EXPERT KNOWLEDGE ELICITATION TO GENERATE HUMAN FACTORS GUIDANCE FOR FUTURE EUROPEAN RAIL TRAFFIC MANAGEMENT SYSTEM (ERTMS) TRAIN DRIVING MODELS

Journal:	*Part F: Journal of Rail and Rapid Transit*
Manuscript ID	JRRT-16-0137.R1
Manuscript Type:	Human Factors in Railways
Date Submitted by the Author:	23-Oct-2016
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Keywords:	European Rail Traffic Management System (ERTMS), Human Factors, Railway Technology/ Engineering, Train Driving Model, Train driving
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Original Article

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Keywords

Train driving, European Rail Traffic Management System (ERTMS), Human Factors

Abstract

The European Rail Traffic Management System (ERTMS) will have an impact on the train driving task and train driver behaviour. This paper presents part of the final study of series of studies that have been conducted as part of a three-year research project, which investigated the effects of ERTMS on train drivers' behaviours. In recent times, a number of models of train driving have been developed in order to inform train driving technology design and understand the implications of the design of the train driving task on driver performance and behaviour. An expert knowledge elicitation study was conducted to evaluate existing train driving models and to generate human factors guidance on future ERTMS train driving models. The study consisted of a workshop which was conducted using rail Human Factors (HF) experts who have been directly involved with projects examining ERTMS. Current train driving models were evaluated and ideas generated about how these should be shaped in the future to include systems such as ERTMS. The findings of the study contributed to bridging the gap between the theoretical understanding of train drivers' cognitive strategies and practical implementation of novel technologies by the rail industry.

Introduction

The European Train Control System (ETCS), as part of ERTMS (European Rail Traffic Management System), is an automation and control system that has been introduced into the the GB rail network. The introduction of ERTMS triggered a need to understand its impact on the train driving task and train driver behaviour, alongside an industry requirement for Human Factors (HF) research and the necessity to understand the effect ERTMS has on drivers' cognitive strategies and demands. In recent times, a number of models of train driving[5,6,7,8,9,10] have been developed in order to inform train driving technology design and understand the implications of the design of the train driving task on driver performance and behaviour. The gradual introduction of ERTMS has also provided an opportunity for the rail industry to use these models to understand and plan for the impact of ERTMS, as well as to inform and update existing train driver models to accommodate these new systems.

The fatal Santiago de Compostela train accident on 23rd July 2013 is an unfortunate example of why it is so crucial to update train driving models to aid decision making in the rail industry. Initial reports of the accident pinpointed train driver error as the only primary causal factor; however, a deeper study of the accident by a judicial investigation implicated the lack of a functioning on-board ETCS system as a critical causal factor[1]. Previous work conducted as part of a three-year research project has included studies to understand the train driving tasks between different forms of train driving in the GB[2], to understand train driver behaviour in more detail with ERTMS[3] and to collect and examine quantitative eye-tracking data with both drivers of conventional train control sysyems and ERTMS drivers[4]. All these studies have been designed to help further the understanding of train driving with ERTMS in the GB.

The purpose of evaluating pre-existing train driving models was to understand their strengths and weaknesses and to understand how their evaluations can be used by the rail industry for future train driving models. In addition, it is crucial to understand how these models need to be updated and adapted for new train technology.

There are numerous train driving models that have evolved from previous expert analysis of the train driving task. These have often been developed with reference to specific technologies, as part of projects to examine the impact of these technologies on the driving task.

This study evolved from a need to use a model of train driving in order to understand the impact of ERTMS. This paper presents a critique of these models and their potential for use in the practical context of informing the deployment of ERTMS in the GB railway. It contributes to bridging the gap between the theoretical understanding of train drivers' cognitive strategies and the practical implementation of HF models by the rail industry, with a particular focus on ERTMS. Furthermore, the study aims to support and inform future Network Rail engineering projects, including the design of signalling schemes, and the development and training of train drivers.

