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A SOCIOTECHNICAL COMPARISON OF AUTOMATED TRAIN TRAFFIC CONTROL BETWEEN GB AND SWEDEN

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There is strong motivation for having rail technology that is both international and interoperable. The practice, however, of moving technology that works well in one operational setting to another is not straightforward. This paper takes one type of technology, traffic control automation, and looks at variability between two contexts – GB and Sweden. The output from this work is a socio-technical framework which will be used to asses the viability of applying new advances in traffic management across a number of EU countries.

Introduction

With growing demands on railway capacity, less room to build physical infrastructure (e.g. rail tracks) and sophisticated technological advances, there is a need to introduce innovative technologies to improve and enhance railway traffic control. Areas for improvement include traffic planning, operational control, train driving, resource management, and handling of perturbations and disruptions. Especially important are strategies and systems for automation, and experiences indicate that the potential improvements to be made are immense.

Sharing knowledge between railway stakeholders in different territories is seen as one means to increase the pace and cost-effectiveness of innovation. For example, can technical innovations in Sweden and Netherlands, such as those above, and the human factors lessons learned during the implementation of these innovations be effectively applied in the GB, US or Asia? This also has implications for the railway supply chain, which is increasingly dominated by multi-national organisations. Ideally, products developed for one territory can be internationalised with little additional work. A second motivation for sharing knowledge between territories is to support interoperability between countries. The demands, especially within Europe, for interoperability, shared technologies and for harmonised systems for rail traffic planning, operational control and train driving, are high and increasing.

Experiences show that it is rarely straightforward to transfer an efficient solution from one organisation to another. The reason for this is successful deployment depends on many organisational, contextual, and local conditions. There are many problems and aspects that must be considered when principles, systems, products or work processes are being transferred. While organisations such as the UIC (http://www.uic.org/) can set out a common framework for operating the railways, there are organisational and local differences, infrastructural differences and differences related to culture, resources, practice, traditions, and more to take into account. It is critical, therefore, to embed change within the view of the railway as a sociotechnical system where humans and technology interact in a complex and dynamic manner.

The following paper aims to make a number of contributions to this topic – first, it presents data from two countries, Sweden and GB, to demonstrate differences between territories; second, it provides data relevant to the exchange of human factors work in one area, automation, that is of a high priority to the rail industry; third, it presents a socio-technical framework for capturing the important characteristics of rail processes, especially automation, that need to be considered across operational contexts.

The case of ail automation for traffic management

One area of much interest is the introduction of automation into train traffic control. The advent in electro mechanical technologies moved lever frames to mechanical panels and enabled remote control and running of the railway services, and more recently into centralised traffic control, supplemented with different kinds of automation to regulate train settings. More recently, this role of automation has increased to include decision-support for operational traffic planning and control (Kauppi et al., 2006) or in aspects of operations such as crew management (Jespersen-Groth et al., 2009).

The risk with such technology is that if the automatic systems are not well understood and transparent, the operator will be less informed about what the automatic systems are doing and will do in the future, negatively impacting situation awareness of traffic conditions. If such automatic functions are active, the human operator will often not be aware of future events leading to “automation surprises” (Bainbridge, 1983). Earlier research (Kauppi et al., 2006) has made a distinction between autonomous and non-autonomous automatic support systems for human operators in traffic control. Autonomous systems have their own independent “will” as implemented by the designer and are allowed to execute their own control actions, often without considering the original intention of the human controller. This often leads to the “turn-it-off” syndrome. A non-autonomous automatic function is only allowed to execute the intention of the human controller. Such automatic functions can still be very advanced and execute high level intentions in an efficient way. In practice both types of automatic systems can be relevant, but wrong use can result in large problems and low efficiency.

Automation is often accompanied by fundamental changes to the organisation of work and work processes. For example, as work becomes more centralised, so the number of dispatchers can decrease. They may also be co-located, often losing local knowledge or being required to use different skills. Work between people carrying out the similar tasks may become less common, and instead, work involves collaboration between people with different responsibilities, skills and knowledge. This requires people to have greater knowledge of the constraints that their collaborators are working under (Woods and Branlat, 2010), including non-human agents, such as control automation. The same automation tools may have to be used by many people with different roles and responsibilities (Dadashi et al., 2011) but without substantial modification to the functions or interface of the automation. This all has to take place not just within one organisation, but the multi-stakeholder environment that constitutes the modern railway (Steenhuisen and de Bruijne, 2009) and these organisational influences will have a bearing on how new technology is used. Also, the processes in which control is embedded is interlinked with technology and artefacts that may differ between and sometimes within countries. These local operating constraints will affect the compatibility of any new technology.

