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Future Train Traffic Control

Development and deployment of new principles and systems in train traffic control

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Abstract

The train traffic control system of the future requires new solutions and strategies in order to better meet tomorrow's demands and goals. Uppsala University and Trafikverket has been collaborating for several years in research regarding train traffic control and how to improve traffic controllers' support systems and working environment. At an early stage in the collaboration studies and analysis of important aspects of the traffic controller's tasks, strategies, decision making, use of information and support systems were undertaken. This research resulted in new control paradigms, from *control by exception* to *control by replanning*. By using this paradigm we developed and designed prototype systems and interfaces that could better meet future goals and contribute to more optimal use of infrastructure capacity. Based on this research, a new operational traffic control system called STEG was developed in an iterative and user-centred design process. The system was deployed and tested operatively at a train traffic control centre in Sweden. The following evaluations focused on what happens when STEG is introduced in train traffic controllers' work places. The evaluation of STEG showed satisfied users with a feeling of active involvement during the design and deployment processes, and gave confirmation that the new control strategies are functioning. STEG was seen as successful and was thereafter developed into MULTI-STEG, intended to be used by several users simultaneously, supporting them to share information in a new way. MULTI-STEG was deployed and tested at another train traffic control centre in Sweden. The following evaluations of MULTI-STEG focused on what happens when several users are involved and how train traffic controllers felt when sharing information, that before would have only been in their own minds, with each other. Some complications occurred due to mistakes in the deployment process, but altogether the evaluation showed positive attitudes towards the new system and MULTI-STEG was received as an efficient system for train traffic control.

The main results are that STEG and MULTI-STEG can be used as an efficient train traffic control system and the new system can reduce the unnecessary cognitive load currently placed upon traffic controllers in today's system. Also the deployment process is fundamental to the acceptance or non-acceptance of a new system by users. STEG was developed in a user-centred design process, but it is important that the deployment process is also user-centred.

Sammanfattning

Framtidens system för tågtrafikstyrning kräver nya lösningar och strategier för att bättre kunna möta morgondagens krav och mål inom tågtrafikstyrning. Uppsala universitet och Trafikverket har samarbetat under många år när det gäller tågtrafikstyrning och hur man ska kunna förbättra trafikledarnas styrsystem och arbetsmiljö. I ett tidigt stadium av samarbetet har det gjorts studier och analyser av trafikledarnas uppgifter, strategier, beslutsfattande, användande av tillgänglig information samt deras tekniska stödsystem. Denna forskning resulterade i nya styr-paradigmer; från att arbeta genom att använda *styrning genom undantagslösningar* till att använda *styrning med omplanering*. Genom att använda den nya styr-paradigmen utvecklades och designades prototyp-system och gränssnitt som bättre kunde möta framtidens mål och därmed bidra till en mer optimal användning av infrastrukturens kapacitet. Ett nytt operativt tågtrafikstyrningssystem utvecklades och kallades STEG, Styrning av Tåg genom Elektronisk Graf, i en iterativ och användarcentrerad process. Systemet implementerades och testades operativt på en trafikledningscentral i mellersta Sverige. Utvärderingarna som gjordes fokuserade på vad som händer när man introducerade STEG på trafikledarnas arbetsplats. Utvärderingen visade nöjda användare som kände att de fått vara med under både utvecklings- och implementeringsfasen av det nya styrningssystemet, samt att den nya styrprincipen fungerar. STEG var framgångsrikt och har därefter vidareutvecklat till MULTI-STEG som är avsett att användas av flera användare samtidigt och därmed ge trafikledarna en möjlighet att kunna dela information på ett nytt sätt. MULTI-STEG implementerades och testades på en annan trafikledningscentral i norra Sverige. Utvärderingarna fokuserade på vad som händer när flera användare delar information och hur det påverkade deras arbete. En del komplikationer inträffade genom att misstag i implementeringsprocessen gjordes, men sammanfattningsvis så var attityden gentemot det nya systemet positiv och MULTI-STEG ansågs vara ett effektivt system för tågtrafiksstyrning.

De huvudsakliga resultaten är att STEG och MULTI-STEG kan användas som ett effektivt system för tågtrafikstyrning och att det nya systemet reducerar den onödiga kognitiva belastningen som trafikledarna upplever med dagens befintliga tågtrafiksystem. STEG är utvecklat i en användarcentrerad process, men det krävs även att implementeringsfasen är användarcentrerad för att ett nytt system ska fungera.

Till Diesel,

för att han gav mig de nödvändiga pauserna för att kunna fortsätta.

List of papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals. Reprints were made with the kind permission of the publishers.

Paper I	**Development and implementation of new principles and systems for train traffic control in Sweden**
Authors	Bengt Sandblad, Arne W. Andersson, Arvid Kauppi and Gunnika Isaksson-Lutteman
Publication	In Proc. Computers in Railways XII in Toledo, Spain. WIT press 2010, 441.
Short summary	This paper describes the development and implementation phase of the new train traffic control system; STEG-Steering of Train Traffic with Electronic Graph.
My contribution	I started my PhD studies at the end of the development process of STEG. My contribution to this paper is mainly in the evaluation part.

Paper II	**Operative tests of a new system for train traffic control**
Authors	Gunnika Isaksson-Lutteman, Arvid Kauppi, Arne W. Andersson, Bengt Sandblad and Mikael Erlandsson

Publication	Presented at Rail Human Factors 2009 in Lille, France. Technical Report, Department of Information Technology, Uppsala University, 2011-027.
Short summary	This paper describes the methods used for the evaluation of STEG and the results of that evaluation.
My contribution	I am the main author of this paper and conducted the interviews, together with Arne W. Andersson, that this paper is based on. Furthermore I did most of the analysis of the data.

Paper III	**Reducing unnecessary cognitive load in train traffic control**
Authors	Gunnika Isaksson-Lutteman, Bengt Sandblad, Arne W. Andersson and Simon Tschirner
Publication	Presented at FALF 2011 (Conference for work environment research) in Luleå, Sweden. Technical Report, Department of Information Technology, Uppsala University, 2011-028.
Short summary	This paper discusses the reduction of unnecessary cognitive load by supporting train traffic controllers' mental models with the new train traffic control system - STEG.
My contribution	I am the main author of this paper and also did all the interviews and most of the analyses that this paper is based on.

Paper IV	**All or nothing - deployment must also be user-centred**
Authors	Gunnika Isaksson-Lutteman, Bengt Sandblad, Arne W. Andersson and Simon Tschirner
Publication	To be submitted to “The Ergonomics Open Journal”.
Short summary	This article describes the importance of using a user-centred deployment process. The article is based on a case study of two train traffic control centres where the same system, STEG, was deployed with different contexts.
My contribution	I am the main author of this paper and performed all the interviews that this paper is based on. I was also the supervisor of the analysis section.

My co-authors

Bengt Sandblad	Professor in Human Computer Interaction at the Department of Information Technology, Uppsala University. Bengt is my main supervisor and has a background in Engineering Physics.
Arne W. Andersson	Research Engineer in Human Computer Interaction at the Department of Information Technology, Uppsala University. Arne is an expert on train traffic control and has a background in the process industry.
Arvid Kauppi	PhD student in Human Computer Interaction at the Department of Information Technology, Uppsala University.
Simon Tschirner	PhD student in Human Computer Interaction at the Department of Information Technology, Uppsala University.
Mikael Erlandsson	PhD student in Human Computer Interaction at the Department of Information Technology, Uppsala University.

Abbreviations

AEF	Automatic Execution Function (later replaced by PEF)
AR	Action Research
CATO	Computer Aided Train Operation
FTTS	Future Train Traffic Systems; Project with Trafikverket
GMOC	Theory framework Goal-Model-Observability-Controllability
HCI	Human Computer Interaction
MULTI-STEG	Basically the same system as STEG, but intended to be used by several users at the same time
NTL	In Swedish “Nationell TågLedning” English translation “National Train Management”
PEF	Plan-driven Execution Function (earlier called AEF)
SIGCHI	Special Interest Group on Computer-Human Interaction
STEG	In Swedish “Styrning av Tågtrafik via Elektronisk Graf”. English translation “Steering of Train Traffic with Electronic Graph”
Trafikverket	The Swedish Transport Administration
UCSD	User-Centred System Design

Contents

1. Introduction

Uppsala University and Trafikverket initiated a research project in 1996 with the aim to develop knowledge regarding train traffic controllers' work and working environment. This knowledge was considered to be necessary in order to develop and design new train traffic control systems. Here it is necessary to briefly explain how train traffic control is conducted in Sweden. There are eight train traffic control centres distributed in different geographical locations that operate the train traffic in their specific region. The responsible organisation for train traffic control as well as maintenance is Trafikverket. In total the eight centres control 8099 kilometres of single tracks and 3805 kilometres of double or multiple tracks. In addition to this there are more than 60 different train operators that are responsible for train passengers and freight traffic that need to collaborate with Trafikverket.

Figure 1. The map shows the eight traffic control centres in Sweden from where train traffic is controlled.

At the centres the current status of the train traffic is displayed on regular computer screens together with large wall panels. Important tasks for the train traffic controller include monitoring the train movements and by automatic and manual functions controlling the train routes. The train traffic controllers intervene when conflicts or disturbances occur, which is called *control by exception* (Sandblad, Andersson, Frej & Gideon, 1997). Swedish train traffic controllers conduct their work by supervising the displays which indicate the current status of the train traffic and by manual operations redirecting trains in case of disturbances from the original programmed traffic plan. They collect information from several different information systems. An important tool is the paper-based time-distance graph that can be used for planning and documentation. There is no efficient support to communicate updated traffic plans to concerned colleagues. Today's systems are designed for the train traffic controllers to react on deviations in traffic, instead of being able to follow the dynamic development over time and prevent conflicts.

Figure 2. The picture shows the work place of a traffic controller today at the train traffic control centre in Stockholm, Sweden. The picture shows large wall panels, smaller computer screens as well as a paper-based time-distance graph.

Train traffic controllers have to keep track of their replanned routes, retaining the problem solving strategies in their minds and having to calculate the consequences of potential conflicts without any external decision support. This increases cognitive work load and reduces the capability to explore and create better traffic solutions that could more efficiently utilize the infrastructure, which is more thoroughly described in Paper III. The unpredictable and complex automatic system can counteract the train traffic controllers' new strategies, which is referred to as automation surprises.

One important concept for improving the work of controlling train traffic has been to change the control paradigm from low-level technical control tasks into higher-level traffic replanning tasks, as mentioned in Kauppi, Wikström, Hellström, Sandblad and Andersson (2003). The result of this research was that Trafikverket, together with Uppsala University, developed STEG - the new train traffic control system. STEG is designed to provide efficient user interfaces and better decision support in order to give the train traffic controllers possibilities to be continuously updated and able to evaluate, act on and prevent future potential traffic conflicts. The control concept also provides the foundation for the sharing of updated traffic plans and information to concerned colleagues more efficiently since the information is accessible to all co-workers. STEG was designed to meet the new control paradigm, control by exception, to better support the train traffic controller in their tasks. This can be read about in Paper I. The STEG system was tested in operative control at a train traffic control centre in Sweden, as is more described in Paper II.

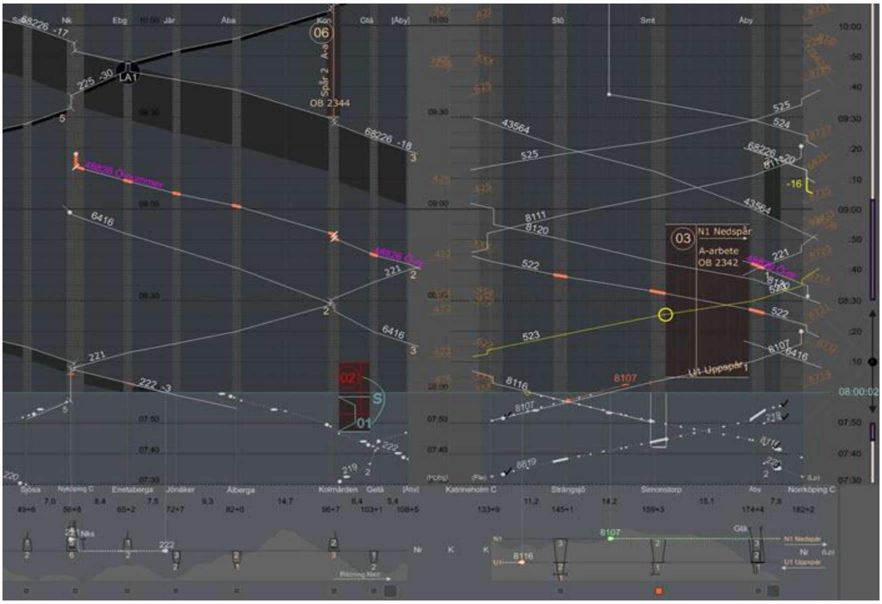

Figure 3. The new dynamic interface of STEG. The diagonal lines are representing the trains' speeds and movements. The timeline to the right is scrolling downwards as times evolves and stations are plotted horizontally. The yellow circle indicates a conflict that needs to be solved. For more information about STEG interface see Paper I.

STEG was positively deployed at the first train traffic control centre and Trafikverket decided to further develop STEG into MULTI-STEG, intended to be used by several train traffic controllers at contiguous geographical traffic areas. The advantage with MULTI-STEG is the possibility to share information. Together with MULTI-STEG, another system was developed by Transrail called CATO (Computer Aided Train Operation). CATO is intended to be used by the train drivers in order to be updated on changing traffic plans in real-time. The main objectives for this cooperative planning procedure are to create energy-optimal plans, save electric energy and reduce equipment maintenance.

The train traffic controllers replan the traffic in STEG or MULTI-STEG and CATO interprets the new plans and creates target points for the train driver to adjust his or her driving to. This way the train drivers can utilize the topography and better optimize train meetings. The train's position is constantly updated by GPS giving the train traffic controllers more solid information about the current status of the traffic situation. Read more about this in Paper IV.

Outline of the thesis

In the next section I will present the *research questions* and the settings where my research was undertaken, the *research area* and my *perspective* on the research, as well as the *project* I have been working on and the *research group* I have been a part of during my time as a PhD student. In the following chapter I will describe the *theoretical* framework to my research and after that the *method* section will walk the reader through the way I, along with the research group, have been working within the project. My general findings are summarized in the *result* section and towards the end of this thesis the reader can find the *discussion* section where I develop my thoughts about my research results. Finally, I will guide the reader towards the anticipated *future work*.

Paper I The first paper deals with the development and design of the new control system STEG and the status of STEG at the first traffic control centre it was implemented at.

Paper II The second paper describes the evaluation period of STEG and its results at traffic control centre 1.

Paper III The third paper describes the evaluation of MULTI-STEG and our findings at traffic control centre 2.

Paper IV The fourth paper describes the differences in the deployment and education processes at two different traffic control centres, and the need for a user-centred design process, as well as a user-centred deployment process.

2. Research settings

In this section my research settings are described in terms of the research questions and the research area I work in. The chapter will also present my research perspectives and my research group.

Research questions

My research questions are based on the problems described above, as well as constraints upon the research project. My research has so far been focusing on what happens when deploying a new system for controlling train traffic. I have been looking at the users' reactions and how the new control paradigm has affected their individual work and the organization surrounding them. Have the goals changed? Do the traffic controllers' mental models change in character? Is the organization changing when the new control system is implemented?

The overarching research question is:

Does the concept control-by-replanning function in train traffic control and what happens when it is introduced in a train traffic control centre?

Additionally, I have been interested in how train traffic controllers learn their work from the beginning. It takes a long time to be a skilled train traffic controller and the education is expensive for Trafikverket. It takes about two years before a train traffic controller can contribute to every day operations at work. Therefore, my research also has been focusing on understanding the following question:

How do train traffic controllers learn their work and how do they develop their skills?

Research group

The focus of our railway research group is the development of systems used by real users in real work settings, i.e. human control of complex systems. The research group consists of one senior professor in HCI, one senior research engineer in HCI, one PhD student and myself. We all work in the department of HCI at Uppsala University. From here on, when I refer to “we”, it is this research group I refer to.

Research is teamwork and in our group we all have different educational backgrounds, hence we see ourselves as an interdisciplinary research team. My contribution to the research is influenced by my educational background, which is a Master’s Degree in Ergonomic Design and Production. My point of view as an ergonomic designer has reflected the methods used, as well as how I interpret the results.

Research area

Human Computer Interaction (HCI) is a fairly young research discipline, but during the last decade it has increased in importance. Human Computer Interaction studies the interactions between computers and humans.

“Human Computer Interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and the study of major phenomena surrounding them” (SIGCHI, 1992).

It started as a research area focusing on information processing, but nowadays it has expanded to deal with social, cultural and organizational contexts (Kaptelinin, 2003). Computers are used more frequently nowadays; people use them both at work and at home. The HCI field turned into a more comprehensive view on human actors in specific situations (Bannon, 1991). The focus changed from just interacting with the work place to studying interactions and relations to culture, aesthetics, experience and emotions (Bødker, 2006). HCI research is an interdisciplinary field which involves applied research and often includes applications. HCI researchers often have multidisciplinary backgrounds and have come from other research areas such as human factors, ergonomics, information systems, cognitive science, information science, organizational psychology, industrial engineering and computer engineering (Grudin, 2005).

In my research I have not been involved with the computer part described in figure 4 on the next page. I have studied humans and their context and use of computers.

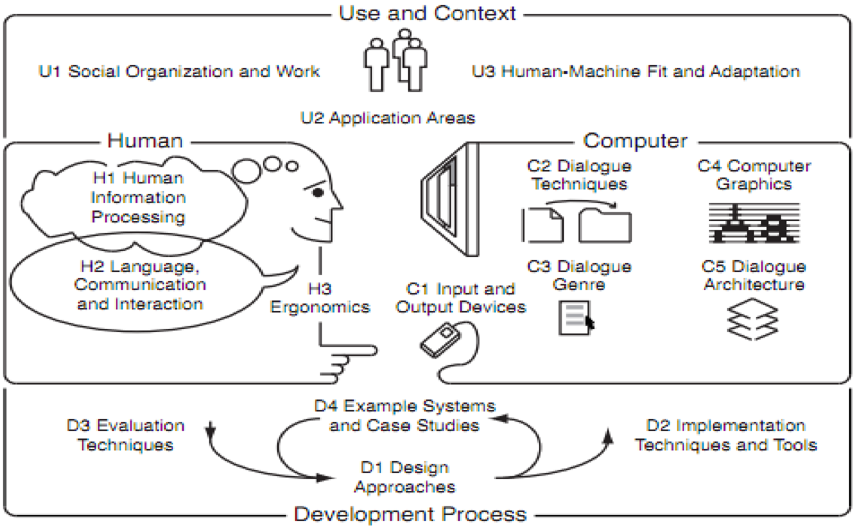

Figure 4. Typical topics in HCI as described in ACM SIGCHI Curricula for Human-Computer Interaction (ACM, 1992).