Six models were selected for this study and are presented below in chronological order:

•Model 1 is a situational model of driver performance in interacting with Automatic Warning System (AWS) by McLeod et al.[5]

•Model 2 is a human capabilities and the recognise-act cycle in the cognitive task analysis model by Hamilton et al.[6]

•Model 3 is a simplified model of the knowledge, and cognitive functions and processes that underlie locomotive engineer performance by Roth et al.[7]

•Model 4 is a Malaysian train driver performance model by Sani et al.[8]

•Model 5 is the skill-based multi-task model of dynamic control in modern and traditional train driving by Naweed[9]

•Model 6 is a model of psychological work characteristics, psychological workload and cognitive requirements of train drivers by Zoer et al.[10]

The approach taken within this study was to ask HF experts to critique the models from the perspective of those involved in the practical deployment of ERTMS. An expert knowledge elicitation workshop was conducted using rail HF experts who have been directly involved with ERTMS, to get their input regarding current train driving models and how these should be shaped in the future to include systems such as ERTMS.

Method

Design

An expert knowledge elicitation workshop was held with ERTMS HF experts at the Rail Safety and Standards Board (RSSB) office in the UK.

Ethics

Ethical approval for this study was obtained from the Faculty of Engineering Ethics Committee prior to the start of the study.

Participants

Participants were invited to the workshop based on their extensive experience working in the rail industry with ERTMS in a human factors role. A total of six experts participated in the workshop, including four males and two females. Their ages ranged between 33 and 60, with an average age of 41.7. They had an average of 13.8 years of HF experience (ranging from 5 to 30 years), 8.9 years of rail HF experience (ranging from 0.75 to 13 years), 5.0 years of experience with ERTMS (ranging from 0.75 to 9 years) and 11.6 years of rail experience (ranging from 0.75 to 29 years).

Pilot

The workshop activities were piloted on a member of the Network Rail Ergonomics team and two members of the University of Nottingham's Human Factors Research Group. Based on the feedback some of the activities were amended, including some of the wording of the stimulus materials and timings of some of the activities.

Apparatus

A consent form and demographic questionnaire was given to participants prior to the start of the workshop, to read and complete. A workshop activity sheet was given to the participants to inform them briefly about each activity and the schedule of activities in the workshop. The workshop was recorded using a dictaphone, with the prior consent of the participants.

Procedure

The workshop lasted four hours, with one break in the middle, and consisted of four different activities. Once the participants had been briefed about the study, they were instructed to read and complete the consent and demographic forms.

Activity one consisted of the participants individually sketching out what they thought a train driving model should look like based on their rail experience and what features it should include. They were also instructed that they could list any additional elements that they thought were important and list any features which current models lack. The goal of this was to elicit their current internal representations of train driving, without explicit influence from any of the existing models.

Activity two was used to evaluate existing models of train driving and consisted of participants initially working individually and then as a group. Firstly, they were instructed to work through six A3 activity sheets. Each page of the activity sheet had a different model of train driving (as listed in the introduction) and participants were asked to rank the models based on how well they thought it represented the train driving task (1= the most and 6= the least). For each individual model they were also asked to write down what they liked and disliked about the model from a theoretical and practical perspective and why. Participants were also instructed to state if they thought there was anything missing from the models and why; and also how useful they would find the model when considering the implementation of new technology, designing new routes and designing new training and why. Once the participants had individually completed the worksheets, they had a facilitated group discussion about the activity. They were asked what they had written down and why. They were asked to discuss if they agreed or disagreed with the points made and asked to rank the models as a group. The goal of this activity was to build up a body of insight into the value and contributions of the different train driving models in informing rail human factors in general.

During activity three the participants interpreted the eye-tracking data graphs of different events in ERTMS and conventional driving, on an individual and group level. However, the results of this activity are not presented in this paper, as it is outside the scope of the paper.

Finally, in activity four, the participants were asked to revisit their sketch from activity one and were given the opportunity to add anything further to their original sketch using a different coloured pen. They were then instructed as a group to discuss what they thought was not captured by the six models of train driving that they thought would be useful in models of ERTMS and non-ERTMS train driving. Furthermore, they were instructed to discuss what elements in a future train driving model would be useful for the rail industry, and also what types of tasks and scenarios could be utilised by train driving models.

Results & Discussion

1. Construction of train driving models by participants

The results of activity 1 and 4, where participants constructed their own train driving models, an example of the constructed model is shown in Figure 1.

