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Applying Simulation Techniques to Train Railway Traction Drivers

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"Though, for Distinction Sake, a Deceiving by Words is commonly called a Lye, and a Deceiving by Actions, Gestures, or Behaviour, is called Simulation or Hypocrisy."

Quoted from Twelve Sermons Preached upon Several Occasions
Vol.1, The Sixth Edition.
Robert South (D.D.) (1643-1716)

Abstract

The writer attempts to establish whether the transition from a conventional training delivery process for traction drivers to a simulator enabled process has been effective. This evaluation of effectiveness is based on a study of Iarnród Éireann's system that was implemented by the author. Evidence is contained within four supporting strands, i.e., the change in relevant operational risk that was calculated using ex ante and ex post runs of Iarnród Éireann's risk model, the internal rate of return on the financial investment necessary to effect the change, the results of an operator attitudinal study and the findings of an independent expert audit.

The author has established that simulation is an effective training medium for railway traction drivers, when implemented correctly. The attributes of the system and the use cases that resulted in this finding are described in the thesis. The writer also presents additional value-adding training objectives that could increase the Internal Rate of Return of such a project. The study affirms that the verisimilitude requirements of a simulator system are a function of the training goals and the nature of the skills being developed. Design features and use strategies can mitigate for the potential negative effects of simulator operation.

The findings have industry-wide relevance for those tasked with providing effective training to the 133,000 train drivers within the European Union.

Railway operating companies in Europe are equal opportunity employers. Drivers may be of male or female gender. In an attempt to improve legibility of this thesis, the use of phrases such as s/he, her/him and her/his has been avoided.

To avoid unnecessary political correctness and pedantry, the terms Ireland, Irish, State, and Government are applied in the context of the Republic of Ireland.

A comprehensive two-part glossary of terms, together with a list of acronyms, is provided at the start of this thesis. These terms are used routinely and are formatted in italics on the first occasion that they appear in the body of the text.

Unless qualified by citation, the views expressed herein are those of the writer solely.

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In the production of a piece of work such as this, the writer has personal motivations to see it through to its completion. Other, less obvious, stakeholders in the process do not have the same motivations and have assisted the writer because of a sense of altruism, good fellowship, repute or a desire to develop and promulgate useful knowledge.

The railway industry is truly a fraternity of like-minded professional people. The writer has found that there are universal concerns within the railway industry and that his concerns, in respect of operator training, mirror closely the concerns of others who occupy similar roles in other railway operating companies. The boundary-less community of practice proved invaluable for this research. Many contacts in the railway, simulation and academic spheres in Australia, Japan, the United States of America, Switzerland, the United Kingdom and Ireland provided extensive background information. The writer would like to express his gratitude to all those, too numerous to mention individually, who freely gave their time to assist him.

The writer was the simulation project's sponsor, manager and owner. However, I.É.'s project, or this thesis, could not have been realised without the assistance of a great many others. The writer acknowledges the contributions of:

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Míle buíochas daoibh go léir! (A thousand thanks to all of you.)

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Glossary of Terms (A) - Railway and Simulation Domains

