Control strategies for managing train traffic
Difficulties today and solutions for the future

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Abstract
In 1996, on initiative from the Swedish National Rail Administration, the department of Human-Computer Interaction at the institute for Information Technology, Uppsala University initiated a research project with the objective to identify the difficulties present in today's train traffic control today and to find solutions to those problems, if possible.

This paper describes the strategy used to control train traffic in Sweden today. Problems and difficulties inherited from the use of the current control strategies and systems are presented. With the goal to solve these problems, and aid the human operator in their work, solutions for new principles for control and a new control strategy are proposed – *control by re-planning*. The proposed control strategy is designed to support the train dispatcher to work in a more preventive manner and thereby avoiding potential disturbances in traffic when possible. The focus of control tasks will be shifted from controlling infrastructure on a technical level to focus more on a higher level of controlling the traffic flow through re-planning tasks. The new control strategy in combination with a new approach to automation, higher availability of decision relevant information and new graphical user interfaces addresses many of the issues and problems found in the control environment today.

Contents

1 Introduction

This paper describes, from a Human Computer Interaction point of view, the strategy used to control train traffic in Sweden today. Problems and difficulties with current control systems are discussed. With the aim to solve these problems, and aid the human operator in their work, a new control strategy is proposed. Chapter 2 briefly presents related international research. In chapter 3 theories and our research methods are presented. Chapter 4 describes today’s train traffic control principles and systems. Chapter 5 contains a description of the new proposed control strategy and the most important aspects, including consequences of the proposed solutions in terms of technological support, automation and decision support.

The Department of Human Computer Interaction at the Institute for Information Technology, Uppsala University, has together with the Swedish National Rail Administration performed research on train traffic control since 1996. The Future Train Traffic Control (FTTC) research project’s goal is to analyze and acquire in-depth knowledge about how train traffic is controlled today but also to investigate what is needed for efficient traffic control in the future.

In Sweden there are 8148 kilometers of single track line and 1734 kilometers of double or multiple track lines. The Swedish National Rail Administration is responsible for the operations of signaling, construction and maintenance of the railway system. There are several train companies running traffic on the railway, e.g. SJ, Connex, Green Cargo and Tågkompaniet. The traffic is mixed with both passenger trains and freight transportation. The Swedish railway system is geographically divided into eight control areas or regions. Each area is controlled from a traffic control centre. At the traffic control centre, information about the traffic process status is presented in track diagrams on large distant panels and/or on several regular computer screens. Train dispatchers monitor the train movements and control train routes by automatic or manual remote blocking. Track usage is controlled either by the use of automates or by manually executing interlocking routes for each station. Today's control systems are often designed to support the operator's possibilities to react on, and to solve disturbances and conflicts when they occur. In order to meet increasing future demands, new principles and technical solutions are required for an efficient train traffic control. Train dispatchers should be able to follow the dynamic development of the traffic system over time and prevent disturbances.

One part of the research concern strategies for the operative traffic control; in particular with the focus to change the work towards pro-active re-planning of traffic flows rather than the more reactive, technically oriented way of control used today. Another part of the project concern design and development of new user interfaces for train traffic control professionals' interfaces that better support early detection of potential problem and at the same time provides all decision relevant information. A third focus is on the resulting work environment for the professional workers. I.e. train dispatchers. Some additional research areas within the FTTC project concern communication between train dispatchers and their environment, e.g. train drivers.

1.1 Background

The Swedish National Rail Administration approached the Human-Computer Interaction department of Uppsala University with an interesting research problem. They had experienced that their knowledge about train traffic control work was not satisfactory for creating requirement specifications when planning for future traffic control systems. The Future Train Traffic Control research project started in 1996. Initially the projects aim was to analyze and gather knowledge, from a human factors point of view, about the work of controlling train traffic in Sweden. Later the research objective included the aim of finding solutions to the problems inherited from the current control systems and approach to controlling train traffic. The main objective of this research is to investigate how systems could be designed to better support the human's capacity and capabilities to control train traffic in an efficient way.

Algorithms for optimization of train traffic plans have been studied within the scope of this research. In consideration to the fact that it today is not possible to keep track of all factors that effect the train traffic in disturbed situations (Hellström, 1998), the FFTC project has chosen to proceed the research in the direction of improving support to the human operator, rather than attempting to use 'optimizing algorithms' for re-planning tasks.

2 Related research

Most of the research performed on train traffic control has had focus on optimizing train traffic with the aid of algorithms and automation. Research with a human factors perspective on train traffic control is unfortunately very limited.

Lenior (1993) studied cognitive processes with Dutch train traffic dispatchers (signalers) and experienced that they tend not to plan ahead because of both the complexity of the network and the risk of change. Roth (1999) performed Cognitive Task Analysis on train dispatchers in USA and found that they did plan ahead. Lee (2004) presents a computer based time-distance graph for train dispatchers and suggests that a similar tool might be useful in the train dispatching work. Her work for the Federal Railroad Administration in USA has primarily concerned the development of a computerized aid for railroad traffic planning and not for dispatching. In the project there has been a user centered approach. Makkinga (2004) reports on research regarding a way of train traffic control similar to the one proposed in the FTTC project. He proposes a user interface which support pro-active planning 20-30 minutes ahead of time. The most interesting part of this research from the FTTC point of view is the inclusion of track-occupancy graphs for each station into the larger time distance graph.

3 Methods

We have found it to be very important and useful to base our descriptions and analysis of today's control principles and systems as well as formulation of requirements and evaluation of new control principles and systems on a conceptual model. This model, the goal, model, observability and controllability model (GMOC), has its roots in Automatic Control but is also influenced by Control Theory as defined and used within psychology. In Automatic Control it is possible to define pure mathematical requirements for control of a dynamic process based on goals, model, observability and controllability. In Control Theory within psychology the term actions is often used instead of controllability. The research in psychology is often focused on understanding how humans formulate goals and mental models as a function of observability and possibilities for actions as properties of the controlled system. One main result of this research is the necessity of supporting the human decision-making process with dynamic information.