[insert Figure 1]

Figure 1: An example of a constructed model by a participant

The models produced by the participants were summarised, as shown in table 1. Participant 1 produced two models which are stated as ‘a’. (for the technical scenario modelling) and ‘b’. (for the train driving as an artefact) in Table 1. The themes were derived from the data collected and include *'representation'* (how the participants had structured their response), *'knowledge/experience'* (i.e. route knowledge, operational experience), *'tasks'* (associated with the train driving), *'cognitive'* (cognitive tasks and cognitive constructs that had been associated with train driving), *'information'* (types of information used by train drivers), *'events'* (types of events present in train driving), *'analysis/procedure'* (types of HF or operational assessments that could be used to inform the models or be used as its output), *'ETCS' (*ERTMS elements included) and *'added post evaluation activity'*(added after activity 4).

Participant	Representation	Knowledge/ Experience	Tasks	Cognitive	Information	Events	Analysis/ Procedures	ETCS	Added post evaluation activity
1	- a. Diagram (technical scenario modelling) - b. Diagram (driving model as an artefact-differentiating interest to infrastructure holder and operators)	- a. Route chart - Train specification - Operational factors - Energy efficiency - b. Operational experience	- b. List of tasks in time sequence mapped against train speed and location	- a. Workload model			- a. Task analysis - Error analysis - Training needs - Recommend-ations - b. HF expertise - Infrastructure rolling stock engineers - Route assessment - Evaluation of new equipment - Evaluation of new task/strategies - Training needs analysis	- a. Speed profile	- a. Model of ETCS display - b. Experimental data

							- Incident analysis - Driver performance monitoring		
2	- Diagram	- Knowledge and experience	- Control speed - Braking - Communication - Emergency procedures	- Anticipate - Process - Recall - Decision - Expectation	- Present situation (environment) - Internal cab information - External information			- ETCS actions	- Details of internal cab information - Details of external information - Driver training - Organisational issues - Understanding of driver behaviour

3	- Diagram	- Rules - Procedures - Operational requirements	Tasks Time keeping Delivery Maintaining performance	Human factors Conscientious ness Diligence Habituation Cognitive overload		Limits of authori ty Shift work			
4	- Diagram	- Passenger /freight - Knowledge & skills - Attitudes - Non-technical skills - Personal awareness training - Development - Assessment - Competency	- Prepare for duty (check roster, collect diagram) - Prepare cab for duty/service (check cab layout, log on) - Drive train in service (running brake test, accelerate, monitor speed)	- Emphasis on why things are done than just what is done		- Degrad ed scenari o (on-board failure, tracksid e failure) Shunt/ depot			- Knowledge Splitting of tasks - What happens? What, how and when?

		assessments - Briefings - Personal development	- Couple/ uncouple (check process) - Stop train (brake) - Evacuate (announcem ents)						
5	- List	- Route (speed, gradient, features, stations, crossings etc.) - Train (maximum speed, traction type etc.) - Driving (speed application, braking, rules in degraded	- Checks at start of journey - Stopping at correct station - Level crossing operation	- Consideration for current environment - Reacting to events - Thinking ahead to future parts of the journey	- Signalling informatio n	- Track worker s present - Level crossin g operati on - Station stops			- Key difference in how signalling informatio n is presented and transitions between them - Degraded mode operation when driver has to drop

		mode etc.)							back to conventional from ERTMS operation
6	- Diagram & table	- Timetable - Stopping pattern - Route experience - Speed limits - Headways from timetable - Gradients - Train dynamics (diesel vs. electric, freight vs. passenger)	- Train preparation - Dispose of train - Observe MA - Speed keeping - Obstacle & failure event management - Controls (brake, power)	- Tracking - Perception /control loops	- Signage - Coloured lights - Semaphores - PSR signs - Other signs	- Degraded mode		- DMI modes - Alerts - Train dynamics affected by braking curve - Planning area indicators - Written orders	- Scheme design - Where information is presented (DMI, outside)

Table 1: Results of the construction of participants' own train driving models

In activity 1, four participants presented their models of train driving as a diagram, one as a diagram and table and one as a list. All participants heavily focused on the themes '*knowledge/experience'* and *'driving tasks'*. *Knowledge/experience* included elements such as train dynamics, routes, rules and operational factors. *Tasks* included activities such as speed keeping, communication, observing movement authorities, obstacle and failure event management.