Absolute Block	This signalling principle permits only one train to be in a block section at a time. [Moloney]
Accident	An accident is defined as an abnormal operation that has resulted in damage to equipment and/or harm to people. [Hughes]
Adhesion	Adhesion is the friction between a wheel and the railhead. It must be sufficiently high to prevent slipping under acceleration (power) and sliding under deceleration (braking). Traction units incorporate creep control devices to maximize adhesion during acceleration and also wheel slide devices to minimise stopping distances. [Moloney]
Approach Release	These signals are implemented to ensure that drivers comply with the speed limit for the route ahead. Approach released signals control traffic flow at junctions and display stop aspects by default. This aspect will clear when the train reaches a specified strike-in point, providing the signal is not being held at danger by the occupation of track circuits on a conflicting route. [Moloney]
Aspect	This is the visual information provided by a fixed line side signal or by the CAWS equipment. A four aspect colour light signal can display one of: (i) Green (proceed), the next signal is showing a proceed aspect (green or double yellow); (ii) Double yellow (preliminary caution), be prepared to find the next signal at yellow; (iii) Single yellow (caution), be prepared to stop at the next signal; (iv) Red (danger), stop. [Moloney]
Automatic Half Barrier	Automatic half barriers are activated by the passage of trains and do not require manual intervention. When operated by an emergency operator in local-control mode, the barriers will not operate by either right or wrong direction traffic movements. They display steady yellow and flashing red lights to advise road users. The barriers span only half of the public road. [Moloney]
Automatic Train Protection	Automatic train protection enforces maximum line speed and compliance with signals. After providing a warning, it applies the brakes if the train is operating outside of the defined braking curve. The system has two override facilities; a bypass switch to permit a faulted unit to take traction, and a ‘running release’ function to permit normal movements in non-fitted depots and in locations on the running line where the normal distance between the impedance bond and the associated stop signal is inappropriate. The latter override facility allows trains to draw up to a stop signal that is positioned at the end of a platform and for station work to be completed efficiently. [Moloney]
Automatic Warning System	The automatic warning system is an in-cab warning or advisory system that requires driver acknowledgement of restrictive signal aspects to avoid an emergency brake application. In Ireland, it is only fitted on Translink lines and on the traction units that operate over them. [Moloney] The extended AWS refers to any situation where the AWS equipment is used to warn drivers of anything other than the aspects of signals. Extended uses can be organised into four types (i) Permanent speed restrictions, (ii) Temporary and emergency speed restrictions, (iii) Level crossings, and (iv) SPAD indicators,

depot magnets and AWS cancellation boards for wrong direction movements. [McLeod *et al.*]

Continuous Automatic Warning System — This is an in-cab signalling system, used on track circuited lines that detects signal codes in the rails by means of vehicle-mounted pick up coils. Lineside signal aspects are continuously displayed and the system requires driver acknowledgement of more restrictive signal aspects on the aspect display unit to avoid an emergency brake application. The driver can act upon less restrictive signal aspects before he catches sight of the fixed lineside signals. This facilitates fluency in driving. This warning system is used in Ireland. [Moloney]

Controller Area Network - Bus (CAN-bus) — A controller area network bus is a communications highway that allows controllers and devices to communicate with each other without a host computer, over a single or dual wire system. The concept was commercialised in the mid 1980s in the automobile industry.

The CAN-bus facilitates communications between subsystems, i.e., it receives feedback from multiple sensing devices and integrates this information to control actuators. Information and commands are transmitted sequentially, i.e., only one string of binary information is transmitted at a given time. Messages are prioritised, security-tagged, framed and, in the event of failure, are retransmitted as soon as the bus is free again. A receiving module is receptive to all of the information being transmitted but responds to the information that is addressed exclusively to it. [Moloney]

Consist — A general term to describe the formation of a train. [Moloney]

Crew — A (train) crew is a group of expert specialists, each of whom have specific role positions. They perform brief events that are closely synchronised with each other and repeat these events across different environmental conditions. [Roop *et al.*]

Critical Incident — A critical incident is a human error or equipment failure that, if not corrected, leads to an undesirable outcome. An accident is the consequence of a critical incident which, because it was uncorrected, progressed to an undesirable outcome. [Arnstein]

Defensive Driving — This is the antithesis of aggressive driving. This driving style avoids the use of maximum braking capability by observing and responding early to anticipated and unexpected events. [Moloney]

Degraded Working/Conditions — Degraded conditions prevail when the complete range of operational safeguards are unavailable, usually because of equipment failure, e.g., failure of the SCE, failure of the CAWS or signal failure. Rather that cease operation, the system is permitted to continue functioning by putting additional processes in place and by transferring additional responsibility onto the operator. This term includes conditions of reduced visibility, inclement weather, low adhesion conditions and degraded yard conditions etc. [Moloney]

Dependency — The term dependency relates to a situation where the probability of failure of supposedly independent components is not, in fact, independent. Human error dependency exists wherever the probabilities of human errors are linked together more closely than if they were random events. In such cases, the probability of failure is greater than that calculated multiplicatively or additionally by ‘and’ or ‘or’ conditions. [Greenstreet Berman]

