Reducing unnecessary cognitive load in traffic control

Gunnika Isaksson-Lutteman, Bengt Sandblad, Arne W. Andersson, Simon Tchirner
Human Computer Interaction
Department of Information Technology
Uppsala University, Sweden
P.O Box337, SE 751 05 Uppsala, Sweden
gunnika.isaksson-lutteman@it.uu.se
+46 (0)70 167 91 40

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.

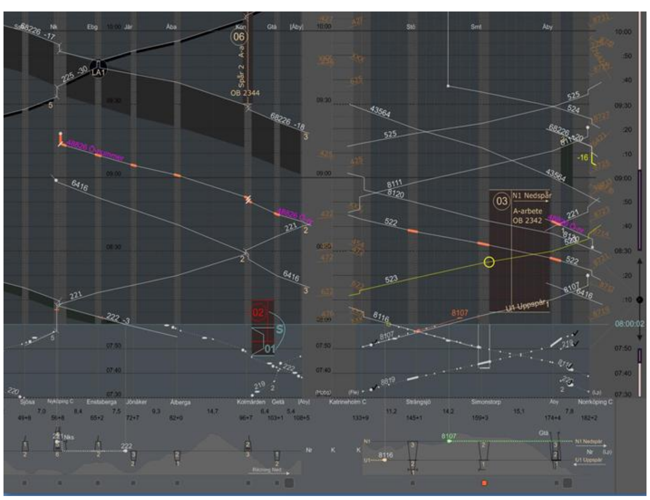

Figure 2. The dynamic user interface of STEG.

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].

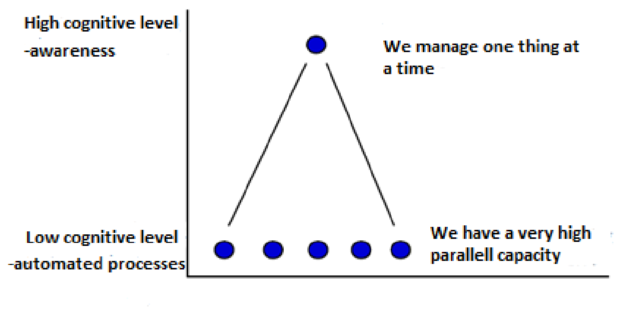

Figure 3. Different levels of cognitive processing.

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.

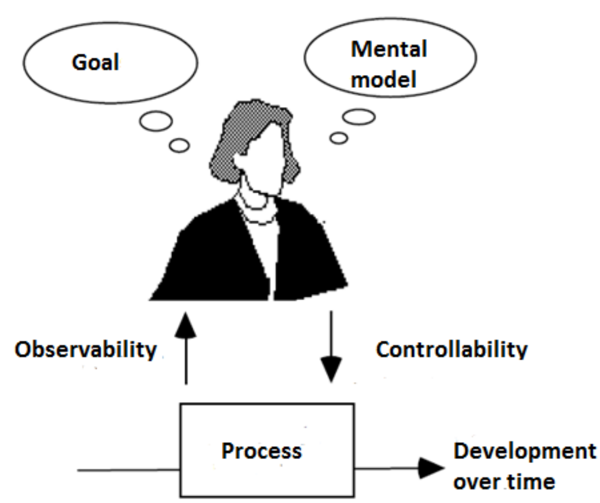

Figure 4. The figure shows GMOC model in a dynamic operational process.

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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