The different participants highlighted different cognitive tasks and constructs within their models. These varied from workload, human information processing, situation awareness, tracking and control loops. The next most used theme included in the models was *'information'* and participants included varying types of both internal and external information to the cab. The following theme was *'events'* and the event mentioned most by participants was degraded mode, whilst events such as level crossings and the presence of track workers were also mentioned.

One participant used two models, technical scenario modelling and driving as an artefact. Within the technical scenario modelling 'processes' such as task analysis, error analysis, and training needs were also included. In regards to the theme *'ETCS'*, participants included aspects such as speed profiles, ETCS actions, DMI (driver-machine interface) modes, alerts, train dynamics affected by the braking curve, planning area indicators and written orders.

In activity 4 where participants were asked to *revisit their models* they included model of ETCS display, *experimental* data, details of internal and external cab information, knowledge, how signalling information is presented and the transitions between them, degraded mode operation when a driver has to drop back to conventional from ERTMS operation, scheme design and where information is presented (DMI vs. outside). Activity 1 provides an insight into existing aspects of train driving models used by practitioners in the rail industry, whilst activity 4 shows aspects that participants view to be equally important after reviewing the eye-tracking events data of ERTMS and conventional driving, the existing train driving models and further discussions.

2 Evaluation of Existing Train Driving Models

In activity 2 the models ranked, based on the mean score, from most representative of the driving task to least representative of the driving task with conventional train driving were:

•Model 3 (1.83 - Roth et al.[7])

•Model 5 (2.17- Naweed[9])

•Model 1 (3.33 - McLeod et al.[5])

•Model 2 (4.17 - Hamilton et al.[6])

•Model 4 (4.67 - Sani et al.[8])

•Model 6 (4.67 - Zoer et al.[10])

The responses to the activity sheets in activity 2 and the discussion that followed are discussed jointly to explore the ranking scores. The data from the discussions was coded into the following categories: 'strength of models', 'weakness of models', 'uses for different models', 'testing models', 'existing route drivability tool', 'future models and tools'; and is presented below.

2.1 Strengths of Models

The strengths of the different models, as expressed by the participants, is discussed in turn. Model 1 (McLeod et al.[5]) was viewed to have psychological validity based on models of decision making and have descriptive qualities. Participants also liked that the model was time-line based.

Model 2 (Hamilton et al.[6]) was also viewed positively as it was based on psychological constructs that could be used as a descriptive tool, and it included a good representation of the cognitive tasks. Another participant liked that it had been used in a route drivability tool to quantify the human information processing acts in train driving and that it could be used to build up task timings for a driver model.

Model 3 (Roth et al.[7]) was the most favourable model and participants stated that it was similar to model 1 (McLeod et al.[5]) but it went further to represent cultural factors and it highlighted some key areas in train driving making it more than just a psychological theory. In addition, it was viewed as a simplified model that managed to cover and contain most aspects of train driving (e.g. communication and timetable aspects), making it more practically useful. Model 3 (Roth et al.[7]) was also considered to imply a development or building of a number of factors, including knowledge and the current situation, that then affected an action.

Model 4 (Sani et al.[8]) and model 6 (Zoer et al.[10]) were not well received by the participants scoring joint last. However, model 4 (Sani et al.[8])'s strength was highlighted for showing driving tasks in a wider organisational context and also discussing error rates. Model 6 (Zoer et al.[10]) also placed the train driving task into an organizational context but also identified some of the psychological demands, however it was considered to be theoretically confusing.

Model 5 (Naweed[9]) was viewed as a strong model in the discussions due to the inclusion of a dynamic train control loop, as well as representing drivers' skills and knowledge. It was suggested it was one of the most detailed models of train driving, including in-cab signalling activities, it was thought to have also modelled strategy and closed loop monitoring. Participants expressed that this model managed to also cover a wider base of external information and include specifics about train driving such as rail head conditions. However, it was concluded that the model was incomplete and in need of some additional elements.

Requirements for a future train driving model were derived from this stage of the analysis. These included constructing detailed models with underpinning psychological models, which can be used in real world train driving contexts. Furthermore, future train driving models require the integration of context, awareness of cultural factors, representation of driver skill and knowledge; as well capturing strategic actions.

