STAMP goes EAST: integrating systems ergonomics methods for the analysis of railway level crossing safety management

Abstract

Various systems ergonomics methods are available to support the design and analysis of rail systems. Whilst the utility of these methods is accepted, the increasing complexity of modern day systems is stretching their capabilities. The integration of distinct systems ergonomics methods provides a means of redressing this. This article presents a study in which the underpinning principles of the STAMP control structure method were added to the EAST framework, and subsequently used to examine railway level crossing safety management. Task, social and information networks for a railway level crossing system lifecycle were developed along with an additional control network showing safety controls and their interrelations. Analysis of the networks points to a need to (1) strengthen activities and controls around proactive risk management and performance monitoring, (2) tighten the coupling between organisations responsible for safety management, and (3) to increase the flexibility of design standards. The implications for future railway level crossing safety management and rail safety research and practice are discussed.

Keywords: EAST, STAMP, controls, networks, rail safety, railway level crossings

Introduction

Safety issues are increasingly being examined through a systems ergonomics lens (Karsh et al, 2014; Salmon et al, 2017; Walker et al, 2017). In line with this, since the turn of the century a range of systems ergonomics methods have either been developed or have experienced a resurgence in popularity. These include: systems analysis frameworks, such as Cognitive Work Analysis (CWA; Vicente, 1999) and the Event Analysis of Systemic Teamwork (EAST; Stanton et al., 2013); accident analysis methods, such as Accimap (Svendung & Rasmussen, 2002), the Systems Theoretic Accident Model and Processes (STAMP; Leveson, 2004), and the Functional Resonance Analysis Method (FRAM; Hollnagel, 2012); and systems design methods, such as the MacroErgonomic Analysis and Design method (MEAD; Kleiner, 2006) and the CWA Design Toolkit (Read et al, 2016).

The popularity of systems thinking is now such that these methods and approaches are being applied across the transport domains including rail (Salmon et al., 2016b; Stefanova et al., 2015), road (Parnell et al., 2017; Salmon et al., 2016a), aviation (Allison et al, 2017) and maritime (Lee et al., 2017). In the case of rail transport specifically, these methods have been applied to a diverse set of issues, including railway level crossings (Salmon et al., 2016b; Stefanova et al., 2015), ticketing system design (Read et al., 2015), accident analysis (Chen et al., 2015; Ouyang et al., 2010; Salmon et al., 2013), signals passed at danger (Madigan et al., 2016), and train cabin design (Jansson et al., 2006). Given the increasing intensity of operations and complexity in rail transport systems (e.g. National Transport Commission Australia, 2011; Read et al., 2013) it is likely that systems ergonomics methods will increasingly be applied during analysis and design activities in rail systems worldwide.

Although all of these methods share a common alignment with systems theory, most have differing theoretical underpinnings giving rise to their own unique analysis approach. STAMP, for example, is based on control theory and seeks to identify what control structure is in place in a given system and, in the event of an accident, how the adaptive control functions failed. On the other hand, CWA focuses on the constraints imposed on behaviour and attempts to describe how they influence decision making and strategy selection. An additional formative capacity enables analysts to determine the impact on behaviour if existing constraints are removed, modified, or if new ones are added. Further differences can be found when considering the focus of other systems ergonomics methods such as Hierarchical Task Analysis (goals), EAST (task, social and information networks) and FRAM (performance variability and resonance). As a result, each method brings with it a unique set of strengths and weaknesses, and many have discussed the potential benefits of combining different methods to enhance comprehensiveness and richness of outputs (Dallat et al., 2017; Houghton et al., 2015; Naweed, 2014; Salmon et al., 2010; 2011, Stanton et al, 2013; 2016; Patriarca et al., 2017).