All of these factors have a bearing on successful technology design, development and deployment. The specific motivation for the work presented here was a collaboration between GB and Sweden, with contributions from other EU partners, to develop new forms of traffic management system that could be used in a number of countries. The first step was identify similarities and differences between two partner countries – GB and Sweden – which is the focus of the remainder of this paper.

Method

The work reported here consists of two parts. First, a joint workshop comprising members of GB railway (Network Rail), Human Factors specialists from University of Nottingham, Swedish railway (Trafikverket) and human factors specialists from University of Uppsala was held in London in March 2012. This workshop allowed developing an overall understanding of the railway control in the two countries, similarities and differences, as well as their research interests and key challenges.

The second part of the study consisted of a questionnaire that aimed to understand current design and practice for automation for rail control. Specifically, this study is aimed front-line staff – i.e. those involved in front-line regulation of traffic (signallers in GB).We are trying to understand current tools, how these tools present information to their users, what form of interaction is possible and what are user attitudes to automatic systems' usability and effectiveness.

In keeping with the socio-technical perspective on railway, and with particular reference with the need to understand the nature of control, and control constraints, in order to understand system performance (Hollnagel and Woods, 2005), data from both of these activities were structured over four themes.

1. The context of control – what is the overall railway context in which control is applied in terms of geography, the aims of the service, and also the business/ administrative context.
2. The organisation of control – how is control structured in terms of roles and functions.
3. The automation of control – what role does automation play in control, and what are the key functional characteristics of automation.
4. Interaction with control – how do humans and automation work together, what are the mechanisms for humans and automation to control the network.

Findings

The context of control

The railways in Great Britain comprise a large, complex and intertwined network of rail across nine regions. There are nearly 20,000 miles of track, 40,000 bridges and tunnels and 2,500 stations (Network Rail, 2010). Network Rail (NR) owns and maintains the GB railway network in order for between 20 and 30 passenger Train Operating Companies (TOCs) and 6 Freight Operating Companies (FOCs) to run services. If there are problems with the service for which NR is responsible, TOCs are entitled to a fine payable by NR due to the damage to their business. Therefore, it is in the best interest of NR that faults are managed optimally to keep delays to a minimum. Hence, it is critical within NR that all processes work together to ensure safe and efficient running of the service. In GB, the needs of passenger services dominate, no more so than in London and the South East.

The rail infrastructure in Sweden consists of 8200 km single track lines and 1900 km double or four track lines. The signalling system is mainly interlocking with automatic remote blocking through switch boxes. ATP (train protection) is installed on all main lines since 40 years. Some traffic areas, especially in the urban areas and the iron ore line in the north is running close to the maximum capacity. Traffic is very mixed and the de-regulation of traffic has resulted in more than 50 different organisations running trains on the tracks. Freight has a higher priority in certain areas in Sweden. Particular attention and emphasis on service quality is applied in the north of Sweden, especially around the Iron Ore line where delay or cancellation of service may cost hundreds of thousands of Euro (this is the major motivation for testing the STEG system in this region). Similarly, fish services, running down to ferries to Germany also take a high priority.

The organisation of control

In GB, Network Rail has a number of control processes responsible for running and maintaining the railways including signalling control which is mainly responsible for running the service (there is also electrical control supplying power to run the electric track and maintenance control is responsible for maintaining the infrastructure). Currently, traffic control is managed through a mixture of traditional lever frame boxes (still numbering in their hundreds) and many Entry and Exit (NX) and VDU-based control centres. Network Rail's strategy is to centralise control into 17 regional control centres, of which a small number are now operational. As well as front line traffic control (i.e. signalling, aka dispatching), route control manages at a more strategic level, for example substantial re-planning during incidents. These control functions may be co-located with representatives ofTOCs, and may in some specific cases be located with, or near, front-line signallers.

