Understanding Train Driver Route Knowledge

Simulator Project Suite Volume I
Understanding Train Driver Route Knowledge

Synopsis:
This report reviews literature substantive to train driver performance modelling in order to develop a greater understanding of route knowledge, and identify the research gaps in the way of developing simulator scenarios for training. Traditionally, route knowledge is understood as a bulk of information that is acquired at the end of the driver training, but very little is known about how railways are internally represented relative to the task’s multidimensional requirements. A better understanding of the way that this knowledge is mentally represented is needed, together with a better definition of the specific route features and railway configurations that may stimulate early skills development, and comprise difficult or challenging tracks. This report seeks to develop a more informed understanding of train driver route knowledge and fill any identified research gaps using initiatives that specifically probe and classify different sections of track according to navigational difficulty.

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Executive Summary

The Cooperative Research Centre for Rail Innovation (Rail CRC) commissioned this project in 2010, in order to explore techniques for optimising knowledge and skills transfer during simulator-based training.

This report reviews literature substantive to train driver performance modelling in order to develop a greater understanding of train driver route knowledge, and identify the sort of research gaps that are in the way of developing intuitive simulator scenarios for training. Traditionally, route knowledge is understood as a bulk of knowledge that has to be acquired at the end of the train driver training programs, but very little is known about how railways are internally represented relative to the task’s multidimensional requirements.

An on-going rail research base has developed models that conceptualise the decisions and actions required to apply route knowledge, and has broadly considered the external and individual contributing factors that comprise this skill, but it has yet to explore how specific route information is actually encoded and how the track is compiled in the train drivers’ memory.

This report reviews the corpus of work related to cognitive train driver performance modelling, in order to examine how route knowledge is mediated in the information processing pathway, and develop a better understand of how its component features may be optimised in simulator scenarios during early phases of skills acquisition.

It is important to note that whilst this report offers little in the way of actual answers, it explores route knowledge sufficiently to establish a theoretical precedence for enhancing competencies and skills acquisition, and expounding the research gap in the way of testing this thesis. A number of questions are raised, specifically around the way that route knowledge is encoded, and how this may vary as a function of expertise. A number of considerations for populating this research gap are subsequently proposed, specifically:

- Focus groups and one-to-one interviews may be used to derive specific experiences and interesting stories associated with challenging routes and driving scenarios. These may incorporate a number of task analysis methods, such as Applied Cognitive Task Analysis or the Critical Incident Technique both of which use dynamic interviewing techniques to elicit intuitive and deeply embedded knowledge;

- Train driving observations may be conducted with drivers during the actual task, drawing on specific examples or previous scenarios in the substantive environment. The verbal protocol analysis has been used in the rail domain before, and this technique may also be employed to garner route knowledge-based data that is more representative of cognition, and the information processing in the task;

- The train driver population should be stratified according to experience, and by extension, expertise, as well as the operation types, engendering route knowledge and driving strategy data from passenger and freight operations; and

- Data pertaining to the way that train driver training courses are delivered should also be analysed to facilitate a better understanding of the methodologies currently employed by the Australian rail industry, and amongst other things, establish how the training frameworks for different operations vary between organisations.
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## Abbreviations and Acronyms

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<thead>
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<th>Description</th>
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<tbody>
<tr>
<td>ARTC</td>
<td>Australian Rail Track Corporation</td>
</tr>
<tr>
<td>ATSB</td>
<td>Australian Transport Safety Bureau</td>
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<tr>
<td>CRC</td>
<td>Cooperative Research Centre</td>
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<tr>
<td>NTC</td>
<td>National Transport Commission</td>
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<tr>
<td>NTSB</td>
<td>National Transport Safety Board</td>
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<tr>
<td>RSSB</td>
<td>Rail Safety &amp; Standards Board</td>
</tr>
<tr>
<td>RGS</td>
<td>Railway Group Standards</td>
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<tr>
<td>SPAD</td>
<td>Signal Passed at Danger</td>
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1. Introduction

1.1. Background

In 2008, figures for employment in the Australian rail industry showed that the number of train drivers in service were at record levels. The median age of this workforce (43 years) was higher than in many other industries (Department for Education Employment and Workplace Relations, 2009). Comparisons of these figures also indicated a high level of job growth, which were largely attributed to train drivers changing jobs within their occupation or leaving the industry entirely. The key implication here is that, as demands for rail services continue to increase, there is a need both to retain the expertise, but also to continue filling train driver positions made vacant by resignation and retirement. However, these issues are complicated by the time that is required to complete training programs, and inconsistencies in the quality of training. Train driver training programs typically incorporate a blend of ‘off-job’ classroom theory and ‘on-job’ practical training, which can take many months to attain, and given the fractured state of Australian rail regulation, vary within and between operation types. Beyond this, route learning is a separate constituent usually featured towards the end of a training program that, depending on the distances involved, can take many months to years to acquire. A general solution to this problem would be to improve train driver training efficiency, such that the time to complete training is optimised, and the quality of skill acquisition or the focus on safety remains uncompromised.

A significant part of every train driving training program is the acquisition and maintenance of route knowledge. Route knowledge is something that has traditionally been delivered via repeated cab rides, and reviewed through routine evaluations of the knowledge to be acquired. Given the many factors uniquely substantive to the train driving task, such as the monotony of the railway environment, the differences in the event rate, the distances involved, and the competing pressures to perform (punctuality, smoothness of ride, energy efficiency), developing route knowledge through repeated trips can be a time-consuming process. However, one way of optimising the time it takes to learn a new route may be to focus on specific railway configurations considered as the most demanding or the most challenging to drive over. In practice, this could involve removing the focus from sections of railway that do no provide any learning opportunities, and applying it to those that do through repetition in a simulated environment. This may decrease the time required to learn a route, enhance the overall process of knowledge acquisition for both novices and experienced drivers, and generally optimise the use of simulators in train driver training programs.

However, despite the fact that train driver training modules unwaveringly emphasise the importance of route knowledge (Railway Group Standard, 2003), very little is known about how railways are internally represented relative to the task’s multidimensional requirements. An on-going rail research base has developed models that have conceptualised the decisions and actions required to apply route knowledge, and broadly considered the external and individual contributing factors that comprise this skill, but it has yet to explore how specific route information is actually encoded or how the track is compiled in the train drivers’ memory. Although route learning may occur throughout the driver training process, route knowledge that is acquired in situ (i.e., as part of on-job driving) is generally one of the last processes to feature in training, thus it is also important to understand any other knowledge or skill-based requirements that its development may rely on.

1.2. Aim and Scope of Review

The purpose of this literature review is to develop a greater understanding of train driver route
knowledge. It will review existing knowledge models in order to establish how routes are mentally represented, and explore cognitive theories of train driving to determine how the decisions and actions required to apply route knowledge are conceptualised. The review will also examine the information requirements of various train driving task types, and broadly consider the external and individual contributing factors that comprise this skill. Developing a greater understanding of route knowledge would help to identify the opportunities that go unmissed during the knowledge acquisition process, and furthermore, provoke an early development of the vestibular and kinaesthetic learning required to drive a train and attain high train driving competencies. To that end, there are three general aims for this review:

1. To identify the constituents of route knowledge from reviewing specific models of train driving performance;

2. To identify any parallel learning demands required for accelerating the process of route knowledge acquisition; and

3. To review and further define the gaps in knowledge required for optimising the use of simulators in train driver training.

