Methodologies for the Application of Non-Rail Specific Knowledge to the Rail Industry

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Abstract

A wealth of information about the impact of technology on human performance is available within human factors literature, however, most of the data underpinning this knowledge has been collected within industries such as aviation, oil and gas. Making effective use of the knowledge gained from other safety-critical industries would help to ensure that rail industry studies are conducted in an efficient and cost-effective manner. However, there is a need to verify the applicability of data from other industries to the rail industry before making use of it. The following paper discusses two methodologies for utilising knowledge from non-rail environments which were developed and used during a twelve month study conducted for the Rail Safety Standards Board (RSSB) investigating train driver route knowledge acquisition and retention. Both methodologies were successfully applied, indicating that industry specific knowledge can be generally applied provided that it is contextualised using human performance data or information from industry experts.

Introduction

As a result of a series of incidents on the UK railway system, including the Ladbroke Grove accident, RSSB commissioned a study to investigate train driver route knowledge. The purpose of the study was to provide detailed recommendations for route knowledge training based on a sound model of the psychological processes involved in the use of route knowledge.

Currently, route knowledge is defined by the rail industry as ‘the types of information required to be remembered, in order to operate over a route’(GO/RC 3551). It is generally acknowledged, however, that information ‘remembered’ must be used in real-time as a driver negotiates a route. This view indicates that route knowledge is more than the information held within a driver’s memory; it is the skilful use of this information to interpret the current and future state of the environment. Therefore, any model of the psychological processes involved in route knowledge should incorporate psychological constructs such as situation awareness and attention as well as considering issues related to memory.

While extensive research on topics such as operator situation awareness, attention, and decision making has been undertaken in industries such as aviation and air traffic control, these constructs have not yet been widely studied within the rail industry (Li & Hamilton, 2003). Due to the scarcity of rail specific information, any consideration of these issues must begin by utilising knowledge gained within other industries. However, the applicability of this information to the rail industry cannot be assumed, and its relevance must be verified.

An example of this approach is provided by Endsley (1999) who modelled the situation awareness requirements of infantry soldiers using psychological models developed in non-infantry environments as a starting point.

This paper outlines two methodologies applied during the Route Knowledge study which utilised knowledge from non-rail environments. *Methodology 1* utilised fundamental literature, available train driver performance data and information from industry experts to develop a model of train driver route knowledge based on the concept of situation awareness. *Methodology 2* utilised information from non-rail industries regarding the impact of advanced technology on operator performance to support an analysis of the potential impacts of new technology on train drivers.

Methodology 1 – Development of a Model of Train Driver Route Knowledge

In order to meet the study aim of defining and investigating train driver route knowledge requirements the research team developed a model of the psychological processes associated with route knowledge. The model was required to identify the relevant psychological processes and describe the relationship between them in a manner comprehensible to the non-psychologist. A two stage approach was used to develop the model:

Stage 1 - Development of an outline model of train driver route knowledge and investigation of the relationship between model components;

Stage 2 - Assessment of the validity of the model to the rail context.

Stage 1 – Development of an Outline Model of Train Driver Route Knowledge

In order to develop a model of train driver route knowledge it was necessary to identify the key psychological processes associated with route knowledge and to develop a description of the relationships between these processes. The following steps were undertaken to develop the model:

1. Interviews with rail industry experts to gather information about route knowledge in order to identify relevant psychological processes for further consideration;
2. A review of fundamental psychological literature to identify models of human information processing incorporating psychological processes identified as relevant during interviews with industry experts;
3. Selection of appropriate models from fundamental literature for use as input into the Route Knowledge Model;
4. Development and population of the Route Knowledge Model.

Interviews with rail industry experts indicated that while remembering the features of a route was a core component of route knowledge, other factors such as the ability to use this knowledge to interpret the current and future state of the environment were also relevant. This indicated that psychological processes such as situation awareness, attention, and memory were all relevant to route knowledge. Therefore, a search was conducted for models that described these processes. A range of models was identified, however, a model of situation awareness developed by Endsley (1995) was chosen as the most appropriate to provide a basis for the route knowledge model as it included all of the psychological processes of interest (see Figure 1).