Desk Simulator	This type of simulator is able to simulate the general vehicle logic and layout. They are often equipped with a touch screen computer that simulates the equipment located at the rear of the original cab, in the engine compartment or on the outside of the train. This type of simulator is not enclosed within a cab. (Schmitz and Maag)
Detection	Detection equipment provides proof that points are locked correctly in the required position. Detection must be achieved before the protecting signal will clear. The system detects the presence of trains by means of track circuit occupation or by axle counter imbalance. (Moloney)
Detonator	A small disc-shaped device, designed to be placed on the railhead for protection or emergency purposes. It detonates when a train passes over it. Drivers respond accordingly. (Moloney)
Distributed Interactive Simulation	This allows operators to be trained while the influences and interactions with other people and systems are simulated. It offers the advantage of providing increased psychological fidelity. With modern communications, simulators do not have to be in the same location as they can be connected to each other by means of local and wide area networks. This type of simulator system is particularly useful in distributed systems, e.g., naval, military or railway activities, where actors are separated by space. (Hardt and White)
District Traction Executive	The role of the title holder (in Ireland), sometimes referred to as Traffic Executive, is equivalent to the driver standards manager (in Britain). He is a functional specialist who coaches, counsels and trains respective operating grades. Those in the District Traction Executive grade are involved exclusively with drivers, and those in the District Traffic Executive grade are involved with guards, signalmen, depot staff and crossing keepers. (Moloney)
Driver Only Operation	Driver only operated trains are operated exclusively by the driver. Other staffs, where provided, are engaged in non-operational matters, such as on-train catering or ticket checking. (Moloney)
Driver's Reminder Appliance	The driver's reminder appliance is depressed by drivers when their train is stopped at a stop signal or station. Activation of the device prevents the traction unit from taking power until reset. It is provided to prevent SASPADs, that is, starting against a signal at danger. (Moloney)
Driver's Safety Device	See Safety Critical Equipment
Emergency Situation	A current, unforeseen situation or unplanned event which has a life threatening or extreme loss implication and that requires immediate attention, for example, a fire or an obstruction on a line. (Railway Safety Approved Code of Practice)
Emulator	See Software interface of cab
Essential Realism	Essential realism is not the realism or fidelity that might be regarded as essential for improved face validity. Rather, it is the amount of realism that is essential for the particular training requirements under consideration. (Parkes)
Event	A specific operational or technical occurrence in the course of a drive. There could be several events in a single drive. An event is also referred to as a situation. (Schmitz and Maag)
Footplate	Driving cab. (Moloney)

Full Cab Replica — Full cab replica simulators are able to simulate the vehicle's logic and behaviour. They incorporate a full cab that is equipped with a touch screen computer(s) that simulates the equipment located in the engine compartment or on the outside of the train. If the simulator is installed on a motion system, the driver gets an accurate feeling of the train's behaviour. [(Schmitz and Maag)]

Full Mission — A full mission simulator is based, not only on the look and feel, but on the functional operations that the simulator can perform. (Anon., 2007)

Geo-specific — A geo-specific visual database is a highly accurate depiction of a real route. By contrast, a geo-typical visual database is inaccurate although it includes typical infrastructure, cultural artefacts and cues, signalling and signage elements that are familiar to the driver. A geo-typical route does not represent a real route with which the driver is familiar. [(Anon.)]

Home Signal — A home signal is the first stop signal on the approach to a signal box. This does not apply on Track Circuit Block lines. [(I.É.)]