In Sweden, train traffic control is since more than 40 years strongly centralised and handled by the Swedish Traffic Authority (Trafikverket), i.e. the infrastructure holder. Traffic control is performed from 8 regional traffic control centres (TCC) from Malmö in the south to Boden in the north. The traffic management systems are similar but of different age and manufacturer. A very important difference between the organisation and roles of the traffic controllers in Sweden compared to most other countries are that the roles of the operational re-planner and the signaller is integrated in one single role, the traffic controller. Traffic plans are transferred 24 hours in advance to the traffic control centre. Traffic controllers monitor the traffic via track structure panels indicating occupation of signal circuits and a number of other information systems, re-plan if needed with the help of pre-printed paper time-distance graphs. Traffic control is performed by typing control commands to the traffic control system. A train controller works as a coordinator in each TCC, taking decisions that concern several individual controllers, communicates with other TCC and with Railway Undertakers (RU). Today the organisation is changed by establishment of four Regional Control Centres substituting the roles of the train controllers at each TCC and a National Control Centre where more strategic decisions are taken during major disturbances.

Automation of control

In GB, automation of route setting (as opposed to a more passive automatic setting of signals in response to passing trains), or ARS. ARS is Route setting tool using the timetable as the basis for sending trains through in timetabled order setting signals and points in accordance with pre-defined route. It cannot make decisions about alternative routes, so it is most effective when the timetable is stable. ARS is used widely, but not everywhere. Many of the larger VDU-based signalling control centres use this kind of automation, but some of the older centres either use VDU with no ARS, or use older mechanical (NX) signalling, which is not automated. Also, not all trains on a workstation will be under ARS. Some are freight, or non-timetabled services, that the signaller will have to route manually.

In Sweden, there are several forms of automation, from a "Local automatic function" that is used in single track stations, through to a "Central programmed automatic function" which is used in single and double track stations, using signal Id, track Id, train Id, original timetable and track usage priority, per station. These are primarily used on single track lines, which are common in Sweden, and may have to deal with high traffic demands. A separate central programmed function for stations and lines. "TLS", which is similar to ARS uses signal Id, train Id, original timetable and track usage priority, per area. This type of traffic control is used in multi-track areas, such as in large cities. Finally, PEF is used in Northern Sweden and Norkopping. This is an integrated part of a new system for operational train traffic control called STEG. STEG helps traffic controllers to observe the dynamic development of the system under their control in an electronic time-distance graph, identify disturbances, perturbations and conflicts of different nature. Re-planning according to the actual situation can be made directly in the graph. When the conflict-free and hopefully optimal plan is close to the real time it is locked and automatically executed by an automatic execution function called PEF. STEG is currently implemented in Northern Sweden, but will form the basis for a new planned national train management system to be developed within the next 6–7 years.

Interaction with Control

In GB, the main point for interaction with ARS is the schematic track overview that makes up most of the workstation). Trains under the control of ARS are in a different colour (blue) and routes set are indicated in the same way as routes set manually by the signaller (a highlight across the track diagram). Trains not under ARS are shown in pink. If the signaller wants to take a train out of ARS, they can click on it with a tracker ball. They can also take sections out of ARS, or they can place 'reminders' on signals which means that a route cannot be set (manually or by ARS) over that track section. The signaller may also choose to take the whole workstation out of ARS.Also, there is a specific HMI for ARS at the end of the workstation – the GPD (general purpose display) (see 2 on Figure 1 below) which allows the signaller to query which routes have been set by ARS, what decisions have been made, but can't really query why it has made the decision.

In Sweden, interaction is similar. Much of the control of traffic is via a schematic of the track, with additional supporting displays. A major difference, however, comes with the predominance of the train, or time-distance graph. Time-distance graphs have previously been used a paper-based planning, and re-planning, tool. With STEG, however, re-planning takes place directly on an interactive implementation of the train graph (visible in the top left of Figure 2). New plans are then executed in real time by PEF.

Discussion

Comparisons are offered over a number of levels. At the organisational level, there are similarities, in that each country has a railway that involves multiple stakeholders. This is in keeping with other countries, at least in the EU (Steenhuisen and Bruijne, 2009) though in Sweden there maybe even more fragmentation of operators, meaning a higher degree of complexity and integration when making coordination and re-planning decisions. The type of infrastructure and traffic is broadly similar, though freight and passenger priorities differ somewhat. Geographically, the predominance of single track traffic, and the need to coordinate passing at loops and stations, means there is potentially different types of planning and decision-making required and different types of constraints on performance applying in these regions. In this respect regions of Sweden and GB may have more in common with each other than with other more complex parts of the network in the same country.