This report takes a traditional inductive approach to the research, and having defined a purpose, aims to develop further questions, modelling classifications, and explore patterns substantive to the topic. The main body of this report is focussed around a review of cognitive train driving performance models, as a means to explicate the nature of the problem and cultivate a better understanding on route knowledge. This review features a core analytical evaluation that considers the state of train driver performance modelling as it currently stands, but moreover, how train route knowledge has featured within this corpus of research.

1.2.1. **What is Out of Scope?**

This report is not intended to be a comprehensive review of all of possible collision avoidance information processing analogies, but it does recognise that there are many approaches to information processing, and indeed, many models from analogous domains that could potentially apply to the collision avoidance analogy. However, whilst these are in too great a number to review within the confines of this report, most of these fall outside its scope too, given that route knowledge is a singular peculiarity and idiosyncrasy of the rail domain. Thus, the focus is primarily honed on specific models of train driving performance.

This report is primarily aimed at reviewing a corpus of research that has explored how route knowledge is internalised and how other cognitive systems interact with this dynamic to engender what is recognised as train driving skill. The way that driver training is currently delivered is invariably touched upon in Section 2 of this report, but learning literature is not presented. Whilst the acquisition of route knowledge is a driver for this research (particularly with respect to simulator scenarios), the topic of learning, and specifically how route knowledge can be learnt efficiently is the applied, qualitative, and empirical focus of the subsequent deliverables in the wider project suite (R2.112 Capturing Driving Strategies, R2.113 Route Knowledge Acquisition), and thus falls outside the scope of this review. For information about driver learning with train simulators, the reader is referred to project P4.103 – Evaluation of Simulators in Driver Training, which core project participants may access from the CRC for Rail Innovation website (http://www.railcrc.net.au/).
1.3. Report Structure

The remainder of this literature review is organised in a number of subsections, as follows:

- Section 2 provides some context around the train-driving task, conveys the role of route knowledge, considers the role of landmarks in navigation, and reviews the theory behind cognitive structures that frame and facilitate internal route knowledge representations.

- Section 3 presents five models of train driving performance that represent a strong corpus of contemporary research carried out in the area. These are categorise in skill- or situation-based classifications, and evaluated according to their treatment of route knowledge.

- Section 4 extends the review to focus on very particular processes encompassed within the train driver information-processing pathway, and considers the respective role of perception, recognition, decision-making, and memory.

- Section 5 explores the role of driving strategies and driving experience, and considers their relationship with route knowledge.

- Section 6 provides a summary of the review and considers the gap in knowledge impeding the design of simulator scenarios that may accelerate route knowledge acquisition and optimise trainee task competencies.

- Finally, section 7 provides a list of considerations for future research that may offer more insight into train driver route knowledge.

The focus of this literature review is to better understand the dimensions of route knowledge. In order to achieve this, it first provides some background on information processing literature at a very general level. This is in order to enhance comprehension of the subsequent train driver models. The information-processing pathway is subsequently explored in greater depth to divulge the role of component cognitive structures in the mediation and application of route knowledge. Thus, the components of route knowledge are first introduced at a relatively general level, before being reviewed according to the role of specific cognitive processes. It is easier to explicate the role of each component factor after reviewing the models, and ascertaining the relevancy of specific cognitive processes, before drawing the focus back to a holistic vantage point.

1.4. Project Method

A literature review was conducted using the following sources:

- Google and Google scholar.

- International industry/government websites, including the Rail Safety and Standards Board (RSSB), Federal Railroad Administration (FRA) and National Transportation Safety Board (NTSB).

- Australian industry/government websites, including but not limited to the Australian Transport Safety Bureau (ATSB), the Rail Industry Safety and Standards Board (RISSB), the Cooperative Research Centre for Rail Innovation (Rail CRC), Australasian Railway Association (ARA), Australian Rail Track Corporation (ARTC), and the National Transport Commission (NTC).
Key peer-reviewed journals that had previously featured railway level crossing research e.g., Human Factors and Ergonomics Society, Applied Ergonomics, Cognition, Technology and Work.

Additionally, reference lists within documents found through these methods were searched for relevant material. Various combinations of the following keywords were entered into these search engines:

- Train driving, train driver, rail industry, training
- Route knowledge, route learning, knowledge acquisition, route maps
- Situation awareness, cognition, information processing, memory, perception, decision making, mental models
- Simulation, simulated task environments, simulator training, simulator human factors, simulator research
2. **Traversing Route Knowledge**

2.1. **The Train Driving Context**

Train drivers have traditionally navigated by processing information from their knowledge of the rail’s infrastructure, and from information sources in their environment like trackside signals, geographical markers, landmarks, and so on. Misreading signals can therefore jeopardise the amount of time or distance left available to stop the train effectively. Although drivers depend on task-related information cues, targets may be out of sight or obscured by changing conditions. Thus, a train driver must remain aware of their position at any given moment, and estimate the distance to the next target accurately. Train drivers are therefore required to perceive and process complex vestibular, kinaesthetic, acoustic and peripheral visual information that are all integral to the task, in order to perform it (Branton, 1979).

From an engineering psychology perspective, train driving is fundamentally a tracking task that displays all the common elements of the tracking loop (Wickens & Hollands, 2000). When operating the train in routine mode, the driver aims to minimise the discrepancy between the speed of the train, as shown by a speed indicator, and the target speed, as shown by the indicators at trackside. The error rate may change as a function of time, and the train driver will apply the throttle and/or brake dynamically, to adjust the acceleration of the train.

2.2. **Background to Train Driver Training**

Traditionally, the Australian rail industry has relied upon the ‘on-job’ learning approach for training train divers. The National Transport Commission (2008) has indicated that this is a time consuming process which loses knowledge and training quotient through the retirement of skilled drivers, and suggests a general move beyond internal learning processes to new ways of thinking. However, given that there are a number of ways that new approaches may be realised, which may also depend invariably on the skills to be learned, this issue is the subject of much debate. For example, it can be argued that given the ‘seat of the pants’ elements that forms popular train driving culture, train handling skills may only be learned ‘on-job’ with one-to-one tuition. On the other hand, route learning could potentially be supported off-job through appropriately designed tools. These are different skills in the same skillset, but in either case, one way to improve training efficiency may be to utilise new and engaging learning tools at critical stages of skills development. The use of simulator-based training is a norm in other collision avoidance industries (aviation, maritime), and more recently, has started a burgeoning uptake in Australian rail. However, the integration of these technologies into existing training programs is being adopted in a somewhat piece-meal manner that is not harnessing them to their fullest potential. The use of simulator-based training to enhance competencies and potentially reduce training time is a current focus in rail research (Cooperative Research Centre for Rail Innovation, 2010).