Research perspectives

I think that HCI research needs to be relevant to practice and therefore the 'action research approach' has suited me and my co-workers well. Our research group has a long tradition of working with action research in studying organizations and work places. Action research entails a dual focus on performing research and making improvements within the organization studied (McKay and Marshall, 2001). Unlike traditional research, as for example in ethno methodology where the focus is only on understanding, action research solves both research questions and problems in practice. But to make successful changes or improvements one needs the understanding as a basis for the research. Thereafter, a changing proposal can be made and after this segment, evaluating and reflecting upon the effects of the change are as vital as everything else. Action research is an iterative process that contains five steps: diagnosis, planning, intervention, evaluation and reflection (Susman & Evered, 1978), as illustrated in the figure below. Action research is a democratic process where both researchers and practitioners work as a team to search for and bring together practice and theory, as well as actions and reflections (Reason and Bradbury, 2001). With the action research approach developing knowledge and developing solutions are both important.

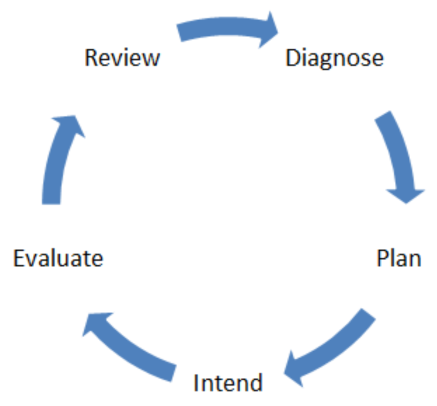

Figure 5. The action research cycle, in its most simple form.

Research project – Future Train Traffic Systems

Over nearly fifteen years Uppsala University and Trafikverket have been involved in research projects with the purpose of creating future systems for train traffic control. Together we changed the control paradigm from *control by exception* to *control by replanning* (Kauppi et al., 2003).

Tomorrow's train traffic systems require new strategies and solutions for efficient train traffic control and utilization of track capacity, especially in traffic systems with a high degree of deregulated and mixed traffic. There are many different goals associated with traffic control tasks and the work of the train traffic controllers. Examples are safety, efficiency of the traffic with regard to timeliness and energy consumption, replanning and recovery after disturbances and supplying a good service and information to passengers and customers. Today's traffic control systems and user interfaces do not efficiently support such goals.

The work presented in this thesis is based on earlier research and development at our department, before I started my thesis work. This has been presented in earlier publications and is shortly summarized here. The research was originally based on a very detailed description and analysis of how train traffic is organized and controlled today, the mental models of the dispatchers and the strategies they use for decisions and control actions. The research consisted of the following steps:

- Observations and interviews with dispatchers and other professionals at the traffic control centres. Analysis of the findings and identification of problems and development areas.
- Workshops with experienced and responsible professionals from the national rail and traffic control administrations. Here the visions and restrictions for future development of control systems were §specified.
- Iterative specifications and evaluations with the help of a working group consisting of experienced operative traffic control professionals.
- Tests and evaluations in a laboratory control room environment using a train traffic simulator system.

Some of the most important results from this earlier research are he analysis of the train traffic control process was analysed according to a model for human control, the GMOC model. This model had earlier been developed for such purposes (Andersson et al., 1997).

In order to support real-time planning of train traffic, the traffic controller was provided with an interactive computerized time-distance graph (Sandblad et al., 2002; Wikström et al., 2004). The computer based time-distance graph was designed in such a way that it visually supports the operators' situation awareness of the current status and the projection into the future (Endsley, 1996). The user interface, with its planning view, can support early detection of upcoming conflicts, identify possible replanning alternatives and their predicted effects.

A prototype, SIMSON, of new user interfaces that support the new control strategy was designed, implemented and tested in a laboratory environment at Uppsala University. The interface was designed to integrate all decision relevant information into one unified interface and to support continuous awareness of the dynamic development of the traffic process (Kauppi et al., 2005).

In order to enable the simulation experiments, a train traffic simulator system was developed, called TOPSIM, (Sandblad et al., 2000).

The research group also earlier evaluated different approaches to the design of decision support systems in operative train traffic control (Hellström et al., 1998; Kvist et al., 2002). They found that more advanced automated decision support systems are today not a realistic alternative for different reasons. More research and development of methods are needed in this field. We have instead decided to focus our efforts on supporting the controllers through better presentation of information, improved information observability and quality, help with early detection of conflicts and disturbances, identification of possibilities and limitations for replanning, and evaluation of the effects of replanning alternatives.

Uppsala University's unique opportunity to do research in train traffic control over a long period of time has resulted in a deep knowledge of train traffic and a real understanding for how train traffic controllers perform their work. The researchers, system developers, train traffic controllers and project management have worked together during the process. In our research we have analysed important aspects of the traffic controller's tasks, strategies, decision making, use of information and support systems. Together with Trafikverket, the new control paradigm and the new operational system STEG were developed. Later on STEG was developed into MULTI-STEG, intended to be used by several users simultaneously. The development process was quite unique. Researchers, users and developers worked together over a long period of time. The relationship was ambitious and respectful. Frequent meetings and workshops, as well as close contacts, made the collaboration unique. The whole process was user-centred (Gulliksen, Göransson, Boivie, Persson & Cajander, 2003) and iterative, which led to STEG being developed into a useful tool. Every phase in the STEG development process was performed very carefully and thoroughly. The development team did not use a static requirement specification. It existed, but it was constantly changing and had a dynamic approach. The future users have shown a long-term commitment and faith in the development of STEG. Train traffic controllers from different parts of Sweden with different experiences along with researchers and management had frequent workshops during the development phase. The development phase lasted for a long time, more than two years, and during this time many prototypes were constructed, tested and evaluated. Everything was questioned and exposed to testing, instead of just modernizing existing train traffic control systems. Also seminars with experienced professionals from the national rail and traffic control administrations were performed throughout the development process where the visions and restrictions for future development of control systems were specified. Prototype testing and evaluations in a laboratory control room environment using a train traffic simulator system were also important during the development.

The iterative and user-centred development process enabled a deep analysis of the real problems in train traffic control.

3. Theory

In this chapter I will present the theories that influenced my research. I will describe the GMOC-model which is used as a theoretical framework. Using the GMOC-model can lead to increased situation awareness and increased feelings of support and control. The demand-control-support-model will be presented later in this chapter. Further on it is necessary to describe how human beings process information and actions outcomes. Therefore, decision making processes and other cognitive processes are described in relation to the GMOC-model as a theoretical framework. The papers, as well as the conclusion chapter in this thesis, are further developing and discussing these theories in relation to the research.

Cognitive processes

Cognitive theories indicate that high level cognitive tasks, e.g. those needed for reading and understanding texts, solving new problematic situations are demanding and “single processing”. On the other hand, for low cognitive level tasks, e.g. well known and automated tasks, the parallel capacity is almost unlimited (Rasmussen, 1983). This means that it is important to allow automatization of tasks and activities where possible, thereby leaving precious cognitive capacity for solving work related problems, e.g. solving traffic conflicts, replanning train activities etc. In order to describe human information processing, it is important here to make a distinction between high level, analytical and low level, automatic cognitive processes. On a very high analytical level we are creative, adaptive and have advanced problem-solving capacities. At this level our parallel capacity is very limited. We can only deal with one item at a time. On a low cognitive level, where we have learned and perform automated tasks, we have an almost unlimited parallel capacity. On the highest level we solve advanced problems, but only one at a time. On the lowest, most automated level, we perform advanced activities in parallel without conscious efforts. This separation between high and low level cognitive processes is in agreement with Rasmussen's model.

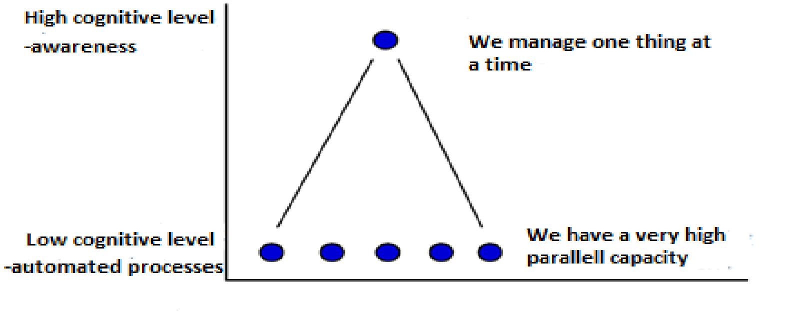

Figure 6. Different levels of cognitive processing.

GMOC – a theoretical framework

During my research I have embraced a theoretical framework, GMOC, in order to conform to the results and findings in the conducted studies. GMOC has been used in the research collaboration with Trafikverket to describe the system processes and organization of train traffic control. The system described here is not the train traffic in itself, such as for example the signalling system, but the control system used by the train traffic controllers when controlling and planning the train traffic, and the train traffic controllers and their work processes. This framework has also been the basis when designing STEG.

GMOC means Goal, Model, Observability and Controllability. This theory is originally from Control Systems Engineering, the engineering discipline that applies control theory to design systems or processes with a predictable dynamic course (Bremer, 1992).To know how to control a system there has to be a *goal* for the system or process to achieve. The user has to understand how the system works and have knowledge about the processes in order to create a *model* of the system. In this thesis the model discussed is referred to as a mental model of the system created in their minds. There has to be the possibility of knowing how to *control* the system to achieve the goals. The system also has to be *observable*, the user must be given the chance to observe what is going on and what the status is in the structures and processes. When talking about GMOC we intend to use the goals and models as characteristics of the user, and observability and controllability has to be characteristics of the system (Bremer, 1992). Users must have goals and mental models in order to meet the observability and controllability of the system and vice versa. However, this is a dynamic loop and all four conditions depend on and influence each other to make the system and the user controlling it function satisfactorily. Train traffic control is a complex process and human beings are complex creatures who cannot be seen in a static state or transferable to plain algorithms. GMOC has to been seen as a dynamic process where feedback is intentional.

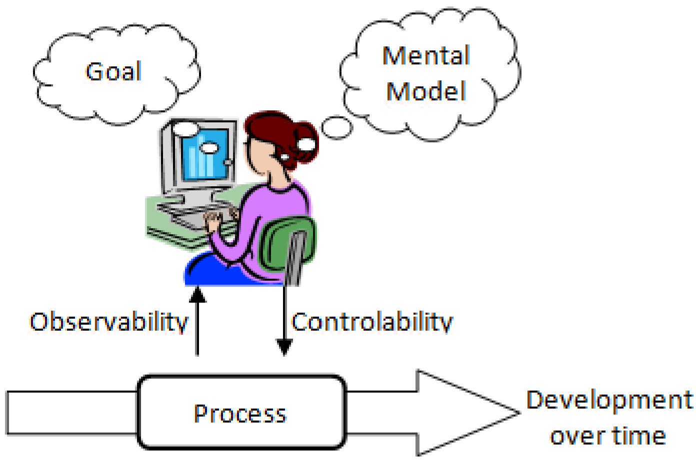

Figure 7. Simplified illustration of the GMOC-model

In a simple technical context, for example when driving a car, it is easy to realize the meaning of having all conditions explained above fulfilled. A clear *goal* for the trip is important, one needs to know where to go to. One needs to have an understanding of how the car works, have knowledge about the road network and traffic rules, i.e. *mental models* of how to understand and handle the system. The driver has to have access to leavers, pedals, steering wheel and so on in order to *control* the car. These features also need to be coherent with a function and the possibility of understanding the interface, i.e. the driver needs to know what the specific leaver outcomes are when moving it. The driver also has to be able to *observe* and gain the necessary information about the status of the car such as speed, gasoline supply and temperature. Surrounding factors, such as weather and traffic, are also to be taken into the process of making decisions about actions for the driver. The control of the system is impossible if not all conditions are fulfilled.

GMOC is transferable to a general description of human control of a complex system as well, for example in our case when talking about a control system for train traffic control. The train traffic controller needs to know what the goals are of train traffic control. For example, the goal can be to get the trains to their final destination on time. To get the trains to their destination, the train traffic controller develops mental models of which actions are needed to get the trains moving there and how the system will react to those actions. The user requires good observability of what is happening in the system and what the status is of the trains' progression. For example, if external circumstances alter, such as a blizzard slowing the trains down causing deviation from the original traffic plan of how to achieve the goal, the user also needs to be able to control the system and change the trains' routes and departing times in order to avoid conflicts with other trains.

In practice, when a problem occurs in system processes it is often because one of the GMOC features is missing (Bremer, 1992). For example, when the user lacks a proper goal to work towards it is difficult to optimize your work tasks and know how to control the system. If the observability of the system is not satisfactory it is difficult to have a proper overview of the process and take the optimal decision. If the user is not able to control the system the way they want it is impossible to execute the decisions made for achieving the goal.

In the following sections I will further develop the relation between GMOC and other theories as I see it.

Goals – an important part in decision making processes

It is important for users, and organizations, of technical systems to have clear, understandable and reachable goals when operating a system, such as train traffic control. Goals can be formal and informal. Formal goals are explicitly formulated in the organization's official document and rules. Informal goals describe what the users actually are working towards, consciously or unconsciously. These goals are used as a foundation for the users' daily work and processes. The users require clear goals in order to interact with the system or organization. Inaccessible and unclear goals create conflicts and problems in the organization and for the users (Paper IV).

The informal goals can be difficult to discover because users performing the same task can have different goals and sometimes the users are even unaware of the goals they are working towards (Paper II and III). The organizations' and the users' goals can be contradictory and this can cause problems and conflicts. For example, in train traffic control the organization's goal can be to get the trains at the arrival destinations according to the preplanned traffic plan. In order to reach this goal the train traffic controllers have to delay some trains due to external circumstances, such as for example snow, to get most of the trains to their destinations on time. The train traffic controllers restructure the goal, and their mental model, of how to achieve the new goal. A decision, as described above, cannot be understood separately, but as a part of a dynamic process. A decision is one of several steps taken along the way to achieve one or more goals. (Brehmer, 1992; Klein, Orasanu, Calderwood & Zsambok, 1993).

Working with dynamic processes, as train traffic control is, is demanding for the users. Human beings' ability to handle complex systems and make decisions is strongly connected to characteristics of the work situation and the work tasks (Beach & Mitchell, 1978; Kuylenstierna, 1998; Payne, 1982; Woods, 1993). Advanced technology has changed the relationship between humans and the working environment, both in the possibilities of gaining information (*observability*) and in how to influence (*control*) the processes.

The organizations' and the users' goals can be contradictory, as mentioned above, but there can also be conflicting goals between an automatic system and the user. Most systems, and so even traffic control systems, contain different automatic sub-systems intended to support the user and his or hers goals. These automatic systems are often autonomous, as they are allowed to change, for example, the present traffic plan, train order, track usage and so on. In critical situations the train traffic controller's first action is often to turn off these automated sub-systems in order to gain full control over the situation and take decisions that will lead to achieving the goals. The result is "automation surprises" leading to sub-optimal solutions and confusion (Bainbridge, 1983) for the user. The automatic system acting according to its algorithms is not always optimal in a complex and dynamic decision making process.

In dynamic decision making some characteristics need to be fulfilled. Several decisions and actions are required to achieve a specific goal. To attain and maintain the control over a process is a dynamic activity demanding many decisions. Every decision can only be understood and related when viewed from the group perspective. Decisions are dependent on each other, which means that a decision made early in the dynamic process determines the coming decisions. The status of decision problems are changing as a consequence of the decision maker's actions. In a dynamic process, decisions are to be made in real-time and during time pressure. A summary of this is that dynamic decision making is decisions that are to be made given a certain context and within time limits. The intention of the decisions is to achieve control. The user has to create a mental model of the system and the work task in order to obtain control (Conant & Ashby, 1970).

Mental models - viewed at as problem spaces

Users, i.e. train traffic controllers, want to understand the system they are working with, not only performing a task. This intention can be both conscious and unconscious (Paper III). Therefore, they are constructing a "mental map" or understanding of the system and their work tasks. If they are "lost" and don't know what the right decision is they can find their way again by visiting this mental map and looking for a solution. This mental map can be referred to as a *problem space* (Andersson, 1987). The problem space consists of several methods to perform and manage assignments and solve problems. A novice's problem space provides less methods and an expert has access to a more enhanced problem space. By time and practice the novice increases the alternatives of accessible methods to use when solving a problem and gradually becomes expert.

The problem space can be categorized into different levels. *Knowledge-based problem solving*, where users solve problems by using gained knowledge about the system or about external aspects and reuse methods that worked in a similar situation before. S*kill-based problem solving,* where routines have been learned by a controllable method and users use gained skills to solve the problem. *Rule-based behaviour problem solving,* where routines have been automatically learned by rules and the problem solving is based on rules that define the organization, and has to be obtain in order to security issues (Rasmussen, 1983).

Train traffic controllers create mental models on different levels, i.e. problem spaces, by interpreting the information they gather from use of different technical systems, communicating with other participants in the train traffic management process, making assessments and taking decisions, implementing actions and evaluating the results. Train traffic controllers also have certain security rules they are obligated to follow.

It is important to support the creation of mental models when control systems are designed (Paper III).

Observability – increases the situation awareness

A system has to be observable to its users. The users have to be able to observe what is going on and what the status of the process is. The users have to be "in the loop" and aware of the situation. When a system provides this, it can increase the situation awareness of the users and lead to more optimal decisions (Paper II).

Situation awareness refers to certain aspects of a human operator's ability to interpret and understand a complex situation in order to find efficient ways to act so that the objectives can be met. The users need to have observability of the system and their work tasks. A basic approach to this problem was developed by Endsley (Endsley, 1996). The question is how well a particular situation that arises can be identified and understood to provide a basis for decisions and actions. Situation awareness according to Endsley is "a state of knowledge that directly relates the properties of a dynamic environment to the operator's objectives, particularly with regard to the controlling of the process". Endsley also divides this "state of knowledge" into three parts. One part is *perception* of the condition, characteristics and dynamics of the dynamic process in its various parts. Another part is the *comprehension* of the process's behaviour and relations between them. This includes identifying what is important in the situation. A third part is *projection*, i.e. to make predictions, based on the present situation and what has happened in the past, for what will happen in the future.

In train traffic control perception is about gathering information from all different systems on the displays, as well as the trains' environments and the weather conditions. The controllers then have to interpret the information, predict the consequences and transform it into decisions and actions that provide smoothly running train traffic.

Situation awareness is often mentioned together with systems and control, but I argue that the deployment process also needs situation awareness (Paper IV). The user needs to be in the loop and understand what is going on during the deployment process. The user also has to be in control of the deployment process. Endsley defines the phenomenon of situation awareness as the perception of reactions to a set of changing events, and a deployment process as a series of changing actions and events.

Controllability – and automation problems

In train traffic control there are several levels of control. The train traffic controllers control the train traffic system as well as the information system that provides the basis for decisions and actions. The traffic controllers also control their own work load, i.e. they can influence different dynamic processes in order to create the best chances of doing a good job.