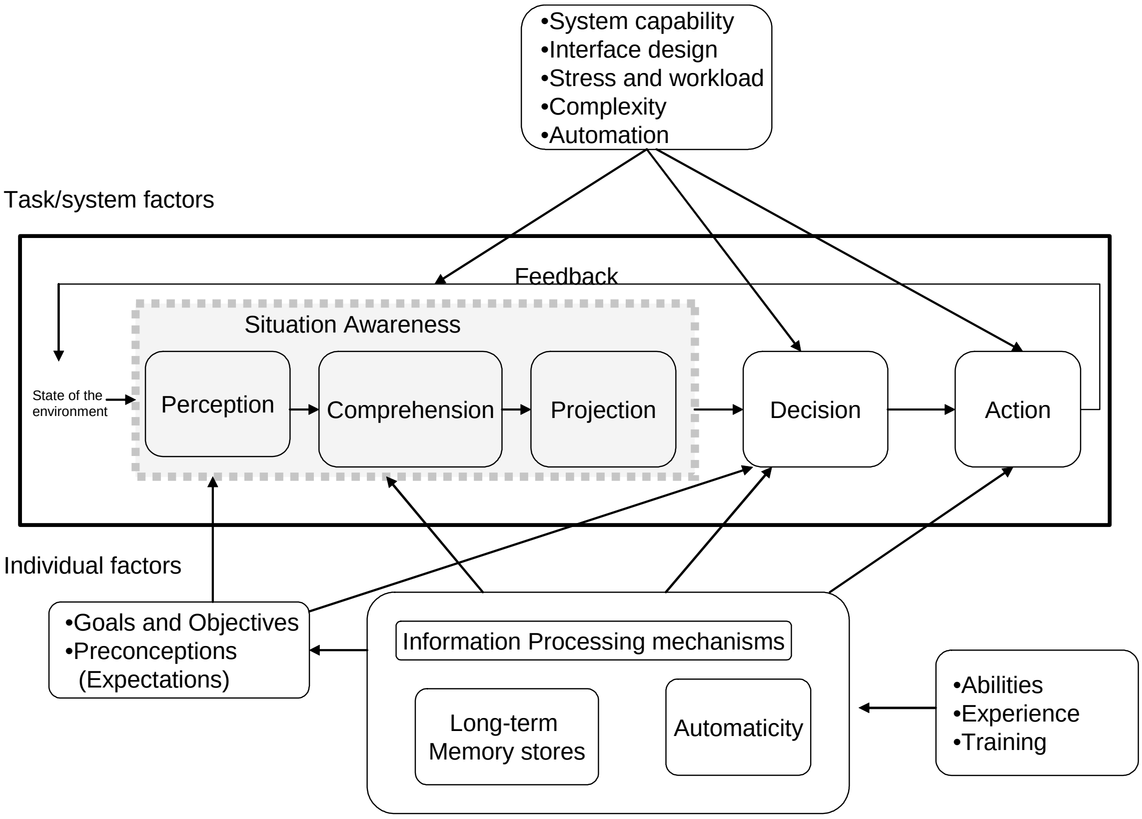

Figure 1: Model of Situation Awareness in Dynamic Decision Making (Endsley, 1995)

While Endsley's model contained the psychological processes required, it was complex and needed to be simplified to meet the requirement of being comprehensible to the non-psychologist. As a result a simplified Route Knowledge Model was developed using Endsley's model as a basis (see Figure 2). The core psychological and information processing components of the model developed by Endsley (situation awareness elements, decision, and action) were retained as this offered an easily understood structure. In order to simplify the factors influencing situation awareness contained in Endsley's model these were divided into:

- Individual Factors - factors that are intrinsic to the individual;
- External Factors – factors that are extrinsic to the individual.