In the UK, the inquiry into the Ladbroke Grove Rail crash (caused by a catastrophic signal passed at danger [SPAD] failure event) led to the establishment of the RSSB, and encouraged the use of a licensing scheme for formal train driver accreditation (Uff & Cullen, 2001). In Australia, this indirectly influenced the advent of the rail safety bill for each worker to perform their duties competently, and for the responsibility of each rail organisation to ensure the competency of workers under their jurisdiction (National Transport Commission, 2007). This includes an understanding of the relevant knowledge, and the skills required for its application. To that end, train-driving codes of practice generally support training initiatives across a wide range of media aids. These include video photography, route maps and diagrams, and simulated or computer generated models of the railway environment (Railway Group Standard, 2003).
Trainee train drivers are required to complete extensive route learning and knowledge retention programs followed by competency evaluations. Rules and principles governing current operations are conveyed through a substantive rulebook or procedures and route maps (Railway Group Standard, 2003). Simulators are generally used to introduce trainees to the domain, whilst training and familiarity with traction is supervised in real units. Route training programs are based on a pre-defined structure of return trips and cab hours that are informed by the demands of a route. Trips are planned using predefined multipliers and the length of the route in order to calculate the amount necessary. For example, a multiplier of 0.28 for a 100-mile (160 km) route necessitates 28 return trips.

2.2.1. Route Knowledge – Definition & Purpose

Route knowledge has been defined by the rail industry as ‘the type of information required to be remembered, in order to operate over a route’ (GO/RC3551), with the general expectation that this information must be recalled in real-time during train navigation. Train driver training modules generally equate good route knowledge with a way of operating over a route safely, and instantiate it as a key component for ascertaining train driving competency. Route knowledge is linked to the key idiosyncrasy in the train-driving context, which is the need to remain aware of where the train is at any given moment. This is the generally accepted viewpoint of the rail industry, and supported by an abundance of evidentiary crash data, which indicate that poor or underspecified route knowledge contributes to unsafe train driving (e.g., Lawton & Ward, 2005). Route knowledge is generally described as the information necessary to apply other types of route learning skills, such as the experience and understanding of train handling characteristics and the foundational rules and regulations. Codes of practice (e.g., Railway Group Standard, 2003) generally consider route knowledge to be an amalgamation of: a) infrastructure features such as stations, junction and tunnels; b) a know-how of the signalling system in use; c) the position of signals and the stopping distances of trains being driven; d) important properties of the railway, such as the track gradients relative to the trains being driven; and e) a familiarity with signals in high-risk categories, including those associated with multiple SPAD events, and those in danger of being misread.

Operationally, route knowledge is considered to be one’s understanding of how to proceed following a point-by-point set of procedures (Bone & Lintern, 1999), suggesting that it is the sum of the knowledge needed to advance to a required destination. The primary purpose of route knowledge is to support the drivers’ anticipation of future task requirement, which suggests that its utilisation involves memory, experience, attention and a high level of spatial planning. Traditionally, route knowledge is thought to permit the train driver to plan ahead and exact control actions based on their expectations of future train driving requirement, enabling the effective management of cognitive resources and perceptual load associated with the task’s evolving demands (McLeod et al., 2005). The consequences of poor, underspecified or ineffectual train driver route knowledge include SPAD events, (Nikandros & Tombs, 2007), and train derailments (Durali & Shadmehri, 2003).

2.3. Navigational Strategies

Train driving is unidirectional, that is to say trains may only move in a direction that has been planned and authorised for them. As a consequence, train drivers do not navigate in the traditional sense; they do not decide the best route to take or perform multidimensional manoeuvre like transport in other collision avoidance domains (e.g., aviation, maritime). Train drivers drive to movement authority and are required only to control speed, maintain safety, and navigate...
to optimise their goals for good service delivery. There is some debate around the structure of route knowledge and its relationship with navigation, but the general consensus is that an internal route map comprised of visual landmarks is used to drive navigational strategies (Biro et al., 2004). In practice, this is where the direction and distances travelled are gauged by comparing the route with its various landmarks, a process otherwise referred to as path integration (Foo et al., 2005). Whilst train drivers must operate according to movement authority, navigation is achieved by processing familiar landmarks, and other external sources of information.

Substantive literature distinguishes between two types of navigational strategies: those that are coordinated around a single landmark (i.e. landmark-based) and those that are coordinated around multiple landmarks in a specific sequent over the course of the route (i.e. route-based). Landmark-based strategies involve path integration through the identification of a single landmark, whereas route-based strategies require multiple landmarks in a specific sequence. Conceptually, both of these strategies incorporate landmarks, both require path integration, and both rely on memory (Foo et al., 2005). For the train driver, the distinction between the two strategy types may not be all that significant. Whilst it may be possible to navigate using a single landmark, a train driver does not act upon directional decisions. Given the idiosyncrasies of the train driving task, train drivers are more likely to navigate by treating landmarks sequentially, and in the case of an immediate landmark, use it apply or queue momentary actions in view of their future driving needs.

2.4. Cognitive Frameworks

2.4.1. Developing Mental Representations

The mental modelling viewpoint generally asserts that an expert picture of a task is attained through practice, and research has demonstrated that increasing the understanding of a system by using its device model can aid with learning and produce performance increases in terms of speed and efficiency (Kieras & Bovair, 1984). These advantages are generally attributed to the development of a dynamically executable mental model, which may also be thought of as an intricate mental representation of the task.

A large number of mental modelling accounts have been produced (e.g., Bainbridge, 1991; Moray, 1998), which ascribe mental representations to the cognitive processes of the operator and the context of the task. Once a presiding model has been established, the repeated mapping of task or device properties can be used to form subsequent internal models. This is further explained by way of loop systems. A novice is thought to operate from a closed loop negative feedback perspective of control, whilst an expert works in an open loop predictive mode, evidenced by increased efficiency, accuracy and far fewer interventions (Moray, 1997). This contention has been applied more overtly in the rail domain (Naweed et al., 2009). A train driver exerts a wide range of skills in order to control a train at speed, but their technical knowledge of its system mechanics may be less developed than say their train driving expertise. This is mainly because the knowledge of how to drive is different from knowing how it works, thus their mental representations are largely constructed around the quasi-mathematics of running masses, force, acceleration and braking trajectories associated with their experience of railway collision avoidance.

2.4.2. Cognitive Route Maps

Research investigating the role of landmarks in route learning has revealed mixed results, which evidence a positive effect on route knowledge acquisition, and no effect at all (Waller & Lippa,
Some studies have shown that the benefits of route learning with landmarks manifest only when task demand is elevated (Tlauka & Wilson, 1994; Wolbers et al., 2004), which suggests that when used to learn a route, landmark recognition facilitates they way information sources are processed and effectively optimise cognitive resource allocation. This begs the question as to whether the cognitive route maps that drive these navigational strategies are internalised as the relational structures, or alternatively, as stringent representations of the landmarks themselves (Jeffery & Burgess, 2006). The general view is that cognitive route maps provide a framework for the integration of route knowledge (Wolbers et al., 2004), and though the two may be viewed as separate elements, they are closely connected and compliment one another during navigation (Krafft, 2001).

