DESIGNING TRAIN DRIVER ADVISORY SYSTEMS FOR SITUATION AWARENESS

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During the past decade, train Driver Advisory Systems (DAS) have been an emerging topic. Many projects have been started with the goal to increase punctuality and decrease energy consumption. We found that many systems provide too little information, e.g. only a speed advice, and thus do neither improve drivers' skills nor their Situation Awareness (SA) of the traffic situation. In collaboration with train drivers, we developed key concepts for future DAS. This paper discusses today's problems and principles to solve them. We explain how SA can be supported and how this can improve overall quality of train traffic.

Introduction

> *"As long as they have green light, they hit the gas, but when they have a red signal, they complain."* – A train traffic controller on train drivers (translated from Swedish)

This quote is a typical representation of the attitude, which traffic controllers have towards train drivers. Drivers are often running close to the speed limit and have to break when they are coming too close to a preceding train with a lower speed limit or when they reach meeting points too early. In the past this has been true for many cases, but today the train drivers' behaviour could be changed.

Situation Awareness

Situation awareness (SA) is a theory that mainly deals with the information environment of operators. Operators who have SA are aware of the state of a system and the environment; they are able to project the future state. This is a prerequisite for influencing states of the system in accordance with their goals. Endsley (2000) defines three levels of SA:

1. Perception: Operators perceive the important information. This means first, that the needed information is available and second, that attention is directed to its important pieces. Without attention to the right information, operators have no chance to understand and control a system.
2. Comprehension: This level describes ability to understand the perceived information. It is the process of interpreting information towards one's goals and to remember relevant parts of information.
3. Projection: If the important information is perceived and comprehended, it is possible to understand the dynamics of a system. This will allow projecting future states and supports decision-making in order to influence and control the state of a system.

Today, train drivers' SA is limited to the process of driving their own train. They are able to perceive the state of their train via indicators, automatic train protection systems (ATP), aural and tactile feedback from engine and wheels, and they can observe the state of tracks within range of vision. Train drivers know how this information affects the train and so they can decide how to apply engine power and brakes in order to reach a certain speed, acceleration, and retardation, combined with a smooth and comfortable ride. However, they almost completely lack SA concerning the traffic situation. Their only source of information is predefined timetables and signal states, visually and via ATP. Based on this, they can only assume that everything is according to the original plans or not; they can neither gain a complete picture of the current state, nor understand changes in the traffic situation or operational plans and thus cannot project future states. Their actions are based on information that often is obsolete. We believe that driver advisory systems can have the potential to improve this situation. Inclusion of information about the current traffic situation and operational planning will allow train drivers to develop a much more comprehensive SA, which will enable them to behave optimal in a global perspective. This will lead to better quality of railway traffic in terms of safety, punctuality, comfort, energy consumption, capacity, and work satisfaction.

Driver Advisory Systems

For several years now, interest in driver advisory systems (DAS) is rising. In many countries and at a number of railway suppliers, separate projects on DAS have been started. It is not so easy to retrieve information about these systems, since they are often developed as commercial products and the developers' interest to share results with academic research is limited. In this section, we will list three DAS that we have more information on and which fall into different categories.

"**RouteLint**" is a DAS developed by Dutch railway infrastructure manager ProRail. The provided information follows two goals: communication between train drivers and traffic control should become more efficient and railway traffic in general should improve in terms of punctuality, energy consumption, and passenger comfort (Albrecht et al (2007)). RouteLint is installed on PDAs. It displays the surrounding traffic situation focusing on track segments lying ahead.

RouteLint indicates their status, e.g. if a segment is set for the driver's train or blocked by another train. Additionally delays of all trains in the displayed area are shown. RouteLint had positive effects on energy saving and efficiency of communication between train drivers and traffic controllers, probably caused by the better information available to train drivers. However, the test phase has not shown enough positive effects and the project has been stopped.