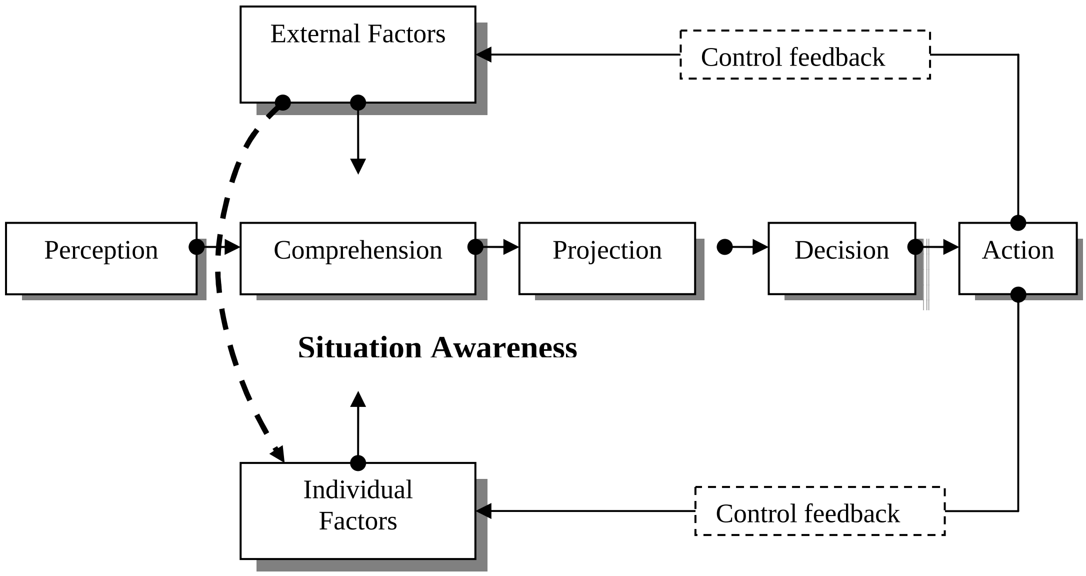

Figure 2: Train Driver Route Knowledge Model

The outline model (presented above) was used to guide an extensive review of research literature to identify specific factors to populate model components, for example, stress was added as an individual factor. Figure 3 shows all of the factors identified under each model component[1]. The literature review also provided a large body of information about the relationship between model components (e.g. between stress and situation awareness).

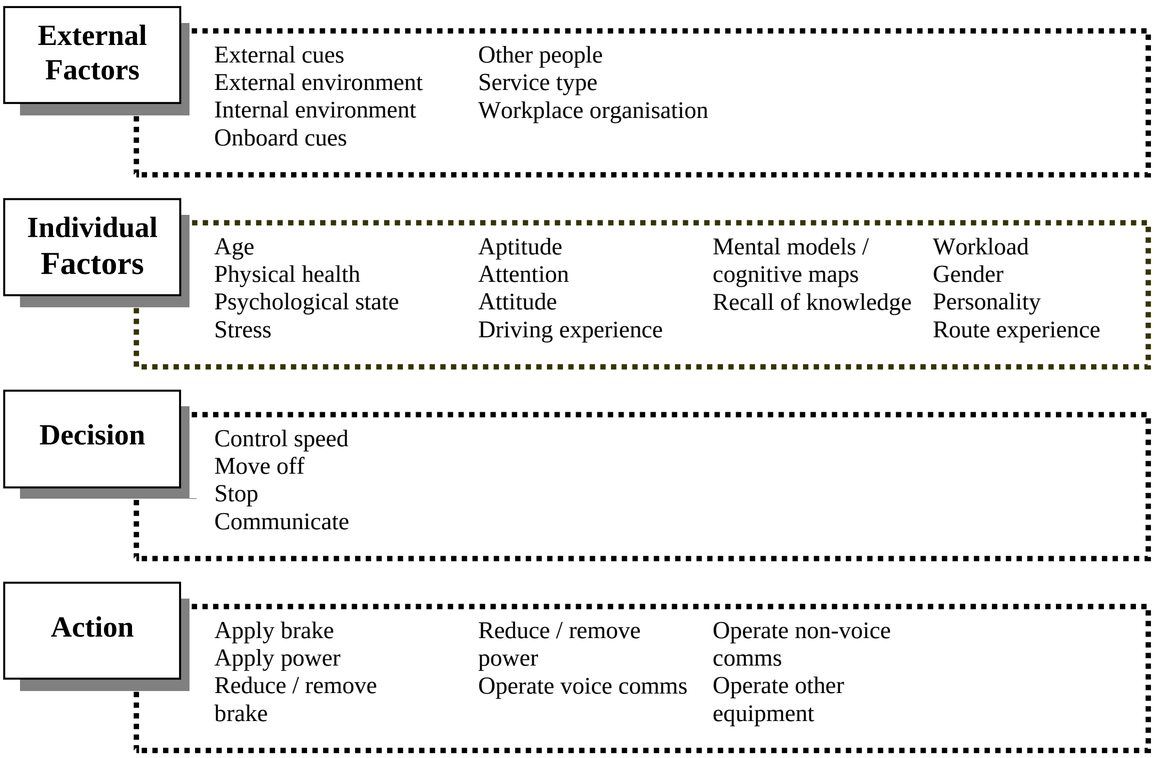

Figure 3: Factors contained within Train Driver Route Knowledge Model Components

[1] Note that Figure 3 also contains model components identified during stage three of the model development where rail industry data was incorporated into the model (e.g. control speed, move off).