3.1 The goal, model, observability, controllability model

To achieve efficient control of systems in general, there are a number of things that need to be considered. The operator controlling the system should have clear goals and an accurate mental model of how the entire system works under various conditions. The system should provide the operator with good observability as to the systems past, current and predicted future status. Adequate possibilities to interact with and control the system (controllability) are also crucial according to Andersson, Sandblad, Hellström, Frej & Gideon (1997).

Based on this we have developed a conceptual framework for describing, analysing and designing control of complex dynamic systems, the GMOC model.

Goal

The goal is a specification of the objectives of the control process, what we want to achieve. Goals can be formal or informal, explicit or implicit, individual and collective, simple or complex, the can change over time and they can be conflicting. The goal is a property of the operator and the organization.

Model

With a model we here mean the mental model of the individual operator, i.e. the operators understanding of the process. Mental models are often very complex, difficult to describe and analyse and can not easily be verbalised by the operator herself. The mental model is used to understand the behaviour of the process, make predictions and to decide on actions. The model is a property of the operator. Operators controlling the same process can have different mental models.

Observability

Observability is a property of the process and especially of the control system and its user interface. The observability is what the operator is allowed to observe through the interface. This is important for the operator’s possibilities to understand what is going on and to identify the present state of the process. It is also essential for the operator’s possibilities to develop the mental model. Without enough observations the development of a mental model is restricted.

Controllability

Controllability is a property of the control system and defines what and how the operator can effectuate control actions. The process can only be reached via what is possible to control. In this way the controllability also has an effect on the possibilities to develop a mental model. The dynamic relations between control actions and observed changes in the behaviour of the process, supports the understanding of the process.

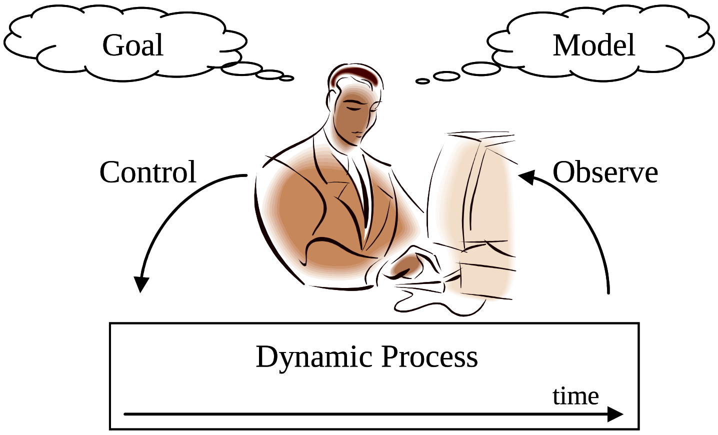

Figure 1. A conceptual model, GMOC – goal, model, observablility, controllability

To be able to control a dynamic process it is necessary to achieve suitable goals, mental models, observability and controllability. A dynamic process is a process where the state can change spontaneously over time and where control actions do not only affect the process behaviour momentary but also in the future.

To be able to control the process in a satisfactory way these four requirements must be fulfilled: goal, model, observability and controllability. This is true both for the automatic control systems, for the human operator and for the organization as a whole. In our conceptual framework we have also included the four basic requirements with some organizational aspects. The total control system consists of different operators with different roles and responsibilities. They can have different goals and models and supplied with different possibilities concerning observation and control. They can communicate and cooperate according to the existing work organization. The result is a very complex structure of cooperating individuals with different roles and tasks with the common goal to fulfill the complete dynamic control assignment.

3.2 A user centered development model

We have used a user centered model for our research and development work. The involvement of real users in all phases of the work is necessary.

Systems design is often understood as the complete software development process, but the user centered or participatory design process described here finishes with descriptions of future work accompanied by design sketches and interactive prototypes.

Designing new systems adapted to organizations and work in change is a challenge. Through our experience from design work in a number of applied projects a participatory design process has been developed (Olsson, Johansson, Gulliksen & Sandblad 2005). Bødker & Iversen (2002) has argued that designers need time for reflection to develop their participatory work practices. The design process described here includes time for reflection on current work practices, on organization as well as work re-design and development of future support systems. Furthermore, the process requires a new perspective on workers and respect for their skills, in line with Bannon’s (1991) description of workers in terms of active and controlling people with underlying values and motivation in the work setting. The workers are the central actors in working life; consequently, we argue that they should have a key position in development of new support systems that are to become their tools and a part of their work practice.

3.2.1 Description and analysis of the existing work procedures

The initial phase of the project produced a detailed analysis and description of the present work within the train traffic control organization. This was performed as a set of observation interviews (or contextual inquiries). The interviews were transcribed and used for analysis of how dispatchers reason about their work today, with a focus on aspects related to goal, mental models, observability and controllability. The goal for this was to give the external project members a chance to gain more insight into the actual work processes, but also to make a map of the basic cognitive models and control strategies of the train dispatchers.

3.2.2 Workshops

The project was then carried out by an active work group consisting of six experiences dispatchers together with usability and design experts, i.e. the researchers. The group was intact and active for several years, with regular one-day meetings every month. During the time gap between group meetings, the design experts analyzed and prepared information and prototypes and the dispatchers further developed and evaluated the ideas about future work processes and technical support systems.

The work in the project group has covered aspects such as problems in present work situation, visions and prerequisites for future organization and work processes, details in future organization and solutions such as work organization, room design, control strategies, information systems, decision support, user interfaces etc. We will only describe some specific results that probably would not have been reached without this work model.

In the beginning, the work focused on improving the fragmented user interfaces by information integration and enhanced visualization. During this work, and based on the earlier mapping of cognitive strategies, we understood that the information the dispatchers really used in the control process was not included in the present system. They based their decisions on dynamic prognoses of the trains' behavior, but the available information was old static data about occupation of track segments. They had to mentally create the information they needed from available information, something that was extremely cognitive demanding and required years of training. When we proposed new systems, where all decision relevant information was simultaneously presented, they could understand the present dynamic traffic situation much faster and save their cognitive capacity for advanced problem solving.