Much like the correspondence between cognitive route maps and route knowledge, a close correspondence between localisation, orientation and wayfinding skills are considered necessary in order to travel to a known destination (Krafft, 2001). Train drivers rely strongly on localisation skills in order to identify current, past and future locations, and their orienting skills generally include an ability to navigate against specified locations within their environmental framework, allowing the anticipation of future locations and objects. Train drivers do not wayfind in the traditional sense but are required to seek and identify movement authority, and given that movements are authorised outside of their control, they are required to verify them against their expectation of the route. The act of orienting and localising are also referred to respectively as relative positioning and position fixing (Biro et al., 2004).

Prior knowledge, in this case that of a route, may be important to direct orienting and localising skills, but it is unclear how closely they inform decision making and how they relate to the drivers’ awareness of their task and the environment as a whole. The mental modelling viewpoint purports that operators use the environment to run a mental model representation, which in turn allows them to predict future states, estimate the times of processes, and ultimately facilitates the understanding of unexpected events. This idea has been researched further and led to the theoretical development of an operator’s dynamic model of the environment, called situational awareness.

### 2.5. The Role of Situation Awareness

Broadly speaking, situation awareness is considered to be (1) an individuals’ knowledge of the environment, (2) their perception and comprehension of its constituents, (3) and a projection of its future states (Endsley, 1995). Problems in these three levels are indicative of information that is unavailable, hard to discriminate, or incorrectly observed through misperception, but breakdowns may also occur if internal maps are poorly developed, incorrect, and default parameters have been overly relied upon.

Figure 1 illustrates a model of situation awareness, which shows that in addition to its three levels, individual factors such as the goals and task-based expectations influence the decision-making process. It also shows that long-term memory directly influences situation awareness, suggesting that whilst cognitive skills like orientation and localisation engage dynamically with decision-making and action, route knowledge is a separate information-processing constituent. Most assessments of safe train operation concur with the accepted definition of situation awareness (Nikandros & Tombs, 2007). Studies have reviewed situation awareness and its applicability to environments that are analogous to aviation, that is, where high rates of visual information, multiple tasks and plans for future action are central to operations. The relationship between situation awareness and the driving analogy has also been very complimentary (Matthews et al., 2002). Applying the situation awareness error taxonomy to the driving domain suggests that errors in operation occur out of failing to plan appropriately, perceive, or incorporate relevant information.
2.5.1. **Static and Dynamic Knowledge**

A UK route knowledge study decomposed situation awareness, as it related to train driving, into a four-factor process that included perceiving environmental information, recalling retained information, action planning, and a perpetual loop of information gathering and task assimilation (Rail Safety & Standards Board, 2006). The study differentiated route knowledge from situation awareness by suggesting that the use of fixed information, such as a signal’s placement, and changing events, such as signal’s aspect, including the regulation and operating procedures, created the situation awareness, but that the actual information recalled was a part of route knowledge. The study further distinguished between a *static* route knowledge, which incorporated route features and risks, and *dynamic* route knowledge, comprising of the route’s momentary state, both of which were secured in memory.

Figure 1 identifies memory in the form of two information processing proponents of decision making: (1) long term memory stores and (2) automaticity, both of which represent prior knowledge and the way it is retrieved and applied, whether that is exercised consciously or achieved automatically (Endsley, 1995). Skills in localising and orienting during train driving may thus be treated as an overarching proponent of prior knowledge as well as situation awareness. The key issue here is that perception triggers memory stores, which in turn, prompt decision-making and forthcoming actions, whether they be deliberated consciously or automatically. The static and dynamic distinctions are key to understanding route knowledge and achieving the aims of this review. The next
section will review cognitive models of train driving specified in the substantive knowledgebase, in order to illuminate this issue, and learn more about the ways routes may be mentally represented.
3. Models of Train Driving Performance

Train driving is a perceptual and cognitive task, and the literature reviewed thus far postulates that strategic driving behaviours and situation awareness must operate concurrently for route knowledge to be applied well. The main cognitive components included in this are memory, expectation, and attention, though the task mobilises a wider range of cognitive processes, including recognition-primed decision making, heuristics, and distributed cognition (McLeod et al., 2005; Rail Safety & Standards Board, 2006; Roth & Multer, 2009). In effort to explain the flow of these cognitive processes, several models of train driving information processing have emerged. Most of these have been developed from detailed cognitive task analysis methodologies and probe route knowledge based on either on the situation, or the skill in the task. The next section will briefly introduce substantive modelling conventions and then go on to review train driver models.

3.1. Human Information Processing

Human information processing essentially describes the method that people use to perceive information and translate it into action. The translation process is thought to treat this information using a number of cognitive subsystems like memory, that help to facilitate this action, and then, process the response and its effect on the environment. The traditional approach to information processing likens the human brain to a computer, and envisages information passing through it in different cognitive stages (Broadbent, 1958; Posner, 1978).

![Figure 2. Simplified Information Processing Models in the Tradition of (a) Open and (b) Closed-Loop Control (Park, 1997; Wickens & Carswell, 2007).](image)

Models of classic information processing have their roots in psychological research and illustrate it as open-loop process that occurs over multiple stages. The three-function model shown in Figure 2(a) illustrates the basic cognitive stages and component systems through which information is thought to flow (Park, 1997). Stage-based distinctions to information processing are supported by research which shows that these stages may, be affected by different types of workload (Wickens & Hollands, 2000), and are responsible for producing different types of errors (Reason, 1990).
Human information processing has also been explained using an ecological perspective that overlooks the importance of separate cognitive stages, and draws attention to the integrated flow of information (Hancock et al., 1995). This viewpoint is context-driven and focuses more overtly on interaction with the environment, in order to derive more meaningful models of its perceptual characteristics (Wickens & Carswell, 2007). Whilst it emphasises a detailed understanding and modelling of the structures underlying knowledge, it also advocates a careful understanding of the environment and task constraints to which they relate (Rasmussen et al., 1994; Vicente, 1999). These approaches have been used to model expert performance in natural environments using information processing analogies rooted in control engineering, and as shown in Figure 2(b), they follow a design consistent with closed-loop feedback where action, perception, and other psychological processes that interact with these systems are closely linked. The next two sections will review a number of train driver performance models that broadly divided into situation- or skill-based categories. Situation-based models illustrate the factors and processes that converge around the driver, and provide a holistic snapshot of the system at any one time, whereas skill-based models describe the train driving process by emphasising the human capabilities of the operator in overtly cyclical information processing analogies.

3.2. Situation-based Models

Luther, Livingston, Gipson and Grimes (2007) created the model of train driver route knowledge shown in Figure 3. Its characteristics are fundamentally based on the model of situation awareness in dynamic decision making (Endsley, 1995); thus for the most part it also suggests that route knowledge is preceded by situation awareness, and that the perception, comprehension and projection sequence informs decisions and actions. In a bid to simplify their model, Luther, et al., (2007) do not detail the influence of various information processing mechanisms, but instead, separate the factors that may affect situation awareness into individual and external components, the latter of which broadly encompasses other people and environmental cues.

