New control strategies and user interfaces for train traffic control

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Abstract

The developing situation with higher speed, more frequent traffic, and many competing train traffic operators, requires new principles and technical solutions for more efficient train traffic control. Control actions are today often mainly focused on controlling the technical parts of the infrastructure, signals etc. We have tried to shift the control paradigm from today's more technology oriented into a more traffic strategy oriented one. This is done by replacing the more traditional control tasks by real-time planning tasks. The new train traffic control tasks will be to continuously, in real-time, produce a functional and efficient traffic plan. Whenever a disturbance can be identified, this must be early detected by the planner and result in the specification of a new functional plan. The plan is executed, by automated systems or by human dispatchers. The user interfaces of the control systems must support this new planning paradigm. Important requirements concern e.g. cognitive load and automated cognitive processes cognitive work environment problems, human error performance and dynamic decision processes. The new interfaces are designed to integrate all decision relevant information into one unified interface.

Another problem that has been addressed is the communication between the train traffic control centres and the train drivers. We see a need to further develop this communication, in order to make the train drivers more aware of the present traffic situation in the region, and at the same time transfer decision relevant information from the trains to the control centres.

1 Introduction

Tomorrow's train traffic, with higher speed, more frequent traffic, and many independent traffic operators, requires new principles and technical solutions for efficient train traffic control.

Today's control systems are often designed to support the operator's possibilities to react on alarms and disturbances and to solve problems and conflicts that occur. However, in order to perform efficiently, operators should be able to follow the dynamic development of the traffic system over time and prevent disturbances. We call this control strategy *control by awareness* compared to the more passive strategy *control by exception* [2,3,4]. In order to achieve this, one main objectives with this project has been to shift the control paradigm from low level technical control tasks into higher level traffic planning tasks. This is done by replacing the more traditional control tasks by real-time re-planning tasks.

The new real-time traffic planning tasks must be supported by efficient user interfaces that allows the planners to be continuously updated and able to evaluate future traffic conflicts so that these can be taken care of in time.

2 Methods

The results from this project is based on a very detailed description and analysis of how train traffic is controlled today, the mental models of the dispatchers and the strategies they use for decisions and control actions. The work consisted of mainly the following steps:

- Observations and interviews with dispatchers and other professionals at the traffic control centres. Analysis of the findings.
- Seminars with experienced and responsible professionals from the national rail and traffic control administrations. Here the visions and restrictions for future development of control systems was specified.
- Iterative specifications and evaluations with the help of a working group consisting of experienced traffic control professionals.
- Tests and evaluations in a laboratory setting using a train traffic simulator system.

3 A new traffic control strategy

3.1 Today's control system

In Sweden, train traffic is today managed by eight centres for "centralised traffic control", se figure 1. Train dispatchers perform traffic re-planning by drawing time table lines on a paper based time-distance graph. The planning of track usage is merely a mental process and the plan need to be remembered by the dispatcher. Dynamic information about process status is presented in track diagrams on large distant panels and/or on several computer screens close to the

individual workplace. Dispatchers observe train movements and control train routes by remote blocking. Track usage is controlled either by ordering automatic functions or by directly executing interlocking routes for each station. Automatic functions are either implemented locally, in the centralised control systems or as a separate automatic control system. Together with the human traffic controller there are up to four levels of more or less autonomous automatic functions that try to solve partially the same problems. Interactions between these levels of decision making and execution are complex. During disturbances, the interactions tend to be too complicated to produce predictable traffic solutions. The automatic support systems are not predictable enough to the dispatchers, because of their internal complexity. To overcome these difficulties, the dispatchers are then forced to take full control by inhibiting all automatic functions in the "disturbed" area and solve the disturbed situation "manually". Intense manual control and oral communication will result in high workload. The result is that the dispatcher is focused on finding working solutions and cannot have the ambition to optimise the traffic. There simply is not enough time available for optimal planning.