The discussed version of RouteLint does not include concrete driving advices; there is for instance no indication of recommended speed or advice for breaking or coasting. The included information is very limited and generates additional mental workload e.g. to calculate distance to other trains or to signals. It mainly shows if the next signal(s) can be expected to show stop or go, thus it supports decisions to reduce or increase speed. Still, these decisions can be contradicting to the traffic controllers' intentions, since RouteLint does only display the current infrastructure state and not deviations of current planning from the time table.

Lüthi (2009) introduces new railway traffic operation principles for the dense traffic in Switzerland. **FARE** is a DAS following these principles. It displays driving advices calculated after a constantly updated schedule planned at the traffic control. In Switzerland, even small deviations of ten seconds from this schedule can cause conflicts with other trains – focus of FARE is to prevent such deviations. It displays maximum delays that can be recovered within a certain time window and gives relevant recommendations. Simple symbols give advice for increasing, reducing, or keeping the current speed.

FARE has a connection to the real-time traffic plan and gives a well founded decision support for driving speed. However, it does not show the current planning itself, i.e. train drivers have no information about the traffic situation, helping them to understand cause of a delay, or about planned arrival times for a train. Train drivers are supposed to strictly follow a schedule without much freedom for self dependent planning.

CATO is a DAS developed by Transrail in Sweden. It combines information about the current real-time traffic plan, infrastructure information, and speed recommendations. Main goal is to reduce energy consumption (Lagos (2011)) and it allows train drivers to actively plan their driving according to current conditions and planning. It is the first DAS that is able to communicate with STEG, a system implementing new strategies for train traffic control (Sandblad et al (2010)). CATOs display contains a speed curve, current speed advice, and information about target points. Target points are restrictions from traffic control, indicating points that have to be passed in a certain time window, in order not to conflict with the traffic plan. The speed curve is a continuous speed-distance-graph designed as an overlay above infrastructure information, including height profile and speed limits; it indicates the optimal speed at a certain position. From this curve and the current speed, an advice for speed adjustment is derived.

We participated in design of CATO including definition of the contained information. Some of the implemented principles go back to TRAIN project (Kecklund et al (2001)). The displayed information, target points, speed limits, and height profile, are also key-factors for calculation of speed advices. We believe that this is important in order to understand and accept the system's advice. Target points set by traffic control and a speed curve for the track lying ahead are displayed to allow train drivers to better plan their journey and to develop better SA. Target points help the drivers to understand how the traffic plan affects their own train and include IDs of other trains involved. However, CATO does not display a complete traffic plan or detailed information about surrounding traffic.

We can conclude that many DAS are developed with very different objectives behind them. Common main goals are reduction of energy consumption and increase in punctuality. The drivers' SA and planning is seldom in focus and thus included information is often reduced to a minimum. Even systems as RouteLint, which were developed with train drivers and their awareness of the current traffic situation in focus, seem to lack some important parts of information – maybe because it is technically unavailable. Another point that usually is not part of DAS is the information flow from train drivers to traffic controllers. Train drivers can observe many details that traffic controllers are not aware of, but which can have importance for planning. E.g. unexpected high passenger volume, reduced acceleration on a train, tough weather conditions. If train drivers get the possibility to easily send out such information, traffic controllers could create a more optimal operational traffic plan.

During development of CATO, we were able to influence technical developments at the involved traffic control centre as well. It has been equipped with STEG, a system that allows control of train traffic via an electronic time-distance-graph. STEG is described in Sandblad et al (2010) and has been extended with the possibility to define target points for trains. This means that we could actually use the current traffic plan to generate information displayed in CATO. However, there are still technical improvements to be made and – a very important point – we were not able to integrate end-users in the development process as much as we wanted. This motivated us to initiate a new project, aiming for a future DAS, which will be the topic for the rest of this paper.

Method

When involving skilled professionals in a research or development project, the limited amount of time that those have available for active participation is a common problem. This is also valid for the train drivers involved in our studies. The researchers or developers have to accept such restrictions. In this section we describe our research questions as well as the method we use in order to organise the participation of train drivers as efficient as possible.