Today the control tasks are completely focused on the control of the technical infrastructure, and we started to develop more efficient systems to support such tasks. When we together analyzed how they were using the proposed new systems, we slowly realized that they actually did not aim at controlling the technical infrastructure, even if this was what the control system allowed. The ultimate goal was to define traffic plans for the trains which were optimal for each train in the given context. This indicated that what they really needed was to be able to identify upcoming conflicts, to find optimal solutions by real time re-planning of each trains traffic plan, and to execute these plans. When we now radically changed the information presentation and included support for re-planning in the user interface, we found that in most cases the plan could also easily be automatically executed. In this way we had created a completely new paradigm for train traffic control: control by re-planning in real time. The train dispatchers are in continuous control of the dynamic development of the traffic process, they are supported to detect upcoming conflicts and disturbances early, they can re-plan each train to obtain an optimal traffic plan and this plan is in time automatically executed. The focus on technical control of the infrastructure has been shifted into a planning process at a higher, more traffic oriented level.

3.2.3 Prototyping

We recommend active involvement of users in the design process, which also involves prototyping, and creation of mock-ups. However, we do not recommend that users spend time on development of prototypes because such practices turn out to be ineffective. Even though users are professionals in terms of their computer support systems, in our experience they are seldom knowledgeable in design tools and programming languages. The threshold to acquire even basic knowledge in this area is high, and users who have to spend time and effort on learning design tools may lose focus on their profession and the possibilities for development and increased skill in that area. In our research, designers have therefore been responsible for visualization and implementation of the design, but it is carried out in close co-operation with users.

The prototype development and evaluation has been a continuous ongoing iterative process, where successive prototypes have been developed according to the ideas from the work group. These prototypes have been implemented in an experimental test environment (Sandblad et al. 2000). Through experiments performed by experienced dispatchers we have been able to test and evaluate a number of different prototypes.

4 Managing train traffic today

The operative traffic control today is performed by train dispatchers. The work tasks performed provides many and complex difficulties. Train traffic on many railway lines are close to maximum of the available traffic capacity. Mixed traffic has introduced increasing differences in train characteristics such as speeds, acceleration, length and weight etc. Demands for special transportations are also increasing and require separate handling from a traffic control perspective. Conditions for train traffic control is based on technology and rules that have gradually changed over a long period of time. The result is that work tasks require that train dispatchers must have detailed knowledge, and be able to use that knowledge, to control train traffic efficiently during disturbed situations. This knowledge about details is also important for optimizing train traffic during more normal conditions.

The train traffic process encompasses the entire infrastructure that the train traffic system consists of, including signals, signaling boxes, signaling safety systems (ATP/ATC), traffic information, the trains running on the railroad and humans that in some way affect the process etc.

The traffic control system keeps track of the traffic process state and conveys control actions to the traffic process either by the aid of automates or by manual control commands performed by the train dispatcher. The control system supports several functions, where the most central is reserving train routes by remote blocking. Train dispatchers interact with the train traffic control system through a user interface. A track layout is visualized in a user interface, usually implemented on a combination of large distant display panel and smaller computer screens, or solely on computer screens at workstations. Another important tool during planning and control tasks is a paper based time-distance graph (a graphical timetable). This is used to plan for upcoming traffic changes and documenting how traffic actually was carried out. It is also used for planning track maintenance and incorporating additional information about important events or restrictions. The timetable graph is not used for planning or documentation of which specific tracks that should be, or have been used by the trains. It is also important to realize that the system is not aware of the plans that the train dispatcher makes in the paper based graph and that automates may act against the dispatchers plan. There are different kinds of automates in use, local, central and traffic plan based automates. Besides this the train dispatcher also uses a number of information systems to acquire and document necessary information and also to communicate with the surrounding environment.

Train dispatchers perform work tasks through interaction with the traffic control system, surrounding information systems and their environment. The work is very complex due to the dynamic properties of what is controlled. Control actions are implemented either through alphanumeric keyboards or with the aid of a computer-mouse or a combination of those two ways of interaction.

The train dispatcher also communicates and interacts with a number of actors, such as train drivers, track workers, traffic informants, electrical and track management responsible and several train operating companies. More detailed aspects of this communication, with focus on interaction with train drivers are available in the project report, FTTS (2000)

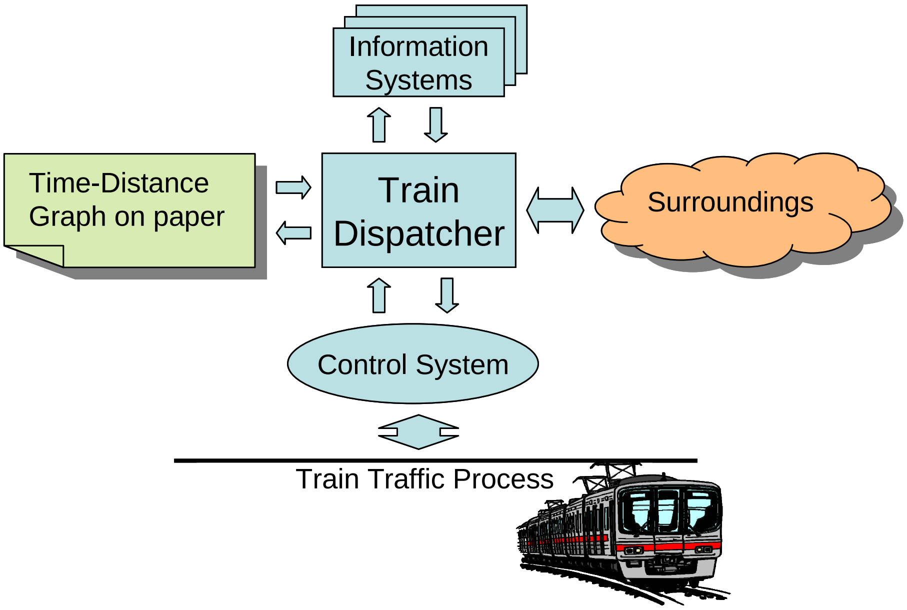

Figure 2. Basic control strategy for the Swedish train traffic control of today.

4.1 Control by exception

Control systems in use today are poorly designed to support pro-active work. Instead of having main focus on prevention of potential conflicts train dispatchers are often restricted to solving problems as they occur. When controlling train traffic today, there is a high degree of focus on managing the technology in order to control the traffic. So the focus is on managing the technology and infrastructure and not foremost on management of traffic and traffic flows. The reasons for this are several. Control commands performed by the train dispatcher to the control system are on a technical level. Presentation of information lacks dynamic information, information about the outcome of previous control measures taken and the potential future development of the traffic in a given situation. The design of the train traffic control system requires that the train dispatcher maintains detailed knowledge about technical aspects of both the control system as well as the infrastructure in order to be able to use available resources to solve disturbances.