As a result, researchers and practitioners are beginning to explore the utility of integrating different systems ergonomics methods. Patriarca et al. (2017), for example, used the abstraction hierarchy from CWA in conjunction with FRAM, suggesting that using the two together enables additional analyses of intra-agent and intra-system level interactions. Houghton et al (2015) combined social network analysis and CWA to analyse military planning tasks, concluding that using the two approaches together enables a better understanding of system structure. Similarly, Stanton et al (2016) combined CWA and social network analysis to compare dual, single and distributed cockpit crewing for system safety on future flight decks. CWA was used to define the system constraints whereas the density metric from social network analysis was presented as a measure of system resilience. Given that modern day systems appear to be stretching the capabilities of our methodological toolkit (Salmon et al., 2017; Walker et al., 2017), it is these authors opinion that the integration of systems ergonomics methods represents an important area of investigation for our discipline. This builds on a long history and tradition of methods integration in ergonomics research and practice (e.g. Kirwan, 1992a, b; Stanton et al., 2005, 2013).

This article pursues this line of inquiry by investigating the utility of integrating principles from the STAMP method (Leveson, 2004) with the EAST framework (Stanton et al., 2013). To test this approach, we present the findings from a case study in which STAMP and EAST were used in an integrated manner to examine safety management during the design and operation of Railway Level Crossing (RLX) systems in Victoria, Australia. To facilitate this, a control network representation showing safety controls and their interrelations was developed for use with EAST's existing task, social and information network representations. All four networks were then used to examine the system and its safety controls with a view to identifying recommendations for strengthening safety management at railway level crossings.

Research Context: Railway Level Crossings

Collisions between trains and vehicles at RLXs remain a persistent road and rail safety issue worldwide. In Australia there were 97 fatalities resulting from collisions between trains and vehicles at RLXs between 2000 and 2009 and 92 collisions between trains and pedestrians at RLXs between 2002 and 2012 (ATSB, 2012; Independent Transport Safety Regulator, 2011).

Overall, RLX fatalities account for almost half of all rail fatalities in Australia (ONRSR, 2015). Whilst Australia is used here as an example, the problem is of a similar magnitude in the United States of America and Europe (Evans, 2011; Federal Railroad Administration, 2013).

On top of the personal and social impacts of RLX collisions, the financial burden is also significant. In 2010, the annual cost of RLX incidents in Australia was estimated to be over one hundred million dollars, taking into account human and property damage costs as well as other costs such as emergency service attendance, delays, investigation and insurance (Tooth & Balmford, 2010). Given the combined personal, societal and economic burden created by RLX collisions, they continue to represent an area of strategic importance for road and rail safety authorities (Read et al., 2017).

Analyses of fatal RLX collisions provide evidence that they have a complex web of interrelated causes spanning overall road and rail systems. In short, they are a systems problem (Read et al., 2017; Salmon et al., 2016b; Stefanova et al., 2015). For example, a systems analysis of the 2007 Kerang semi-trailer truck and train collision identified various systemic control and feedback failures that led to the truck driver's lack of awareness of the train (Salmon et al., 2013). These included a failure of the warnings to alert the driver to the presence of the train, an inadequate RLX risk assessment process, and communications failures regarding risk and near misses at the crossing involved. Salmon et al (2013) argued that interventions to improve RLX safety should focus on strengthening controls both at the RLX itself (e.g. warnings) and also within the wider RLX system (e.g. improved risk assessment processes).

This systemic nature of RLX collisions and interventions has important implications for the methods used to understand and improve RLX safety. Describing and understanding RLX systems requires analysis methods that consider the behaviour of overall road and rail systems (Read et al., 2013; Wilson & Norris, 2014). Key elements requiring analysis include:

- the tasks that are undertaken across the system as part of RLX design and operation;
- the diverse set of agents that undertake RLX design and operation tasks;
- the interactions between agents (human and non-human) when undertaking these tasks;
- the information required for successful completion of these tasks;
- the factors influencing behaviour across the system, including safety controls, environmental factors, and financial and production pressures.

Based on our previous applications of systems ergonomics methods in transport safety, including EAST (Salmon et al, 2014), CWA (Salmon et al., 2016b; Stanton et al, 2016), STAMP (Salmon et al., 2016a; Allison et al., 2017) and Accimap (Newnam & Goode, 2015; Parnell et al., 2017), it is apparent that no one method can completely fulfil these requirements. EAST for example considers tasks, agents and information, but does not explicitly consider safety controls and their impact on behaviour. STAMP, on the other hand considers controls and control failures but does not detail the tasks and information required when enacting controls. It is the authors' contention then that a richer analysis of sociotechnical systems behaviour can be achieved by integrating different systems ergonomics methods.