In order to simplify the storage of information about the relationships between model factors and components, the Route Knowledge Model was used to structure a relational database which was populated with natural language statements derived from the review of the research literature (see Figure 4). The relationships were restricted using the permissible links defined in the Route Knowledge Model. More than one statement defining a link could be entered into the database and statements could reflect either a positive or negative influence on situation awareness. Having both positive and negative statements from the fundamental literature enabled the complexity of the relationships within the model to be highlighted. For example, literature indicated that stress had the potential to have both a positive and negative impact on situation awareness.

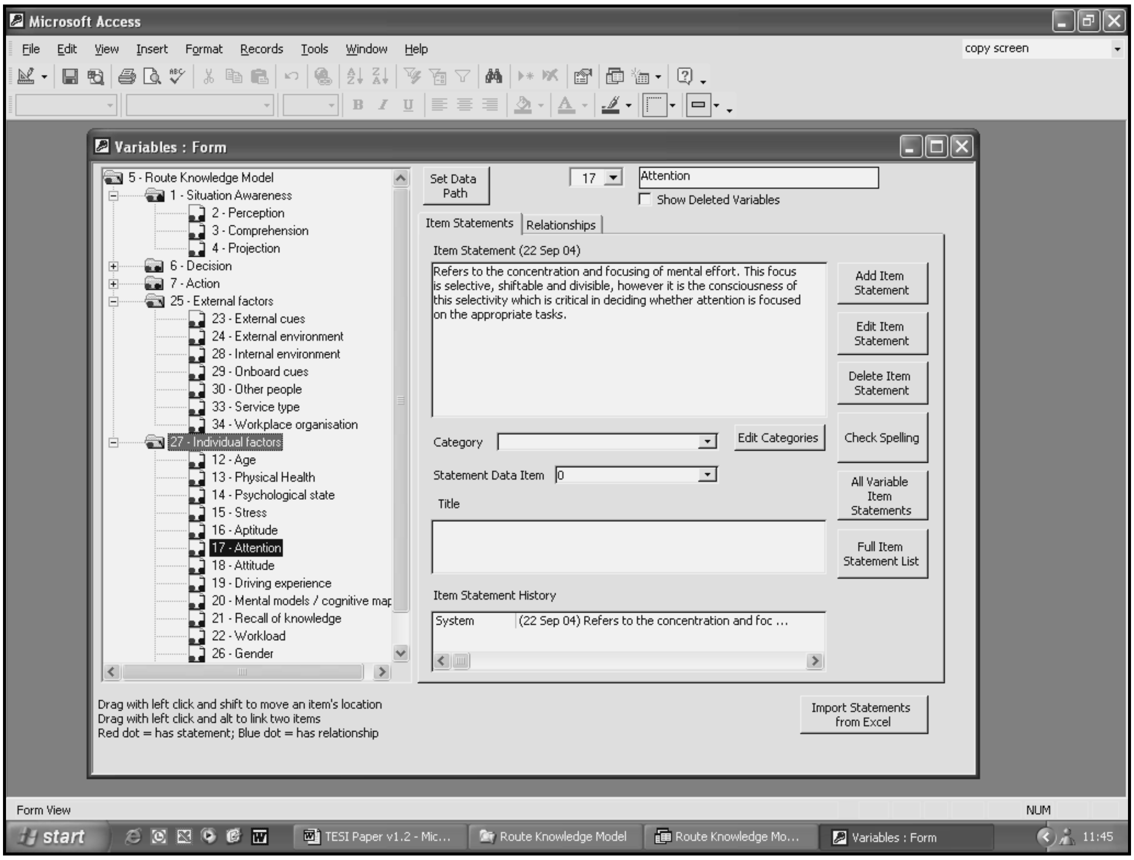

Figure 4: Screen Shot of Relational Database

Stage 2 - Assessment of the Validity of the Model to the Rail Context

Stage 1 of the development of the Route Knowledge Model was conducted using information gathered from research conducted in a range of industries. Therefore, it was necessary to assess the validity of the Route Knowledge Model to the rail context. In addition, it was necessary to identify factors relevant to the rail industry to populate some model components (e.g. the factors contained in the action components of the model, see Figure 3). The Route Knowledge Model was validated and further populated using information gathered during an analysis of route knowledge errors. The error analysis was based upon two sorts of data:

- Rail incident reports;
- Interviews with rail subject matter experts, regarding safety related errors and their possible causes.