Most systems, and so even traffic control systems, contain different automatic sub-systems intended to support the user. These automatic systems are often autonomous, as they are allowed to change, in this case, the present traffic plan, track usage and so on. In critical situations the train traffic controller's first action is often to turn off these automated sub-systems in order to gain full control over the situation. Otherwise the result will be "automation surprises" leading to sub-optimal solutions and confusion (Bainbridge, 1983).

Working towards the demand-control-support-model

As explained earlier in the theory section the users, or the traffic controllers in this case, need to feel control over the situation at work, the system they are working with and their work tasks. To discuss this further I will look into the control-support-demand-model. During the 1970s Robert Karasek enhanced a model to analyse work-related stress interconnected with cardiovascular illness. At first the model only contained the link between control for the user and demand from the organization. This model was further developed by Töres Theorell. Today it is often used for describing psycho-social work conditions, stress and their effects on health. Figure 8 illustrates the relation between demands and the level of self-control the user perceives.

High demands and low perceived control is not a good combination for your health. High demands are normally not a stress factor if it is combined with high self-control over the work situation and a strong social support from the management, colleagues etc. Research shows that the control and support factors often decrease when, for example, new systems are deployed at a work place (Åborg, 2002).

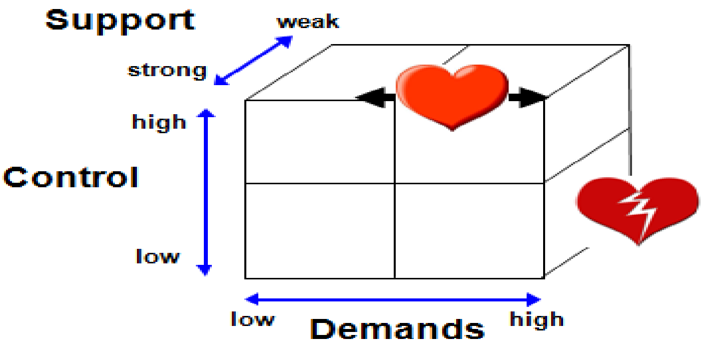

Figure 8. The figure shows demand-control-support-model of stress related factors.

The demand-control-support-model explains why many users feel stress when new systems are deployed at their work place. This is due to lack of control over the new work situation and the new systems. They have to learn something new instead of using the old system they already know and can manage. They have to create new mental models and map the new preferences of their work. Often when this happens the users do not get sufficient support to regain or maintain control over the system and their work situation. The users feel that the demands on them are increased because they do not understand the new system and, in combination with lack of support and a feeling of losing control, this creates stress (Åborg, 1999). Stressed users do not perform well in their jobs, do not make good decisions and do not feel satisfaction. In such a situation it is easy to blame the new system for being poorly designed for the occasion, but sometimes it can be as simple as a poor deployment process where the users don't have the chance to learn the new way of thinking that the new system requires (Åborg, 2002).

4. Methods

This section describes the methods used and the methodology used for evaluations of the new control paradigm.

Methods of collecting and analysing data

In my research the main methods of collecting research material have been through interviews, questionnaires and observations at different train traffic control centres.

The interviews have been unstructured with some open-ended questions. At all levels in an organization unstructured interviews render fruitful data, although structured information is the aim (Rasmussen, J., Pejtersen, A. M. and Goodstein, L. P., 1994).

“Attempts to use an interview form structured according to the analytic model repeatedly cause interruptions in the interviewee's train of thought. Similarly, attempts to make recordings of the information gathered in prestructured records during the conversation tend to distract both the interviewer and the interviewee.” (Rasmussen, J., Pejtersen, A. M. and Goodstein, L. P., 1994)

The respondents have been able to freely speak about their work and work situation during our interviews that lasted for 2-3 hours. The interviews were deep and thorough, and we often have been able to come back to the same person several times to widen our perspectives or clarify things. In this way we found sets of information we did not know we were searching for. During the interviews sometimes there were two interviewers from our research group and sometimes just one. The interviews have been audio-recorded with the interviewed person’s consent. The interviews were conducted in Swedish, citations in the results section are translated into English. The interviews have been transcribed and from the transcription, citations and findings have been highlighted and further analysed by our research group with the support of the GMOC-model. An unstructured path to gather structured knowledge was used in collecting research data.

Questionnaires have been a helpful support to the interviews and also helpful in getting a wider range of people involved in the research. The questionnaires consisted of questions with a rating scale to consider in the answers. Same questionnaires were handed out before, during and after the deployment of STEG in order to compare the train traffic controllers' perceptions and knowledge of STEG.

Observations of train traffic controllers' work, with and without STEG as an operative tool, have been conducted at several train traffic control centres, both in Sweden and Europe. The observations have been audio-recorded combined with notes, with the respondents' consent. During the observations I have also written down comments, conversations, thoughts etc. The material has been analysed in our research group with the GMOC-model as a framework.

Evaluation of STEG at train traffic control centre 1

STEG was implemented as an additional module on top of the regular train traffic control system. The system was tested operationally for six months at one segment of the main rail line from Stockholm to southern Sweden, including one double track line, one single track line and some less frequently used freight traffic lines.

The first evaluation of STEG performed in spring 2008 was conducted through unstructured interviews, observations at the work place and questionnaires. Interviews were also conducted in autumn 2008. The same questionnaire was handed out before and after the deployment of STEG. The results were compared and the changes the train traffic centre and their users were going through were analysed. Observations at the work place were made before, during and after the deployment of STEG. The users also kept a "digital diary", which we had access to, about the process they were going through and the new system they were facing. The users wrote down their thoughts, questions, reflections and proposals for improvements.

Train traffic controllers using STEG and those who did not use STEG participated in the evaluation made with questionnaires. Approximately 35% of the total staff participated in this section. There were four STEG-educated users and all of them participated in the evaluation, which for them consisted of unstructured deep interviews before and after the deployment, as well as participating in the two questionnaires. See more in Paper II.

Evaluation of MULTI-STEG at train traffic control centre 2

MULTI-STEG was also implemented as an additional module on top of the regular train traffic control system. The system was tested operationally for six months at one segment of the main rail line in northern Sweden, consisting of single track lines with iron ore freight traffic.

At centre 2 the new system, MULTI-STEG, was part of a test with three work stations for cooperative planning of three different traffic areas. During the examined period only one operator station was implemented. A second objective was evaluation of CATO, a new system for automatic communication of modified route plans to train drivers. Train traffic control centre 2 was at the time procuring an update of their basic control system and therefore the decision was made that MULTI-STEG would not include the PEF (Planned Execution Function), earlier referred to as AEF (Automated Execution Function).

The evaluation at centre 2 was performed using unstructured deep interviews with both non-STEG users and STEG users in spring 2010 and autumn 2010. Interviews were performed before and after the deployment of MULTI-STEG.

Observations at the work place were performed before and after deployment, and a questionnaire was performed during the deployment period. Five of ten STEG-trained train traffic controllers participated in the evaluation and approximately 60% of the total staff answered the questionnaire. The users also kept a “digital diary” where they wrote down everything that came up in terms of questions and reflections about the system during the whole period of time. See more in Paper III.

5. Results

In the result section I will summarize the results from the papers included in this thesis. First I describe the results from the first paper where STEG was developed and deployed at a traffic centre in Sweden. The results of Paper II, III, IV, which describe the evaluation processes and the results of it at two different traffic control centres in Sweden, are structured according to the GMOC-model to clarify the results in relation to the theories.

At traffic control centre 1 the implementation of the STEG system was added as an additional module on top of the regular train traffic control system. STEG was running operationally at traffic control centre 1 and our evaluation period lasted for six months. After this period, the traffic planners were pleased with the system and decided to continue using it in their work. STEG was implemented at one segment of the main rail line from Stockholm to southern Sweden. This segment included one single track line and one double track line.

When using STEG the train traffic controller continuously observes the dynamic development of the traffic. The planning view in the time-distance-graph is automatically scrolling downwards as time evolves. When conflicts occur, considering for example track usage between the stations and at the stations, this is indicated automatically on the interface. This gives the train traffic controller more time to prevent and act in solving the conflict. Instead of working with immediate solutions they are now working approximately one hour ahead with planning the traffic. If the traffic is running without conflicts, as planned from the original state, the planned actions can be executed automatically by the AEF, which is a separate system. The train traffic controllers perform replanning in STEG, even if there are no occurring conflicts, in order to optimize the train traffic. However, STEG does not allow automatic algorithms to change the traffic plans, and therefore the human train traffic controller is always in control of the situation. The AEF never executes anything that the train traffic controller has not decided. The AEF is contributing to avoid automation surprises (Bainbridge, 1983). However, as STEG was not integrated fully with the existing control systems, this made it more problematic than it should have been during the deployment process. Additionally, some technical errors in old interlocking systems made the STEG system not work as planned from the beginning.

STEG also visualizes information in one integrated interface that before had to be searched for from several different sources. Information, such as track structure, train positioning, detailed information concerning trains and stations, are now integrated in STEG and this creates a better overview and situation awareness for the traffic controllers.

During the evaluation processes we did find that the basic concept, control by replanning in real-time, and automatic execution of the constantly updated traffic plans, was working in practice and was well accepted by the users.

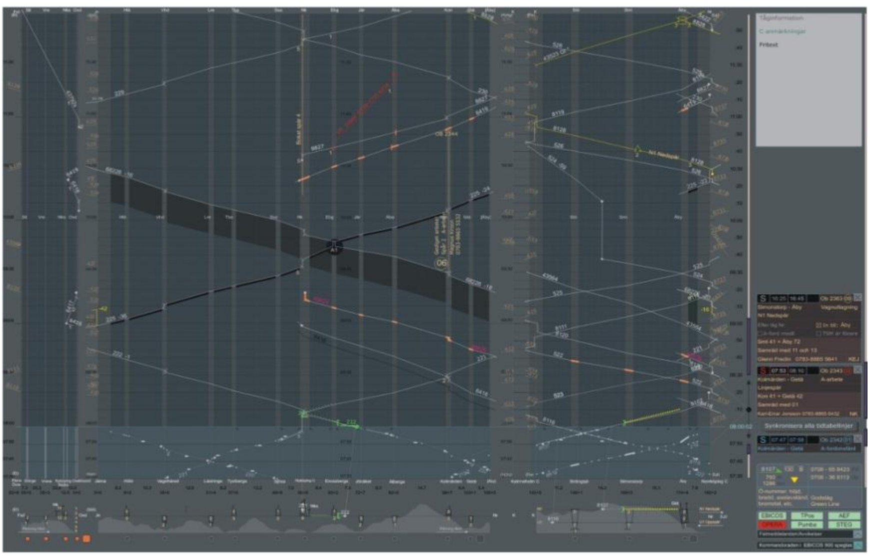

Figure 9. The figure shows the united interface including the planning view and the history in the time-distance graph, track structure, train and station information and planned maintenance work.

Goal-oriented results

At traffic control centre 1 the train traffic controllers have found that the accuracy of their plans has been improved with STEG. They also claim they have more time to execute more creative and optimal solutions to upcoming traffic conflicts. The feeling of actually reaching the goals, both their individual goals and the organization's more formal goals, made them feel contented after a work shift. They could better see that the goals of today's work as well as long-term goals were being reached.

The users at train traffic control centre 1 had constant feedback from project management, the development team and the design team, as well as experts in Human Computer Interaction. They understood well the goals and deadlines of STEG deployment and the education process. At traffic control centre 2 the new users did not receive enough support from these kinds of resources. They lacked the feedback and support in the demand-control-support-model, at the same time as the demands on them increased. The users at train traffic control centre 2 lacked understanding of the specific and clear goals of the deployment and education process. Citations from the interviews like: "I have no clue what is going to happen with STEG, I even heard rumours it will be shut down", indicates this. The goals for the organizational change, that are necessary when introducing a new system, were not clear and defined at traffic control centre 2.

Mental models-oriented results

At both centre 1 and centre 2 the STEG-educated train traffic controllers thought it easy to learn how to operate STEG. There was no need for them to change their planning strategies, because STEG already supported their mental models of working with train traffic disturbances. Citations from the interviews like: "I did not need to change my way of thinking when using STEG and I did not need to keep track of all the information I usually have to gather from other systems or just guess what has happened", indicates that STEG not only supported their mental models, but also that the users don't need to use unnecessary cognitive load when gathering information. The feeling of STEG as an efficient tool at this early stage of usage is proving that the new control principles and systems, developed through our research and studies on how the train traffic controllers really think and act, work in practice. The traffic controllers felt their work has been made easier when using STEG and this can also be an indication that the system is supporting their mental models. Citations like: “I am not as tired as I used to be when I use STEG and feel less stressed after a day with STEG”, indicates that STEG is reducing unnecessary cognitive load. STEG also provides the users with better feedback about the history of the actual traffic situation which is good for learning and developing skills, and strategies for solving traffic problems. This feedback can enlarge their problem spaces (as mental models can be viewed as).

STEG allows them to try different scenarios and see the consequences of their actions before they make a final decision. Using scenarios as they do in STEG can provide them with more complete knowledge and quickly create a basis for the “map” of problem solving, skill-based problem solving and rule-based solutions known as mental models needed for becoming a skilful train traffic controller.

The attitudes towards MULTI-STEG among younger and older traffic controllers at train traffic control centre 2 were different. The younger traffic controllers were more positive and could see the benefits with MULTI-STEG, while the older traffic controllers felt that MULTI-STEG could never outshine their expertise, skills and long experience. Citations from the interviews point towards this: “I don’t trust the system, but I trust my own knowledge and experiences”. The citation is also an example of how inadequate education effect attitudes towards the system and understanding of how the system is intended to work. The two attitude groups of more experienced and less experienced operators at centre 2 might have a negative effect on the expectations of a new system.

Observability-oriented results

The train traffic controllers experience that STEG and MULTI-STEG give them better decision support in their every day work, because they can see the effects of their decisions before the decided decisions are executed. Citations like: “It is now easier to detect conflicts and I can try different solutions before I decide what is best to do. It gives me a better overview of every part of the traffic problem”, points out that STEG and MULTI-STEG create a better overview of the traffic situations.

More citations from the interviews like: “Now I can plan the traffic and test different options before executing my actions” and “I feel like I have a better overview with STEG”, further indicate this. The traffic controllers can see the consequences of their actions and they know where they are in the process which contributes to a better picture of the traffic situation, it enhances the feeling of being in the loop. In STEG and MULTI-STEG the trains' dynamic movements and positions also contribute to a better understanding of the traffic process. STEG, as well as MULTI-STEG, is displaying the information they need to make decisions about the traffic. This information earlier had to be gathered from several different systems, integrated in their own minds and not shared with colleagues. But the new system eases the burdens and reduces the cognitive load. STEG and MULTI-STEG seem to create a better understanding and a more refined overview of the traffic situation, hence their situation awareness increases.

At traffic control centre 2, the education of MULTI-STEG was intermittent. The education management focused on teaching the functions and commands in MULTI-STEG and did not teach enough about the way of thinking about the work tasks. The AEF was not implemented due to an upgrading of hardware in the existing control system. Without the AEF, MULTI-STEG is not as meaningful in making high precision plans because you have to execute them by yourself anyway. The planning in MULTI-STEG therefore lost its most important part. MULTI-STEG then created restricted benefits and no system feedback, and the observability was not as required. The purpose with MULTI-STEG was not fully evaluated due to only one station implementation.

Controllability-oriented results

When the traffic controllers are using STEG they experience that they can make more exact predictions. This is beneficial to their colleagues who are depending on them to make correct predictions and also for providing information to the passengers about arrival times for trains. MULTI-STEG also has the ability to constantly inform colleagues about changes in the traffic that will affect their control areas. As mentioned before, the traffic controllers are able to identify potential conflicts earlier and therefore experience more control over the system and their work. They are not surprised at the last minute and do not have to feel stressed about this. STEG and MULTI-STEG are contributing to a more continuously work process that keeps them alert and focused at all times. Despite the focus, they do not feel tired or stressed when using the new system. Actually they feel less stressed when using STEG and MULTI-STEG because of the increased control. The train traffic controllers rely more on the new automatic system AEF than the old automation programmes embedded in the control system. The trust placed in STEG and MULTI-STEG shows in citations like: “I trust the information displayed in STEG and I feel like I am in charge when I am working”. The displayed information gives them the support and control they need to better meet the demands they are facing.

At traffic control centre 1 the users had been involved in the development process and they felt strongly about “their” product. At traffic centre 2 the users felt they were being forced to use a new system that they did not have the chance to influence. “It felt like they just threw this system at us and did not ask us how we felt about it” and “our traffic situation here is different and specific, and can’t be compared to centre 1” are citations from the interviews. During the education the train traffic controllers felt they did not get enough feedback and could not get answers to their upcoming questions. “I had no one to ask when I got stuck in the system” was mentioned in the interviews and since they only used one operator station, they did not see that they could work more closely together and use each other’s experiences and information to make better decisions and find more optimal traffic solutions.

6. Discussion

In this section I will point out some of the problems encountered during the research work and what might have affected the results. I will also discuss some of my reflections about how the new control paradigm is affecting train traffic control and train traffic controllers, as well as important aspects of the deployment process of new control systems.

Reflections on research outputs

During our evaluation at traffic control centre 1 there was a problem with a shortage of staff trained in operating STEG. This might have influenced the results.

At traffic control centre 2 the deployment project was delayed. The PEF was not deployed due to upgrading of the existing control system and therefore this function, which is one of the basic features with STEG, could not be fully evaluated. STEG was used more as a digital planning tool rather than for control and information sharing. MULTI-STEG was intended to be tested on several work stations at the same time, but was only deployed at one work station, therefore, we could not evaluate the outcomes of shared dynamic information. CATO was only implemented in one locomotive in the iron ore line. This made it difficult to evaluate the total effect of the CATO system. We were not able to evaluate whether CATO and STEG supported better planning and if the train driving was more energy efficient. CATO had some technical problems and was not working as desired, which meant that train drivers sometimes ignored the system. The train traffic controllers were also not customized to share information and the replanned traffic plans with train drivers, and this prevented them from fully using the problem solving possibilities. The goal was that train traffic controllers and train drivers could share the same information and act on that. In the future the goal is that all stakeholders share the same information. If train drivers, train traffic controllers, train companies and passengers share the same information it is easier to make decisions to solve traffic problems and all are able to know where in the process they are. The information from the updated traffic plans will in the future be made available to the train drivers, hopefully with additional positive effects on traffic flow, energy consumption and punctuality.

The STEG system was, as mentioned before, implemented on top of the existing traffic control system meaning that there was an extra computer keyboard and mouse at each traffic controller’s work place. STEG is controlled by the computer mouse and these kinds of movements have increased. Some of the train traffic controllers have been complaining of pain in their shoulders after operating with STEG. Alternative devices for interaction should be further explored.

According to the questionnaires performed before the implementation of STEG, with regard to the answers on how they experienced their work from the four educated train traffic controllers at train traffic control centre 1, there were significant differences to the train traffic controllers who were not operating with STEG, and one has to consider the factor of bias in this case.