The study was undertaken to identify the range of factors influencing behaviour and safety in RLX systems and identify opportunities for introducing new interventions designed to improve safety. To achieve this, the EAST framework and STAMP control structure methods were integrated and used together to examine a RLX system 'lifecycle' including all activities involved in the design, implementation, operation and removal (for grade separation) of RLXs in Victoria, Australia. A short overview of each method is given below along with a description of how EAST was extended through the addition of STAMP control structure principles. The analysis is then presented followed by a discussion focussing on the implications for RLX safety management and the strengths and weaknesses of the new EAST control analysis framework.

Part 1: Integrating EAST and STAMP

The Event Analysis of Systemic Teamwork

EAST (Stanton et al, 2013) provides an integrated suite of methods for analysing the performance of complex sociotechnical systems. The framework supports this by providing methods to describe, analyse and integrate three network-based representations of activity: task, social and information networks. Task networks are used to provide a summary of the interdependence of activities performed within a system. Social networks are used to analyse the organisation of the system and the communications taking place between agents (both human and non-human). Information networks describe the information used to support task performance and how this information is distributed across different tasks and system agents. The EAST 'network of networks' approach is represented in Figure 1.

****INSERT FIGURE 1 HERE****

Recent applications of the framework have also adopted a composite network analysis approach whereby the three networks are integrated to show the relationships between tasks, social interactions and information (Stanton, 2014). Since its development EAST has been applied in a wide range of domains to understand sociotechnical system behaviour (e.g. Salmon et al, 2014; Stanton, 2014; Walker et al, 2010). In the context of system safety and safety management; however, limitations are apparent. First, analyses have not typically focussed on whole systems (with the exception of Stanton and Harvey, 2016). Salmon et al (2014), for example, used EAST to examine the behaviour of intersection systems incorporating road users, their vehicles, and the road infrastructure only. The analysis did not include other agents such as road designers, policy makers, police, and the road safety authorities. Second, the networks produced do not focus specifically on safety-related tasks, interactions, or information. This has resulted in EAST analyses incorporating aspects of safety management without analysing them in-depth (e.g. Salmon et al., 2014; Walker et al., 2006; 2010). In addition, the first limitation described above has typically resulted in consideration of only safety-related activities at the front-line or sharp-end of the system. These limitations provided the impetus to extend EAST to incorporate some of the principles of Leveson's (2004) STAMP method.

STAMP and control theory

STAMP (Leveson, 2004), originally developed as an accident analysis methodology, is underpinned by systems and control theory. It takes the view that accidents result from the inadequate control or enforcement of safety constraints - when disturbances, failures, or dysfunctional interactions between components are not handled by control mechanisms (Leveson, 2004). In the RLX context, for example, the model might suggest that collisions involving vehicles and trains at RLXs occur when controls such as flashing lights and warning bells, education campaigns, and road rules and regulations fail to prevent drivers from attempting to traverse the crossing when a train is present. Safety is viewed as an issue of control and one that is managed through a control structure that has the goal of enforcing constraints on actors across the system.

It is worth noting that a broad view of controls is adopted when using STAMP. Leveson (2004) describes various forms of control, including managerial, organisational, physical, operational and manufacturing-based controls. That is, system behaviour is controlled not only by engineered systems and direct intervention, but also by policies, procedures, shared values, and other aspects of the surrounding organisational and social culture. The first phase of STAMP involves building a control structure to describe the control relationships that exist between actors and organisations during both system design and system operation. The control structure model views systems as comprising interrelated components that maintain a state of dynamic equilibrium through feedback loops of control and information (Leveson, 2004). Accordingly, control structure models incorporate a series of hierarchical system levels and describe the actors and organisations that reside at each level. Control and feedback loops are included to show what control mechanisms are enacted down the hierarchy and what information about the status of the system is sent back up the hierarchy.