In terms of organisation of control, there is a far greater degree of centralisation and co-location in Sweden than is currently the case in GB. Also, there is a shift to this combined dispatch/traffic planner role in Sweden, especially with the introduction of STEG, whereas as signalling/traffic regulation remains distinct roles, and is often still physically separated in GB. These differences have major implications for the successful integration of new technology, as the roles that use information, and the knowledge and skills brought to bear have important implications for the success of the technology (Dadashi et al., 2011). It is interesting that work with other EU countries (France, Germany, Netherlands) suggest that GB and Sweden may form the two poles of control organisation, though all territories are showing some move to more integrated roles as the reliability of automation for train regulation improves and the need for hands-on control of the signalling system decreases.

At the technological level, there are similarities in that both countries currently use automation, and are seeking to deliver greater automation as part of their services. In GB automation has been implemented for some time, and is more relevant at the route setting level. Sweden has a mixture of manual routing and automation of different nature implemented in different parts of the traffic management system, but is now moving to a more strategic form of automation that supports re-planning and automatic execution (signalling) of the plan. As well as differences in underpinning automation technology, there are also differences in representation with greater use in Sweden of time-distance graphs. It is critical to note that graphs are already an accepted tool for traffic planning in Sweden, and therefore the move to control through graphs is a far less radical step than might first appear to those currently using control based on track schematic.

Through the process of capturing the structural differences between automation in different territories, it has also been possible to capture and compare attitudes to the role of automation. In theory, one of the concerns with automation is that the dispatcher starts to control by exception, rather than by forward planning or proactive control (Isaksson-Lutteman et al., 2012) and a move from feedforward control to feedback (Balfe et al., 2012). In practice, one of the major issues with rail automation is developing an underpinning mental model of how the automation is selecting routes, and through inefficient routing options, dispatchers may have limited trust in automation (Balfe et al., 2012) – a result found both in GB and Sweden. As a result, incompatible automation becomes a source of workload in its own right, demanding constant attention and intervention on the part of the dispatcher (Golightly et al., 2012). Lack of trust is seen most acutely in a reaction to switch automation off as soon as the timetable moves into an unpredicted state due to minor or major disruption. The "turn it off syndrome" has often been reported in different control settings and across both countries, with similar experiences from partners in other ON-TIME countries. When the situation becomes problematic, with many conflicts to solve and time critical decisions, the operator chooses to turn automatic functions off in an attempt to be more in control. This can be seen as an example of the "irony of automation". When the traffic controller really needs help, the potential help from automatic functions must be eliminated (Bainbridge, 1983).

Conclusions – a sociotechnical framework

As well as being useful findings in their own right, these comparisons serve to illustrate the multilayered nature of control in railways, and how systems that functionally are essentially similar can vary hugely depending on differences in implementation. Human factors aspects can only be understood in their contextual setting. Based on the studies above, we conclude that there is a need for a sociotechnical framework for comparing principles, systems, products, roles and products for automated control across organisations and countries. A framework for this, in a preliminary form, is presented in Table 1. The main parts of this framework, that must be further developed and evaluated, are:

- National characteristics
- Organisation of railways
- Organisation of control
- Roles
- Communication
- Technology
- Automation
- Interfaces

The value of this framework for the ONTIME project will be to understand when design or deployment decisions that make sense for one country will be applicable to all. This framework will be tested and extended to cover the other participating countries within ONTIME. In the short term, data from partners in France and Germany is being used to complement the data presented from GB and Sweden, and later the aim is to use the framework to derive predictions as to how operators in different countries will respond to design proposals. The aspiration is that this framework can be applied beyond the lifespan of this project to cover human factors applying to a host of innovations, whether technical, procedural or organisational, which could be applied across territories wishing to improve their railway.

One limitation to address is that the focus of the framework is currently on frontline traffic control and minor incident management, and it is important for the current

Table 1. Socio-technical framework for transfer of rail automation technology.

National characteristics	Density, complexity, service and performance context; organisation of the railways (e.g. unbundling)
Organisation	Centralisation vs. decentralisation; Work organisation, division of control tasks between different roles
Roles	Structure and relations between different roles. Work processes and control tasks for each role.
Communication	Communication patterns and channels between different roles in the control process e.g. other control roles, train drivers, railway undertakers etc.
Technology	Type of signalling and safety system, traffic control system, switch box technology, interlocking system, train protection system etc.
Automation	Structure and complexity of automation. Single automatic systems or a complex structure. Interaction between different automatic systems. Different modes of automation. Control-by-awareness or Control-by-exception
Interfaces	Observability. Are the automatic functions and their actions transparent and easy to understand? Controllability. Possibilities for turning on/off, changing modes, re-programming etc. Representation (eg schematic versus train graph)

project that it can also demonstrate value for train driving and for major incident management, two other areas with significant deviations between countries.

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