Thoughts on how the new control paradigm affect train traffic control

When train traffic controllers are using STEG, even though complications and disturbances in train traffic occurs, it seems as though the train traffic controllers can still visualize the goal and know what they are working towards. They can more easily create an overview of the traffic situation and see the consequences of their decisions before they execute the decision. They can try out different scenarios before executing the decision and can see which action matches the goals. When MULTI-STEG is used in its full extension it gives the train traffic controllers the chance of working towards common goals and using common strategies to solve problems. This feature can also provide new train traffic controllers with methods to solve upcoming problems because of the opportunity to learn from experienced traffic controllers.

It is also interesting to consider if STEG is changing their mental model about the train traffic system or if the system is better supporting the creation of mental models of the system. Referring to Paper IV in this thesis, it is more likely that STEG is supporting them in the construction of mental models and can therefore reduce unnecessary cognitive load. They do not have to keep in mind information that is necessary for decision making when solving problems, instead, the information is displayed to them. STEG gives the train traffic controllers opportunity to focus on more high level tasks such as solving traffic problems more efficiently, rather than low level tasks that can be transferred to more automated routine tasks, as Rasmussen is explaining in his model of cognitive processes. STEG seems to reduce the complexity in train traffic control and therefore reduce the unnecessary cognitive load that occurs when focusing on the wrong things. STEG is supporting the mental models and therefore train traffic controllers probably will develop skills faster. They will be skilled in their main tasks, i.e. handling disturbances and deviations from the preplanned traffic plan, solving conflicts etc. With STEG, train traffic controllers can focus on optimizing problem solving.

The train traffic controllers felt that STEG gives them a better overview of the traffic situation and facilitates their work.

Interviews at the beginning and end of the evaluation periods showed that the feeling of having control was increased towards the end of the test period. It is important to remember that every new system has thresholds to overcome. New users' first focus is just to learn the systems' functions. Then it is possible to take advantage of the system in their work. In addition to proper support and demands, the feeling of control can be increased and reduce stress at work.

Thoughts on deployment

When introducing a new system to users it is important to use a user-centred approach in the deployment phase as well in the development phase of a system, see Paper IV. Today train traffic controllers handle the system how it is, with all its malfunctions. They learn to work "around" built in problems and that becomes the normal state of the system. Developers and designers develop systems based on how it should be, and not how it is. This is contradictory and maybe an answer to why so many new systems fail when introduced to the users. It is also important when introducing a new system to look into the organization. New systems often need to be faced in tandem with organizational changes. New systems change the work tasks of the users and therefore affect the whole organization. There needs to be a combination of systems development and organization development when deploying a new system. This is an iterative process and the changes influence each other. Also, I think one of the problems with projects aiming at developing and implementing new systems into a work place is that the project itself is often finished with the implementation part. Management forgets to include the highly creative phase right after implementation in project plans and project budgets. As a consequence the new system will be less useful, because the users' important opinions are not captured.

As seen in Paper IV, some of the features in the GMOC-model were missing in the deployment process at train traffic control centre 2 and they were not as successful as train traffic control centre 1 in their deployment process.

7. Concluding remarks

The experiences so far are that the new control principles and interfaces contribute to improved quality in train traffic control, better possibilities to plan and solve conflicts in time and to use cognitive capacity to strive for more optimal solutions.

To manage traffic effectively requires sophisticated mental models of traffic systems, signal and safety systems and maintenance work. It appears that traffic controllers use highly sophisticated mental models, i.e. empirical pictures of how everything works, how different features interact, how the processes develop as functions over time etc. As today's user interface does not show all information needed for the construction of the mental models, it is necessary to devote a lot of time and effort to create these models. This effort is not conscious, but affects the work and means that it takes a very long time to become truly skilled in being a traffic controller. The introduction of STEG has probably enhanced the conditions needed to create the mental models necessary for the goals of the traffic controllers and their organization. Traffic controllers have access to more comprehensive information in one unified system, which gives a better basis for decision making and better explaining of where in the process they are. This means that when they do not have to scan several different systems for relevant information, they reduce the cognitive load caused by unnecessary work tasks and increase the feeling of being in control. With STEG they perceive the status of the process better because STEG is supporting them with comprehensive information and presents it in an efficient interface. The situation awareness is increased. STEG has a dynamic interface and shows the exact positions and speeds of the trains, and therefore creates an overview of the traffic situation in a way that was not possible with the old systems. The train traffic controllers can use their cognitive capacity to make optimal plans for the traffic instead of using it on unnecessary and resource demanding mental activities. With the old system they use a lot of cognitive capacity just to understand the traffic situation, but with STEG they can reduce this unnecessary cognitive load. It seems that STEG is also more consistent with their existing mental models, created through long experience in train traffic control. Their mental models seem to be supported by the interface of STEG. STEG does not strive to make their work easier and less complex, but STEG interface gives them the opportunity to focus their cognitive capacity on the most important tasks, such as planning and optimizing the train traffic, as well as dealing with critical situations.

Our results show that it is important to take users' mental models into account when designing a control system. As a designer, it is therefore important to understand the users' tasks and what they actually do in their work. If a system is consistent with the users' mental model, it is probably faster for the users to learn the new system because they have no cognitive “clash”. It is also important that the system supports the development of mental models and therefore shows all the information needed by the user to make decisions and to obtain situation awareness.

It is also important to analyse which parts of the users’ work are really important. That is used to be able to design interfaces that reduce the cognitive load of unnecessary tasks and free cognitive capacity for the really important work, in our case traffic planning and optimization. Then the users do not have to keep information in their mind when they try to maintain an overview of their working processes and make optimal decisions. The system must support the goals and mental models of the user, as well as give them controllability, observability and situation awareness.

All traffic controllers that have used STEG so far have been experienced controllers. We do not know what the effects will be for new traffic controllers who start their professional life using STEG.

8. Future work

In this thesis I have presented a thorough evaluation of the new control paradigm and STEG, but in the future I will focus more on how STEG changes the organization and work roles, as well as develops competences and skills. These initial studies were necessary to conduct in order to understand how the train traffic controllers work and how they think about their work tasks.

Train traffic controllers probably develop strategies to solve upcoming conflicts and problems, and with STEG it is possible to share these strategies and use feedback to enhance the learning loop. Maybe it is possible to develop common strategies and methods of problem solving with STEG. Trafikverket is changing their organization and it will be interesting to see how this will affect the train traffic controllers' situation and work roles.

Furthermore I will have the opportunity to study how other countries in Europe handle their education of train traffic controllers within the project "On-time" financed by the European Union.

NTL – the future system for national train traffic control

STEG is solving the real-time replanning for individual traffic segments and MULTI-STEG does the same for larger traffic areas, with more users collaborating in solving train traffic conflicts. MULTI-STEG supports common solutions and strategies for the train traffic controllers, however, this is not enough to optimize train traffic in Sweden. Today the traffic is controlled as several isolated traffic segments in each of the eight regional control centres. To obtain continuously updated traffic plans that cover the entire traffic system, a national system and organization must be created that integrates all separate traffic plans. On this national level more strategic decisions regarding planning can be made, which better coordinate the local and regional activities. Trafikverket has initiated a project to solve this called NTL - Nationell TågLedning (National Train Management in English) - and will implement STEG at all traffic centres in Sweden. Furthermore, it will look into the changes that are necessary to be made within the organization as well as the work places regarding ergonomics and information overview. In this project the communication with the train drivers will be developed, possibly based on the CATO system. The traffic controllers have to be given the chance to communicate their new plans to the train drivers in an efficient way. In 2015, NTL is to be deployed at one train traffic centre in Sweden as a prototype to be tested and evaluated. In 2018, NTL is preliminary to be deployed nationwide. It is going to be interesting to follow this process and what happens to organizations, work roles and learning skill strategies.

Traffic control in complex stations

STEG is a system that functions very well when controlling train traffic on the traffic lines between stations, but for controlling train traffic inside large complex stations another system must be developed.

STEG functions well in complex stations, but needs to be enhanced especially when it comes to more complex stations such as Stockholm, Malmö and Gothenburg, where a large number of trains occupy the tracks in high frequency. The design of support systems, such as interface elements and decision support functions, for traffic control in more complex stations needs to be investigated more thoroughly. This is part of the NTL project as well and is called STRATEG. To specify a complete traffic plan from start to end station, complex stations must also be covered by the replanning tool.

A prototype in smaller scale has been developed at traffic control centre 1 and is about to be tested and evaluated during the coming year.

Learning and education

It is our hypothesis that STEG can shorten the time it takes for traffic controllers to become skilled in their profession. STEG seems to have an interface that supports the mental model building. The fact that the mental models do not need to be as extensive with STEG's interface, will shorten training time for future train traffic controllers. If our hypothesis is valid remains to be seen, but this can only be studied in the future, because we have to make a comparison between train traffic controllers who learn their profession using STEG from the beginning.

STEG enables information sharing in a new way and hopefully this will contribute to an enhanced cooperation and exchange of experiences between the train traffic controllers.

9. Acknowledgements

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Paper I

Development and implementation of new principles and systems for train traffic control in Sweden

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Abstract

The trend towards higher speed, more frequent traffic and many traffic operators requires new strategies and solutions for efficient train traffic control and utilization of track capacity. Operative control is today focused on controlling the infrastructure. In earlier research we have shifted the control paradigm from today's technology oriented into a more traffic oriented one. This is done by real-time re-planning. The continuously updated traffic plan is normally executed by automated systems. After tests and evaluation in a simulated laboratory environment, the Swedish Rail Administration (Banverket) decided to develop and deploy an operative system to be installed at a traffic control centre. This system, called STEG, implements the main research results. Features of the new system are a dynamic planning view in form of a time-distance graph, decision support that helps the controller to identify disturbances and conflicts and automatic systems for execution of the traffic plan. The traffic controller can re-plan traffic (time aspects, track usage) via direct manipulation of the graph lines in the interface. Track maintenance and other activities can also be planned. The system automatically calculates all consequences of the changes and shows the effects on all trains within the actual time-distance space. A very careful process has been used to go from research results and prototypes to a fully operational system. The process has been very user centred and numerous iterations have been performed. Through this elaborate work we have been able to ensure

that the intentions of the prototypes have been correctly implemented in the final product. The new operative planning and control system will be tested and evaluated during spring to autumn 2008. Preliminary results and experiences will be presented.

Keywords: Train traffic control, dispatching, traffic planning, user interfaces, automatic execution.

1 Background

Tomorrow's train traffic, with higher speed, more frequent traffic, mixed traffic and many independent traffic operation companies, 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, conflicts and disturbances and to solve acute problems and conflicts. However, in order to perform efficiently, operators should be able to follow the dynamic development of the traffic system over time and prevent disturbances. In order to achieve this, we must change the control paradigm from technical control of the infrastructure into higher level traffic planning tasks. This is done by replacing the traditional control commands by real-time re-planning (Andersson et al [1], Sandblad et al [7], Wikström et al [9]).

Advanced laboratory prototypes have successively been implemented and tested. By connecting user interface prototypes to a train traffic simulator, Sandblad et al. [8], it has been possible to perform experiments with the design of new user interfaces and decision support tools, and to test and evaluate new control strategies for the train traffic control operators. Based on numerous laboratory experiments, a step has now been taken in order to build a fully operational system and to test and evaluate this in a real traffic control centre environment.

2 Earlier research studies

Our research has been 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 tasks. The research has consisted of mainly the following steps:

- Observations and interviews with dispatchers and other professionals at the traffic control centres. Analysis of the findings and identification of problems and development areas.

- 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 have been specified.
- Iterative specifications and evaluations with the help of a working group consisting of experienced operative traffic control professionals.
- Tests and evaluations in a laboratory control room environment using a train traffic simulator system.

In order to support real-time planning of train traffic we provide the traffic controller with an interactive computerized time-distance graph. Prototypes of new user interfaces that support the new control strategy have been designed, implemented and preliminary tested in the laboratory environment at Uppsala University. The interface is designed to integrate all decision relevant information into one unified interface and to support continuous awareness of the dynamic development of the traffic process, Kauppi et al [5].

The computer based time-distance graph is designed in such a way that it visually supports the operators' situation awareness of the current status and the projection into the future (Endsley [3]). The user interface, with its planning view, can support early detection of upcoming conflicts, identify possible re-planning alternatives and their predicted effects. The 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 hinder this. Automatic functions that support execution of the traffic plan must be transparent, predictable and easy to understand. The automatic functions must never change the controllers' traffic plan but are only allowed to strictly execute the actual traffic plan. The traffic plan mainly consists of time table and track usage information, including maintenance work. Detailed interface design, easy to interpret, concerning the automation helps to keep the human in-the-loop and to avoid automation surprises (Bainbridge [2]). By re-planning, the operator is in control of what the automatic function will do and when. Hence, the operator is continuously in full and active control.

We have also evaluated different approaches to include decision support systems in operative train traffic control (Hellström et al [4], Kvist et al [6]). We have found that more advanced automated decision support systems are today not a realistic alternative of several reasons. More research and development of methods are needed in this field. We have decided to focus our efforts on supporting the controllers through better presentation of information, improved information observability and quality, help with early detection of conflicts and disturbances, identification of possibilities and limitations for re-planning and evaluation of effects of alternative actions.

3 From research prototypes to an operational system

Experiments with the new control strategy, operator interfaces, decision support systems and automatic execution functions have been performed in our laboratory environment with satisfying results (Sandblad et al [10]). Many important aspects can be investigated in the simulated environment at Uppsala University, but some issues must be evaluated in a real operative environment. To work in a laboratory environment, and to control a simulated traffic system, will always mean that we have simplified the situation. The real traffic system is more complex and stochastic compared to our laboratory models. The work tasks of the controllers are also more complex and diversified then what we can create in the laboratory, e.g. concerning communication with other persons in the complex and dynamic environment. It will never be possible to evaluate all relevant aspects of the new control system in a pure simulated environment.

We also face large practical and economic problems when the laboratory prototypes shall be implemented and deployed as a part of the real train traffic system. It will not be possible to develop a complete traffic management and control system only for test purposes, but we must implement the new control functionalities on top of the existing basic control infrastructure. Our prototype system has a focus on planning, re-planning and automatic execution of control commands. All other tasks are not supported by functionality in our system. When malfunctions in the infrastructure hinder the automatic execution the controllers must go back to the old control system. Thus, the new control system, control by re-planning, must for test purposes be implemented as a complementary module to the existing system.

The research and technical implementation questions that we try to answer in the project are mainly:

- Does the new control paradigm, principles, tools and interfaces really contribute to more efficient traffic control and a better work environment for the traffic controllers?
- Is it possible to implement the new control principles and tools as an integrated part of the already existing infrastructure? What of the original ideas must be changed in order to make the implementation possible and economically realistic?

- How can our research prototype support requirement specifications and evaluation for the implementation and development process?

4 The STEG project

4.1 Project phases

The STEG project has been divided into several different steps or phases. On a high level the following main steps have been identified:

- Benefit-cost analysis.
- Risk analysis and assessment of the project as such, including backing procedures if certain parts of the project fail.
- Identification of test site. A test site was selected that fulfilled a number of requirements, e.g. availability of different track structures, single track, double track, mixed traffic types, more complex stations, connections to other traffic control regions, availability of input data for track diagrams, technical specifications etc.
- Requirement specification for the test system.
- Several different technical investigations concerning compatibility, availability of input data, technical platform, technical performance, safety, security, communication etc.
- Specification and test of control algorithms, e.g. for the automatic execution of control commands from the traffic plans.
- Technical development according to specified development model, including a user centred process.
- Implementation. Operative tests and evaluation.

4.2 The development phase

Of special interest in a research context is the process to come from the research prototype to a fully operational system without loss of essential requirements and functionality. This has successfully been achieved through a very close cooperation between researchers, designers and developers, including numerous iterations. We have earlier found that it is not so easy to create a system that to full extent meets all relevant requirements.

In this project there has been a very strong focus on usability issues, minimizing the operator’s mental workload, support of the operator’s situation awareness, avoiding automation surprises etc. In order to achieve all this in an optimal way, it is not possible to supply the technical development team with a comprehensive list of requirements, and passively wait for the final system. Every step in the development process must be followed, analysed and evaluated by skilled interface designers with a deep knowledge in appropriate knowledge areas. Of course this requires both enough time and resources together with a development team that is open to continuous iterations, tests and modifications.

5 The STEG system today

The STEG system is today implemented as an additional module on top of the regular train traffic control system. This allows the traffic planner to go back to the old traditional system at any time. Via STEG the traffic planner can continuously observe the dynamic development of the traffic within the actual track segment. The planning view in the time-distance graph is automatically scrolled downwards as time evolves. Identified conflicts with respect to track usage on the train lines or in the stations are automatically indicated in the interface. Such conflicts can now be early identified and eliminated by the traffic planner by re-planning of time table and track usage for each train involved in the conflict. Other sets of information shown in the interface are track structure, train positioning, detailed information concerning trains and stations etc. The user interface is continuously updated by dynamic data from the train traffic and signalling system. The results of all re-planning actions and the total effects of the valid traffic plans are always shown in the interface. See figure 1.

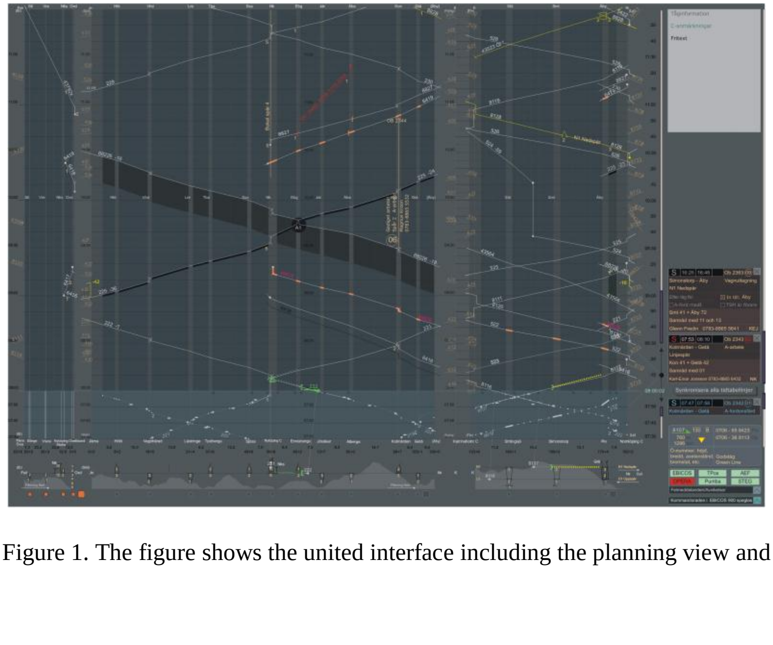

Figure 1. The figure shows the united interface including the planning view and

the history in the time-distance graph, track structure, train and station information and planned maintenance work.

Through manipulation of the time-distance graph lines, directly in the user interface, the time-table and the track usage can be re-planned whenever the traffic planner finds this appropriate. See figure 2. When the traffic plans are without conflicts they can be automatically executed. This is done by a separate system that executes the plans exactly as they are specified by the traffic planner. By not allowing the automatic algorithms to change the traffic plans, all "automation surprises" (Bainbridge [2]) can be eliminated. The human traffic planner is always in total control of the situation.