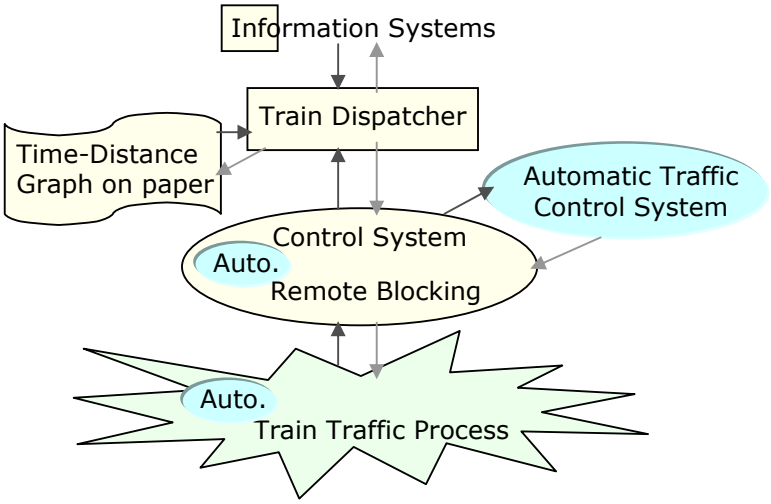

Figure 1. The structure of today's traffic control system in Sweden

3.2 The new proposed control strategy

The main problems of today's control strategy and system, as far as we have identified them in our research, are:

- sub-optimisation caused by lack of overview in the time/distance domain
- fragmented information as the control system is implemented as several

separate information systems

- lack of precision in data, e.g. concerning exact train position and speed; departure time of trains
- time and event dependent complexity caused by autonomous automatic functions
- interlocking routes have train-id as prerequisite
- time consuming phone or radio communication with train drivers and others

This means that the dispatchers will expire a lack of efficient support when this is most needed, i.e. during severe disturbances. In order to change this, so that the control system better can support continuous awareness, early detection of disturbances and re-planning decisions, we have introduced some new concepts and strategies. The main idea is illustrated in figure 2 below.

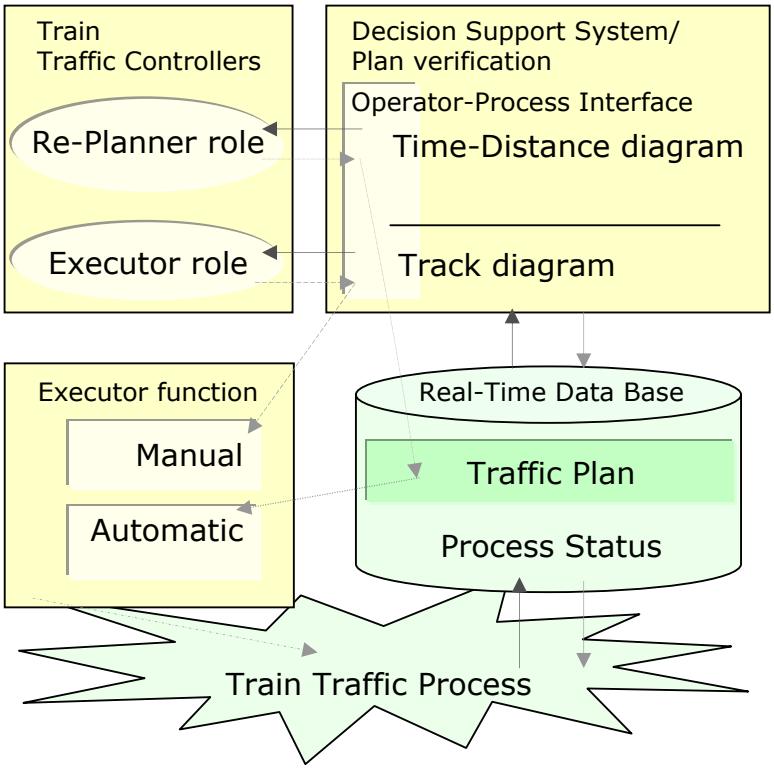

Figure 2. The conceptual structure of the new proposed control strategy.