Hot Box Detector — A hot box detector (HBD) is a wayside detector for alerting the controlling signalman that an axle box is operating at an excessive temperature. The equipment generates an audible warning and print out. [(Moloney)]

Independent Brake — The independent (or locomotive) brake-handle controls the application of the locomotive brake. It does not affect the brakes on trailing vehicles. [(Moloney)]

In Rear — In rear, is the area through which a train has travelled before reaching a given location. In advance, is the area through which a train will travel after passing a given location. [(Bailey)]

Integrated Definition for Function Modelling (IDEFØ) — This process is used to model the manufacturing or service delivery functions of a system, and to illustrate the connectedness of the subsystems. The inputs, controls, outputs and mechanisms that are necessary to perform each function, are represented by a set of arrows that impinge with that particular function. The model is hierarchical in structure; lower and more detailed levels of the model are decompositions of higher levels. [(Moloney)]

Interlocking — The logic equipment by which routes that conflict are prevented from being set at the same time. [(Bailey)]

Latency — Latency is the time lag between information processing and presentation. It is greater for networked simulators that use a central server. It can reduce simulator realism and increase the likelihood of sickness. [(Hardt and White)]

Normal Operation(s) — The operation of the railway in the way in which it was designed to operate, including planned peak periods. [(Railway Safety Approved Code of Practice)]

On-Train Monitoring and Recording — The on-train monitoring and recording (OTMR) system is a data recorder that is fitted in the cab of a traction unit for recording a defined set of parameters or functions, such as speed, position of train, brake cylinder pressure, use of the horn and notch position etc. It is analogous to an aircraft's black box. [(Moloney)]

Operator (simulator) — The operator of the simulator is the person who is driving the simulator, i.e., the trainee. The operator of the simulator is just one

	use case. See User (simulator) for lines of demarcation with other stakeholders. (Moloney)
Out-of-Course Working	The term out-of-course working refers to abnormal or non-routine train working. The term includes diversionary routing (mainline and shunting manoeuvres), e.g., a train from A to B can go via routes C or D; a suburban or freight train can be placed in the running loop to clear the route for an express train; a train can be moved from the up main to the down main under shunting signals; a train can be stopped because the failure of another train or an infrastructure failure or obstruction or other exceptional cause, as well as passenger emergencies. (Moloney and Tuohy)
Overlap	It is a region of safety in advance of a stop signal. It is provided in the design of the signal scheme plan to cater for events of minor overruns that are caused by poor driver judgment. The length is dependent on the line speed. It is usually 180 metres in length but in some areas where speeds are very low; there may be no overlaps at all. (Moloney)
Overspeeding	The term overspeeding applies to any situation where the train exceeds the current authorised speed. This includes the train moving when it should be stationary. (Independent Transport Safety and Reliability Regulator)
Permanent Speed Restriction	A permanent speed restriction (PSR) is imposed due to track curves or other permanent infrastructure conditions that are present on a particular track section. (Andersen)
Permissible Speed	The permissible speed is the maximum permitted speed for a track section as shown in the Working Timetable. (Moloney)
Pilotman	A pilotman is a person who is appointed to oversee the passage of trains over a double line during single line working, or over a single line or a bi-directional line during a failure of equipment. (I.É.)
Placements	Placements are representations of real world objects that can be placed within the virtual environment to enrich the vista provided to the operator. The vista presented to the operator is designed to elicit particular responses, e.g., the presence of a static van adjacent to the line should act as a visual cue that trackside workers are in the vicinity. Placements can be incorporated readily within a scene by a simple ‘cut and paste’ process. (Moloney)
Presence	It is the ability of an operator to suspend disbelief in the simulated environment. (Wallis, Tichon and Mildred)
Protection	Protection procedures are used by the train crew when a train derails, fails, is obstructed or is involved in an accident or other exceptional incident. They are enacted to protect the failed train and any other train that may come into conflict with it. (Moloney)
Push/Pull Train	A push/pull train formation consists of a control car at one end and a suitably equipped locomotive at the other end. The driver operates the train from the leading cab, which may be either on the control car or on the locomotive. This saves shunting at terminal stations. (Moloney)
Reliability	Reliable methods or processes produce the same results consistently. (CAS)
Reversible Line	Reversible working is not regarded as normal operation; it is implemented as a result of system degradation. (Moloney)