A generic control structure model is presented in Figure 2 (Leveson, 2004). The left hand side of Figure 2 shows a generic control structure for system development whereas the right hand side shows a generic control structure for system operation. The arrows flowing down the hierarchy represent control relationships (or reference channels, Leveson, 2004) and the arrows flowing up the hierarchy represent feedback loops (or measuring channels, Leveson, 2004). For example, in RLX systems the crossing infrastructure enacts the control of 'warnings' on road user and train interactions. In turn, information regarding collisions, near misses, violations of the warnings and road rules, and maintenance requirements for the warning infrastructure represent forms of feedback that would be passed back up the system. These feedback loops enable road and rail safety authorities and policy makers to assess the status of controls and whether they are having the desired impact.

****INSERT FIGURE 2 HERE****

The control structure has been employed as a modelling tool to describe systems and the control and feedback loops involved in safety management (Salmon et al., 2016a). Whilst the usefulness of the control structure has been reported, there are some notable limitations: (1) it describes control and feedback loops only and does not examine the relationships and interactions between controls; (2) it is difficult to represent control, feedback loops, and relationships that exist between actors and/or organisations who operate at the same levels of the hierarchy; and (3) it is often difficult for analysts to place actors and organisations across the five levels provided, which in turn can lead to an artificial representation of the system hierarchy (Salmon et al, 2016a). Whilst using EAST as an analysis framework overcomes these limitations, integrating principles from the STAMP control structure with EAST also removes the EAST limitations described earlier. Therefore, integrating EAST with STAMP's controls structure approach ostensibly provides a more comprehensive framework for analysis RLX safety management.

Integrating EAST and STAMP: A network of controls

The intention of this article is to demonstrate the utility of integrating EAST and STAMP's control structure approach. Integration of the two methods was achieved by adding a fourth 'control network' to the EAST framework. This is based on the notion that it is important to understand both the relationships between different controls (e.g. design standards dictate the nature of the train warnings provided at the RLX) and the relationships between controls, tasks, agents, and information (e.g. enacting a particular control requires certain tasks to be undertaken by certain agents using specific information). As well as providing a richer EAST analysis, the intention was to tackle some of the limitations associated with previous EAST and STAMP analyses outlined above. The new four network EAST approach is represented in Figure 3. Conceptually in a given system the control network sits around the task, social and information triad of networks, with controls acting to constrain the interactions within and between these original networks. Figure 4 provides a representation of the relationships between controls, tasks, agents, and information.

****INSERT FIGURE 3 HERE****

****INSERT FIGURE 4 HERE****

For example, the task of negotiating a RLX safely undertaken by both road vehicle drivers (Agent A) and train drivers (Agent B). When negotiating the RLX, both use various pieces of information such as the status of the warning devices, speed and location of the train, and the behaviour of other users such as pedestrians. Road vehicle drivers and train drivers are bound by controls such as the warnings themselves, rules and regulations, and standard operating procedures. Likewise, the nature of information they are using is influenced by controls such as design standards (e.g. timing of warnings). It is important to note that controls are enacted on tasks, agents and information and also on the interactions between them. For example, various controls at the RLX (e.g. boom gates, flashing lights, train horn, road rules and regulations) are designed to manage the interactions between drivers, their vehicle and train drivers and the train.

Part 2: Applying the Integrated Method to Rail Level Crossing Safety

Methodology

Data inputs

Seven analysts with significant experience in applying either EAST, STAMP or other systems accident analysis methods in a range of domains (e.g. defence, road and rail transport, aviation, maritime) were involved in conducting the analysis. The analysts had extensive experience in the area of rail safety (see Naweed et al., 2015; Read et al., 2016; Salmon et al, 2016b; Stanton & Walker, 2011;). More specifically they had extensive knowledge and experience of the Victorian RLX system as they had recently completed a four year research program involving various analyses of different RLXs and the wider Victorian RLX system (see Read et al., 2017; Salmon et al., 2016b). This background knowledge and information was also supplemented by an additional documentation review (e.g. road and rail safety strategy and policy documents, crash investigation reports, relevant academic literature).