Control is mainly performed through a continuous real-time re-planning. This means that the main parts of the traffic control tasks are transformed into re-

planning tasks. These operative tasks are performed by the traffic planner (re-planner), based on the information extracted from the user interface, and documented as the traffic plan in a real-time database. The plan can normally be automatically executed by efficient automatic functions (see below), as long as not severe infrastructure malfunctions hinders this. When such malfunctions occur, there is a need for manual execution to solve the disturbed situation so that the traffic can be returned to normal, and again controlled by the re-planning professionals. We here can identify two different but coordinated roles: the planner (re-planer) and the manual executor. These two roles can sometimes be taken care of by the same individuals that change between the roles when required, sometimes by different individuals that cooperate. The following functionality of the automatic execution and support systems must be at hand:

- Automatic execution of the continuously updated traffic plan.
- Automatic stop of execution when needed.
- Automatic test of planned train way in due time, as early as possible, in order to test the feasibility of the actual plan.
- Automatic interlocking of tested train way according to plan, and train signalling orders.
- Automatic functions are made predictable, easy to understand and usable also during severe disturbances.
- Automatic functions are for execution, not for changing plans.
- Automatic functions *does not* autonomously change track usage or train order.
- Automatic and continuous information exchange between train and control centre, e.g. estimated time of arrival to defined positions, "if you arrive to early you will be late" because the train will meet speed restrictions from the train protection system.

4 Development of user interfaces and decision support systems

Prototypes of new user interfaces that support the new control strategy have been designed, implemented and preliminary tested in a laboratory environment. The interfaces are designed to integrate all decision relevant information into one unified interface and to support continuous awareness of the dynamic development of the traffic process and early detection of upcoming conflicts and disturbances. The user interfaces to the control systems must support the proposed "control by re-planning" paradigm. Knowledge about human-computer interaction in complex and dynamic work situations also gives a framework for specification of the interfaces [2]. Important such requirements concern e.g. cognitive load and automated cognitive processes, limitations in human memory capacity, cognitive work environment problems, human error performance and dynamic decision processes.

The train traffic process is a complex system of interacting parts. Events and continuous changes propagate with time. Traffic plans must make use of

available operational capacity, and the sensitivity with respect to deviations in time and track usage is high. Even small deviations tend to propagate. Larger deviations lead to loss in transport capacity. Traffic controller's most important method to manage the process is to maintain overview and system awareness and plan the traffic so that available resources are optimally utilised. To meet expected and unexpected events, the traffic controller need to have available – and simultaneously visible – a large amount of data. To manage, plan and control the traffic, the controller need to know what resources are available at each time interval, and what are their attributes and actual states. Most important is track usage and train characteristics. The user interface needs to show the data train controllers need to decide what actions to take. All relevant data is visualised simultaneously. Information is grouped in a structure that corresponds to train controllers' mental models of track system and traffic processes. Data is shown in fixed positions so that it forms a well-known pattern that can be interpreted by the traffic controller with minimal mental workload. The structure of the user interface is shown in figure 3 and an example of the final design in figure 4.