Knowledge recalling is specified under individual factors, and depicted as having a reciprocal relationship with the situation awareness process. Other factors consolidated into this process include attention, cognitive maps, and driving experience, but they also extend to age, physical

Figure 3. Model of Driver Route Knowledge (Luther et al., 2007).
health, aptitude, gender and personality, demonstrating a wide-range of individual variables that are involved in the use of route knowledge.

McLeod, et al., (2005) proposed the situational model shown in Figure 4 as a framework for investigating train driving performance. The model is decomposed into four layers that converge around a proximal assessment of the current situation, referred to as the ‘Now,’ which incorporates attention, driving strategies, expectations and immediate priorities. The most distal layer is that of ‘Knowledge’ and ‘Experience,’ which incorporates the background information and memory stores needed to assist the driver at a specific time. These also include route knowledge, recent driving history, standard operating procedures and driving style. This layer underpins the ‘Current World Model,’ which contains elements that equate it to the lower levels of situation awareness, including a precise state of the environment, meaning of its features, and so on.

The situational model (McLeod et al., 2005) has been designed using the standard information processing sequences seen in earlier models, and presents a series of variables that may impact train driver behaviour in a variety of situations. As a snapshot of the drivers’ cognitive state, the model conveys much reciprocity in the cognitive processes, and indicates that route knowledge, along with experience, is required to augment and contextualise the drivers’ recognition and interpretation of the current rail system state. Conceptually however, the model implies that route knowledge is a static proponent of cognition, which together with driving experience regulates the perception and comprehension of the current world model, and the decisions and actions that follow.

Roth and Multer (2009) developed a situation model of train driver performance shown in Figure 5 that, much like McLeod, et al., (2005), underpins a current situation model that informs decisions and actions from prior skills and knowledge. In addition, the model identifies anticipation, future
planning, monitoring, and communication as key cognitive components involved in train operation. Situation awareness has been incorporated into the current situation as a transition between the layers of knowledge and decision-making, illustrating stored route knowledge as a primary cognitive operation for train driving. Thus if memory is inadequate, or there are problems in retrieving it, an incorrect or inappropriate decision or action may ensue. However the properties in the current situation model, such as knowledge of the last signal, current speed limits and concurrent timetable matching, fundamentally specify a dynamic property to route knowledge. It is therefore likely that whilst route knowledge invariably represents a sum of all substantive stored knowledge, an actively engaged route knowledge stream is required for relative-positioning and position-fixing activities.

**Figure 5.** Situation Model of Locomotive Engineer Performance (Roth & Multer, 2009).

### 3.3. Skill-based Models

Hamilton and Clarke (2005) developed the model of skilled train driving performance shown in Figure 6. Much like the earlier situation-based models, it incorporates the information-processing analogue involved in train driving, but also provides a detailed account of the relationships between the various cognitive functions at each sequence, specifically that of the knowledge structures. The model refers to knowledge recall as a human capability, and decomposes it into a process that suggests the need to seek out information initiates the act of remembering, and this in turn triggers knowledge retrieval from memory structures. Of particular note is that the model considers route knowledge retention to be more an act of memorising than of learning. Furthermore, the model does not link knowledge with action overtly, suggesting that prior knowledge only forms the basis for the recognition and decisions, and that more dynamic information held in short term memory stores is involved in goal setting and event driven process.
Naweed (2010) developed the model of train driving shown in Figure 7 to further expound the nature of dynamic train control and qualify the information requirements of the train driving task. The model differentiates between train driving and how this fits within the overall processing and knowledge requirements of the task. The core constituents of dynamic train control (see Figure 7a) are shown, in no particular order, as monitoring the environment, anticipating future requirements and establishing the current state, all of which comprise the decision making process. These cognitive functions are illustrated in a dynamic cyclical pathway that feeds back and forwards to maintain train control. Situation awareness and route/traction knowledge are shown as associative elements that help maintain the process and mediate any intrusive disturbances.

The model of dynamic train control sits within an information processing pathway (see Figure 7b) that requires the drivers’ knowledge base, train state data, and the perception of the environment to exact appropriate speed changes in an overall tracking loop (Naweed, 2010). Much like the previous models of train driving performance, this model postulates two separate route knowledge components: a static version situated in the overall process that consolidates route information with a predisposed driving style, and a dynamic version that interacts with situation awareness and the train controlling process (monitoring, anticipation, current state). It also details the external proprioceptory cues that inform the constraints in the environment, and contextualise the dynamic decision making process.
3.4. Analytical Evaluation

The preceding section reviewed a number of train driver performance models divided broadly into situation or skill-based categories. The models in the situation-based category illustrate the factors and processes that converge around the driver, and provide a holistic snapshot of the system at any one time. This includes a diverse list of factors encompassed in layers of knowledge, experience and a working representation of the evolving situation. The model designed by Luther, et al., (2007) generally illustrates the convention adopted by the others in that category, which is to extend situation awareness as described by Endsley (1995) and specify it to the train driving process. Although a wide number of internal associative factors are defined, they occupy a very broad range that lacks the specificity or depth of the other situation models. Whilst this does not detract from a high-level understanding of the information-processing pathway, as a model of route knowledge, it is lacking in the detail that would explicate this utility.

The two skill-based models describe the train driving process by emphasising the human capabilities of the operator in overtly cyclical information processing analogies. Hamilton and Clarke (2005), emphasise the role of memory as a supporting process, and decompose it in some detail, conveying train driving as a recognition-act cycle that uses route knowledge and information held in the environment to prime the process and conduct memory checks. In comparison, the train control and information processing model (Naweed, 2010) emphasises dynamic train control as a separate skill concomitant to the overall process, which whilst drawing heavily from prior route knowledge, is also influenced by a strong predisposition for a certain driving style.

Whilst, the situation and skill grouping clearly emphasises the focus of the models, some clear differences within the categories also exist. For example in their situational model, McLeod, et al., (2005) identify memory, situation awareness, expectation and directed attention as key elements...
required to operate a train; however, Roth & Multer (2009) extend beyond these in theirs to include monitoring, detection, communication, planning and decision-making. It is important to note that both type of models, either directly or indirectly, incorporate the need for good situation awareness, which is to say that perceiving the surrounding environment, comprehending its elements, and using them to plan future events is unanimously considered an important part of the task.

Other than integrating the use and retrieval of route knowledge into the information-processing pathway, these models do not generally explicate how it is retained. The only exception (Hamilton & Clarke, 2005) chooses to describe this process as one of memorisation, as opposed to learning. The distinction between memorising and learning is subtle but strong; the act of memorising is to commit something to memory whereas learning is to acquire a skill by systematic study. That is not to say that the model undermines the skill in the task; on the contrary, the recognition-act cycle demonstrates a need for highly skilled performance. Thus, in the context of train driving, stored knowledge does not necessarily constitute a skill, but is important to augment the skill necessary to apply and maintain it. This distinction once again draws attention to the static and dynamic component of route knowledge.