2.2 Weaknesses of Models

It was proposed that model 1 (McLeod et al.[5]) needed more explanation of speed keepings. As suggested by the title it is focused on driving with the AWS, however participants expressed that it lacked practical understanding of the AWS. It was thought that it was too complicated and missed the time factor and the consequence of not acknowledging the AWS. One participant highlighted that not all the elements in the three layers mapped against 'perceive', 'decide' and 'act'. For example, immediate route history isn't linked to 'act'. Participants did not consider this as a useful model to look for errors and didn't like the fact that it was a closed loop micro-model. In addition, it was pointed out that model 1 (McLeod et al.[5]) does not deal with train driving elements such as timetable and start of task etc. Also, similar to some other models it is very signal orientated, does not include factors such as communication and is very GB based.

Model 2 (Hamilton et al.[6]) despite being a heavily theoretical model was viewed to not have a logical flow. One participant thought 'it was a model for psychologists with not a great practical merit.' Participants felt that it didn't have sufficient detail about the driving tasks, it had poor visual representation which looked messy and confusing. It was thought to be a very difficult model to use as communication tool. It was also viewed to be very stimulus-response driven with no real explanation of how human capabilities impinge on the recognize-act cycle.

Critiques for model 3 (Roth et al.[7]) included that it did not have a sense of weightings for the plan/decide components nor the impact of the outcomes. It was suggested that it could also be more expansive, as it did not account for what the driver was doing.

Both model 4 (Sani et al.[8]) and model 6 (Zoer et al.[10]) were perceived to lack detail of the driving task, be too simplistic, too generic and without a practical link to train driving. For model 4 it was also viewed that the model had negative outputs, possibly due to cross-cultural issue and the model was not train driver-specific.

Model 5 (Naweed[9]) was perceived to be quite complex on first glance and it was suggested that the meaning of the arrows would need to be tested using a real route. Overall it was suggested it was quite a complex model that needed time to fully understand, with unclear terms such as 'aggregates of driving strategy'.

Overall participants expressed that prioritizing the importance of factors was beneficial and it was important for models to emphasise which factors influenced when and where in a particular scenario. Descriptive models were critiqued for not showing explicitly how factors interacted. Factors that were considered missing from the models included timings, errors and weightings. Generally, some of the models were considered too theoretical and simplified for academic purposes, as opposed to a practical working model.

Further requirements for a future train driving model were derived from this stage of the analysis. These included sufficient explanation of driving tasks and the train technologies. The need for model[5] to be comprehensive and also internationally relevant. Furthermore, future models should be analytical rather than just descriptive and be appropriate for practical application.

2.3 Uses for Different Models

Participants agreed that the different types of models (e.g. strategy. decision making, organizational) could have different uses in the rail industry. The strategy models were considered useful as they can be generative and can be built into computer programs, by creating a rule-based system which can extrapolate train driver behaviour. Decision making models were described as more descriptive and could be beneficial when understanding train driver behaviour (e.g. post incident analysis) as an evaluation tool by providing a checklist to understand the process behind the decision. On the other hand, organizational models could be used for evaluating organizational changes (e.g. to examine how introduction of big changes to recruitment policies could affect the train driving task).

Generally, the models could have several uses and examples included the design and evaluation of new routes, reduce human error, introducing new technology and systems, training needs analysis, selection and post hoc analysis e.g. post incident analysis. When implementing new technology, it was proposed that designs needed to reduce the likelihood of error, therefore also need to highlight the relative importance, size and effect of the different aspects of a model. Models which are too focused on the cognitive aspects, may provide very little practical help when implementing new technology or designing routes.

Model 4 (Sani et al.[8]) could be useful for safety briefing conversations with drivers, as it emphasis joint responsibility between the driver and the system. In addition, it could be used in designing training, drawing recommendations after an incident or evaluating changes to organizational systems.

Model 1 (McLeod et al.[5]) and 3 (Roth et al.[7]) were considered good representations of the qualitative aspects of the train driving task and would be a very useful communication tool with a variety of stakeholders including engineers and designers, as it broke down the different steps and processes. Explaining driver behaviour was considered particularly useful when discussing errors. Model 5 on the other hand was deemed more amenable to being a quantitative tool which could be applied in a rule based computer program like the Network Rail Route Drivability Tool (see section 2.5 for further detail). However, the language from the qualitative models could be used to communicate the quantitative data with rail projects.

