design of the train operators' work environment, and not on the dispatchers' control systems. The purpose of this paper is primarily to describe a structure for modelling the control system together with the dispatchers' control and information handling tasks.

**A systems analysis approach**

Based on traditional conceptual models from systems analysis and control theory, we have adopted a framework for modelling complex and dynamic control structures.

It is well known that the control of complex and dynamic systems cause problems of different types for human controllers [Mackinnon and Wearing 1985], [Brehmer, 1992]. Complexity relates to the fact that many state variables, with varying time constants, are to be controlled simultaneously, that the goals are multidimensional with conflicting parts, that several consecutive decisions and series of actions, are needed to fulfil the goals etc. The term dynamic does not only relate to that the states of the system are varying with time, but also that the system change it's behaviour because of internal and external influences and that the system does not react immediately to control actions but the responses develop over time.

In order to *control* a system, four necessary requirements must be fulfilled:

*The goal condition*

The goals and objectives must be clear, completely describe the desired behaviour and understood by the operators, e. g. the train dispatchers.

*The model condition*

There must exist models of the system, including the operators' mental models of the system they are supposed to control. The model must describe and explain the controlled and uncontrolled behaviour of the system and the effect of control actions.

*The observability condition*

The observability criteria concern whether or not enough information for the control objectives can be obtained from observations of the system. This means that information systems must be able to supply the operators with all relevant information needed.

*The controllability condition*

The controllability criteria relate to if all system states can be controlled so that the objectives can be reached, i.e. if there exist enough possibilities for control actions.

While analysing real-time control of a time-critical system it is of importance to make a distinction between decision and action. Effects of decisions are hypothetical effects of what the operator aims at. Effects of control actions are effects of what the operator really was able to do of what was aimed at. If the operator is short of time, synchronise badly or discover something unexpected, pausing (if possible) and reconsidering the situation, is needed.

The model must also describe which disturbances of different nature and sources that may occur, and the operators' strategies for how these are treated and solved. Further more, the model should describe the structure, contents and use of the information systems as well as the organisational structure of the control situation, i.e. which different roles and competencies that are involved and the relations between these.

**Findings from the observation interviews**

In order to construct models of this kind, a set of observations and interviews of train dispatchers and other experts on train traffic control have been performed.

The observations and interviews have been documented and analysed according to the described model structure. Some important findings are e.g.:

*About goals*

- Unambiguous criteria for priority between trains, are missing. More obvious and operational goals are needed. Some conflicts between goals may be solved by analysis of how skilled operators make their priorities.
- Many different types of tasks need to be performed. Switching between different goals leads to high cognitive load. Operators need to make priorities between goals, based on uncertain information.

*About models*

- Operators, often refer to the necessity of long time experience, to be able to make good decisions fast, especially when severe disturbances occur.
- Creation of the operators' mental models are not always efficiently supported by the operator-process interface, e. g. dynamic visualisation of time related interrelations are missing. The operator-process interface should explicitly be designed to utilise learning about process dynamics while managing everyday situations.
- When operators make good decisions, they take into account information about a large number of specific details, probably unique for each situation.
- Most experiences indicate that learning by doing, training, under certain conditions, creates possibilities for operators to use "automated processes", on a low cognitive level. "Automated processes" are of importance for operators to be able to utilise good mental models, and strategies, while making decisions in time-critical tasks. The operator simply lack the "time to think". They more or less has to make decisions, and take actions, by identifying the situation and acting according to trained procedures, with some adjustments to the actual process status.
- Train dispatchers ask for exchange of knowledge and experiences between operators, and other professionals, related to performing train traffic control tasks. Their knowledge development seem to be too much dependent of the individual interest and initiative. Learning and exchange of knowledge ought to be more an integrated part of the work organisation. Train dispatchers also ask for education and more knowledge, about "interlocking units", automatic control algorithms, and control systems.

*About observability*

- Train position and speed are indicated with low precision and not continuously in real-time. This puts heavy restrictions on the way operators are able to perform their real-time control tasks. It implies tedious information gathering and a lot of information processing to indirectly deduce imprecise and time delayed values for these decisive variables.
- Train dispatchers need to manage large quantities of information about details that frequently change. Information needed in different decision situations can not be observed simultaneously. This leads to high cognitive load and may cause memory overload. The operators are being forced to unnecessary remembering information quantities during the work process. Furthermore, humans have problems with taking into account information which they can not directly observe.
- Much information exchange is performed by speech via e.g. telephone. This is often troublesome, time consuming and leads to unnecessary cognitive load. This is especially devastating when handling time-critical control tasks.