Statements derived from rail sources were entered into the relational database and the source of the statement was recorded. As a result, it was possible to assess whether model factors, model components and the relationships between them, as described by the review of literature from other industries, were supported by rail industry data.

Application of the Route Knowledge Model

The data contained in the Route Knowledge Model relational database, derived from both fundamental literature and rail based sources was used to support the following activities:

- *Development of route knowledge training objectives:* statements contained within the database were reviewed and those issues that could be supported by training were identified. A content analysis was conducted on statements where training related issues were identified and key themes developed. These themes were used to frame the training objectives;
- *Prioritisation of training objectives*: the validation of model components using incident data provided a means by which a risk based prioritisation of training objectives could be conducted. Training objectives with error analysis data linked to them were given a high training priority, as the presence of error data indicated that the objective was associated with either an actual or potential incident.
- *Development of Knowledge, skills and behaviours (KSB)*: KSB associated with training objectives were developed based upon the information contained within the database.

Methodology 2 – Analysis of the Impact of Future Railway Operations on Train Driver Psychological Processes

In order to meet the study aim of considering how new rail technology might impact on route knowledge training and assessment requirements, the research team developed a methodology to assess the risks that new technology posed to train driver situation awareness. The methodology contained three main steps:

Stage 1 - Analysis of planned changes to rail operations;

Stage 2 - Analysis of the impact of advanced technology on operator situation awareness in other industries;

Stage 3 - Analysis of the impact of identified technologies on driver route knowledge and identification of mitigation strategies.

Stage 1 – Analysis of Planned Changes to Rail Operations

The aim of Stage 1 was to gather information about advanced rail technology and select technologies for inclusion in the study. A search for new rail technology was undertaken using three sources, an internet search, a review of existing studies, and consultation with rail industry experts. Once a technology had been identified, a short description was developed to assist in assessing it for possible inclusion in the study. To be included, each technology was required to meet two criteria:

1. The technology had the potential to impact upon the route knowledge related decisions and actions as outlined in the Route Knowledge Model.
2. The technology has not currently been broadly implemented within the UK rail network but had been considered by either railway bodies or technology providers.

Technologies that met these criteria were presented to RSSB and those selected were put forward for detailed consideration in later stages.

Stage 2 –Analysis of the Impact of Advanced Technology on Operator Situation Awareness in other Industries

Due to the lack of information within the rail industry about the effect of advanced technology on the factors contained in the Route Knowledge Model (e.g. situation awareness) a review of information gained in other industries was conducted.

Twenty-five studies from a range of industries including aviation, road transport, air traffic control and petrochemical were identified for review. Each study was reviewed to extract statements about how new technology might affect operator performance. Because the aim of this activity was to gather information about the effect of technology on operator route knowledge, the Route Knowledge Model was used to structure the review. This ensured that only risks (directly or indirectly) related to the model constructs were documented. The relationships predicated by the model structure (see Figure 2) provided a set of 'rules' that statements extracted from the studies had to comply with. On this basis the studies were reviewed for the following types of statements:

- The impact of advanced technology on situation awareness;
- The impact of advanced technology on any of the individual factors identified in the model;
- The impact of advanced technology on any of the external factors identified in the model.

In total 181 statements were identified. These statements were stored in the route knowledge model relational database providing information about how advanced technology could affect each relationship within the model. In addition, a content analysis was conducted on the 181 statements to provide consolidated, descriptive statements of the 'key risks' that advanced technology posed to the psychological processes described by the model. Examples of key risks included:

- Automation/high technology can reduce operator situation awareness due to poor system design (poor feedback, complex modes, and mode changes without notification);
- If technology is unreliable (e.g. only detects and displays 5/10 events) operators will have to devote attention to gathering missed information from other sources (e.g. through outside observation) rather than attending to other tasks;
- Technology that places the operator in a monitoring role can induce reduced vigilance, both to the system being monitored and to other cues available outside the system.