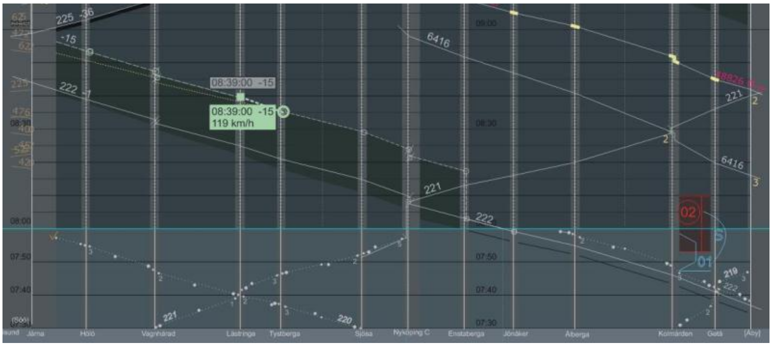

Figure 2. The figure shows re-planning of a selected train. The traffic planner can easily change arrival time, departure time or track usage for the selected train and station.

6 Preliminary tests and evaluation

The STEG system has been used for operational tests at a Swedish train traffic control centre. Via STEG traffic planners can monitor and control by re-planning one segment of the main rail line from Stockholm to southern Sweden, including one double-track line, one single-track line and some less frequently used freight traffic lines.

The experiences so far, when the test period is not finished, are mixed. On one hand the system works according to the intentions and requirements. On the other hand a number of different problems have appeared which have made the tests somewhat problematic.

We have found that the basic concept, control by re-planning in real time and automatic execution of the traffic plans, is working in practice and is accepted by the traffic planners. However, we have also been faced with a number of problems of a more practical nature. Some of the more important problems and obstacles, which have disturbed the tests so far, are:

- Technical errors in old interlocking systems, difficult and expensive to eliminate.
- The user interface should show more relevant states of the automatic execution system. Otherwise the traffic planner will not be able to predict the effects of technical malfunctions.
- A larger presentation area would improve the usability.
- Lack of a complete integration with the ordinary traffic control and signalling system leads to robustness problems.

More advanced tests and evaluation procedures are planned for the remaining test period. These include e.g. data analysis, observations, interviews, questionnaires and video recordings with following analysis of the planners' behaviour. The evaluation will focus on two main questions: does the system contribute to better traffic performance and does the system contribute to more efficient work of the traffic planners. The full results of the evaluation will be presented later.

7 Future research

From our earlier research and experimental studies in the laboratory, which has been shortly discussed above, we have a more or less complete solution for the new proposed control paradigm, control by re-planning. When the operative test system is being specified and developed, it is not possible to implement the full prototype system. Some parts are not relevant to the operative test environment, other parts are not possible to implement because of limitations in the existing infrastructure etc. Some of the more important, and from a research point of view most interesting, problem to be solved in the future are:

7.1 Traffic planning on a national level

It is not enough to solve the re-planning problem for individual traffic segments. In Sweden today the traffic is controlled as several isolated traffic segments in each of the eight regional control centres. In order to obtain continuously updated traffic plans that cover the total traffic system, a national system and organisation must be created that integrates all separate traffic plans. On this national level more strategic planning decisions can be taken, which better coordinates the local and regional activities.

7.2 Automatic execution functions

The purpose of the automatic execution functions is to generate and deliver control command sequences to the underlying control system in time. Because of the lacking quality in traffic predictions, the algorithms must have large margins. This results in a non optimal performance. Measures to improve precision in data are most important, since this can significantly improve the total performance. The traffic controllers could e.g. be allowed to update the traffic plans closer to real-time. The actions of the automatic functions must be clearly shown in the user interface in order to support good situation awareness and avoid automation surprises.

7.3 Detailed track diagrams

Today it is unclear how much track diagram information that is needed for the controllers. The presentation must be detailed enough to support the understanding of conflicts, status of the infrastructure, restrictions and degrees of freedom in the re-planning activities etc. Different level of detail in the presentation will be tested in the future.

7.4 Traffic control in complex stations

The design of support systems, e.g. interface elements and decision support functions, for traffic control in more complex stations is not investigated enough. In our operative test environment we will not cover complete traffic regions, and because of that we do not now need advanced solutions. On the other hand we will not be able to evaluate the total performance. In order to specify a complete traffic plan, from start to end station, also complex stations must be covered by the re-planning tool.

7.5 Work environment and design of the workplace

We have a rather detailed picture of what kind of presentation system that is needed for optimal performance and a good work environment. This should require very large presentation areas with high resolution and quality and without disturbing frames. Because of economic and practical reasons, we will not be able to implement an ultimate technology. The exact lay-out of the work place will be made so that the individual traffic controller has an optimal solution concerning ergonomics and information overview.

7.6 Remaining design and implementation questions

There are some important problems concerning the available technical solutions that we will not be able to solve within the STEG project. This will restrict our possibilities to develop efficient support systems and to evaluate the new control paradigm. The two most severe limitations in this respect are:

- Train speed and position. There are no technical solutions available that now allow us to observe train speed and position with high precision. Today the best precision is the identity of the block section. In the future positioning systems with a high precision will be available.
- Communication with train drivers. Today we are not able to automatically communicate new traffic plans to the train drivers. This means that the train drivers will drive according to old and obsolete plans. By doing so they will not be able to perform optimally. In very urgent cases the controllers can phone the train drivers to inform them about changes in traffic plans, train stops etc. It is also not possible for the train drivers to easily inform the traffic controllers about late departures, speed restrictions caused by machine problems etc. In the future we will have efficient communications links for such purposes, e.g. when ERTMS/ETCS systems have been fully implemented.

8 Acknowledgement

This project has been financially supported by the Swedish National Rail Administration. We especially thank all professional traffic controllers and planners who have been engaged in the research and test activities.

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Paper II

OPERATIVE TESTS OF A NEW SYSTEM FOR TRAIN TRAFFIC CONTROL

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Keywords: Train traffic control, dispatchers, operator interface, decision support, situation awareness.

Abstract

Tomorrow's train traffic systems requires new strategies and solutions for efficient train traffic control and utilization of track capacity, especially in traffic systems with a high degree of deregulated and mixed traffic. There are many different goals associated with the traffic control tasks and the work of the traffic controllers (dispatchers). Examples are safety, efficiency of the traffic with regard to timeliness and energy consumption, good service and information to passengers and customers etc. Today's traffic control systems and user interfaces do not efficiently support such goals.

In earlier research we have analyzed important aspects of the traffic controller's tasks, strategies, decision making, use of information and support systems etc. Based on this research we, together with Banverket (Swedish Rail Administration), have designed prototype systems and interfaces that better can meet future goals and contribute to more optimal use of infrastructure capacity.

1. Introduction

In Sweden there are eight train traffic control centres distributed in different geographical locations that operate the train traffic in their specific region. At the centres the current status of the train traffic is displayed on regular computer screens together with large distant panels. Important work tasks for the train dispatcher include monitoring the train movements and by automatic and manually blockings control the train routes. The dispatchers only intervene when conflicts or disturbance occur, which is called *control by exception* (Sandblad, Andersson, Frej & Gideon 1997; Andersson, Sandblad & Nilsson 1998). Dispatchers today use pen and time-distance graphs on paper in order to solve and record their solutions to upcoming conflicts and delays in traffic. There is no efficient support to communicate updated traffic plans to concerned colleagues. Today's systems are designed for the dispatchers to react on deviations in traffic, instead of being able to follow the dynamic development over time and prevent conflicts. One important concept for improving the work of controlling train traffic during this research has been to change the control paradigm from low-level technical control tasks into higher-level traffic re-planning tasks, as mentioned in Kauppi, Wikström, Hellström, Sandblad & Andersson (2003). In order to evaluate concepts and ideas derived from the research a system called STEG has been developed. STEG is designed to provide efficient user interfaces and better decision support in order to give the dispatchers possibilities to be continuously updated and able to evaluate, act on, and prevent future potential traffic conflicts in advance. The control concept also provides the foundation for the sharing of updated traffic plans and information to concerned colleagues more efficiently since the information is available for digital exchange. The STEG system has been tested in operative environment in one of the traffic control centres in Sweden.

2. Control strategies

2.1 Background

Over a period of many years we have collaborated with the Swedish Rail Administration in order to analyse, develop and evaluate techniques and new principles for train traffic control. Earlier research studies have consisted of mainly the following steps:

- Observations and interviews with dispatchers and other professionals at the traffic control centres. Analysis of the findings and identification of problems and areas of improvement.
- Seminars with experienced professionals from the national rail and traffic control administrations. Here the visions and restrictions for future development of control systems have been specified.
- Iterative specifications and evaluations with the help of a working group consisting of experienced operative traffic control professionals.
- Tests and evaluations in a laboratory control room environment using a train traffic simulator system.

(Sandblad, Andersson, Kauppi &Wikström 2005)
This was the foundation for the STEG project that is more thoroughly described by Sandblad, Andersson, Kauppi and Isaksson-Lutteman (2008).

2.2 Today's train traffic control, control by exception
Swedish dispatchers today is conducting their work by supervising the displays which indicates the current status of the train traffic and by manual operations redirect trains in case of disturbances from the original programmed traffic plan. They are collecting information from several different information systems. Among other things a paper based time-distance graph that can be used for planning and documentation. Although when short of time and heavy traffic load, the new planning only takes place in the dispatchers' minds and they have to calculate the potential conflicts without any decision support. This is of course increasing cognitive work load and reducing capabilities to explore and create better traffic solutions that more efficiently would utilize the infrastructure. Also the dispatchers' new strategies can counteract the unpredictable and complex automatic system because the plans are not automatically incorporated into the system and can therefore cause an unnecessary conflict and problems for the train traffic. This is referred to as automation surprises when control actions of the automates contradicts the dispatchers' mental plans. (Bainbridge 1983). The result of this is when the dispatchers are in most need of

automation they feel forced to take manual control of the train traffic instead, evoking unnecessary executions of manual commands. Billings (1991) is reporting that the probability of human failure in monitoring automation increases when operators are not alert to the state of the automation. To summarize this section the dispatchers today is not provided with adequate tools to perform optimal solutions during severe traffic disturbances. High cognitive workload induced by intensive manual control and extensive verbal communication, may unfortunately cause dispatchers to execute less than optimal traffic solutions.

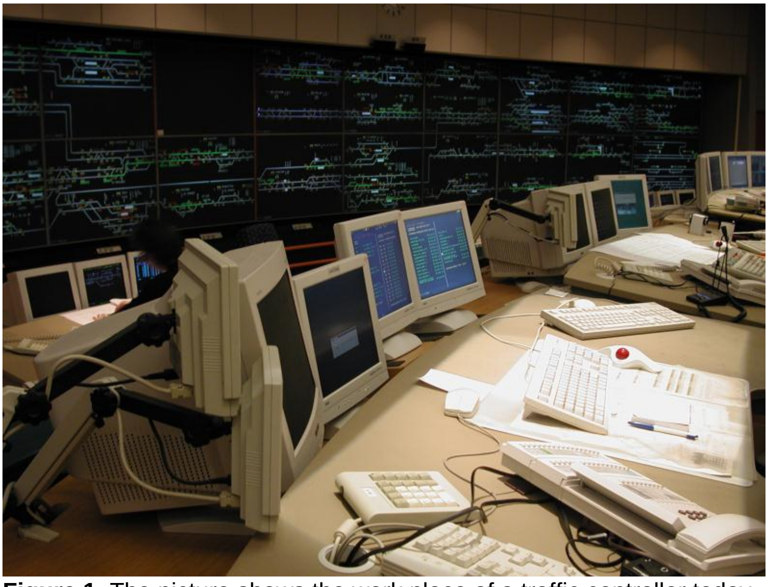

Figure 1. The picture shows the work place of a traffic controller today at the train traffic control centre in Stockholm, Sweden. The picture is displaying large panels, smaller computer screens as well as a paper-based time-distance-graph.

2.3 Human Factors theories behind the new design principles and the new system

There are many different human factor aspects that have been considered in analysis of the present control tasks and procedures as well as in design of the new principle, system and user interface. It is not possible to describe this in detail here, but these are the main aspects that we have found to be necessary to relate to.

A model of human control

We have developed a very useful model for description and analysis of human control work situations. Main components of this GMOC model (Andersson, Sandblad, Hellström, Frej, Gideon 1997) are:

- Goals of different nature and on different levels, sometimes in conflict with each other.
- Model, meaning a mental model that helps the human operator to analyse and understand the behaviour of the system under control and supports their dynamic decision-making.
- Observability, i.e. the possibilities the human operator has to get information from the controlled system via the user interface.
- Controllability, i.e. the possibilities that the system offers the human operator to influence the behaviour of the system via the user interface.

Automated cognitive processes

Cognitive theories indicate that high level cognitive tasks, e.g. needed for reading and understanding texts, solve new problem situations, are demanding and "single processing". On the other hand, for low cognitive level tasks, e.g. well known and automated tasks, the parallel capacity is almost unlimited (Rasmussen 1983). This means that it is important to allow automatization of tasks and activities where this is possible, thereby leaving expensive cognitive capacity for solving work related problems, e.g. solving traffic conflicts, re-planning activities etc.

Automation problems

Most traffic control systems contain different automatic sub-systems intended to support the human controller. These automatic systems are often autonomous, as they are allowed to change the present traffic plan, e.g. train order, track usage etc. In disturbed situations the first action is often to turn off these of in order to gain full control over the situation. Otherwise the result will be "automation surprises" leading to sub-optimal solutions and confusion (Bainbridge 1983).

Situation awareness

We have seen that it is necessary to provide high situation awareness (Endsley 1996) in the design of the control system and the control tasks. We call this “control by awareness” in contrast to “control by exception”. The traffic controller must always be “in-the-loop” in order to perform control tasks efficiently.

HCI and interface design
From traditional human-computer interaction (HCI) we can learn a lot about efficient information coding and interface design. We have also found it extremely important to work according to a very user centred development model, therefore letting the experienced traffic controllers participate in all phases of the analysis, design, development and implementation phases. Use of scenarios and prototypes have shown to be successful.

A good work environment
In order to provide a good work environment for the traffic controllers it is necessary to create a good balance between experienced demands, degree of personal control over the work and social support (Karasek-Theorell 1990). Otherwise it may be difficult to meet demands with potential stress related problems and an un-healthy work situation as a result.. When the demands are very high, which they often are in traffic control, the control system and the user interface must provide good possibilities for high self control over tools, tasks and procedures.

2.4 Future train traffic control, control by re-planning
Kauppi, Wikström, Hellström, Sandblad and Andersson (2003) states “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 a clear *goal* and an accurate *mental model* of how the entire system works under various conditions. The system should provide the operator with good *observeability* 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).
The key in future train traffic control systems is control by re-planning, and to strive for situation awareness which is a base for good decision making and human performance. Endsley

(1988) defined *situation awareness* as "*the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.*"

The STEG system provide operators with the possibility to continuously improve the current traffic plan and directly see consequences of their decisions, because they do not only have access to the current status of the train traffic but also to the predictions of what will happen which improves the situation awareness. The actual plan is executed by an automatic function that do not change train order nor track usage in train routes; the human operator is always "in control" of the train traffic process and responsible for adjustments to any course of events. The STEG system's ambition is also to integrate several information systems into STEG's user interface in order to decrease the heavy workload involving all the information systems that the dispatcher have to scan to gather all decision relevant information necessary.

3. Testing STEG in an operative environment

3.1 STEG, a new system for train traffic control

Operative control is today focused on controlling the infrastructure mainly by giving commands for train routes. We have shifted the control paradigm into a more traffic oriented one. This is done by real-time re-planning of the traffic plan. The continuously updated traffic plan can normally be executed by automated systems. After tests and evaluation in a simulated laboratory environment, the Swedish Rail Administration decided to develop an operative system, STEG, which now is installed in a traffic control centre. Features of the new system are a dynamic planning view in form of a time-distance graph, decision support that helps the controller to identify disturbances and conflicts and together with automated systems for execution of the traffic plan. The traffic controller can re-plan traffic (time aspects, track usage) via direct manipulation of graph lines in the interface. The system automatically calculates consequences of the changes and shows the effects on all trains within the actual time-distance space. In comparison to other control systems in Sweden today STEG applies a different approach to automatic execution of train routes that reduces the risk of automation surprises and is more transparent to the human operator. See more about STEG in the article by Sandblad, Andersson, Kauppi, Isaksson-Lutteman (2008).

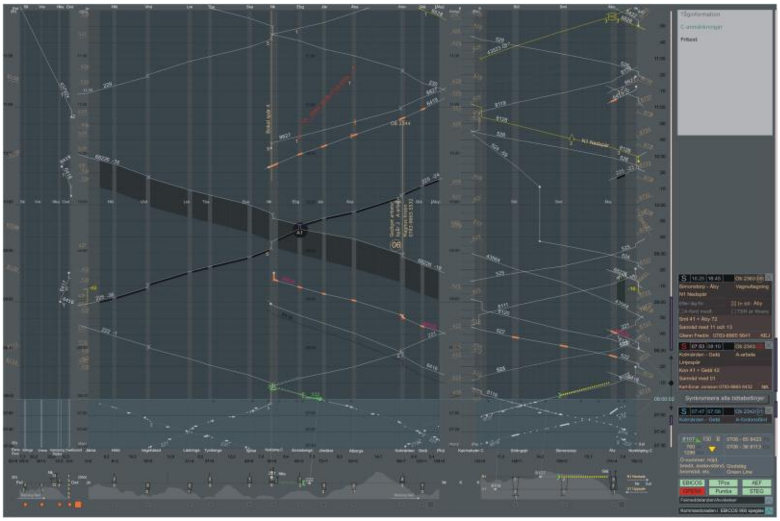

Figure 2. The figure shows the integrated interface including the planning view and the history in the time-distance graph, track structure, train and station information and planned maintenance work.

3.2 Lessons learned from the implementation period

Since STEG is a prototype, it was implemented to create and test alternative solutions regarding functions and design. The objectives for implementation were twofold: to find problems that indicates failure of the concepts and at the same time to create a detailed requirement specification for a “goal-system”, in case of success. The task to plan and control train traffic in real time is complex. The implemented functions are therefore complex. A user interface for complex functions is therefore also complex, but not necessarily difficult to learn or to use for a trained professional.

Each detail need to be implemented exactly as specified or else it may cause failure to the overall functionality. Most functions and design decisions have impact on many others. Some functions need to be created during the implementation process. However, it is not possible to decide about all details without iterative testing together with the users, the traffic controllers. To keep track of proposals, rejected and selected solutions and implemented alternatives, a rigorous formal structure for documentation is required. The requirements

and system specifications for a complex prototype system are comprehensive. The contacts between the designers and the system developers need to be extensive and at the same time strictly controlled. To utilise the creativity from all individuals involved in the implementation process is a prerequisite for success. This cause problems but at the same time ensure that the implemented solutions are in agreement with the complex integrated whole.
Due to economic aspects and limited time there have been a lot of tradeoffs between proposed functions. Some of the postponed functions needed to be implemented due to requirements from traffic controller as a result from the iterative evaluation process.