2.4 Testing Models

From a practitioner perspective it was expressed that future models should be designed to aid the rail industry to gain a practical understanding of the train driving task and how to use that understanding in terms of technology and routes. Participants stated that even though model 5 (Naweed[9]) on face value appeared to be a strong model that clearly represented train driving, that they would wish to put a scheme or route through the model to test it. Additionally, models could be tested using post-incident analysis.

2.5 Future Models and Tools

The existing models were analysed for their general use within rail human factors. This section considers any further recommendations that were suggested when considering the value of the models for the evaluation and implementation of ERTMS. Tools such as the Network Rail owned Route Drivability tool (RDT), which was built to assess driver workload in the design stage, need to be adapted so they can be used with ERTMS. Participants suggested that decision latitude or autonomy of ERTMS drivers also need to be included in new driver models due to the shift of responsibility of speed keeping. It was stated that model 6 could be used for its aspects of decision latitude (e.g. how much autonomy the driver has), however ERTMS would not remove it but restrict it and place more of the responsibility of speed keeping onto the system. Furthermore, the requirements that were extracted based on the strengths and weaknesses of the existing models need to be considered in future models and tools.

It was proposed that future models and tools needed to help aid project decisions and help address existing industry questions, such as what is the maximum number of transitions per route. Participants considered it crucial to understand the task of driving with ERTMS and feed research into the RDT or other equivalent tool. An example given was that it may be a temptation to think that an ERTMS driver will become a ‘slave’ to the system but data from previous work have shown that drivers will over time adjust their previous route knowledge within the narrow parameters of the system. They also emphasised the importance of using pre-existing eye-tracking research to help understand drivers’ behaviours and to inform new train driver models. Train data downloads could also be used to aggregate data and errors to further understanding.

Overlays on new routes, where a driver would have their movement authority via in-cab signalling but with the presence of conventional trackside signals, should also be accommodated for in new or adapted train driver models. In addition, ERTMS and ATO (Automatic Train Operation) transitions need to be considered to predict driver performance. One participant thought it would be interesting to see the effect of ATO on drivers, as drivers would be predominantly driving defensively and be risk aversive, but then the activation of ATO may expose drivers to a more aggressive type of driving with heavy braking. This could potentially shift a driver's style of driving to a more aggressive one. There is a need to consider aggressive driving of ATO and how this will affect drivers when they transition from ATO back into ERTMS level 2.

Conclusions

The study demonstrates that several models are needed to help address some of the issues raised, as they could provide different uses, acting as 'building blocks' to the overall picture. Qualitative models can be used to provide the framework and language as a communication tool, whilst more quantitative models can be used to compute error and workload. Models need to be informed by cognitive theory but also focus on the train driving tasks and information used by train drivers.

Requirements for a future train driving model were derived and included constructing detailed models with underpinning psychological models, which can be used in real world train contexts. In addition, future train driving models require the integration of context, awareness of cultural factors, representation of driver skill and knowledge; as well capturing strategic actions. Furthermore, sufficient explanation of driving tasks and the train technologies are required. New models need to be comprehensive and should be analytical rather than just descriptive and be appropriate for practical application.

Creating a new train driving model for ERTMS, which includes transitions and overlays, could prove to be an invaluable tool for the rail industry. It could help address many design questions, not only with designing new routes and the adoption of new technology but also driver training. Elements of ERTMS highlighted by the experts should be considered when constructing a new model of train driving with automation and control technology. These included aspects such as elements from ERTMS, but also train dynamics that could affect braking, degraded conditions, transitions and associated experimental data.

The study highlighted that it is critical to test new train driving models, with the input of rail experts, and using a real world rail scheme or route; or using a post incident analysis. Existing models and tools (such as the RDT) need to be updated for the new automation and control technology, including new elements such as the autonomy of drivers; but also to help address rail project decisions such as the number of transitions in a route and overlays.

The findings of the study critique and evaluate current train driving models, identify a series of requirements or ‘best practice’ elements of models, and analyse the specific requirements of train driving models for the implementation of ERTMS. It contributes to bridging the gap between the theoretical understanding of train drivers’ cognitive strategies and its practical implementation by the rail industry, with a particular focus on automation and control technology. New train driving models, for both conventional train drivers and ERTMS drivers are required to shape and support future Network Rail engineering projects; including the design of signalling schemes and the development and training of train drivers.