Research questions

Earlier, in TRAIN project (Kecklund et al (2001)), we explored the general work and information environment of train drivers. We investigated e.g. influence of working hours on their performance or need for supportive information. In our new project, we focus on DAS with three main questions:

1. Eco-driving: How should a DAS include and display recommendations for eco-driving in a way that does allow drivers to develop their skills and not just follow a simple speed advice?
2. Exchange of information with traffic control: Which information do train drivers need about the current traffic plan and traffic situation, in order to optimise their train operation and experience self control, support, and satisfaction? How could this information be displayed and what needs to be included in order to support their Situation Awareness?
3. How can train drivers contribute to improve operative traffic planning? Which information can and do train drivers want to share with traffic control?

Since the time frame for this project is limited to five months, our goal is not to develop a complete prototype for a DAS. The project is more of a pre-study with the goal to identify the benefits that additional information can have for train drivers' performance. Expected outcome will be a recommendation for DAS development, including an evaluation of the overall gain and the information that should be included in a complete and implemented system. Safety aspects are not a major concern at this point.

Methodology

Our project is based on a series of workshops including one introductory meeting followed by three half-day seminars following the concept of "vision seminar process" (Johansson et al (2007), Hardenborg et al (2007)). In the process, we work closely together with a group of five professional train drivers. In-between these seminars, we observe drivers in the drivers' cabin and make several semi-structured interviews. We also give the participants "home work" between the group meetings, mainly to reflect on conclusions so far and to relate these to their normal work days. The main elements of our vision seminar process are group wise workshops where we analyse today's work, problems, anticipations for possible future "ideal" work, details of future work organisation, processes and support systems, motivations for this, scenarios of future work contexts, and more detailed requirements for future information and support systems.

User group

The DAS we intend to specify and develop must be based on knowledge and experiences of skilled experts. The objective is to support them to better meet the demands they are facing and to support their work towards improved skills, reduced obstacles, and better performance in relation to the overall traffic goals. Our work group consists of eight train drivers with many years of work experience. They have the additional task of being expert on specific types of locomotives and experiences from training other train drivers. They are from the same railway undertaker, who operates different types of passenger train services. Most have earlier been involved in projects to develop DAS. All are men. Even though this group is not fully representative for all types of drivers, they can support our goal: to identify the information skilled experts need to improve their performance and live up to future traffic demands. In future work for development and evaluation of DAS, it will be necessary to involve new and broader groups of train drivers.

Today's problems identified by train drivers

During our work with the user group so far, we discussed common problems occurring today. We were focussing on problems that have to do with planning and information from traffic control. One result is a list with 14 problems identified by the train drivers. It is possible to divide these problems into four groups:

- General, organisational problems at the infrastructure manager.
- Problems related to the original timetable.
- Lack of information at traffic control, leading to suboptimal planning.
- Problems caused by insufficient communication from traffic control to train drivers. These problems usually occur when the current plan differs from the timetable and train drivers do not have according information. More than half of the identified problems fall into this group.

Problems at the infrastructure manager

The train drivers criticised slow computer systems and cumbersome routines. This is not solvable by a DAS, but ideas came up, how DAS could ease train drivers' work, assuming changes at the infrastructure manager. One improvement would be digital submission of new driving orders, e.g. in case of alternative routeing. Another problem seems to be handling of forms, which need to be filled out by train drivers and traffic controllers in case of certain, usually safety critical incidents. This work is tedious and further delays continuation of traffic. Train drivers think that routines should be changed so that they ideally just need to confirm a prefilled form provided by a DAS and the traffic controller.

Issues with the original timetable

Thoughts behind the original timetable are seldom obvious to train drivers: some line sections are (almost) impossible to serve in time, while others include possibilities for recovery of several minutes. Knowing in advance where and why possibilities for recovery exist, would allow them to better plan their journey – today this has to be learned along with route knowledge. A DAS could include this information. Additionally, train drivers would like to have a chance to participate in the timetabling process with their experience.