4.2 Problems with the current way of controlling traffic

Controlling train traffic today is a complex and highly dynamic task. The system to be controlled is complex because there are several different codependant components affecting each other. The train dispatcher has to interact and cooperate with other people within and outside of the control centre that also affects the traffic process. Difficulties presented below are organized according to the *GMOC* model.

Goal

The goals which an operator are striving to achieve are often complex and only in part explicitly formulated. Train dispatchers construct their own operative goals based on experiences acquired. E.g. goals include minimizing delays, not delaying trains that are on time, achieving robustness in traffic solutions so that further complications does not evolve, prioritize important trains etc. More detailed information i.e. about train operating companies' desired prioritization of trains would aid the train dispatcher to maintain more specific goals.

Model

Acquiring information is cognitively demanding and in many cases unnecessarily difficult. Much of the information needed to sufficiently comprehend the current situation is not available. Instead train dispatchers' based on their experience create their own knowledge of what they think the situation is, often successfully, but at times with poor results. This process of constructing knowledge increases cognitive workload and removes focus and capacity from the real task of assessing the situation and deciding on suitable measures. Research and experience show that human abilities to maintain efficient control under such circumstances are limited.

To be able to control train traffic efficiently it is important to have extensive knowledge about the infrastructure, signaling systems, etc. and their often very complex functionality, the short and long-term effects of taken control measures etc. Graphical user interfaces in use today don't show all information required in a clear unified way, train dispatcher must spend much time and effort into creating, adding pieces to the puzzle to gain the information needed. This effort is not necessarily a conscious process, but it affects the overall efficiency in work. Due to the complexity and lack of suitable information it also takes a unnecessary long time to get proficient at the work (typically several years).

Observeability

Complex situations and disturbances are difficult to grasp. When a severe disturbance has occurred it is important to quickly be able to understand what happened and what the effects might be. Often the information received by the train dispatcher are out dated and in poor detail. (e.g. poor precision in positioning and speed of trains.) This makes it more difficult to grasp the current situation. Information is often delayed. There are numerous time delays in information supply. This induces two types of problems. If the time delays are not known or vary in length it may be difficult to interpret the information. If the information arrives too late it might be too late to perform the control measures that would have been the most efficient ones. There is a lack of information and it can be unnecessarily difficult for a train dispatcher to obtain information about surrounding traffic that will affect his/her control area, especially if the neighboring control area is controlled from another train traffic control centre.

Lack of overview in the time-distance domain makes the train dispatcher to focus on current situation and sub-optimizing solutions instead of achieving the overall best traffic solutions. It is difficult to observe the current state of automates and to ascertain if the automates will react and perform control actions in accordance to the wishes of the train dispatcher.

The graphical user interfaces used are poorly integrated and designed. Today the information used to make decisions is separated into different systems with different user interfaces. Information is thereby divided and scattered over several systems where the information is not coded in uniform or easily recognizable ways. The fact that the user interfaces used today does not provide all decision relevant information in an easy to obtain manner makes the decision making process more complex, time-consuming and cognitively demanding than it would have to be.

Controllability

The train traffic process is highly dynamic, it spontaneously develops over time. Control measures can only be applied at certain points in time, such as before or after a train passes a certain point. The train dispatcher always has to be aware of that and adjust the work tasks according to when control actions can and should be made. Control measures don’t always take effect right away and may influence traffic over some time to come. To understand the situation at a given moment the operator must understand the development that led to the current state, which external disturbances that might occur, which earlier measures has been made or should be taken when and how etc. The term ‘*automate*’ within the traffic control context commonly refers to a function that based on static and dynamic criteria decide what control measures that should be done and then performs those control actions in the same sequence. Automates in use today can change the order of trains and also the track usage. What automates should perform is chosen by the operator from a number of pre-defined alternatives. The control actions taken by automate can then be affected by the exact time when a train passes a certain trigger point. *Decision* and *execution* is performed in the same sequence. Because of this automates used today is not practical to use during disturbances since the situation may change quickly and accurate information about the process often are insecure or missing. It is also difficult to control what automates should perform, control options are in practice often restricted to the choice of using or not using automates.

During traffic with low or none disturbances it is usually relatively easy to manage minor problems. However, the “normal” condition of the traffic process is that deviations and disturbances are present. As a consequence to the reasons given above it is difficult to manage disturbed traffic in an optimal way and instead the train dispatcher often has to settle for merely working solutions to disturbances.

4.3 Need for new ways to manage train traffic

The main argument for reconsidering the work of controlling train traffic as it is today is the difficulties discussed above. The goal is to design a system that is easier to use, by implementing a control system that better supports the cognitive processes of information gathering, analysis, decision making and interaction. Train traffic development today also provides arguments for considering new ways of control. The traffic is increasing; there are more train operators acting on the same infrastructure, more and faster trains and increasing demands for punctuality. In connection with the current development of new technology (ETCS etc) towards new information and user interfaces to the train driver within EU there is also the opportunity to further develop the cooperation between the train driver and the train dispatcher. Technical advances also provide opportunities to improve both control strategies and the technology used to perform traffic control. I.e. exact position and speed of trains, automatic information transference between the train and the traffic control system.

Building new infrastructure is very expensive. If it is possible to better utilize the existing and future infrastructure through a more effective traffic control system much is gained.

5 Managing train traffic in the future, a proposed strategy

We call the proposed proactive control strategy, *control by re-planning*. This can be compared to the more reactive strategy of today. One main objective during this research has been to shift the control paradigm from low-level technical control tasks into higher-level traffic re-planning tasks. Re-planning tasks must be supported by efficient user interfaces that allow the train dispatcher to be continuously updated and able to evaluate future traffic conflicts so that these can be taken care of in time. Improving the train traffic control can be a very cost efficient way to improve utilization of existing and future infrastructure.