Stage 3 – Analysis of impact of Identified Technologies on Driver Route Knowledge and Identification of Mitigation Strategies

The 'key risks' identified during Stage 2 were used to assess each of the selected rail technologies identified during Stage 1 in terms of their possible effect on driver route knowledge. This process ensured that the relevance of each risk to each rail technology was considered (rather than assuming all the risks found from other industries would be relevant). This assessment involved the following activities:

1. Discussion with rail industry experts about the key risks related to each identified technology;
2. Review of rail-based studies on the impact of new technology on drivers;
3. Analysis of the key risks associated with each technology, based on information gathered;
4. Identification of mitigation strategies.

Discussion guides for interviews with rail industry experts were developed by creating probing questions associated with each key risk identified during Stage 2, ensuring that each risk was fully discussed. Using the discussion guide, interviews were conducted with rail industry experts who had specific knowledge of each of the technologies under consideration. Where possible, this information was supplemented by information gathered from existing studies of each technology.

An analysis of information gathered from industry experts and rail-based studies was undertaken to establish whether any of the risks identified during the 'other industry' review were relevant to the application of the technology in the rail industry. Information relating to a key risk was recorded in a risk review template. Evidence supporting or contradicting the risk was recorded. During this analysis, data from industry experts and rail-based studies was also reviewed to ascertain whether any risks discussed were not covered by the list of key risks developed from reviewing studies from other industries. Any extra risks identified were added to the list of key risks. Therefore, this analysis was also used to evaluate the applicability of the list of key risks for the rail industry.

Those risks identified as relevant to each technology were analysed to determine how they might be avoided or mitigated. Mitigation strategies were identified using a systems-based approach to ensure that a comprehensive range of mitigation and avoidance strategies were considered for each risk (rather than simply looking at training interventions).

Conclusions

This paper discussed two methodologies for utilising knowledge from non-rail environments which were developed during a study of train driver route knowledge undertaken for RSSB. Both approaches provided structured processes for gathering relevant knowledge from other industries and assessing its validity to the rail industry.

Methodology one involved the development of a Route Knowledge Model which described the psychological processes involved in the use of route knowledge. The development of the model ensured that full use was made of a large body of existing knowledge available from psychological literature. The use of a relational database to store information about the relationships between model components ensured a large body of qualitative data (in the form of statements) could be stored and searched with relative ease. The key benefits of the relational database were that it enabled complex relationships between model factors to be mapped with relative simplicity and provided a clear audit trail of which relationships were validated with rail industry data. The development of the model ensured that the route knowledge training objectives and associated KSB developed during the study were well grounded within existing applied psychological literature but were also validated by information gathered from within the rail industry.

The Route Knowledge Model was developed specifically to describe the psychological processes associated with route knowledge. The approach could however, be potentially applied to other complex, cognitive tasks to support the identification of training objectives. The data collected from fundamental literature to populate the relational database within this study is essentially generic, and therefore applicable to all safety critical industries. The model could be adapted for use in other industries by:

- validating the internal and external factors;
- developing industry specific decisions and actions;
- collecting industry specific error data to populate the relationships between the model components.

Methodology two involved the assessment of the impact of new technology on route knowledge. The method that was developed supported the identification of a range of route knowledge related risks posed by new technology. The key benefit of this methodology was that by using the Route Knowledge Model to structure a search of key risks posed by advanced technology in other industries, a broad range of possible risks to route knowledge were identified. The identification of these possible risks ensured that a detailed and structured questionnaire for use when discussing rail technologies with industry experts was developed. This approach ensured that a broad range of issues were discussed and considered during interviews and that discussion was focused around factors that represented risks to route knowledge.

The approach used in methodology two was akin to an Early Human Factors Analysis (EHFA). EHFA is an established process used within the defence industry to identify and assess human related risks early in the development cycle. Human related issues are captured and logged in a risk register during the early phases of a project. Using the risk register, mitigation strategies can be identified and integrated into the business case. The approach is particularly powerful when projects are first starting up as it structures thinking about issues and risks. The method used in this study enabled the identification of a specific set of human factors risks, those related to route knowledge as defined by the Route Knowledge Model, to be identified and logged for a range of technologies.

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