Suboptimal planning at traffic control

Train drivers realise common situations with suboptimal operational traffic planning. Most of these can be related to missing information and resulting wrong calculations at traffic control. Examples are weather conditions and train defects which increase runtimes continuously. In other situations it is the other way around and traffic controllers seem to assume problems that delayed a train once as recurring and thus plan with a suboptimal, slow runtime. Also sometimes traffic controllers seem to have an incomplete picture of the influence that local speed limits, e.g. at points, can have on long and heavy freight trains. Especially meetings and overtaking seem to be problematic; train drivers e.g. reported situations where overtaking is time consuming, because the faster train is lead over a slower path through a station, while the slower train is stopped on the fast path. In other meeting situations, stopping a freight train takes so long, that it would actually be faster for both involved trains, if the passenger train stops instead.

If train drivers would be aware of such traffic situations or suboptimal planning before they actually approach signals and waiting trains, they could inform traffic controllers and support their planning. However, today communication is only possible by phone. This is problematic, since it would distract both sides from their actual task – when information exchange is needed, there is simply no time. DAS should include means for communication that integrate well with the work environment at the driver's cabin and the control centre.

Insufficient information from traffic control

Many problems today are due to absent information about the current planning, i.e. planned track usage and updated timetable. Train drivers can only plan their journey according to original timetable data. As soon as the current situation deviates – which is just normal in the complex and dynamic train traffic process –, train drivers have no other chance than to act suboptimal. Common situations at single track lines are moved meetings. If the original plan is to wait for a meeting train at a certain point, train drivers usually adapt their driving so that they approach the waiting station coasting, which reduces energy consumption and improves comfort, but is more time-consuming. First when they pass a pre-signal indicating that the signal at the meeting point is set to green, train drivers can guess that a meeting has been moved or cancelled. At that moment they already have lost time, which could have increased margins in tightly timed corridors lying ahead or which could cause later delays. Besides information about meeting and takeovers, train drivers lack information about subsequent trains. This information is especially important in eco-driving, to prevent train drivers from blocking other train when coasting. Train drivers expect this problem to grow when eco-driving becomes widely spread. In general, there are many possibilities and situations where train drivers could behave more optimal in a global perspective, if they had access to a real time traffic plan.

In addition to improved traffic flow, train drivers would appreciate a shared traffic plan because it can help them to provide better information to passengers.

Train drivers see passenger information as an essential part of their work; they are obliged to inform customers adequately about delays, their reasons, expected solutions, and consequences on train connections. If a problem has lead to accumulation of trains, drivers see a common message to all affected trains as a feasible solution. In the best case, this could contain information about reason, place in queue, and estimated waiting time. Short text messages displayed in a DAS about important changes in planning, e.g. moved meetings, seem to be preferred by train drivers in general.

Solutions in future systems

At the time we are writing this paper, two of three main workshops have taken place. This means that we have gotten quite a clear picture about the information required by train drivers and developed some main concepts useful for designing DAS. We have not sufficiently covered the question, how this information should be visualized, yet. Thus this section will only introduce the concepts.

Display of the current traffic plan

A key concept is display of the traffic plan to train drivers. Train drivers can meet a certain point at a certain time quite exact, but they need to know distance in terms of time and space to this point, e.g. in form of *target points*. Today such points are given as driving orders prior to a train's initial departure. They include arrival and departure times at stations, times for passing certain spots, train meetings, and exceptional situations such as infrastructure failure or changed speed limits. The given times are based on the timetable but include deviations introduced by known exceptions as planned maintenance. However, unexpected disruptions and deviations are characteristic for train traffic. They do not only arise from sudden problems in the infrastructure as e.g. slippery rails or signal failures, but also from cancelled, delayed, or early trains, unexpected passenger volume, engine problems, counterproductive automation in signalling systems etc. Many of these incidents require traffic controllers to reorganise the traffic plan. If they do not have time to communicate these changes, which is usually the case, train drivers will plan their journey according to obsolete target points. As a result, they usually can only perform suboptimal and important margins remain untapped. Passengers can experience this problem in form of a journey at maximum speed, mixed with hard deceleration and mysterious stops.