EAST network development

Initially task, social and information networks were developed in a workshop setting involving four analysts. Two of the analysts had extensive experience in applying EAST in a range of transportation settings (Salmon et al., 2014; Stanton, 2014; Stanton et al, 2016;

Walker et al., 2006; 2010). The remaining two analysts were human factors researchers with significant experience of applying systems ergonomics methods in a range of safety critical domains (e.g. Newnam & Goode, 2015; Read et al., 2016; Salmon et al., 2014). One of these analysts also had significant experience in the area of rail safety (having worked for 9 years in rail safety regulation and on various rail safety research projects).

Prior to the workshop participants were provided with the following materials to support network construction:

1. *Hierarchical Task Analysis (HTA) of the RLX system lifecycle*. A HTA (Stanton, 2006) of the RLX system lifecycle was developed based on the data described above. The HTA describes the goals, sub-goals and operations required when designing, implementing, operating and removing RLXs in Victoria, Australia.
2. *ActorMap of Rail Level Crossing Stakeholders*. An ActorMap was developed to identify the stakeholders involved in the RLX system lifecycle (Read et al., 2017). The resulting ActorMap showed which stakeholders currently share the responsibility for RLX design and operation in Victoria, Australia. The stakeholders were placed across a hierarchy of systems levels in line with Rasmussen's risk management framework (Rasmussen, 1997).

The task, social and information networks were developed independently based on a process of first identifying nodes, then identifying relationships between the nodes, and finally by reviewing the nodes and relationships for internal consistency. The analysis rules surrounding what constituted a node and a relationship for each network representation are presented in Table 1.

Following the workshop, a draft control network was constructed by two analysts based on: a review of Salmon et al’s (2016a) in-depth analysis of rail level crossing systems; Salmon et al’s (2016b) road safety control structure; and a STAMP control structure model of rail safety under development by the authors as part of a separate project. Development of the control network followed the process above whereby nodes (controls) were first identified followed by the relationships between them (see Table 1 for examples). The draft control structure was subsequently reviewed by the other analysts from the original workshop.

****INSERT TABLE 1 HERE****

Network analysis

Each network was analysed using a selection of quantitative metrics that have previously been used to interrogate EAST networks (e.g. Salmon et al., 2014; Stanton, 2014). In the present study, the following metrics were applied to each network:

1. *Network Density (overall network)* – Network density represents the level of interconnectivity of the network in terms of relations between nodes. Density is expressed as a value between 0 and 1, with 0 representing a network with no connections between nodes, and 1 representing a network in which every node is connected to every other node (Kakimoto et al, 2006; cited in Walker et al, 2011). Higher density values are indicative of a well connected network in which tasks, agents, information and controls are tightly coupled. The formula for calculating network density is presented below.

****INSERT FORMULA 1 HERE****

2. *Sociometric status (individual nodes)*. Sociometric status provides a measure of how 'busy' a node is relative to the total number of nodes within the network under analysis (Houghton et al, 2006). In the present analysis nodes with sociometric status values greater than the mean sociometric status value plus one standard deviation are taken to be 'key' (i.e. most connected) nodes within each network. These nodes represent either key tasks, agents, pieces of information, or controls. For example, in the case of the control network the node with the highest sociometric status is the

control which is the most interrelated with other controls. Sociometric status is calculated using is calculated using the following formula (g is the total number of nodes in the network, i and j are individual nodes and are the edge values from node i to node j).

****INSERT FORMULA 2 HERE****

3. *Centrality (individual nodes).* Centrality is used to examine the standing of a node within a network based on its geodesic distance from all other nodes in the network (Houghton et al., 2006). Central nodes represent those that are closer to the other nodes in the network as, for example, information passed from one to another node in the network would travel through less nodes. Houghton et al (2006) point out that well connected nodes can still achieve low centrality values as they may be on the periphery of the network. For example, in the case of the control network nodes higher centrality status values are those that are closest to all other controls in the network as they have direct rather than indirect links with them. The following formula is used to calculate centrality.

****INSERT FORMULA 3 HERE****

Whilst the formula for each metric is presented above, in the present analysis these calculations were performed using the Agna social network analysis software tool.