All of the models consider route knowledge (or closely associate it) with general ‘knowledge,’ ‘route and traction knowledge,’ the ‘recall of knowledge,’ and the ‘act of remembering,’ all of which indicates that the term is used broadly, encompasses more than just the route, and is used to describe stored knowledge as well as the process of recalling it. Taken together, this supports the argument for both static and dynamic proponents to route knowledge; much like the study (Rail Safety & Standards Board, 2006) discussed earlier (see Section 2.3.1), these models suggest that route knowledge can be static or dynamic, the former as an aggregate of stored route and traction information, and the latter as its ‘active’ proponent, which is primed and retrieved according to the demands of the task.

Very few of these models clearly illustrate the ways that routes are mentally represented. The current situation layer of situation-based models describe track composition to some extent (McLeod et al., 2005; Roth & Multer, 2009), and one of the skill-based models provides some detail of the proprioceptory indicators that may comprise route knowledge (Naweed, 2010), but these are more an indication of the information requirement required to fulfil the task than a reflection of the way internal maps are encoded. Some of these models describe mental or cognitive maps as intrinsic factors (Luther et al., 2007) but the information comprised into knowledge and experience is generally too underspecified to illuminate this issue.

The models reviewed make a point of highlighting the integral role of driving experience and driving strategies. These individual factors are included either overtly or covertly in the pathway of several train driver information processing models (Luther et al., 2007; McLeod et al., 2005; Naweed, 2010; Roth & Multer, 2009). Traditionally, train driver training programs treat route knowledge as a bulk of data that are memorised generally after driving skills have been learnt, practised and evaluated (Railway Group Standard, 2003). It is important to explore the interdependency in these processes, not only to establish how they interact with route knowledge when applying it during expert driving performance, but also how they interrelate during the route knowledge acquisition process.

Reviewing these models has emphasised the importance of route knowledge mediation, but also highlighted the role of other component factors, such as route experience and driving strategies. These are key issues for exploring the link between route knowledge and train driver train efficiency. All of the models subscribe to the information processing analogy on some level and feature perception, decision-making and action, as core stages. As with other domains, the models of train driving connect these cognitive components with conceptual processes that emphasise the role of the situation and of skill, but also highlight the role of memory and contextual knowledge.
The next section will broadly explore the role of the general processes that comprise the information-processing pathway in an effort to better understand the way that route knowledge is internally represented, but also to explore how the decisions and actions to apply it are conceptualised. The section after that will consider the relationship between route knowledge and specific component factors, such as driving experience and driving strategy, in a bid to identify the extent of their co-dependencies with respect to the acquisition process. Both of these sections with consider this literature in view of the train driving models.
4. Exploring the Information Processing Pathway

4.1. Perception

Train driver information processing models generally concur that the likelihood of an unsafe action is greatest when perception, decision-making and memory are inaccurate. Most of the information that train drivers rely on is visual and sought from the driver-cab interface or the external environment. The accuracy of this information is therefore wholly dependent on what is perceived as well as the way that it is perceived. The importance of visual perception is emphasised by a body of research that has focussed on issues like vigilance, perceptual load and search strategies (Luke et al., 2006). In the context of detection and recognition, this has generally involved signals and other infrastructure features (Li et al., 2006) which may act as landmarks and prompts for specific driving activities (e.g. braking distance markers). This renders perception an integral component of the information-processing pathway, and more specifically, a key component of situation awareness.

In situation-based train driving models (see Section 3.2), perception or detection occurs at the start of the process. The only exception to this contextualises perception from planning and decision-making processes, and uses it to feed forward to the knowledge and current world model layers (Roth & Multer, 2009). Similarly in skill-based models (see Section 3.3), perception is augmented by goal driven processes and informed by action, but interacts more freely with establishing the train state and anticipating future requirement. This intimates a close relationship between perception and route knowledge, the key to which may lie in recognition.

4.1.1. Recognition

Hamilton and Clarke (2005) extend perception to recognition and identify it as a key component of the information processing pathway in their model. Luther, et al., (2007) incorporate missed perceptions and misperceptions as individual factors in theirs, emphasising the potential for driver error at the recognition and/or interpretation of visual information stage. The link between recognition and route knowledge has also been explored during the development of train driver perception measures (Li et al., 2006). Verbal protocol and driver response measures that require perception-based annunciation and statement of meaning allude to the dynamic interplay between stored memory, and short-term memory, illustrating the type of cognition that may be involved in applying orientation and localisation skills. In terms of situation awareness, recognition arguably corresponds to the second level which involves comprehending the situation (Endsley, 1995). In terms of route knowledge and the direction of this review thus far, this may be better understood as the dynamic constituent of route knowledge.

4.2. Decision Making

Decision-making is widely acknowledged to be an intensely dynamic process (Brehmer, 1992; Gonzalez et al., 2005). It is also very complex, particularly in dynamic environments, and mediated almost entirely by memory. The process itself has been decomposed into several stages: first, environmental cues prompt mental representations of the event or situation in progress from long-term memory; second, that shorter term memory receives these representations and holds as many as it can; and third, working memory evaluates, matches and compares this information with that held in long term memory to select the most appropriate course of action (Thomas et al., 2008). In practice, this would translate into 1) seeing a specific landmark prior to a level crossing, 2) recalling the potential scenarios or hazards substantive to the upcoming crossing, and then, 3) assessing the potential outcomes associated with the situation based on previous experience.
The level crossing example is an instance in which route knowledge is applied to decision making, that is to say the information in long term memory is comprised of static knowledge, which the matching and assessing processes represents via the dynamic knowledge handling process. Decision-making is also thought to incorporate what has been referred to as the ‘remember-know’ paradigm (Thomas et al., 2008). This postulates that a memory prompt produces two kinds of response; a remember response where there is a recollection of precise detail, or a know response where there is a familiarity with aspects of the overall situation (Rotello & Macmillan, 2006). In practice, for a train driver, this may be illustrated by the example of approaching a signal. A driver that frequently travels over a particular route would produce a remember response, given that they would have prior recollection of seeing the signal, and would recognise it based on their knowledge of track features around its location. However, a driver that is new to a route and has yet to develop knowledge of it would produce a know response, in that they are familiar with the signalling convention being used and know what it means, but do not possess any specific details of that particular signal, or indeed, the condition of the environment around it. Thus, the remember-know distinction would invariably influence the decision-making process, and in this example, subtly or significantly change the way drivers choose to proceed past the signal.

4.3. Memory

The literature review has thus far revealed route knowledge as a sophisticated construct linked to multiple memory types and cognitive maps in the information-processing pathway. The preceding section highlights the role of memory as a mediator for decision-making. Classic studies have also shown that when scenarios falling outside the bounds of previous experience are encountered, explanatory representations of the situation are created (Pennington & Hastie, 1988). The structure of these representations influences decision making, thus, if they are incorrect or inaccurate, an inappropriate decision and course of action may be taken. Given this, there are multiple opportunities for aspects of the memory process to fail; memory may be incorrect, inadequately encoded, improperly stored, poorly executed, and its retrieval may be disrupted by a human threat factor (fatigue, high workload, etc.). A vast number of memory models have been theorised, so much so that it is difficult to locate a single model that may explain all of its aspects in the context of train driving, or indeed other domain analogies.