5.1 Objectives for the new control principles

The purpose with the proposed control strategy is to achieve control on a higher level, allowing the operator to focus on traffic rather than on how to manage technically oriented control commands. This is done by moving focus from managing the technical conditions for how the trains are able to run, into updating and maintaining a functional plan for how the traffic should run. This will allow the operator to concentrate more on what will happen in the near future and to identify and solve potential conflicts before they are manifested. In this way, some disturbances may be prevented completely instead of spending time on solving problems once they have occurred. One goal with the proposed control strategy is to improve the process's predictability. Presenting detailed and clear information helps in understanding and predicting what will happen in the future, so that no unnecessary surprises overthrow the operators' traffic plan. With improved traffic control, available resources and capacities can be used more efficiently. Since disturbances are common, it is also important make sure that traffic can be controlled as efficiently as possible in particular when disturbances in traffic have occurred.

5.2 Control by re-planning

The aim of *control by re-planning* is to provide the train dispatcher with a control strategy which better support a pro-active way of work. Focus will be shifted from controlling traffic on a technical level into a more traffic oriented level. *Control by re-planning* in combination with a new approach to automation, enhanced availability, higher precision and presentation of decision relevant information through well designed graphical user interface will improve usability, utility and effectiveness in use of new traffic control systems. *Re-planning* is the activity of in real time updating an obsolete traffic plan. As long as the plan is maintained, control commands can be automatically issued by an *automatic execution function* in accordance to the valid traffic plan. In some sense the train dispatcher *re-programs* what the automatic execution function will perform just by re-planning and updating the traffic plan.

5.2.1 A traffic plan

The term *traffic plan* is here used to describe a timetable schedule which also incorporates planned track usage for each object or event occupying a track resource. A traffic plan contains information on how traffic and related activities should be carried out in the time and space domain. The most important property of the traffic plan is in which order each resource-user is planned to use a certain track resource. Typically a resource user is a train, but it may just as well be a construction or maintenance work.

To execute the traffic plan, only the current plan is necessary. For reasons of documentation and re-planning, also outdated information such as original traffic plans and all changes made to the original plans may be of interest.

5.2.1.1 Shared knowledge between the human and the control system

One major benefit of always having a complete updated traffic plan is that it can be shared between the human(s) in control and the control system. Having an in common plan for how traffic will be executed, opens up the possibility for improving the way automation is used, making it to execute what the human have explicitly decided and thereby minimize the risk of automation surprises. Also the fact that the updated traffic plan is available through a computer system provide us with the opportunity to automatically share the traffic plan with other stakeholders such as traffic informants or to train dispatchers in control of surrounding traffic areas.

5.2.2 Re-planning, changing the traffic plan

Re-planning is the activity of changing and updating the current traffic plan. The aim of re-planning is to turn a traffic plan with conflicts or inefficient traffic into a better more optimized plan. The train dispatcher is always in full control and decides which track a train can use, in which order trains may use a certain track resource and at which point of time a train at the earliest may pass specified signals (points).

Making decisions on a traffic level, i.e. controlling by re-planning at a traffic level, includes:

- Optimizing the traffic plan all the way to the final stop of the train
- Continuously re-plan and thereby updating the traffic plan in real-time.
- The possibility to test alternative solutions in advance
- Plan for optimal resource usage so that no deadlock situations occur.
- Plan and decide on time and track allocation for infrastructural repairs or maintenance etc.
- Incorporate decision relevant information into the traffic plan.

It is possible to focus on optimizing traffic solutions if time is available, or just perform fast re-planning to obtain a valid traffic plan when necessary. Re-planning concerns both track usage and timetable for every type of resource user that will use a certain track resource over a period of time , e.g. trains or maintenance work etc. The human is always in charge and makes all decisions. Decision making is separated from execution of the decisions. Decision supporting functions can be used to aid the operator in the decision making process. Initially, decision support will be of a less advanced sort, only providing enhanced information to the operator (e.g. emphasizing potential conflicts or showing how fast it is possible to get a certain train to a certain location etc.). The kind of decision support we are reasoning about is not the kind that is allowed to make decisions automatically (Hellström, 1998). The goal of decision supporting functionality is to provide an improved information basis for the operator to make decisions regarding planning and control.

There are two basic work roles that the future train dispatching work can be divided into:

- Planning – controlling traffic through re-planning in real time on a traffic level.
- Execution – controlling through executing at a technical level, affecting signals and switches etc. more directly.

Both work roles require the same basic competencies. Normally both roles will be performed by one operator for a particular control area (work station). It is possible to have two operators assuming one role each if the traffic situation is extremely problematic.

5.2.3 Executing the traffic plan

There are two ways to execute control actions. Interlocking of train routes (execution) according to a plan can be performed either by automatic or manual execution. The train dispatcher decides on what should be done and this is incorporated into the traffic plan. Under most conditions the traffic plan can then be automatically executed. However, under some circumstances manual execution (or interlocking) will still be required.

If the train dispatcher so desires, it must be easy to inhibit the automatic execution function either by turning it off completely over the entire control area, for a particular track resource or even a particular train.

5.2.3.1 Automatic execution

Given a valid traffic plan it is feasible to have automatic execution functions that are transparent to the user. The user will always be able to know exactly what the automatic execution functions will do since functions are not allowed to change the order of which trains can use a certain track resource. Automatic functions will never execute a plan containing conflicts.

The following functionality of the automatic execution and support systems must be available:

- Automatic execution of the continuously updated traffic plan.
- Stop of the automatic execution function. (By the operator or autonomously.)
- Automatic test of planned train way in due time in order to test the feasibility of the current traffic plan.
- Automatic interlocking of tested train way according to plan and train signaling orders.
- Automatic functions are made predictable, easy to understand and thereby more 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.

If, according to the traffic plan a certain train is next on turn to use a certain track resource, automatic functions immediately tests the train way by setting switches in the desired position. This is done in order to detect potential infrastructural problems as early as possible. Final reservation of the planned train way however is performed as late as possible but early enough to ensure that the train won’t have to halt if it’s not supposed to do that. At which point in time a train route will be reserved is influenced by train position and speed. The reason for interlocking train routes as late as possible and with as short track stretch at each time as possible is to ensure that maximum time for re-planning is available. Once the track resource is reserved it requires manual interaction if the train dispatcher would like to release the reserved track resource. In other words, once automatic execution has been performed it is too late to re-plan the part of the traffic plan concerned.