Obviously the information available from a DAS should be based on a continuously updated traffic plan. Additionally we believe that the plan itself or at least relevant excerpts has to be visible to train drivers. This will make it much easier to understand advices from a DAS and increase trust developed towards the system. If reasons for deviations are explained, train drivers will be able to participate more in the traffic process. They could use their expertise to anticipate how incidents will affect the own train and thus report back if they see the need for further changes in the planning.

Surrounding traffic

All three moments, observations, interviews, and workshops, even with different groups, have shown that train drivers are very interested in the surrounding traffic. Especially when they have to wait, they want to know why and how long this will probably take. Train drivers stressed, that it is also important to know about subsequent trains. They do not want to hinder those e.g. by too excessive eco-driving. We see display of the current traffic plan as an instrument for this. Instead of only showing planning for one's own train in form of target points as CATO or the current traffic state as RouteLint, displaying a plan including surrounding traffic seems feasible and will improve SA of the traffic situation. Designing a special view of STEG, focussed on one train, could be a start.

Motion profile and speed advice

Train drivers mentioned several goals: safety, punctuality, passenger comfort, and eco-driving (including energy saving as well as careful treatment of the material). Especially deviations or tight schedules led to conflicts in these goals. A train driver would go late or slower in order to maintain safety, passenger comfort and eco-driving are secondary if a rougher driving style would allow the passengers to reach an important connection, etc. In general, a larger distance to target points leaves train drivers with more possibilities to adapt their driving e.g. for energy saving. This is even more so, when the timetable leaves good margins. However, larger distance also correlates to larger numbers of interfering factors, which train drivers need to take into account to plan their driving. Considering all these factors can easily require too much cognitive capacity. Thus additional support e.g. in form of speed advice is desired.

All advices we want to include in a DAS should have one property: they have to be traceable. There are several reasons for this. If train drivers can easily understand the reasons for an advice, they will develop trust in the system. As a side effect, it will be easier to track obviously wrong recommendations from the system. Drivers can understand the reasons easier, when they are aware of the current traffic situation, and not only factors with direct impact on their own train. Traceable advices will make it easier to learn from them and, this is why they should be built fitting for expert train drivers, to develop personal skills.

Our approach to speed advice is a motion profile for the train, i.e. a continuous line showing the recommended speed until next stop, or a target point they are not allowed to pass too early ("*If you travel fast, you will be late*"). This profile will fit the optimal case under optimal conditions, but with respect to current planning. Understanding this profile will certainly give positive impact, if it can easily be related to infrastructure properties such as height profile and speed limit. It will be the task of the human train drivers to translate this profile into actual driving and adjust it to complicated exterior conditions like reduced acceleration or retardation of the engine or slippery tracks, which might be hard to handle by algorithms. Goal is collaboration between human and algorithm, where algorithms can give train drivers important incitements and ideas towards a more effective way of driving and to evaluate a more complex mental model.

Communication shortcuts

As discussed, today's traffic planning could benefit not only from improvements to train drivers' SA, but also from train drivers sharing information with traffic controllers. Since communication by phone has shown to be not feasible in many essential situations, we suggest specifying common types and topics of communication. At least those types important for better planning should be considered to be included or even automated in future DAS as well as traffic control systems.

Conclusions and future work

We have discussed three DAS and can conclude that none of these creates comprehensive SA of the current traffic situation. Together with train drivers, we have identified problems and possible solutions in today's train traffic. Our collaboration has shown that drivers have strong interest in the surrounding traffic, need up to date information about the traffic plan, and have valuable information that could improve operative planning. We believe that DAS, implementing the concepts we have listed, could significantly improve train drivers' SA of current traffic situation and planning. They will be able to make more accurate projections of future states and this will result in more optimal behaviour, quality of train operation, and higher work satisfaction. We still need to explore to which extent information is needed and how it should be displayed, also under the aspect of safety.

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