One perspective suggests that experiences are stored within memory, and that previously used decisions and actions are utilised because they have been successful in the past (Sträter, 2005). In contrast to this, another perspective argues that memories and learning experiences are only acquired when a decision or an action fails, and is required to create an experience in the first place (Schank, 1999). Despite the differences, these two perspectives do share common ground in the form of task repetition; stored experiences are instantiated directly from repeat exposure (Sträter, 2005), or scripts derived from repeat exposure (Schank, 1999). Given that train driver route knowledge is currently acquired from repeated exposure, either of these theories may be utilised to project learning efficiency.

Neurologically, cognitive maps have been associated with the limbic system and hippocampus, both of which are linked to episodic memory (Jeffery & Burgess, 2006). Episodic memory is described as a type of memory created from a single episode (Tulving, 2002), which for the train driving context, lends support to the argument that memory or experiences may only be acquired from decision-making failure in novel situations (Schank, 1999). At the extreme-end of the argument, this would suggest that memory may also be created from a single episode, rather than from repeated, similar, near-identical or non-eventful episodes. This provides a basis with which to theorise that, whilst novice and new train drivers may develop route knowledge from repeated exposure, this may serve a limited purpose and may be enhanced by exposing them to varied routes, novel situations and challenging scenarios; this may cultivate more experiences and promote the development of episodic memory.
5. Exploring the Relationship with Component Factors

5.1. Driving Strategies

Although train drivers depend on task-related cues, targets are often out of sight, creating the requirement for anticipation in the task. The ability to judge and calculate braking distances in the face of changing conditions has been studied at length (Branton, 1979). Cognitive route maps are thought to be supplemented by what is termed as ideal and reality calculations, which interact intuitively and quasi-mathematically to solve time-distance journey equations. The issue of driving strategy is therefore an important consideration when considering route knowledge application, a point that is drawn on in some of the cognitive models under the guise of driving discipline (McLeod et al., 2005), train handling (Roth & Multer, 2009), attitude (Luther et al., 2007), and style (Naweed, 2010). As the preceding section indicates, the task requires perception and memory, the joint functioning of which may be affected by a wide range of factors and lead to differences in the way the train is driven.

On the one hand, a driver may be predisposed to drive as fast as the speeds will allow, but a more sophisticated style may be informed by the type of cargo being pulled in order to perform a smoother, more efficient journey. The literature review has thus far shown that to achieve this, a driver must determine their position at any given moment, and use their static knowledge of the route to estimate the distance to the next target, such as a signal or speed restriction. They must also combine their knowledge of the track’s topography with the engine’s capability and recognise any potential constraints in the environment, such as speed restrictions, track works, low adhesion, and so on. Train drivers must therefore process complex and crucial information subsystems that are all integral to the task (e.g., perception of vestibular, kinaesthetic, acoustic and peripheral visual information) in order to carry it out (Branton, 1979). The diversity in the railway environment and the variance in train driving operations create a vast array of driving conditions that influence the way a train is driven.

It may for example, be surmised that passenger train drivers have traditionally managed the scheduling-safety conflict, whereas freight train drivers have only dealt with the energy efficiency-smoothness of driving trade off. However, there are a host of imponderable events and scenarios that may motivate inter-dynamic driving strategies. A wide number of driving strategies have been consolidated into very particular driving policies, which can be generally defined in two classes: 1) professional driving and 2) defensive driving (Association of Train Operating Companies, 2003). Professional driving is aligned with the routine driving, and encompasses attitudes, behaviours and driving techniques that fall under the umbrella of the minimum competency required to manage the task and incidence of driver error. Conversely, defensive driving encompasses specific driving techniques that may be used to engage with changes in operating conditions. These include the variance associated with cautionary signals, truculent weather, isolation of on-board protection systems, and degraded operation ascribable to temporary block or single line working.

The application of specific driving techniques is also likely to change or adapt in the face of mounting pressure or demands. Most of the train driver models allude to this component as a goal or event driven factor (Hamilton & Clarke, 2005), as progress against the timetable (McLeod et al., 2005; Roth & Multer, 2009), or a combination of events/feedback and the schedule diagram (Naweed, 2010). Clearly, applying specific driving strategies requires an equally strongly application of route knowledge. Train driver training programs try to instantiate the skill required to apply sophisticated driving techniques by varying their driving conditions. These include night and day driving, weekend driving, and driving in adverse weather conditions. Delivering a standard of training in this manner is uncontrolled and unpredictable, and although it is recognised that these skills are independent of traction types, the use of hi-fidelity simulation is not necessarily used to
cultivate experience with these scenarios (Railway Group Standard, 2003).

5.2. Driving Experience

Most of the cognitive models of train driving account for driving experience whether it is in the form of an individual factor (Luther et al., 2007), knowledge and experience (McLeod et al., 2005), knowledge and skills (Roth & Multer, 2009), or a proponent of driving style (Naweed, 2010). The theoretical underpinnings for experience are explicated by the mental modelling viewpoint and by and large, the issue is an extension of the cognitive route-mapping framework (see Section 2.3). In that respect and within the confines of the train-driving context, experience is garnered through repetition, familiarised by applying route knowledge, practiced with the various driving techniques, and encountered in a multitude of diverse scenarios. In complex task domains, particularly with rail, the objective of training programs is to cultivate a degree of task competency that would develop task-based expertise and correspond well with evolving experience.

Whilst a body of route knowledge may be contained, the skill associated with its application is clearly an experience-based phenomenon. This issue of experience reiterates the purpose of this review, which is to understand route knowledge, and establish its co-dependencies on other processes in order to determine how the process of route knowledge acquisition and simulator usage may be combined to accelerate the training process without compromising competencies.
6. Summary

6.1. The Constituents of Route Knowledge

In summary, the train driving performance models that have been developed to date provide a reasonably cohesive picture of the task's information processing pathway, and though the sequence of steps may differ between them, they generally converge around the notion that a route knowledge process has two distinct components. Whilst route knowledge is a store of route data consistent with the approach adopted by train driver training programs, it is also a fluid and heavily dynamic construct that lends heavily from individual factors.

The static route knowledge store is invariably populated with infrastructure-based information, such as level crossings, signals and other landmarks, and also includes the qualitative data attached to them, such as multi-SPAD hotspots, signals with poor visibility, and so on. This qualitative data may be used to inform and shape the way that specific driving strategies are executed. The train driving models do not clearly distinguish between dynamic route knowledge, either as a store of information or a series of schema, which are dynamically executed when all the external sources of information are available. In either case, this does not alter the theoretical pattern divulged from the models that dynamic route knowledge is inhabited by data that are very sophisticated, and potentially includes data which allow them to assess the relative position of each feature relative to their positions in the whole route.