It will not change the order of which trains use a certain track or which track a train should use. The *automatic execution function* follows the traffic plan exactly according to planned track usage and in which order a particular track user (could be construction work etc. as well as trains) should be allowed to use that track stretch. The automatic execution function will always act so that the order of trains and planned track usage is maintained even if it's not optimal in aspects of planned time. By ensuring that the order of track usage is guaranteed the human train dispatcher won't have to suffer from the same kind of automation surprises common today.

The '*automatic execution function*' referred to in this research is not an automate in the same sense as the ones used in train traffic control today. It is a function that prepares, tests and reserves train way – completely without exceptions – according to the current traffic plan.

Local queuing of commands may in some cases be used when a track resource is earlier reserved or in use by i.e. another train. Local queuing means that the command for reserving a train route is stored locally in a signaling box and allows the signaling box to immediately execute the requested command as soon as the track resource is available. It is used to avoid delays in reserving of track resources due to in some cases rather extensive transmission times. In the proposed concept we prefer if local command queuing is only used when absolutely required to ensure smooth transitions. The main reason is that if signaling malfunctions would occur it becomes more difficult to manually remove queued commands.

Poor automation design can be directly linked to lack of feedback, monitoring difficulties, passive decision making, poor mental models and thus resulting in situation awareness problems. Billings (1997) studied automation in the aviation sector and reports that the probability of human failure in monitoring automation increases when operators are not alert to the state of automation. Automates used today are often perceived as unpredictable by the train dispatcher. In comparison to that, the proposed automatic function is only executing exactly what the traffic plan states. It will not compromise situation awareness in the same sense as today's automates since it will always be known by the operator what the automatic function will do next.

5.2.3.2 Manual execution

Manually applying control commands to achieve the planned traffic flow will be performed much in the same way as today. The train dispatcher prepares, tests and reserves train routes manually as a part of handling the exceptions when malfunctioning technology/infrastructure occurs. Especially in regards to safety related work tasks such as running a train against signals etc.

The work role as *manual executor* is performed by a train dispatcher that executes control actions when the current plan cannot be carried out by the automatic execution function. This might be the case in a variety of different cases:

- When the signaling or safety system is out of order.
- When a train engine has failed and a new one must be sent out against signals in stop.
- When releasing of previously reserved train way is required.
- When the traffic plan needs changing and the train dispatcher decides that it will be more effective to manually reserve a train route and then later adjusting the traffic plan.
- Etc.

Manual control can be exerted through performing control commands via keyboard or point and click devices which convey the control action to the train traffic control system or in some instances via oral communication.

Manual control tasks include:

- Prepare and test the system prior to actually reserving a train route.
- Reserving a train route
- Releasing reserved train route
- Re-claiming locally queued train route reservation commands.
- Overriding what the automatic execution function would have performed for a certain train by manually implementing control commands. In some cases this requires manual shutdown of the automatic function.
- Manually performing control commands for changing a railroad switch.
- Managing reparation work on infrastructure through blocking track resources and maintaining oral communication with responsible parties.
- Safety critical operations such as leading trains against stop or areas without working safety technology require continuous oral communication with responsible train driver.

A work task parallel to manual execution is the requirement of documenting safety related information, decisions and actions. The manual execution discussed here work along the same principal way of how manual control is exercised today. The biggest difference will be the improved availability of necessary information and upgraded user interface interaction.

5.3 The new work situation

In the new work situation it will be important to continuously maintain a functional traffic plan, as optimal as the situation allows, for how the traffic should run. Figure 3 below is an introductory illustration of the basic parts of the proposed solution.

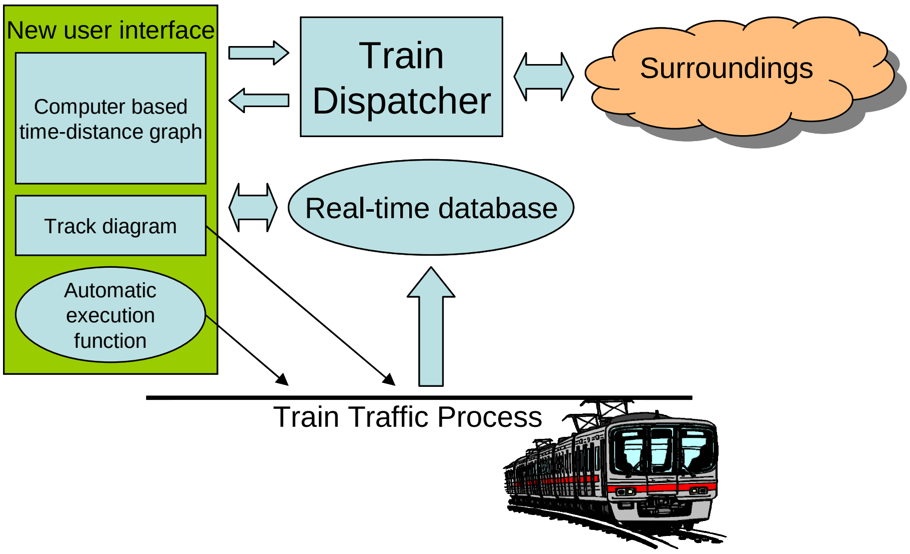

Figure 3. The proposed new control strategy, control by re-planning.

Within the context of the train traffic process, we have the infrastructure with all the track components and their characteristics (tracks, rail switches, road protection bars, slopes, curves etc) and the signaling safety system (track circuits, signals, signaling boxes, automatic train protection etc.). The train characteristics describe objects that have the dynamic property that they can move along a track and thereby change the state of the traffic process. Naturally humans play intricate roles in the process, making decisions and controlling functionality in different positions in the process, i.e. as train drivers, train dispatchers, traffic informants, maintenance staff, passengers etc.

In a real time database information about the status of the traffic process can be continuously updated with current information of adequate resolution. The real time database will be used to supply different systems with required information. One important purpose of the database will be to hold the original, all changes made, and the current traffic plan. The database will contain all of the updated decision relevant data that will be presented in the graphical user interface. E.g. accurate train position and speed.