There exists other ways of transferring information, about the state and development of the process, that could facilitate the information handling.

- Disturbances are frequent and an important part of the work concerns disturbance handling. Information about deviations and anomalies are not handled efficiently. Information about variables indicating deviations that may cause problems and disturbances, and variables that help the operator to identify the status of the process, need to be visualised in a more obvious way.
- The operators can be better supported in their attempts to, as fast as possible, establish a view of how different alternative decisions and actions, propagate in the train traffic process. This could e. g. be made by visualising side-effects; time for arrival to decision points or stations; time to arrival; where connections to other trains burst; where conflicts occur.
- Operators need information that facilitates their ambition to reach better planning in advance. Some suggestions on information relevant to visualise could be:
  - train speed and position continuously in real-time,
  - actual and predicted deviations and attendant consequences, per decision situation, per controlled object, etc.
  - variables and side-effects that are approaching critical limits, and therefore demand decisions and actions, e. g. train position in time-table channel,
  - where conflicts, that demands to be solved, arise.
- Goals are time related. Process interrelations and effects of control actions, which are time discrete, can be time related and visualised in a more obvious way.
- Relevant information is often delayed, need to be collected manually or is missing. Information delays occur in several links in the communication chain. Humans have problems with interpreting and processing delayed information. It becomes difficult to relate cause with effect, and to make correct decisions about appropriate control actions and the timing of control actions.
- Functional and geographical mapping are sometimes missing. In track diagrams, static information about the track structure is segmented in a way that obstructs orientation, identification, and perception of the traffic flow.
- Information for planning (the train diagram) is static, and need to be manually redrawn. It is not integrated with the continuously updated information related to control decisions and actions (the track diagram).
- Line-specifications and train-specifications, i. e. information relevant to the control task, are not integrated in the track diagram. It need to be searched for in different systems and sources. This is time consuming and disturb the cognitive process used for the control task. Furthermore, humans are inclined to take more notice of information they can directly see.

- One basic question concern in what form the information should be presented to the operator, to minimise cognitive load during information gathering and information processing, prior to decision making. That is, what concepts do operators use when they think about the process, make judgements and decisions? Time, and time related interrelations seem to form the basis of operators' decisions.

#### *About controllability*

- The controllability of the train traffic process is limited by many restrictions: the process is continuous but can only be controlled by a few (in each specific situation) time discrete actions, (although it takes many control actions to handle the propagation of side effects); with an optimised timetable, the speed of the trains can not be increased, i. e. a lost minute can almost not be recovered.
- Operators need to transfer a lot of their control actions through speech, via e. g. telephone. This cause problems with uncertainty and timing. It might be an advantage if they could communicate their control actions through some computer supported system.
- Some control actions takes time do be executed and the feedback from the manoeuvring system is often delayed.
- Functional differences between different generations, and individuals, of "interlocking units" and other technical components, are today allowed to influence the operator-process interactions. The same action command may perform differently in different "interlocking units", and different command actions may be needed to perform the same action from different "interlocking units".

#### **Discussion - relevance for design of control system and user interfaces**

Our main research goals is the design of efficient user interfaces between the operators and the systems for control of future train traffic systems. In order to create a knowledge base for the design and development of these systems and interfaces, several different problem areas must be penetrated.

In two other publications [Sandblad et al., 1997, and Hellstrom et al., 1997] we have presented the role of human-computer research for design of the user interfaces, and algorithms and control systems for computer-aided train dispatching. The main focus is here to understand the cognitive processes involved in the control procedures, the strategies for control decisions and actions and the organisation of the total complex planning and control activities. The objectives are to develop systems and interfaces that allow the operators to perform efficiently, with a minimum of extra cognitive load imposed by the interface, and that leads to a good work environment.

Specification of scenarios for future train traffic system according to the described model structure will help us to identify necessary requirements for high utility and usability of the new control systems.

The purpose of the systems analysis approach to modelling of the control of train traffic presented here, is both to define a framework for analysis of the present control system and control activities, and for specification of tomorrow's. Within this framework we can describe the basic components and requirements concerning goals, models, observability and controllability. We can also describe the complexity of the control organisation and the information systems used in the control activities. Problems of different nature can be identified and hypotheses for solutions can be specified.

Future research activities will include further field studies in order to model details of the operators strategies, decisions, actions and use of information. Prototypes of new parts of control systems and their interfaces will be designed, implemented, tested in a simulated environment and evaluated. This will be facilitated by the model structure described here, together with the human-system interaction knowledge base discussed above.

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