Results

Task network

The RLX system lifecycle task network is presented in Figure 5. The outcomes for the task network analysis are presented in Table 2. For the sociometric status and centrality analysis Table 2 includes the values for the nodes that scored above the mean sociometric status and centrality values for the network. Nodes that achieved values above the mean + standard deviation for sociometric status and centrality are shaded grey. This approach has previously been used to identify key nodes within the EAST networks (e.g. Houghton et al., 2006; Salmon et al., 2014; Stanton, 2014; Stanton et al, 2016; Stanton and Harvey, 2016; Stanton et al, 2017).

****INSERT FIGURE 5 HERE****

****INSERT TABLE 2 HERE****

As shown in Figure 5, the RLX system lifecycle is underpinned by a network of 15 core tasks. Analysis of the task network in Table 2 reveals a network density of 0.2, which is indicative of a relatively loosely connected network in which most RLX design and operation tasks are undertaken largely independent of one another. The sociometric status and centrality analyses reveal that ‘Risk management’ and ‘Monitor performance’ are the key tasks within the network.

Social network

The RLX system lifecycle social network is presented in Figure 6. The outcomes for the social network analysis are presented in Table 3. Table 3 follows the same convention as Table 2 for the sociometric status and centrality values.

****INSERT FIGURE 6 HERE****

****INSERT TABLE 3 HERE****

As shown in Figure 6, a diverse set of 27 agents undertake tasks throughout the RLX system lifecycle and operation. These agents range from RLX components (e.g. barriers, flashing lights), RLX users (e.g. drivers, pedestrians, road vehicles, trains), infrastructure owners and rail operators to the regulator, government departments, unions, courts and the media. Analysis of the social network shown in Table 3 reveals a network density of 0.18, which is again indicative of a relatively loosely connected network in which agents are not tightly coupled. This suggests that the agents responsible for RLX design and operation do not interact extensively with all agents across the social network during the design and operation of RLXs. Rather, small cliques of agents interact with each other. The sociometric status and centrality analysis reveals that 'Government departments', 'Rail operators', 'Rail infrastructure managers', 'Regulators' (sociometric status) and 'Train drivers' (centrality only) are key agents within the social network.

Information network

The RLX system lifecycle information network is presented in Figure 7. The outcomes for the information network analysis are presented in Table 4. Table 4 follows the same convention as Table 2 for the sociometric status and centrality values.

****INSERT FIGURE 7 HERE****

****INSERT TABLE 4 HERE****

As shown in Figure 7, 28 information nodes are required throughout the RLX system lifecycle. Analysis of the information network in Table 5 reveals a network density of 0.09, which is indicative of a very loosely connected network. The sociometric status analysis reveals that 'Risk level' and 'Design concepts' are the key nodes within the information network. The key nodes according to the centrality analysis are 'Budget', 'Demographics', 'Mitigations', 'Speed' and 'Surrounding land use'.

Control network

The RLX system lifecycle control network is presented in Figure 8. The outcomes for the control network analysis are presented in Table 5. Table 5 follows the same convention as Table 2 for the sociometric status and centrality values.

****INSERT FIGURE 8 HERE****

****INSERT TABLE 5 HERE****

As shown in Figure 8, 30 controls are used to constrain activities across the RLX system lifecycle. Analysis of the control network in Table 5 reveals a network density of 0.11, which is indicative of a relatively loosely connected network in which most safety controls interact with only a small number of other controls within the network. The sociometric status analysis reveals that 'Audits and Inspections', 'Design standards' and 'Road rules' are the key controls within the control network. Key controls according to the centrality analysis are 'Insurance premiums', 'Timetables', and 'Train protection devices'. Other nodes that achieved sociometric status and centrality scores above the mean include controls relating to the RLX itself (e.g. 'Train', 'Vehicle', 'Signals'), safety strategy (e.g. 'Policy and strategy', 'Targets') enforcement (e.g. 'Enforcement', 'Legal Penalties') and education (e.g. 'Education', 'Initiatives').