3.3 Description of the evaluation period

During spring and autumn of 2008, STEG has been tested at the train traffic control centre in Norrköping, Sweden. The STEG system has been implemented as a module that may be used on top of the regular train traffic control system. Four traffic controllers (dispatchers) have been educated and have been controlling the train traffic on the north area of Norrköping's district with this system in a total of 744 operative hours. The dispatchers have controlled the train traffic with STEG between 11 to 27 working periods each, every working period lasts 8 hours. The north area of Norrköping is occupied with passenger traffic as well as freight traffic. The area contains mainly single track lines but also some double track lines. During the test period several major external deviations occurred and the traffic had to be rerouted extensively which also affected the STEG system. The infrastructure has been under reconstruction during the test period which has conveyed traffic problems beyond the usual.

3.3 Description of the evaluation process

During the evaluation period the dispatchers have been writing an interactive "diary" where they put down their thoughts and proposals for improvements of STEG. The dispatchers have been part of the development process all along, within the collaboration between Uppsala University and Swedish Rail Administration, which is important in order to get a successful result when implementing new IT-solutions. (Gulliksen, Göransson, Boivie, Blomkvist, Persson, Cajander 2003). We have also performed semi-structured interviews, observations and a questionnaire in order to find out if the train traffic can be controlled with the STEG system. The same questionnaire was handed out before and after the implementation of STEG and was answered by total 14 people and 4 of them were the ones that operated STEG. Interviews and observations were mainly performed on the four dispatchers who operated STEG, but additional interviews and observations have been done on other dispatchers at the Train Traffic Control Centre in Norrköping. Our research team have also used and evaluated a new method called collegial verbalisation, for studying users that performs complex and time critical work, together with the four dispatchers (Erlandsson, Jansson, 2007). The results from this evaluation will be published later.

4. Results

The result of the questionnaires shows that it is possible to control train traffic with the STEG system. The four dispatchers who operated STEG are very optimistic to the new system. The questionnaires are showing small but important improvements in the work to control the train traffic. The dispatchers' experience of STEG is that it gives them more decision support in their every day work with the traffic, because they can see the effects of their decisions right away. They also claim that it is easier to detect potential conflicts with STEG because it is even easier to find out the trains' position and dynamic movement with STEG. STEG seems to create a better understanding and more refined overview of the traffic situation.

The dispatchers use the STEG system to maintain a more accurate and more updated plan for the next one to two hours of traffic, but on the other hand the STEG system does not improve support to the dispatchers when they have to make last-minute-changes, there are too many manual operations that have to be performed. Although, the dispatchers claim they are more satisfied with their traffic plans when they are using STEG, and the number of situations when they have to solve traffic problem at the last minute has decreased. The dispatchers experience that they

can rely on the new automatic system AEF (Sandblad, 2009) to a higher degree than the old interlocking automation programs embedded in the control system. They are more comfortable with letting the new AEF operating the traffic at normal operation; they more seldom feel the urge to take control manually over the traffic with the AEF system.
The selected dispatchers thought that it was easy to learn how to operate STEG, and they all appreciated the test period. They all feel that their work have been made easier with this new system and way of thinking. The four selected dispatchers all feel that the accuracy of their plans have improved with STEG.
Of the four dispatchers that have operated STEG all of them thought that in the future the train traffic will be run by a system similar to STEG, but their co-workers were more restrictive to this matter.

5. Discussion

According to the questionnaire performed before the implementation of STEG the answers on how they experienced their work from the four selected dispatchers were significant different from the other dispatchers', and one have to take under consideration the factor of bias in this case.
The dispatchers whom were not involved in STEG had less confidence in their traditional control system tools after the test period. This is may or may not be because they have seen that improvements can be made to their work tools, such as STEG. The dispatchers who weren't involved in STEG experienced a greater resistance towards the STEG system and meant that it caused unnecessary disturbances in their work place. This might be due to the lack of attention and resources as the selected dispatchers experienced.
One can also argue that four people are not a large population enough to draw any conclusions. But with the extended interviews performed with the four selected dispatchers, which is about to be presented in later papers, it is enough.
The selected dispatchers experienced a better accuracy in the train traffic, but this effect have not been verified by comparing real data about traffic delays during the period.

The Swedish Railway Administration is missing proper tools and techniques to measure this.

The STEG system is, as is mentioned above, implemented on top of the existing traffic control system. This means that there are an extra set of keyboard and computer mouse in the traffic controllers' work places. STEG is controlled by the computer mouse and this kind of activity has increased. One of the dispatchers has been complaining on pain in their shoulders after operating on STEG. Alternative devices for interaction should also be explored if the STEG concept is to be used for future train traffic control.

The experiences so far are that the new control principles and interfaces really contribute to improved quality, better possibilities to plan and solve conflicts in good time and to use cognitive capacity to strive for more optimal solutions.

6. Concluding remarks

During the evaluation process many possible improvements to the system was discovered, e.g. concerning information and communication between the traffic controllers and their environment such as train drivers, traffic operators, information services etc. The organizational aspects, both on a local and a national level, must also be further analyzed. In a future paper the summarized evaluation results from the operative test period will be presented.

Norrköping Train Traffic Control Centre will continue to operate STEG during 2009, an initiative that came from the dispatchers themselves. Swedish Railway Administration has approved the application and hopefully this will increase the number of users and the competence of STEG will evolve even more amongst the dispatchers of Norrköping. And hopefully our team can continue to develop the system.

Our research group are now also working on a project called STRATEG with the Swedish National Railway Administraion, where among other issues, an application similar to STEG is being developed but for more complex traffic areas where the traffic are more intense. Also we are looking forward to a new test period at "Malmbanan" in Sweden where STEG will be operated at several adjacent work stations, so that dispatchers may get the advantages of seeing each others updated plans. This time information from the updated traffic plans will be made available to the train drivers hopefully with additional positive effects on traffic flow, energy consumption and punctuality. The main objectives for this cooperated planning procedure are to create energy-optimal plans, save electric energy and reduce equipment maintenance.

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Paper III

Reducing unnecessary cognitive load in traffic control

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ABSTRACT

Uppsala University has collaborated with Swedish National Railway Administration in research about train traffic control and how to improve traffic controllers' work environment, so that they can better meet future demands. This has resulted in a new operational train traffic control system called STEG. The traffic controllers are today forced to develop and use very complex mental models which take a long time to learn. We have also found that their cognitive capacity is more used to indentify, understand and analyze the traffic situation and less to solve problems and find optimal solutions to disturbances. The objective for developing STEG was to change this situation and reduce unnecessary cognitive load. Interviews with traffic controllers show that STEG has reduced the complexity of their mental models and contributed to less unnecessary cognitive load in operation. Our conclusion is that by reducing the complexity of their mental model, they can be skilled much faster and they are now able to use their cognitive capacity and skills on the important parts of their work.

Keywords

Mental models, cognitive load, learning, operator interface, decision making, situation awareness, perception, train traffic control.

INTRODUCTION

There are eight regional train traffic control centres in Sweden that control the train traffic in their specific region. At the centres the current status of the train traffic is displayed on regular computer screens together with large distant panels. Important work tasks for the train traffic controllers include monitoring the train movements and by automatic and manually blockings control the train routes according to the time table. The train traffic controllers often only intervene when conflicts or disturbance occur, which we call *control by exception* [1]. This is in contrast with the other main control principle, *control by awareness*, where the operator is continuously "in the loop", i.e. follows the dynamic development and can act pro-actively.

The train traffic controllers today use pen and time-distance graphs on paper to solve and document their solutions to upcoming traffic conflicts and disturbances. There exists no efficient support for more advanced planning or for communicating updated traffic plans to colleagues and to train drivers. Today's systems are designed for the train traffic controllers to react on deviations in traffic, instead of being able to follow the dynamic development over time, prevent conflicts and find more optimal solutions.

Figure 1. Time-distance graphs on paper are a main tool in today's control of train traffic.

Increasing demands in train traffic have made it necessary to change the control paradigm from low-level technical control tasks into higher-level traffic re-planning tasks. Earlier research has identified several important problems in today's control systems and in the controllers' work tasks [2] and [7]. To summarize the findings, we have seen that the work is very demanding, gives a high cognitive load, is difficult to learn and to be skilled in and that the traffic controllers are not supported by the control systems and user interfaces in an efficient way. The system they are supposed to monitor and control is very complex and dynamic. The information which they can monitor has a limited precision, has partially unknown time delays and some decision relevant information is lacking. Control actions can only be taken at certain times which mean that planned decisions must be remembered. Disturbances and traffic conflicts cannot be detected early enough, and sometimes not at all, and efficient re-planning tools do not exist. Autonomous automatic functions can cause "automation surprises" and are often turned off so that they do not cause additional complexity. The result of these, and many other problems, is that (i) the development of efficient mental models takes a long time and requires much effort, and (ii) most cognitive resources are spent on understanding what is going on and leave very limited resources to perform efficiently in relation to the organisation's goals.

The new control paradigm is called *control by continuous re-planning* [2]. To support this new way of working, the system STEG, Controlling Train traffic by Electronic Graph, was developed. STEG is designed to provide efficient user interfaces that give the train traffic controllers the opportunity to solve potential conflicts and re-plan the traffic situation whenever needed. STEG presents a greater range of integrated information to the traffic controllers and enable them to take decisions about solutions to train traffic problems. The system also displays dynamic data [2]. This gives the traffic controllers a better basis for decision making and can provide improved situation awareness. STEG has been tested operationally in a traffic area around Norrköping's control centre in central Sweden since 2008 [3]. Development of STEG will now continue and a multi-user-STEG will soon be tested in Boden's control centre in northern Sweden. This means that from being a single user system, several traffic controllers can control the train traffic using STEG simultaneously, in their respective traffic area. In this way, the exchange of information about changes in the traffic plan between traffic controllers will cover the whole traffic area and the traffic controllers can continuously see each other's updated traffic plans.

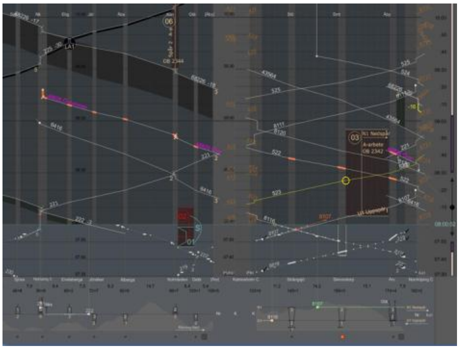

Figure 2. The dynamic user interface of STEG.

THEORIES

Cognitive processes

To understand how people are interacting with technical systems of different types, it is necessary to base this on theories about human perception and cognition. In order to describe human information processing, it is here important to make a distinction between high level, analytical, and low level, automatic, cognitive processes. On a very high analytical level we are creative, adaptive and have advanced problem-solving capacities. At this level our parallel capacity is very limited. We can only treat one item at a time. On a low cognitive level, where we have learned and perform automated tasks, we have an almost unlimited parallel capacity. On the highest level we solve advanced problems but only one thing at a time. On the lowest, most automated level, we perform advanced activities in parallel without conscious efforts. This separation between high and low level cognitive processes is in agreement with Rasmussen's model [4].

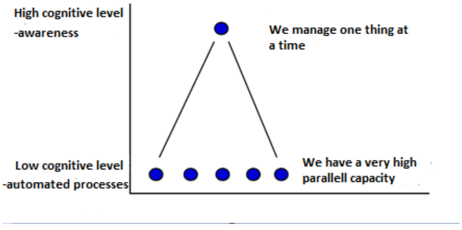

Figure 3. Different levels of cognitive processing.

This has important implications for the design of a system for train traffic control. We must let the traffic controllers be optimally focused on the actual problem solving and planning tasks. All other more supportive tasks, such as controlling the information systems, monitor and interpret information from various sources, understanding their relevance for decisions, evaluating alternative solutions, communicate with others, take necessary control measures etc. must mainly be automated for the experienced operator. If the administration of the user interface distracts the user, this will interfere with the problem-solving activities. The operator will make more mistakes, be slower, take fewer decisions, experience cognitive overloaded and be stressed.

Situation awareness

Situation awareness refers to certain aspects of a human operator's ability to interpret and understand a complex situation in order to find efficient ways to act so that the objectives can be met. A basic approach to this problem was developed by Endsley [5]. The question is how well a particular situation that arises can be identified and understood to provide a basis for decisions and actions. Situation awareness according to Endsley is "a state of knowledge that directly relates the properties of a dynamic environment to the operator's objectives, particularly with regard to the controlling of the process". Endsley also divide this "state of knowledge" into three parts. One part is *perception* of the condition, characteristics and dynamics of the dynamic process in its various parts. Another part is the *interpretations* of the process’s behavior and relations between them. This includes identifying what is important in the situation. A third part is *projection*, i.e. to make predictions, based on the present situation and what has happened in the past, for what will happen in the future.

Situation awareness is extremely important for a process controller. If this is provided, the operator can monitor and predict the system’s dynamic development and decide when and how to act. The skilled and experienced operator is continuously “in the loop” and can perform efficiently, prevent unwanted system behavior without unnecessary cognitive load. Control without situation awareness is associated with cognitive overload, safety risks, un-optimal performance, stress and severe work environment problems.

GMOC-model

We have based much of our observations and analysis of the train traffic controllers' work, as well as the design of the new control system and user interface, on the GMOC-model, (Goals, Mental models, Observability, Controllability) [1].

This model describes the need for clear operational ***goals*** which can be translated directly into action. Goals should be clear and understandable. There are different levels of goals, including informal and formal and organizational and individual. Goals can be very complex and also often contain conflicts. If the control system, user interface, communication systems, organizational structure etc. do not support the operator is a way which is consistent with established goals, the possibilities to live up to these goals will be very limited.

A ***mental model*** of how the system functions, and how other actors in the process act, is necessary to control the system. The mental model, i.e. the operators understanding of the complex, dynamic behavior of the system, is slowly developed during education, basic training and continuous experiences. The design of the control system and user interface should not only be designed to support efficient control, but also to support efficient development of the operator's mental model. The mental model is important for decision making. Decisions are based on the operator's understanding of the system. The mental model is also fundamental for obtaining good situation awareness, with regard to interpretation and projection, but also with regard to what to observe in a specific context.

Observability is what the operator is able to observe through the control systems and its interface. The design of the operator interface must consider not only what is needed for efficient control activities but also for supporting the operator's mental model. The visualization of information is extremely important. This is not only a question about which information that should be visualized but very much about how. For an operator it is important to see all decision relevant information in one single view, which makes the design very difficult. Information must also be presented in such a way that the operator can find the information they need about history, present and future. If properly designed, the amount of information is not a problem for an experienced operator. They are able to immediately identify what is relevant in the actual situation and focus on that. If they have to administrate the interface, jump between different windows etc., this will require cognitive efforts. We have clearly seen that too little information most often will result in cognitive overload, while much information, if properly designed, will result in reduced cognitive load. A good observability is necessary for reaching situation awareness.

Controllability refers to what the operators must be able to influence in the system. They must be able to control, maneuver the process towards the goals. The operators must have the ability to implement all measures required to influence the system so that it behaves as intended, in order to reach the control goal. This can be very complex and result in high cognitive load, e.g. when control tasks do not only affect one system state, but several interacting states, when effects are not direct but dynamic or when control tasks only can be performed at specific times. If decisions about a control action can be separated from its effectuation, e.g. with the help of automatic systems, the cognitive load can be reduced.

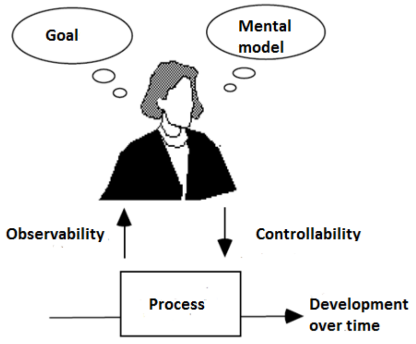

Figure 4. The figure shows GMOC model in a dynamic operational process.

METHODS

STEG was thoroughly evaluated after the first six months of testing [6]. This showed some benefits and a conclusion that the STEG concepts can be used for operational train traffic control systems in Sweden. The survey, interviews and observations made at that time were the basis for interview questions and discussions for a new interview study performed 1.5 years after the introduction of STEG in Norrköping. We wanted to find out long time effects of how STEG has affected the mental models and the cognitive load of the train traffic controllers.

The interviews were detailed and the questions asked were about how they describe their work and how they act when they use STEG compared to when they use the old traditional control system. During the interviews we were two researchers and one traffic controller at a time.

The presentations and discussions in this paper are based both on the first evaluation procedures and on the new interviews.

The evaluation is partially based on a number of questions related to cognitive load, mental models, goals, controllability, observability and situation awareness. The result of this part is presented here. Other parts of the evaluation were more directed towards the quality of traffic planning, handling of disturbances and delays etc., and will not be further discussed here.

RESULTS

The traffic controllers that have operated STEG for 1.5 years are still very positive towards it and still think it is efficient to plan train traffic with STEG. They feel that they control the system better now then in the beginning of the test phase but they also feel that they still have more things to learn. After work shift with STEG they always feel content and happy with their work and the train traffic solutions made. The traffic controllers feel that they can trust STEG and the information displayed there. They experience more control over their work using STEG. The traffic controllers definitely feel that STEG is facilitating their work.

Unfortunately they experience some ergonomic problems in their right arm and shoulder because STEG is operated with a regular computer mouse device. When using paper-based graph they change their focus from the computer screens to the paper quite often which is good for the eyes. When using STEG they don't have that natural relaxation for the eyes and therefore they experience more tiredness in their eyes.

The result from the interviews tells us that the traffic controllers don't experience any difficulties to switch between STEG and the old paper-based system, although the work is different. The traffic controllers are so used to the different user interfaces that they quickly adjust to it. There is no special way of thinking when using STEG, the traffic controllers say that their planning strategies have not change. But they experience STEG as a much more efficient planning tool then using the paper graph. They don't believe that they are solving the traffic situations differently when using STEG, but they feel that they have more time to do more creative and optimal solutions. Instead of working with immediate solutions they are now working approximately one hour ahead. STEG allows them to try different scenarios and see the consequences of their actions before they make a final decision. In this way they can use the margins more efficient and find more optimal solutions. Using scenarios as they do in STEG can provide them with more competent knowledge and faster create a basis for the mental models needed for becoming a skilful traffic controller.

The traffic controllers experience that STEG is more precise and easier to use than the old paper-based graph. STEG is showing more information, which they earlier had to gather from several different systems and integrate. STEG is a faster system for controlling the traffic, because it allows them to quickly assemble information and to make decisions. STEG is also displaying information that they earlier used to keep in their minds. With STEG they see the actual facts and don't have to calculate and keep track of trains and control commands. When the traffic controllers are using STEG they experience that they can make more exact predictions. This is beneficial to their colleagues who are depending on them to get correct predictions and also for information to the passengers about arriving times of trains. They are able to early see potential conflicts and therefore experience more control over the system. In the paper-based graph it sometimes can be difficult to see what colleagues have written, but with the computerized STEG this is no problem, everything is visual and easy to see.