Acknowledgements

The participation of the rail HF experts in this study was greatly appreciated by the authors.

Funding

This study was part of a three-year research project which was co-funded by Network Rail and the Engineering and Physical Sciences Research Council (EPSRC reference: EP/J500483/1).

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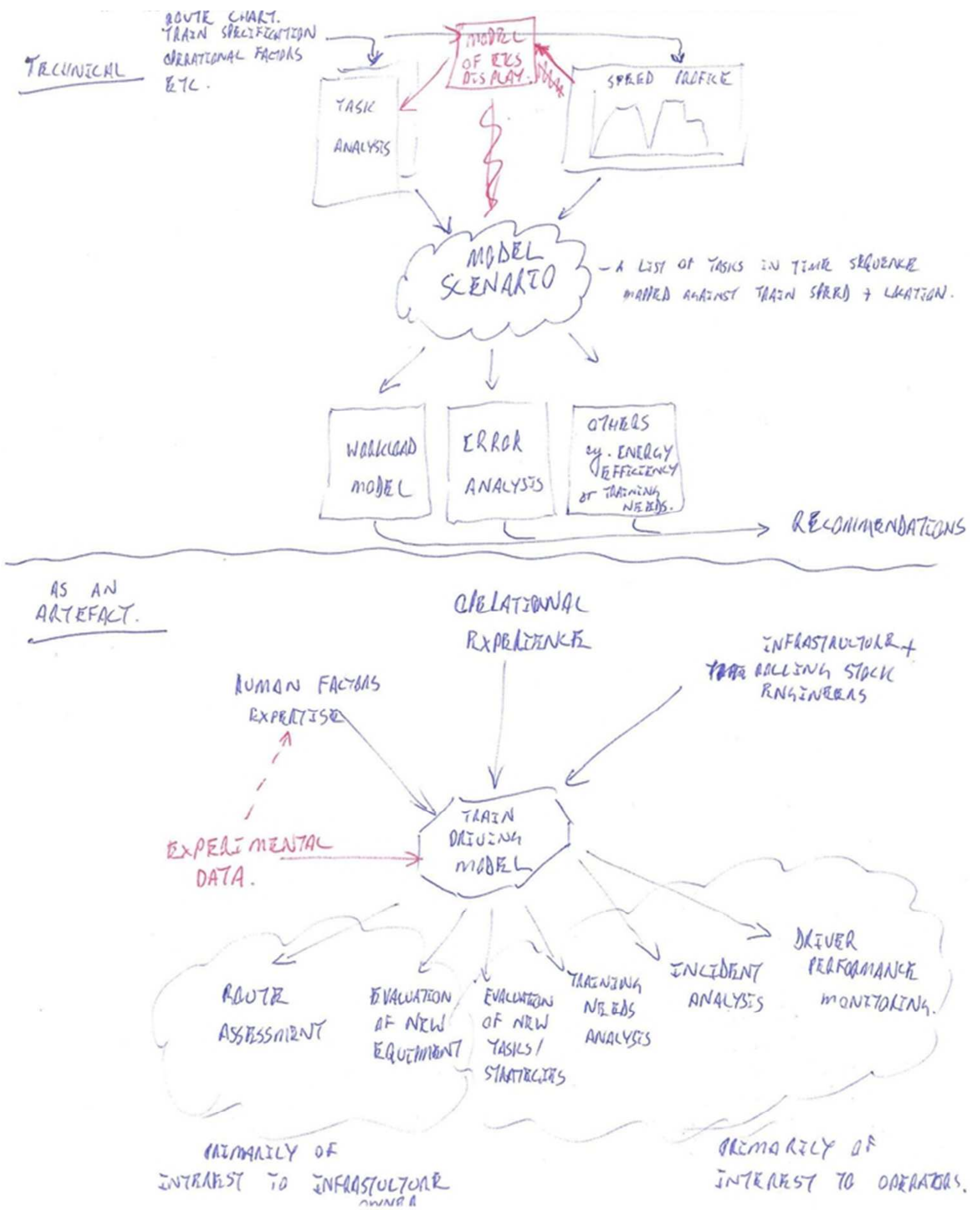

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