Train dispatchers will use a graphical user interface to monitor, plan and control the train traffic. The user interface is always updated with information from the real time database. The planning view of the user interface could be designed in different ways, but the most promising so far is the use of a two dimensional time-distance graph for re-planning actions. The planning view will typically show a control area from current time and a few hours into the future. How much time is displayed is depending on which kind of traffic that usually runs on the controlled area. Typically at least something between 1.5–2 times the time it takes for a regular train to complete a journey across the control area should be visualized. There is also a history graph displaying how traffic has performed in comparison to the plan during the last hour. A track layout displays the exact current state of the infrastructure and where trains are positioned. Detailed information about each train and safety critical issues such as construction work etc. is available. Decision support can be integrated into the interface to aid the train dispatcher, e.g. functions that highlight potential conflicts in the traffic plan etc.

A more detailed presentation of the user interface developed within the FTTC project is available in Wikström et al. (2006). Integrated in the user interface there are different decision support functions that help the train dispatcher to identify, understand, analyze, and see available planning space, identify potential conflicts ahead of time and support the work with re-planning the current traffic plan. With decision support we mean functionality that supports the train dispatcher. It is today *not* about advanced algorithms that more or less automatically optimize the plan. Even if we have found that such algorithms are not possible to use today, we don’t exclude the possibility of that in the future.

The train dispatchers are those that have as their main work task to perform operative planning and control of the traffic. The train dispatcher has the responsibility to, at all times, in real-time make sure that there exist an updated and functional traffic plan. Information necessary to perform the work tasks come primarily from the integrated user interface and possibly some other information systems, co-operation and communication with other people etc. Decisions about changing the traffic plan are taken and effectuated into the user interface. The updated traffic plan is then available via the database to all those interested in that information. The train dispatcher can control the traffic in this way until the point when malfunctions occur in such way that the traffic plan can no longer be executed automatically.

The train dispatcher may assume two work roles. The planning role: maintaining the traffic plan. The executor role: manually executing actions to control traffic. Manual execution is primarily done when there are technical malfunctions that hinder automatic execution. The executor also gets the information required via the user interface, but there may in some cases be a need for more detailed information visualization and interaction. The executor role is more similar to how the work is performed today. The train dispatcher, acting in the executor role, performs necessary actions that via the user interface are mediated into the traffic control system and out to the signaling system in the railway line.

Increased availability and precision in information, and also the fact that information from the traffic plan may be accessed by others than the controlling train dispatcher, will affect how people cooperate. More detailed information regarding trains and their movements, and automated information transfer to train drivers about why he has to halt at certain points, will probably decrease the need for oral communication. The work environment should have a design that supports the proposed work in a good way. A special focus has been on how the new work roles can be designed so that the new work situation can be performed without harmful mental workload or stress. The train driver should, as fast as possible, inform the train dispatcher about changes in conditions that might affect the traffic plan. If a train departs late, or if a train is forced to run at reduced speed, it means that conditions are changed and that the traffic plan requires adjustment. The sooner this information reaches the train dispatcher the better. The train driver should also be made aware about changes in the traffic plan. If the train drivers are aware of the new plan, they can adjust their driving according to the new plan, in order to avoid restrictions that lead to loss of capacity. The solution requires new information channels between traffic control centers and train drivers. Information about changes in the traffic plan should be available and shared with everyone that is dependant of this information. E.g. train dispatchers in charge of surrounding control areas, train drivers, train operating companies, traffic informants etc.

5.4 A vision of the new work in practice

Most of the people working with train traffic control are situated in train traffic control centers. For different reason there are also activities performed by personnel at other locations. Effective channels for communication e.g. telephones and computer based systems, are necessary to enable information exchange between train dispatchers and personnel with other work tasks. The focus here is on the work situation of the dispatcher. The dispatching work is performed in close cooperation with train drivers, maintenance personnel, traffic informants (responsible for informing passengers), electricians and personnel at the different train operating companies.

The aim is to provide the train dispatcher with the possibility to focus on the main work task, to find optimal solutions when there is time enough or just sufficiently good solution when under intense time pressure. The latter means to find solutions that merely works, and that can be effectuated within the time available for decision and execution.

The graphical user interface is a large coherent presentation area where the upper part is a planning view in the form of a time distance graph. In the graph the timetable and planned track usage for each train etc. are presented. Below the graph there is track layout according to a linear scale which is in line and the same as the distance axis of the graph above. Combined, these views provide the information about infrastructure and trains required by the train dispatcher to make decisions regarding changes in the traffic plan. Data and information is updated at sufficient rate and anomalies are presented as soon they occur, in real time or as fast as the technology allows. The track layout is the view used by the train dispatcher for manually reserving and releasing interlocking train routes as well as other control actions performed today. The time distance graph is the planning view where the train dispatcher performs re-planning through manipulation of the timetable lines.

With a good overview of the traffic situation the traffic can be planned so that solutions are optimal considering all trains present in the area and the resources, in particular tracks, that are available at that time. Since plans and prognoses will rely on updated information with good precision, re-planning can be made in good time when a deviation slowly starts to reach threshold values, or immediately if a more acute problem occurs.

Repetitive data exchange (with exception of safety related communication) between communicating parties can be automated. From the train and train driver information is transferred that influences traffic control decision making. From the traffic control system information is transferred, that the train driver needs to be able to follow the traffic plan in the best way possible. In similar ways information can automatically be exchanged between train dispatchers and other interested parties.

New technology for speech communication with short connection delay can be used. Calls can be made via role- or object identity instead of telephone number, to make the information exchange more effective when oral communication is required. One example on underlying technology that can be used for information exchange between dispatcher and driver is the SIR-system, a GSM based radio communication link.

Restrictions known by the control system can be visualized in the user interface to indicate which plans that are possible to execute. To be able to create good decision support functions it is important to show all relevant dynamic information about train movements. To be able to create good operative plans for the train traffic, it is necessary to have access to data, with good precision, about the current state of the traffic process, which resources that are available and these resources properties and states. Accuracy of certain variables is essential for the quality of the prognosis that provides the base for decisions. In particular this concerns train position and the calculated runtime of a train. It is also important that the train dispatcher has a good overview over the result of the traffic plan a relevant number of hours ahead. The train dispatcher is responsible for that the traffic plan is valid both in aspects regarding timetables and track usage.