On a theoretical level, the cognitive representations that shape internal route maps embody this constituent of route knowledge. Acquiring route knowledge may therefore be considered to engender two specific skillsets in the train driver cohort: 1) a demonstrable ability to retain vast amounts of knowledge, and 2) a demonstrable ability to interrogate it outside of a strict sequence, and thus, cater for the skills associated with train handling and driving strategies. The theories garnered from reviewing the way that route knowledge is mediated in memory, supports the contention that an exposure to different types of track and scenarios may expedite route knowledge competencies when the driver comes to learn their substantive routes.

6.2. Route Learning

The sum of information derived from the train driving models supports the perspective that route knowledge may be approached in a manner that no longer treats its acquisition as a ‘bolt-on’ process at the end of the training, but rather, as a dynamic process that may be cultivated early on. That is not to say that additional route detail may not be learnt once underlying theory and traction training has been delivered, but rather, that the skills acquisition phase be enriched with route knowledge material, and optimised to include the component factors and parallel learning demands that route knowledge application relies on. The contention here is that the underspecified simulator phase be seized and utilised to its fullest extent to deliver scenario-based training that capacitates the route learning opportunities in this phase. These should include experiences that draw upon a variety of railway and track configurations, and respectively, a wide range of scenarios that, in addition to the development of route knowledge, stimulate the retention of specific driving strategies and generate a baseline proclivity for good driving form.

6.3. The Research Gap

The literature reviewed over the course of this report offers support for the argument that specific scenarios and experiences encountered early during the training process may optimise the time required for retaining and applying route knowledge, but this contention is largely theory-driven and must be tested. Despite this, it is certainly arguable that this enhancement would capture the
learning opportunities that are currently going unmissed during the simulator stages of driver training programs. However, there are a number of gaps in the research that need to be filled. The first gap is centred on identifying the specific scenarios and experiences that will potentially optimise subsequent route knowledge acquisition. Codes of practice and driving policies provide rudimentary information that may guide this process, but this is approached in a very piece-meal fashion, and more information is required. A better understanding is generally needed to identify those specific track components that on their own, are simply infrastructure-based features, but when united, present a difficult configuration that challenges route navigation.

The second gap is centred on driving strategies; in particular, those driving strategies that are needed to engage with route knowledge, which also optimise the way that subsequent route knowledge is acquired. Once again, skill-based modules in train driver training programs provide some guidance for this issue, but it is unclear which of these do and do not influence the way that route knowledge is assimilated and applied. The third gap in knowledge relates to the number of scenarios that are required as well as the variety, before both experience and familiarity breed saturation and introduce redundancy. This is largely an empirical question and one that again, must be tested. All of these research gaps may be addressed by ascertaining precisely how routes are mentally represented in the train driver. The key question here is how are they represented in novices and experts, and how does this change as a function of time? This may invariably elucidate the features of the route that are largely rendered to intuition in the face of growing expertise, enhance the current understanding of route knowledge and provide more data on how it is actually encoded.
7. Considerations for Research

The research gaps that have been identified may be filled by research initiatives that specifically probe and classify different sections of track according to navigational difficulty, towards providing a better understanding of how route knowledge is encoded. Given that challenging scenarios may also be the product of mounting performance pressures, these will also need to garner the event and goal driven processes motivating the mobilisation of specific driver strategies. A suitable research program will therefore need to collect data on both the internal representation of route knowledge and array of relevant driving strategies. Given the nature of the topic, the data will be qualitative, but there are number of proven methodologies which may be incorporated into a suite of methods to optimise knowledge elicitation.

Focus groups and one-to-one interviews may be used to derive specific experiences and interesting stories associated with challenging routes and driving scenarios. Given the combined dynamic and static nature of the subject matter, interviewing techniques that probe intuitive knowledge may be most effective. These may incorporate a number of task analysis methods, such as Applied Cognitive Task Analysis (Militello & Hutton, 1998) or the Critical Incident Technique (Klein et al., 1989) both of which use dynamic interviewing techniques to elicit deeply embedded knowledge. Further, the features and characteristics of the knowledge to be elicited, that of routes, railway complexity and driving strategies, may easier to extract by incorporating generative methods traditionally used in participatory design. These could for example include visualisation strategies (Sperschneider & Bagger, 2003) and diagramming sessions that invite the participants to invent sections of challenging route. They may also involve sessions that invite participants to reproduce routes from memory, proving insight into both scenario design and internal route representation.

Observations are another powerful method in the knowledge elicitor’s toolkit. Informal interviews may be conducted with drivers during the actual task, drawing on specific examples or previous scenarios in the substantive environment. The verbal protocol analysis (Hughes & Parkes, 2003; Li et al., 2006) has been used in the rail domain, and this technique may also be employed to garner route knowledge-based data that is more representative of cognition, and the information processing in the task. The exact array of methodologies in the suite need to be diverse, and participants from various passenger and freight operations are required to draw a sufficient representation of the train-driving domain, and compensate for disadvantages ascribable to the interviewing process. The train driver population should therefore be stratified according to experience, and by extension, expertise, as well as the operation types, engendering route knowledge and driving strategy data from passenger and freight operations.

Compiling and analysing all of the scenarios and strategies that are currently being adopted in the train driving task will help design experiments that probe the topic on an empirical level, and identify scenarios that enhance route knowledge acquisition and ‘positive; skills transfer. This is where the skills acquired carry-over to the real environment in a way that improves performance and yields a good response. It is also recommended that the data pertaining to the way that train driver training courses are delivered be collected from relevant organisations. This should include, where possible, an indication of course structure, critical evaluation and competency assessment points, and an indication of the media used to facilitate route knowledge acquisition. This will facilitate an analysis of the methodologies currently employed by the Australian rail industry, and amongst other things, establish how the training frameworks for different operations vary between organisations.
8. Conclusions

The literature reviewed indicates that route knowledge is comprised of a static store of knowledge, such as infrastructure-based information (e.g., level crossings, landmarks, and signals), and a dynamic components, (e.g., signal aspect, temporary speed restrictions, time-tabling), which interplay heavily with driving strategies. The data comprising route knowledge are also very sophisticated, and appear to be encoded in a manner that allows drivers to assess the relative position of each feature relative to their positions on the route as a whole. The acquisition of route knowledge involves retaining and maintaining a vast amount of positional track knowledge, and having an ability to probe this knowledge outside of strict sequence, thus, skilled application of route knowledge should be extended beyond the traditionally held view that it is only a stored bulk of information, into a classification that defines its static and dynamic components. The literature reviewed also offers support to the argument that familiarity and experience enhances the way that these skills are handled, suggesting driver learning programs may benefit from its early development.

This report aimed to garner a better understanding of route knowledge, and in terms of the wider project suite (R2.112, Capturing Driving Strategies; R2.113 Route Knowledge Acquisition), has established a basis for: (1) exploring how drivers represent the knowledge in their heads; and (2) how different aspects of this knowledge may be learned through training driving simulation. The second point relies on outcomes from the first one and will be the focus of the next volume in this research, that is, a better understanding of the way that route knowledge is internally represented, together with a better definition of the specific route features and railway configurations that may stimulate early skills development, and comprise difficult or challenging tracks. This will enable us to explore learning and development research questions in the third and final volume of the project, and specifically, test simulator scenario initiatives that optimise various aspects of route knowledge acquisition.
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