The traffic controllers feel that STEG is especially good to use when large deviations in traffic occurs. It is a reliable system when planning train meetings and it makes it easier to keep track of each individual train. When using STEG they have a more continuously work process that keeps them alert and focused all the time. Despite the focus they don't feel tired or stressed when using STEG. Actually they feel less stressed when using STEG because of the increased control.

STEG also provide them with better feedback about the history of the actual traffic situation which is good for learning and developing skills. The time axis has a different orientation in the two systems and it seems like they still used the old mental model about the time line from "left to right", but it does not cause any problems. They have a large amount of pre-programmed "pictures" in their head and they can visualize the structure of the infrastructure without looking. They "know" what everything looks like and can easily recognize something diverging from normal situations.

DISCUSSION

To manage traffic effectively requires sophisticated mental models of traffic systems, signal and safety systems and maintenance work. In previous interviews, it appears that traffic controllers use highly sophisticated mental models, i.e. empirical pictures of how everything works, how different features interact, how the processes develop as functions over time. As today's user interface does not show all information needed for the reconstruction of the mental models it is necessary to devote a lot of time and effort to create these models. This effort is not conscious, but affects the work and means that it takes very long time to become truly skilled in being a traffic controller. The introduction of STEG has probably increased the conditions to create the mental models necessary as well as supporting the goals of the traffic controllers and their organization. Traffic controllers have access to more comprehensive information in one unified system, which gives a better basis for decision making and better explain where in the process they are. This means that when they don't have to scan several different systems for relevant information they reduce the cognitive load of unnecessary work tasks and increase the feeling of being in control. With STEG they perceive the status of the process better because STEG is supporting them with comprehensive information and presents it in an efficient interface. The situation awareness is increasing. STEG has a dynamic interface and show the exact positions of the trains and therefore creates an overview of the traffic situation in a way that was not available in the old systems. The train traffic controllers can use their cognitive capacity to make optimal planning for the traffic instead of using it on unnecessary and resource demanding metal activities. With the old system they use a lot of cognitive capacity just to understand the traffic situation, but with STEG they can reduce unnecessary cognitive load. It seems that STEG also is more consistent with their already constructed mental models created by the long experience of train traffic control. Their mental models seem to be supported by the interface of STEG and the memory is therefore relieved as some tasks that are not as important as planning are set to a more automatic level. STEG does not strive for making their work easier and less complex, the STEG interface gives them the opportunity to focus their cognitive capacity on important tasks as planning and optimize the train traffic as well as dealing with crisis situations.

All traffic controllers that have used STEG so far have been experienced controllers. We do not know what the effects will be for new traffic controllers, who start their professional life using STEG.

CONCLUSION

Our results show that it is important to take users' mental models into account when designing a control system. As a designer, it is therefore important to understand the users' tasks and what they actually do in their work. If a system is consistent with the users' mental model, it is probably faster for the users to learn the new system because they have no cognitive "clash". It is also important that the system supports the construction of mental models and therefore shows all the information needed by the user to make decisions and to obtain situation awareness.

It is also important to analyze which parts of the users' work that are really important. That is to be able to design interfaces that reduce the cognitive load of unnecessary tasks and free cognitive capacity for the really important work tasks, in our case traffic planning and optimization. The system should reduce the load of their memory and display important information. Then the users don't have to keep information in their minds when they try to maintain an overview over their working processes and make optimal decisions. The system must support the goals and mental models of the user, as well as give them controllability, observability and situation awareness.

FUTURE WORK

It is our hypothesis that STEG can shorten the time it takes for traffic controllers to become skilled in their profession. STEG seems to have an interface that supports the mental model building. The fact that the mental models do not need to be as extensive with STEG's interface, will shorten training time for future train traffic controllers. If our hypothesis is valid remains to be seen, but this can only be studied in the future, because we have to make a comparison between train traffic controllers who learn their profession using STEG from the beginning.

Next step in our research is the introduction and evaluation of multi-user--STEG in Boden's train traffic control centre. When using STEG on several work stations in parallel it will support common solutions and strategies. The traffic controllers will be forced to collaborate more and this will require a learning process to become more competent and open for new creative traffic solutions. We will probably see more of an organizational learning and more cooperation.

When STEG is introduced nationwide in 2015 it will be necessary to also look into the organization. STEG will require another organization and workplace design than what we have today.

It will be important to introduce some parts of STEG to the train drivers as well. They lack information about the process that are a part of and this often force them to contact the traffic controllers via telephone. The traffic controllers receive too many time consuming telephone calls from drivers just asking about what is going on. The traffic controllers could better focus on optimal solutions if the drivers got updated information from STEG.

STEG is a very well functioning system for controlling train traffic on the traffic lines between stations, but for controlling train traffic inside large complex stations another system must be developed.

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Paper IV

All or nothing- deployment must also be user centred!

Abstract. Uppsala University and Trafikverket (Swedish Transport Administration) has been collaborating for several years in research regarding train traffic control. A new operational traffic control system called STEG has been developed in a user centred iterative process and was deployed at train traffic centre 1. The evaluation showed that STEG was received as an efficient system for train traffic control. STEG developed into MULTI-STEG, intended to be used by several users simultaneously, and was deployed at train traffic centre 2. Surprisingly, this evaluation showed more pessimistic results. This article discus why the STEG-system was not perceived equivalent at both places. Our case study shows that a user centred development process is not enough to create a well functioning system. A user-centred deployment is also very important. It is therefore necessary to create supportive conditions in order to build connecting bridges between the development processes and the deployment processes.

Keywords: User-centred system design, deployment, work environment, situation awareness, train traffic control, development.

1 Introduction

User centered methods for design and development of information systems have since long been considered to be important and necessary when developing usable systems. User centered system development (UCSD) has been defined and discussed by many authors during the last decades, e.g. by Norman and Draper [1] and Karat [2]. The USCD framework has been applied in numerous projects for requirement specification, systems design, iterative development etc. Also when usability evaluation is discussed, a user centered approach is often promoted. However, it is very clear that one important phase in systems development is not equally well discussed and developed: the deployment phase. Janols [3] have done studies of deployment of electronical patient journals at hospitals, she is mentioning different aspects that influences the process.

In systems engineering literature and methods the technical implementation of an information system is well described, but deployment is really not only about technical implementation. Deployment involves all aspects of how a new system is introduced. When a new system is introduced in an organization, not only the computer systems are changed, but also the work organization, work processes, work roles, competencies, communication patterns, work environment etc. To be successful, it is important to apply ambitious programs for information, education and training during the deployment phase. If not all relevant factors are considered in a good way, there is a risk for problems of different nature, e.g. concerning lack of participation, negative attitudes and low acceptance. The basic approach to prevent and solve such problems is to make also the deployment phase user centered.

When the literature is studied it is obvious that the deployment phase has not been studied as much as all other phases in the systems development life-cycle. Most often the term is only mentioned but methods and techniques for successful deployment are not discussed.

It is the purpose of this paper to discuss the importance of making also the deployment phase user centered, and give some important advice for how this can be achieved. We will do this based on an application example where a system for train traffic control was introduced in two different work environments. In one of these the deployment was successful while in the other many problems occurred.

2 Introduction to train traffic in Sweden

In Sweden there are eight regional train traffic control centers which control the train traffic in their geographic region. At these centers the present status of the train traffic is visualized on computer screens and/or large panels. The train traffic controllers work tasks consist of monitoring the movements of the trains and supervise the automatic blockings of train routes according to the time table. Some manually blockings are performed by keyboard commands. The train traffic controllers often only intervene when conflicts or disturbance already have occurred, which we call *control by exception* [4]. This is in contrast with the other main control principle, *control by awareness* [4], where the operator is continuously “in the loop”, i.e. follows the dynamic development and can act pro-actively.

The train traffic controllers main work tools today are time-distance graphs on paper, where they solve the upcoming traffic problems and document their solutions manually. What one controller does is unknown to the others, if they do not talk to each other. There exists no efficient support for more advanced and coordinated planning or to get a dynamic overview. The only way to communicate updated traffic plans as well as new conditions to colleagues and to train drivers is by telephone. The traffic controllers´ work tools available today force them to develop complex mental models for understanding the traffic situation and to predict upcoming situations, since not all the information needed are displayed.

Today's train control system demands that the operator have to wait for the right moment to execute the planned actions.

The automatic functions test conditions and execute commands in a closed sequence, leaving the human controller mainly out of the loop.

Fig. 1. Time-distance graphs on paper are a main tool in today’s control of train traffic. The large panels on the walls are for tracking the trains’ movement. Five other different systems shows required information for decision making about the traffic situation.

2.1 Earlier research for mapping problems

Earlier research has identified several problems in today’s control systems and in the controllers’ work tasks [5], [6]. A summary of the findings is that the work is cognitive demanding and takes a long time to learn and to be an expert. The train traffic controllers are not supported by the control systems and user interfaces in an efficient way. The dynamic traffic system they are supposed to monitor and control is not visualized to support their decision making. The information displayed also has limited precision. Disturbances and traffic conflicts are detected when they already have happened and efficient re-planning tools do not exist. Autonomous automatic functions often cause "automation surprises" and are often turned off so that they do not cause additional complexity. Furthermore the train traffic controllers have to develop efficient mental models that require unnecessary cognitive resources in order to get an overview and understanding of the traffic situation. The controllers do not have the required prerequisites or support to perform their task in an efficient way.

2.3 The description of STEG and MULTI-STEG

In order to create an understanding for STEG and MULTI-STEG which this case study is based on we would like to describe this very shortly. STEG presents a greater range of integrated information to the traffic controllers and enable them to take decisions about solutions to train traffic problems. The system also displays dynamic data [5]. This gives the traffic controllers a better basis for decision making and can provide improved situation awareness. Instead of making decisions while stroking the keys on the command board, the decision making and the command actions are separated. The train traffic controllers are planning the traffic in STEG and can try different solutions before the AEF, Automation Excavation Function, take care of the actions in real time. The AEF execute the plans and decisions of the controller, and therefore there are no automation surprises for the controller.

STEG was developed for one user at a time and MULTI-STEG was developed to be used by several users simultaneously at different work areas. The advantages of MULTI-STEG was information supply to the traffic controllers' co-workers. They would be able to see each other's traffic plans and can therefore make more optimal solution for the whole traffic area. The interface is the basically the same and the general functions to, some correction were made for train traffic centre 2's specific traffic situation.

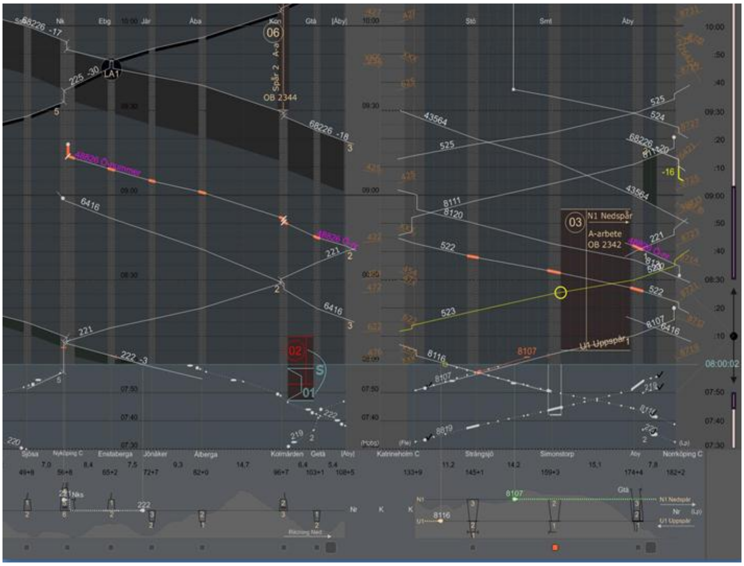

Fig. 2. The dynamic interface of STEG shows more exactly the trains' positions along the tracks. It is also possible to plan ahead and see your consequences of your decisions before the plans are executed.

3 Methods and methodology

This chapter consists of two parts, the first part describes the theory-based method we used to analyze our data and the second part describes the method of how STEG and MULTI-STEG was developed, deployed, evaluated and analyzed at the two different train traffic control centres.

3.1 The GMOC-model

As a framework for the analysis of the train traffic controllers' work with STEG and MULTI-STEG we used the GMOC-model, (Goals, Mental models, Observability, Controllability) [4] & [8]. The GMOC-model is usually mentioned with process control but we applied this in the deployment practice. This model describes the need for clear and understandable ***goals*** which can be translated directly into action. A ***mental model*** of how the system functions, and how other actors in the process act, is necessary to control the system. ***Observability*** is what the operator is able to observe through the control systems and its interface. The design of the operator interface must consider not only what is needed for efficient control activities but also for supporting the operator's mental model. The visualization of information is extremely important. A good observability is necessary for reaching situation awareness. ***Controllability*** refers to what the operators must be able to influence in the system. They must be able to control, manoeuvre the process towards the goals. The framework was used for structuring the large quantities of material we perceived from our research. The GMOC-model provided a consistency in the research and analyze work.

3.2 The development of STEG

Increasing demands in train traffic have made it necessary to change the control paradigm from low-level technical control tasks into higher-level traffic re-planning tasks. During many years Uppsala University and Swedish National Railway Administration collaborated and developed the new operational system STEG. The development process was quite unique. Researchers, users and developers worked closely during a long period of time. The relationship was ambitious and respectful. Frequent meetings and workshops as well as close contacts made the information loop constantly updated which made the collaboration unique. The research results showed what the users really needed in a cognitive way and how they actually performed their work tasks. The whole process was user-centred [6] and iterative, which led to that STEG was developed into a useful tool. Every phase in the STEG-development process was performed very carefully and thoroughly. The development team did not use a static requirement specification. It existed, but it was constantly changing and had a dynamic approach. The prospective users have showed a long-term commitment and faith in the development of STEG. Train traffic controllers from different parts of Sweden with different experiences along with researchers and management had frequently workshops during the development phase. The development phase was, as we call it, extreme user centred system design and lasted for a long time, more than two years. During this time many prototypes were constructed, tested and evaluated along the way. Everything was questioned and exposed to testing, instead of just modernizing existing train traffic control systems.

The iterative and user centred development process enabled a deep insight analyze of the real problems in train traffic control, and the new concept of control by re-planning instead of just by exception was formed. Also the distinction between traffic situations decisions and control actions were separated and enabled less automation surprises.

STEG better provided the information enquired and increased their situation awareness. And furthermore they used their cognitive capacity to indentify, understand and analyze the traffic situation instead to just solve already arisen problems and disturbances. STEG changed the way the train traffic controllers were working with train traffic control, from control by exception to control by awareness.

3.3 The deployment of STEG at train traffic control centre 1

During the deployment process at the first train traffic control centre, the users where involved along the whole process. Since the system was not fixed they had the chance to affect the system and their point of view was listened to by the developers and managers. The project leader was well understood with the traffic situation at this centre and was situated at this centre. The process was iterative and the users had support and constant feedback. The creative phase that occurs directly after indicating deployment was intercepted and seen as an important phase in the process in order to develop the system further more. It is when a system is used concretely that new ideas are created. At this centre we did what most project leaders often forgot, we integrated the implementation phase and the deployment phase along with the users point of view. It is when the users, as well as developers and usability experts, start to work with the system that you realize what is missing and the team finds new solutions to “expected but unspecified” problems and possibilities. We say “expected” because experienced project leaders knows that in complex organizations there is no possibility to define all functions that generate usability before the system is implemented and deployed.

3.4 Evaluation of STEG at train traffic control centre 1

The first evaluation of STEG performed in 2008 was conducted through semi-structured interviews, observations on the work place and questionnaires. The same questionnaire was handed out before and after the deployment of STEG. The results were compared and identified the changes the train traffic centre and their users were going through. The interviews were conducted in Swedish. citations in the results section are translated into English.
Train traffic controllers involved with STEG and those who were not involved with STEG participated in the evaluation made with questionnaires. Approximately 35 % of the total staff participated in this section. There were 4 educated STEG-users and all of them participated in the evaluation, which for them consisted of semi-structured deep interviews before and after the deployment as well as

participating in the two questionnaires. The interviews were detailed and the questions asked were about how they describe their work and how they act when they use STEG compared to when they use the old traditional control system. During the interviews we were two researchers and one traffic controller at a time. Their answers where then interpreted by our research group and analyzed into the GMOC-model and terms of cognitive load and situation awareness. Some parts of the evaluation were more directed towards the quality of traffic planning, handling of disturbances and delays etc., and will not be further discussed here [9].

Observations at the work place were made before, during and after the deployment of STEG. The users also kept a "digital diary", which we had access to, about the process they were going through and the new system they were facing. The users wrote down their thoughts, questions, reflections and proposals for improvements. [10].

The evaluation showed benefits and a conclusion that the STEG concepts can be used for operational train traffic control in Sweden.

3.5 The development of MULTI-STEG

When developing MULTI- STEG the process was not as iterative as when developing STEG. The users or the management in train traffic control centre 2 were not involved in this process and the changes were made from the perspective of train traffic control centre 1. The project leaders disregard the fact that the users and the traffic situation at centre 2 hade different specifications than centre 1. They relied on the fact that STEG had already been a success at centre 1 and should therefore work at centre 2 as well. The development phase of MULTI-STEG was practically non existing and were not user centred system designed. The project management was still situated at train traffic control centre 1 and had less knowledge about the work situation and the traffic situation at train traffic control centre 2. The development team did not work user centred and basically made changes without calculate the consequences for the users. The design experts and researchers were not as closely involved as in the development of STEG.

3.6 The deployment of MULTI-STEG at train traffic control centre 2

At center 2 the new system, MULTI-STEG, was part of a test with three work stations for cooperative planning of three different traffic areas. During the examined period only one operator station was implemented. A second objective was evaluation of a new system function for automatic communication of modified route plans to train drivers. The new functions together with the lack of “The Plan Controlled Automatic Execution Function”, AEF, created different prerequisites for the deployment.

The deployment at train traffic control centre 2 was made with directions from the management and no involvement from the users. The users at centre 2 had during a long period of time been testing different new systems for train traffic so they were already “a bit tired” of new systems that didn’t work sufficiently. Train traffic control centre 2 was at the time procuring an update of their operational system and therefore the decision were made that MULTI-STEG would not include the AEF-function. The education for the new users at centre 2 was inadequate and focused on the wrong things. The deployment phase was interrupted by summer vacation when a big part of the staff was off work.

3.7 Evaluation of MULTI-STEG at train traffic control centre 2

The evaluation at centre 2 was performed with semi-structured deep interviews with both non-STEG-users and STEG-users. Interviews were performed before and after the deployment of MULTI-STEG. The interviews were detailed and the questions asked were about how they describe their work and how they act when they use STEG compared to when they use the old traditional control system. During the interviews there was one researcher and one traffic controller at a time. The interviews were conducted in Swedish, citations in the results section are translated into English.