Composite network

Whilst it is beyond the scope of this paper to present a full composite analysis incorporating all four networks, it is worth demonstrating how combining the networks enhances the richness of the analysis produced. Figure 9 presents an example composite network showing the agents, information, and controls relating to the two identified key tasks of 'risk management' and 'performance monitoring'. Within Figure 9 the active controls for risk management and performance monitoring are shaded black. Information nodes within the grey shaded area represent the information required to complete risk management and performance monitoring tasks during RLX design and operation. Finally, each information node is shaded based on which of the eight agents responsible for both tasks use that particular piece of information.

****INSERT FIGURE 9 HERE****

The composite network shows that there are eight agents who share the responsibility for risk management and performance monitoring during RLX design and operation. In addition, it shows that 11 controls influence these tasks, ranging from finances, policy and strategy, targets and design standards to standard operating procedures, audits and inspections, and accreditation and licensing.

Discussion

The aim of this article was to: (1) investigate the utility of integrating two systems ergonomics methods, STAMP and EAST, by adding a control network adapted from the principles of STAMP's control structure method to the EAST framework; and (2) test this with a modified EAST analysis of a RLX system lifecycle that incorporated a control network analysis. The following discussion focusses first on the key findings regarding RLX safety management and second on the utility of the modified EAST framework.

Implications for RLX safety management

Taken together, the analysis findings highlight opportunities to improve safety management at RLXs. The task network analysis identified risk management and performance monitoring as critical tasks within the RLX system lifecycle. The information network analysis identified 'risk level' as one of the key information requirements and the control network identified audits and inspections as one of the key controls required. Whilst risk management and performance monitoring tasks are currently undertaken, recent Australian studies have suggested that elements of these tasks may be sub-optimal. Salmon et al (2016), for example, suggested that appropriate incident and near miss reporting and analysis mechanisms may not be available. Salmon et al (2013) also found key limitations associated with RLX risk assessment tools. As key nodes in the task, information and control networks, the findings suggest that road and rail stakeholders should attempt to strengthen their risk management and performance monitoring activities. This could be driven through the development of more comprehensive risk management processes (e.g. incorporating human factors data) and performance monitoring controls (e.g. incident and near miss reporting systems, regular behavioural assessments, and increasing data collection mechanisms at RLXs such as Closed Circuit Television Cameras).

The social network analysis indicates that the key agents in the RLX system lifecycle reside at the higher levels of the RLX system. These include Government departments, rail operators, rail infrastructure managers and the regulator. This finding is in line with systems theory and is interesting given recent arguments that important risks exist away from the RLXs themselves (e.g. Read et al., 2017; Salmon et al., 2013, 2016b). Indeed, it provides further evidence that interventions focussed only on improving the behaviour of users (e.g. drivers and pedestrians) at RLXs are likely to have minimal success. Rather, clarifying roles and responsibilities around RLX design, implementation, operation and removal along with introducing interventions aimed at influencing the behaviour of agents at the higher levels of RLX systems may be important. As a first step, educating agents and organisations at the higher level on how their activities influence behaviour at RLXs will be useful. In addition, further systems analyses of RLX accidents and near miss incidents that highlight the contribution of agents at higher levels of the system are required (e.g. Salmon et al., 2013).

Interestingly, all of the networks had relatively low density scores, indicating that when considering the RLX system lifecycle as a whole, it is loosely coupled. This intuitively makes sense, as what is being represented are activities, decisions and actions occurring across various temporal and spatial planes. However, it may be that attempting to increase the coupling of tasks, agents and information in some cases will prove beneficial for safety management. For example, in the social network standards setting bodies and local governments were not well connected with other nodes in the network. Ostensibly there would be benefits in better integrating both throughout the RLX system lifecycle. In the case of standards setting bodies this would ensure that design standards are flexible, appropriate, and are updated based on feedback regarding performance throughout the RLX system lifecycle. This suggestion is confirmed through the control network in which design standards was identified as one of the key controls in terms of impact on other controls. Again, this is in line with other recent studies. Read et al (2017), for example, highlighted the improvement of design standards as a key requirement for enhancing RLX safety.