When disturbances occur, the train dispatchers' work is often complicated and is performed under time pressure. Work tasks usually include intense speech communication with concerned personnel. Automates used today can affect traffic in ways that contradict the train dispatchers wishes and they are consequently turned off in disturbed situations. Execution must then be performed manually. To improve the train dispatcher's work during disturbed situations we suggest that autonomous automates that chooses track usage and at the same time reserves train routes should not be used any more. The reason is that this kind of automation, if not turned off, increases the cognitive workload in situations when it already is very high. In these situations automates often make disturbances even worse. The train dispatcher may then spend too much cognitive capacity to understand what automates will do. By not using autonomous automates the train dispatcher can be certain to have full control over:

- Which track resources each train will use
- In which order trains are allowed to use a certain track resource

Within areas where signaling safety system works, the automatic execution function can – without changing the plan – execute the traffic plan as defined

by the train dispatcher. The order in which trains runs and planned track usage is then maintained during execution and the risk of automation surprises is eliminated.
The automatic execution function will:

- Prepare and test the infrastructure along the train route
- Reserve train routes by sending request to signalling boxes.

Particularly in situations where the signaling safety system is not intact, the train dispatcher will have to perform control tasks in a way similar to how it is done today, according to safety regulations. The train dispatcher in this work situation has a more explicit role as a barrier against safety risks. The basic idea behind the proposed control strategy is simple. When disturbances occur there are no automates that create uncertainties about which track resources that will be used by trains. The train dispatcher is in total and unthreatened control. Trains can only run in the order and with the track usage as stated in the traffic plan. There are no exceptions to this rule. Besides changing the traffic plan, the operator also can chose to manually reserve and release train routes etc. Everything that can be controlled manually today should also be possible to control manually when using a future implementation of the proposed system.

6 Evaluation

Working user centered, i.e. iteratively, in cooperation with the end users, means testing of ideas and design solutions continuously. Ideas, sketches and more functional prototypes can be tested and evaluated during both early and later phases in the design and development process.

At an early stage these tests are based on heuristic evaluation of sketches and illustrations. By presenting different scenarios, the train dispatchers in the work group can describe how they would act if and when using the prototype system. This type of preliminary evaluation gives important information regarding how realistic the proposed solutions are. However, before any real conclusions concerning the usability of the proposed design solutions can be drawn, a series of more detailed evaluation experiments must be performed.

The project has been supported by an active work group consisting of six experiences dispatchers together with usability and design experts and researchers. The group has been intact and active for several years, with regular one-day meetings every month. During the time gap between group meetings, the design experts analyzed and prepared information and prototypes and the dispatchers further developed and evaluated the ideas about future work processes and technical support systems. The work in the project group has covered aspects such as problems in present work situation, visions and prerequisites for future organization and work processes, details in future organization and solutions such as work organization, room design, control strategies, information systems, decision support, user interfaces etc.

We have also developed a more realistic tests environment, using a simulator system where the design solutions can be tested (Sandblad et al., 2000). In this test environment, the graphical user interface is projected on a large screen by two DLP-projectors mounted in the ceiling. A camera records the test persons as they carry out the test scenarios. The screen is also be recorded by screen capture software that create a movie of the test session. This enables us to see the detailed performance of the test persons and how they solve the presented problems. The prototype can also log a large number of other test variables for later analyzes. A portable variant of the prototype was implemented to facilitate the need to reach test persons more easily. Studies have been performed with the aid of the portable prototype environment at traffic control centers with satisfactory results (Kauppi, Wikström Sandblad & Andersson, 2006).

7 Discussion

The train traffic process is and will remain complex regardless of new control concepts, decision support systems and new sophisticated user interfaces. Traffic must be controlled and an important part of that work is the management of unpredictable situations, disturbances and events. One main reason for disturbances and unpredictable events is problems with quality and maintenance of the infrastructure and rolling stock. However, except efforts towards a more reliable infrastructure and improved maintenance, it has been shown to be efficient to develop support systems designed to improve cooperation between people in different roles, technical systems and the organization. Our research concerning new principles and systems for traffic control is important in this respect.

The new concepts and support systems have been developed during a long time period and in work groups where experienced traffic control professionals have played an important role. This process has not been easy, and the proposed solutions have sometimes been met with skepticism. There have e.g. been reactions that user interfaces will provide too much information to overview and handle. “How is it possible to be able to handle this much information at the same time?” Our answer to this question is that since train dispatchers obviously try to make decisions based on this information today but without proper support, the situation can only be better if the information actually is updated and available in an easy to obtain manner. Today it is necessary to recreate decision relevant information mentally, a cognitively demanding task that removes capability and attention from the more important tasks, such as identifying and solving disturbances etc. We believe that direct and simultaneous access to the information will make the work easier to manage and that more focus can be used on solving the more complex control tasks. All decision relevant information should preferably be available through the graphical user interface. It will take some time to learn to quickly and effortlessly overview and decode the information in the user interface, but once this done the work can be performed more efficiently. It takes much more time today to learn how recreate information that is not visible. Today it takes several years to become really good at the train dispatching work. This learning process can probably also be reduced in the future.

The traffic situation in Sweden varies significantly between different control areas and over time. There are large differences between controlling long single track lines with sparse traffic during night hours and controlling areas with intense traffic and multi-track lines during rush hours. Each situation provides its own challenges (Hellström, 1998). Because of the fact that traffic situations differs so much, it is difficult to find one general work process or technical solution for traffic control systems, user interfaces, decision support tools etc, which is optimal in all situations. The demands for effective technical support may require that a technical solution to some degree is optimized for the individual situation. This means that in the future we have to more consider differences in situations, requirements and solutions when new traffic control systems are being developed.

We are looking forward to follow the STEG project that just has been initiated by Banverket, the Swedish National Rail Administration. Following this project, it will give us both the possibilities to experience how our concepts and solutions will function in real applications and, of course, the possibilities to perform real evaluations of how the systems work and how the train dispatchers are supported in their complex tasks.

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