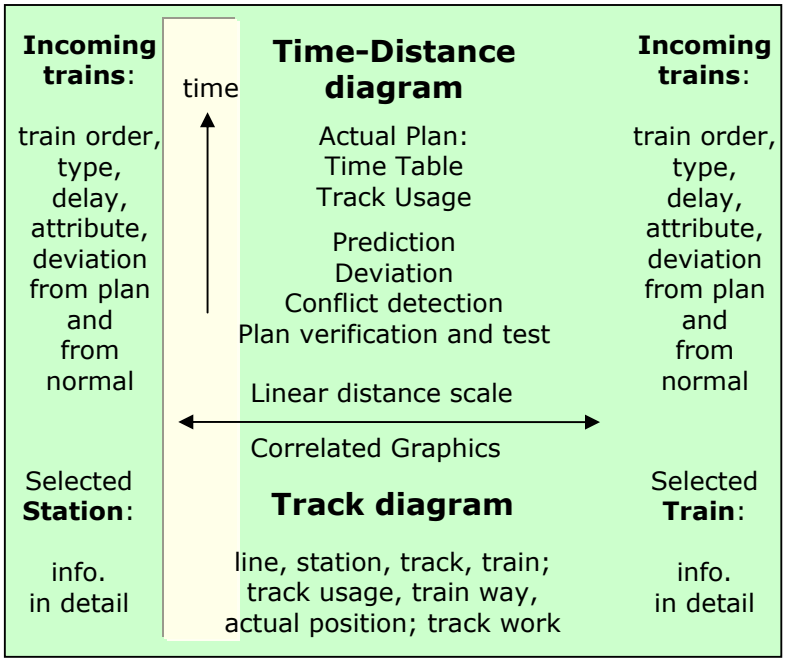

Figure 3. The information structure of the new user interface. The central segment is divided into two parts, the track diagram with its detailed information about track structure, usage, function etc., and the dynamic planning part based on a time-distance diagram. Incoming trains and their characteristics are shown to the left and the right.

Figure 4. The detailed design of the main part of the new user interface, with the track diagram (bottom) and the dynamic planning graph (top). Incoming trains are shown at their position in time. Identified conflicts are indicated in the graph to support early detection and continuous re-planning tasks.

5 Communication between control centres and train drivers

As a consequence of the new strategies for traffic control proposed in this paper, there is a need to improve the communication between train drivers and the dispatchers in the traffic control centres. In order to perform efficiently, the traffic planners need more precise and updated information from the train drivers, e.g. concerning expected delays, technical problems etc. On the other hand, the train drivers should also be made more aware of the present traffic situation, so that they can plan their driving better. This kind of information is needed to fulfil the new planning goals and it must be integrated into the user interfaces of both the train drivers and the traffic planners. Technical channels for communication must also be further developed in order to implement the proposed solutions.

5.1 Information *from* the train drivers

The main purpose is to give the traffic controllers access to decision relevant information as early as possible, and since some of this information only can be obtained from the train drivers, there is a need for direct transfer to the traffic

control centers. Today much of the communication between train drivers and traffic controllers is spoken, via telephone or radio. This is a problem, because when more complex disturbances occur, there is very little time for oral discussions. It would be more efficient if such information was coded and directly integrated into the user interface of the traffic controllers.

This will not be further discussed in detail here, but some examples of what we have found to be of high importance are:

- Weather related information, fog, low adhesion etc.
- Malfunctions of the infrastructure, train protection system, signal system etc.
- Reduced speed caused by technical error in the train
- Train is standing still, expected time until start
- Expected delayed departure in minutes

5.2 Information *to* the train drivers

In addition to the information environment specified in ETCS [x], we see a need for additional information to the train drivers. The purpose of this information is to make the train drivers more aware of the surrounding traffic and to give them better possibilities to plan their driving. If they are provided with information about the surrounding traffic, the will be able to understand the decision-making of the traffic controllers and in this way minimize the need for spoken conversation. When they see how other trains behave, they will also be able to plan their own driving with respect to the developing traffic situation. These ideas have been further specified and presented in e.g [9].

6 Discussion

The proposed new control strategy has a potential to better support the traffic controller's ability to handle continuous re-planning, with the goal to always have a functional traffic plan at hand. This plan can be automatically executed except when technical malfunctions hinders this. The user interface, with its planning view, can support early detection of upcoming conflicts, identify possible re-planning alternatives and their predicted effects.

The feasibility of the proposed new strategies and systems have been tested and evaluated in restricted simulated laboratory experiments. In order to better estimate the benefits and possible problems of the new systems, we must develop operative demonstrators that can be tested in full scale. This will take long time to develop and implement, but this is planned for the coming years.

7 Acknowledgement

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