The composite network examined the relationship between tasks, agents, information and controls for the key tasks of risk management and performance monitoring. An important finding was that, whilst much of the information used to support risk management and performance monitoring is required by multiple agents, it is questionable whether these agents are accessing and sharing the same information. For example, in the case of the information nodes ‘hazards’ and ‘risk level’ it is apparent that different organisations may use different methods and data systems to gather this information – and that there may be differences as a result. For risk, all agents may not currently have access to the current RLX risk assessment tool and its outputs, which in turn means it is difficult to develop a shared understanding of risk across the rail network. New controls around the processes adopted as part of risk management and performance monitoring provide a way of addressing this.

Does the control network extend the utility of EAST?

The aim of modifying EAST through the addition of a control network was to extend its utility for analysing the behaviour of complex sociotechnical systems. The extension achieved the aim of enabling EAST to identify and analyse the relevant controls involved in the RLX system lifecycle. This enables analysts to identify a. the controls present within a particular system, b. how different controls are related to one another, and c. how controls are related to tasks, agents, and information. This also removes some of the limitations associated with the STAMP control structure method regarding the allocation of agents to hierarchical levels and the representation of relationships between controls. Adding the control network to EAST enables the explicit consideration of controls and allows the EAST analysis to focus exclusively on safety-related tasks. It also enables the use of network metrics to interrogate and compare the relevant importance of controls. This provides an additional capability over and above the STAMP control structure and it is anticipated that it will be useful for safety critical systems that rely heavily on the use of controls to manage risk.

An important contribution of the analysis presented was the consideration of the overall sociotechnical system and system lifecycle. As noted earlier, apart from Stanton et al (2016) previous EAST analyses have focussed on the lower levels of sociotechnical systems surrounding the sharp end of performance (e.g. road users, vehicles, the road environment; Salmon et al., 2014). The present analysis demonstrates a. that it is possible to use EAST to analyse the behaviour of overall systems, and b. that a richer analysis is produced in doing so. This represents an important next step in the evolution of the method. Further systems analyses involving EAST are encouraged.

In the present analysis only an example composite network showing the interactions between controls, tasks, agents and information for the tasks of risk management and performance monitoring was presented. This is a noteworthy limitation and was beyond the scope of the present analysis and article. Further research should explore the integration of the four complete networks, following Stanton (2014), into a composite network showing the relationships between controls, tasks, agents and information .

Finally, it is worth considering how the extended EAST framework compares to other currently popular systems ergonomics methods by returning to the key requirements of sociotechnical systems analysis discussed earlier. A judgement on how well contemporary systems ergonomics methods respond to each of the requirements is presented in Table 6.

Each cell within table 6 is shaded to denote whether, in the authors' opinion, the method in question explicitly (black shading) or implicitly (grey shading) describes each element. An explicit rating is applied when the method is deemed to specifically describe the element in question whereas an implicit rating is applied when it is deemed that the information is presented within the analysis but is not explicit. For example, for safety controls the modified EAST method receives an explicit rating as the control network presents all controls and their interrelations. CWA on the other hand receives an implicit rating as controls may be present within the work domain analysis, decision ladder and strategies analysis outputs, however the focus of these analyses is not explicitly on safety controls.

****INSERT TABLE 6 HERE****

As shown in Table 6, it is these authors opinions that the extension of EAST to incorporate STAMP principles has enhanced its capability and has extended its comprehensiveness beyond that of other systems ergonomics methods.

Conclusion

Safety controls play an important role in the behaviour of sociotechnical systems. This article has demonstrated an extended version of the EAST framework that enables it to analyse safety controls in addition to task, social and information networks. It is concluded that the extension has enhanced the analytical and explanatory power of the EAST framework and that the analysis presented has provided a rich understanding of the RLX system lifecycle and RLX safety management. In particular, the analysis enabled identification of potential improvements around design standards, the coupling of agents and organisations, risk management and performance monitoring, and the clarification of roles and responsibilities across the RLX wider system. It is hoped that researchers and practitioners both conduct further applications of the modified EAST framework and continue to explore the integration of systems ergonomics methods.

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