Observations at the work place were performed before and after deployment and a questionnaire was performed during the deployment period. Five of ten STEG-trained train traffic controllers participated in the evaluation and approximately 60 % of the total staff answered the questionnaire. The users also kept a “digital diary” where they wrote down everything that came up in terms of questions and reflections about the system during the whole period of time.

4 Theories

It is difficult to find theories that support user centred deployment. User centred system design (USCD) is a well known subject but user centred deployment is often forgotten. It is easy to find studies showing deployment examples which has not succeeded, but very little analyzing of why the failure occurred. Often this reports do not make a clear distinction between the different phases a system project often include, such as project specifications, design development, implementation and deployment. It is therefore easy to blame a poor design when figuring out what went wrong in IT- projects, when sometimes it might just have been a poor deployment process where the users never got a chance to fully understand the system.

We would also like to make a distinction between deployment and implementation. By implementation we mean the technology itself. This is when all technical fragments are suppose to piece together and where you should get the new system running and working satisfying, this also include the debugging phase and so on. By deployment we mean the part where the users learn to use the new system, and not only to manoeuvre the functions in the system. The user need to learn the new work processes in the system and this requires the organization to develop and maybe also form new work roles at the work place. Users and their competence have to be "tuned in" to the new system, as well as the system needs to be" tuned in" to the users. This is what we call deployment. Both implementation and deployment phases are important in a design process but the deployment part is often forgotten and mixed up with the implementation part.

4.1 User-centred system design and deployment

User involvement is very important in the development processes as well as in deployment processes. The user need to feel engagement and dedicated to the new system, and if they are involved in the deployment this feeling can be achieved. The deployment also has to be user focused. The education is not only to be focused on learning the new functions in the system, the user also has to be given the chance to learn the new way of thinking and doing their job with the new demands and requirements. They have to grasp the set of mind of the new system [11].
We would like to mention user-centred system design in our theory section because STEG was developed according to this principle. We can also see similarities between the development and the deployment phase in the UCSD-way of thinking.

There is no general definition of user-centred design and the expression is vague and is interpret differently within the HCI-area. But it is fair to say that user-centred design puts the users in the centre and is an approach where knowledge about the users and also their participation in the development process is something important. [1]. User centred system design is based on involvement and participation. The needs of the users and the urge to find out how the users really use the system and design the system for those inquiries are at focus in user-centred system design processes. This is more important than usage of a specific technology or highly qualified programming. The interface should be designed after the needs of the users and should dominate the system design process. According to Gulliksen et al. [7] user centred system design is based on 12 key principles. Some of the principles are transferable to deployment, such as user focus and active user involvement. Furthermore should the systems deployment be both iterative and incremental, simple design representations should be used and the deployment should be performed by effective multidisciplinary teams and users. A user centred attitude should always be established, as well as in development and deployment.

4.2 Framework theories

In the section "Methods" we described the GMOC-model which we used as framework when categorizing our research material. The theories we based our work on are associated with this framework. Parallels to these theories are founded in our results. It is important to distinguee that none of the theories we are describing are "made" for supporting deployment, but we see the deployment as a process and therefore these theories are compatible.

4.2.2 Goals – an important part in decision making processes

It is important for organizations and users of new systems to have clear, understandable and reachable goals when introducing a new system at the workplace. Goals can be formal and informal. Formal goals are explicitly formulated in the organization's official document and rules. Informal goals describe what the users are working towards, consciously or unconsciously. These goals are used as a foundation for the users' daily work and decision making processes. The informal goals can be difficult to map because users performing the same task can have different goals, and sometimes the users are even unaware of their goals they working towards.
The users require distinct goals in order to interact with the system. Inaccessible and unclear goals create conflicts and problems in the organization and can be difficult to discover.

The organizations' and the users' goals can sometimes be contradicting and this can cause problems and conflicts in the train traffic. For example in train traffic control the organizations' goal can be to get the train on their arrival destinations according to the pre-planned traffic plan. In order to reach this goal the train traffic controllers have to delay some trains due to external circumstances, such as for example snow, to get most of the trains to their destinations on time. The train traffic controllers restructure the goal and also their mental model of how to achieve the new goal. A decision, as described above, can't be understood single-handed, but as a part of a dynamic process. A decision is one of several steps along the way to achieve one or more goals [8].

4.2.3 Mental models – viewed at as problem spaces

Users do want to understand the system they are working with, not only performing a task. Therefore they are constructing a "mental map" of the system and their work tasks. If they are lost they can easy find their way again by visiting their problem space and look for a solution [12].The problem space consists of several methods to perform and manage assignments and solve problems. Novices' problem space provides less methods and experts have access to a more enhanced problem space. By time and practice novices are increasing the alternatives of accessible methods to use when solving a problem and becoming gradually experts.

The problem space can be categorized into different levels. Distinguished knowledge based problem solving, skill-based problem solving where routines have been learned by a controllable method and rulebased behavoiur problem solving where routines automatically have been learned by rules [13].

4.2.3 Observability – increases situation awareness

A system has to be observable to their users. The users has to be able to observe what is going on and what the status of the process is. The users has to be "in the loop" and aware of the situation in all. When a system provides this, as long with the other parts of GMOC, it can increase the situation awareness of the users and lead to more optimal decisions.

Situation awareness refers to certain aspects of a human operator's ability to interpret and understand a complex situation in order to find efficient ways to act so that the objectives can be met. The users need to have observability of the system and their work tasks. A basic approach to this problem was developed by Endsley [14]. The question is how well a particular situation that arises can be identified and understood to provide a basis for decisions and actions. Situation awareness according to Endsley is "a state of knowledge that directly relates the properties of a dynamic environment to the operator's objectives, particularly with regard to the controlling of the process". Endsley also divide this "state of knowledge" into three parts. One part is *perception* of the condition, characteristics and dynamics of the dynamic process in its various parts. Another part is the *interpretations* of the process's behaviour and relations between them. This includes identifying what is important in the situation. A third part is *projection*, i.e. to make predictions, based on the present situation and what has happened in the past, for what will happen in the future.

Situation awareness is often mentioned together with systems and processing, but we liked to say that the deployment also needs situation awareness. The user need to be in the loop and understand what is going on during the deployment process. The user has to be in control of the deployment process as well. Endsley define the phenomenon of situation awareness as the perception of reactions to a set of changing events, and a deployment process is a series of changing actions and events.

4.2.4 Controllability – working towards the Control-Support-Demand-Model

Users need to feel control over the situation at work, with the system they are working with and their work tasks. To develop this further I will look into the control-support-demand-model.
During the 1970's Robert Karasek enhanced a model to analyze work-related stress interconnected with cardiovascular illness. At first the model was only containing the link between control for the user and demand from the organization. This model was further developed by Töres Theorell who added social support as an important factor too. Today it is often used for declaring psycho-social work conditions and their effects on health. The figure below illustrates the relation between demands and the level of control the user perceives. High demands and low feeling of control is not a good combination for your health. High demands are normally not a stress factor if it is corresponding towards high self-control over the work situation and a strong social support from the management. Research shows that the control and support factor decrease when new systems are deployed at a work place [15].

The Control-Support-Demand-Model explains why many users feel stress when new systems are deployed at their work place. This is due to lack of control over the new work situation that interconnects with new systems. They have to learn something new instead of using the old system they already know and can manage. Often when this happen the users do not get sufficient support to regain or maintain the control over the system and their work situation. The users feel that the demands on them are increased because they don't understand the new system and in combination with lack of support and a feeling of losing control, this creates stress [15]. Stressed users do not perform a good job and do not take good decisions and they do not feel good about doing their job. Times like this it is easy to blame the new system for being poorly designed for the occasion. But sometimes it can be as simple as a poor deployment process where the users don't had the chance to learn the new way of thinking that the new system requires [16].

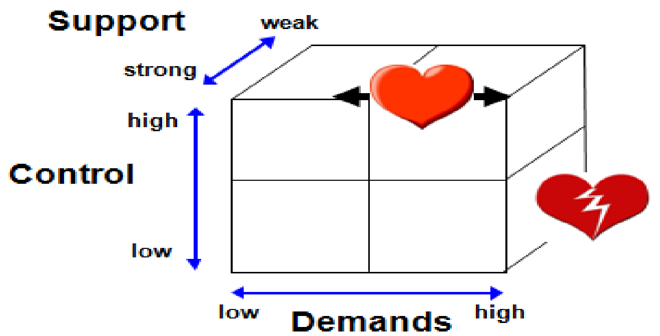

Fig. 3. The figure shows Karasek-Theorell model of stress related factors.

5 Results

The results are divided into the GMOC-model to clarify our results towards our theories.

5.1 Goals-oriented results

During the education at center 1 the users had constant feedback from project management, the develop team, the design team as well as experts in Human Computer Interaction. They were well understood with the goals and deadlines with the STEG process.

At center 2 they did not receive enough support from this kind of resources. They lacked the social support in Control-Support-Demand-Model, at the same time as the demands on the users increased. The project management was not situated at center 2 and the users lacked specific and clear goals and also time plans of the deployment. Citations from the interviews "I have no clue what is going to happen with STEG, I even heard rumors it will be shut down". The operators lacked support and sufficient guidance from the project management and as said before when demands increase and support and control functions decrease you are in a dangerous zone for stress related diseases according to the Control-Support-Demand-Model. Some of the users felt stressed and therefore they did not like the new system. Human Computer Interaction experts and design experts were not enough involved in the development process at center 2, as they were at the same process at center 1. This probably affected the unexpected consequences which caused problem when deployment phase started. The management underestimated the change in the work place that was necessary to take place at center 2 and the goals for the organizational change were not clear.

5.2 Mental models-oriented results

The train traffic controllers at centre 1 thought that STEG and the AEF-function gave them more cognitive resources devoted to efficient problem solving than before. Citations like "I am not as tired as I used to be when I use STEG and feel less stressed after a day with STEG" indicates this.

At centre 2 some of the traffic controllers thought that the lack of AEF was a good thing, because that meant that they did not have to change their way of thinking. The users lacked trust for the new system. The questionnaires revealed a distinction in attitudes between older and younger traffic controllers. The younger were more positive and could see the benefits with MULTI-STEG, while the elders felt they were turned into robots and MULTI-STEG could never outshine their expertise skills and long experience. Citations from the interviews point towards this: "I don't trust the system, but I trust my own knowledge and experiences", "I don't want to feel like robot, I would like to think for my self".
The two attitude-groups of more experienced and less experienced operators at center 2 might have negative effect on the expectations on a new system. Experienced operators are safe in their expertise and are more suspicious about the possibilities for a computerized system to fulfill the complex requirements from the task to control train traffic. Also before you learn a new system it is a high edge to climb over before all the functions are understood and you can really start using

the complexity in the system. The examined period was in the early phase of deployment.

5.3 Observability-oriented results

At centre 1 the STEG-users thought that the new system where better than the old one in terms of dynamic overview, planning and conflict detection. Their situation awareness increased and the new system better supported their mental models of their work. Citations from the interviews like "now I can plan the traffic and test different options before executing my actions" and "I feel like I have a better overview with STEG" indicates this.

At center 2 the education of MULTI-STEG was intermittent, the education management focused on teaching the functions and commands in MULTI-STEG and did not teach enough about the new way of thinking about the work tasks. Due to the lack of AEF there was no real reason to change the way of working. The operators could just replace the paper graph with the computerized one, and still work in the old fashion way, especially as only one operator station was deployed. This was clear when we executed our observations at centre 2.
The controllers at center 2 had some problem with understanding the advantages of using MULTI-STEG, especially since the "MULTI"-part was not implemented. This was also probably due to the education being interrupted by summer holidays and partly because the AEF-function was not implemented. The later because of an upgrading of hardware in the existing operational system. No AEF means in principle that their existing paper graph just got digitalized. Without the AEF-function it is not so meaningful to use MULTI-STEG to make plans with high precision because you have to execute them by yourself anyway. The traffic controller still needs to make the operations to protect the train routes manually by using local automatic functions in the switch-boxes, independent of what is planned in MULTI–STEG in the computerized graph. The planning in MULTI-STEG therefore lost its most important part. MULTI-STEG then created only a mental meaning and not system feedback.

5.1 Controllability-oriented results

The evaluation at center 1 showed positive attitudes amongst the staff towards STEG. They were hopeful about the future and happy to finally have a system that developed train traffic control work. "Finally it happens something good with the train taffic systems" was citaded in the interviews. STEG was appreciated by the whole staff and when talking about STEG at the work place it was in terms of good hope for the future. At center 1 many of the users had been involved very much and they felt strongly about “their” product. They felt they had influence over both the development process and deployment process. They had the opportunity to be involved with the design process of STEG and adapt STEG to their work situation. Changes were made specific for the traffic situation at this particular control center. At center 1 there was enough resources in time, staff and financial resources to develop the system STEG in the deployment part. The diary at this center was used frequently and the users got feedback to what they wrote in the diary. The developers and project management got – and gave - instant feedback on what was wrong with the system and could grasp new ideas and important viewpoints.

At center 2 the users were not sufficiently involved and some did not feel positively about MULTI-STEG. They more felt that they were forced to use a new system that they did not have the chance to influence. “It felt like they just threw this system at us and did not ask us how we felt about it” and “ our traffic situation here is different and specific, and can not be compared to centre 1” is citations from the interviews.
At center 2 the train traffic controllers were already tired of testing new systems that did not work efficiently. Some of them were skeptic from the beginning and not so convinced that MULTI-STEG was as good as their collegues from center 1 told them.
It might have been better not to introduce and evaluate so many systems at once.
During the education the train traffic controllers felt they did not get enough feedback and could get answers to their upcoming questions. “ I had no one to ask when got stuck in the system” was cited in the interviews. Also some of them did not seem to have grasped the whole concept with the MULTI-STEG. And since they only used one operator station, they did not see that they could work more together and use each other’s experiences and information to get better decisions and find more optimal traffic solutions. Most of the controllers continued to just work with their responsible area and did not see the whole and the consequences of their decisions to the total traffic situations.
The trust for the system was not very high; this was probably due to recurring technical problems with the system. The diary at center 2 where not followed up by the management and the users did not get enough feedback at first of what they wrote in the diary and therefore stopped using it.

6 Reflections to the results

To omit "The Plan Controlled Automatic Execution Function" AEF - in center 2 - had effect on the overall way of working with the computerized graph. The new system was used only as a planning tool. The execution of commands then was performed in the same way as before. This makes comparison between deployment in the two centers less relevant. The difference in operation required more engagement from the management. When introducing the new system at center 2, management relied on the results from center 1 and underestimated the importance of careful deployment. At center 2 where the users were less involved in the design process, in the development process and in the deployment process, the system did not reach the same immediate success.

It is important to build bridges between all processes a system are going through and build bridges between the people who are going to use it and the people who are going to deliver it to the users. Mutual respect for the involved in all processes is the base for good collaboration. The users need to be able to take active responsibility in the deployment process and this process has to be planned carefully. Design development and deployment processes require an organizational change. An organizational learning process is starting within the organization when deploying a new system. There has to be a relation between the implementation phase, the deployment phase and the organizational change the work place are going through.

In IT-projects the project itself are often finished within the implementation part and the deployment – and the highly creative phase right after - is not included in plan and budget. As a consequence the new system will be less useful.

7 Conclusions

Based on the experiences from the projects as described above, we can formulate the following recommendations for a user centred deployment process. First of all the foundation for a successful user centred deployment process is of course a successful user centred development process. Second, systems are bounded to the organization they are appearing in and users adapt their way of working to the system. It is therefore important to customize the deployment phase to each organization.

Goals-oriented conclusions

- What is deployed is never only a new technical system, information system, but also a new work, organisation and work processes. It is necessary that the new work is described in enough detail and that the new work processes are developed in close cooperation with the end users. There exist efficient models for this, e.g. future workshops, vision seminars etc. [17]. The goal of the deployment process must be well understood of all participants.

- It is equivalent that the users are aware of the goals with the project and the process. Deadlines and information about the process is important to share with the users.

Mental models-oriented conclusions

- It must be the well understood, and generally accepted, that the project is not finished when the deployment starts. The deployment, as well as the evaluation after the actual deployment must be considered as an integrated part of the project. Many experiences can only be obtained in connection with and soon after the actual deployment. There must also be resources available to make changed based on such findings. The mental model of the whole process must be common to everyone.
- Many unforeseen things will occur and it is important to create a mental preparation for such events of different nature.

Observability-oriented conclusions

- It is important to create a good participation in deployment. All planning for what, when and how different parts of the deployment work are performed must be made in close cooperation with users or user representatives. This is necessary of many different reasons. There must be a common positive attitude towards the coming changes and the deployment process and it is necessary to create trust and confidence in the new system and in the deployment process as such. When this is achieved the users observability demands is satisfying.

Controllability-oriented conclusions

- What is deployed is not only technology, but a new work, and the introduction to the users must focus on learning not only to handle the new technical system, but how to perform the new work in practice, using the new system. Programs for education and training must mainly focus on the new work processes.
- The new work, supported by the new system tools, must be properly understood by all users. It is necessary to develop educational material that supports this. Often the objectives and basic ideas behind the introduced changes are not known to the users, and this can make it difficult to work and use the system in a correct way.

- The full support of the management on different levels is essential. The management must allow and support users to participate in deployment activities. Users must be allowed to take as much time as needed for education and training.
- The users must have efficient support continuously during the deployment phase. Good preparation and initial support is not enough. Also during some time period after the actual deployment there is a need for continuous evaluations, active support on the site and complementary education if needed.

Fig. 4. The figure shows the iterative process within the organisation and deployment of new systems.

8 Future work

The problems at train traffic centre 2 has been discussed and dissected. The project management has been enlightened of the problems and are now working towards a solution. Design experts and researchers are now involved in the redesign and restarting of the MULTI-STEG project. All train traffic controllers at centre 2 are now educated in STEG and improvements has been made according to the users wishes. Centre 2 is about to upgrade their existing control systems in a couple of months and with that the PEF function is also deployed within STEG and gives the train traffic controllers the ability to execute their plans and solutions in a new way. It is going to be interesting to follow the process and the outcomes.

8.1 NTL – the future of train traffic planning

Today the traffic is controlled as several isolated traffic segments in each of the eight regional control centers. To obtain continuously updated traffic plans that cover the entire traffic system, a national system and organization must be created that integrates all separate traffic plans. On this national level more strategic decisions regarding planning can be made, which better coordinates the local and regional activities. Trafikverket has incited a project to solve this matters and it is called NTL – Nationell TågLedning (English for National Train Management) and are aiming to implement STEG at all traffic centres in Sweden and further more look into the changes that are necessary to be made within the organization as well as the work places regarding ergonomics and information overview. In 2015 NTL is to be deployed at one train traffic centre in Sweden as a prototype to be tested and evaluated. In 2018 NTL is to be deployed nationwide.

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