Running Signal	A running signal controls the movement of trains en route along a running line. (Bailey)
Safety Control Equipment	The term safety control equipment (SCE) is used to describe the totality of the locomotive deadman's equipment and the vigilance equipment. In Britain, it is called the driver's safety device (DSD). (Moloney)
Scenario	The actual configuration of a drive, e.g., the sequence of events, the choice of the routes, specific train settings and weather conditions etc. (Schmitz and Maag)
Section Signal	A section signal is a stop signal that controls the entrance to a block section. (Moloney)
Shunter	A shunter is any person who performs shunting duties, e.g., marshalling trains, conducting low speed movements or setting routes manually in yards. (Moloney)
Signal Box	The term signal box includes any mechanical, relay based, or integrated electronic control centre. It also includes an Emergency Control Panel or Personal Computer Electronic Control Point which is open. (Moloney)
Signaller	A signaller is a person who is involved in controlling the movement of trains. In different countries, signallers are variously called controllers, signalmen, planners and dispatchers. (Wilson and Norris.)
Signalman	The term signalman (Ireland) is used interchangeably with signaller (Britain). The term is gender neutral. (Moloney)
Signal Passed at Danger	This term specifically applies to situations when the train passes the signal without the signalman's permission. It excludes instances when the train passes a danger signal with the signalman's permission, e.g., for assistance purposes or when the signal is defective. (Moloney)
Simulation	A simulation is a situation or environment which is produced but not necessarily by a machine. It is further defined as any device, process or created environment used to represent the actions or functions of the real equipment under operational conditions, for training or assessment. (Railway Safety Approved Code of Practice)
Single Line	A single line is used for traffic movements in both directions. (Moloney)
Software Interface of Cab	A simulator using a software interface of cab equipment representing the real driving desk on screens. Trainees operate a software representation of the desk, i.e., the handles and buttons etc., with standard computer interfaces (mouse and keyboard). (Schmitz and Maag) The term emulator is also used to describe this type of equipment. Emulators can have the full functionality of a simulator but have a different MMI. (Moloney)
Starting Against Signal SPAD	An SASPAD, at type of Signal Passed ad Danger (SPAD) occurs when a train is (re)commencing its journey after being detained at a signal at danger, e.g., where the train is stopped at a station to facilitate traffic activities and the section signal is at danger. When the driver is notified that the station work is completed, the driver may set off and pass the signal at danger. (Davies and Downes)
Station	The term station includes a terminal, depot, halt or yard. (I.É.)

Stop Signal	A stop signal is any main signal which can display a stop aspect or indication. (I.É.)
Tail Lamp	The term tail lamp includes integral red lights on traction units and rolling stock. Their presence signifies train completeness. (Moloney)
Temporary Speed Restriction	Temporary or emergency speed restrictions are imposed by the engineering department when the condition of the line does not permit operations at normal speeds. These are normally communicated to drivers by means of a Weekly Circular or Shed notices. (Andersen)
Token	The term token includes any single line token or train staff. (I.É.)
Track Circuit Assistor	A track circuit assistor is provided on certain trains to improve the operation of track circuits and, hence, train detection. Trains with low axle loadings cannot be guaranteed to operate track circuits. (Moloney)
Track Circuit Block	The safety of trains operating on a track circuit block section of line relies on the use of track circuits or other means of automatic train-absence detection, e.g., axle counters. The controlling signalman does not use block instruments. (Moloney)
Track Circuit Operating Device	The track circuit operating device (Geismar bar or clip) is placed on the line to provide signal protection in an emergency situation. It operates track circuits and reverts signals to danger. (Moloney)
Traction Unit	The term traction unit refers to a locomotive, multiple unit, self propelled rail vehicle or road/rail vehicle when operating in rail mode. (I.É.)
Train	The term train includes locomotive hauled rolling stock, light locomotive(s), self propelled rail-vehicle(s) and road/rail vehicle(s) when they are operating in rail mode. (Moloney)
Trainee	A trainee is an individual who is undergoing instruction and training. This term applies to those engaged in the formal classroom element of the driver training process and also to those who are developing their driving skills by operating as a second man on the footplate. For the purpose of this thesis, the term is extended abnormally to include qualified drivers who are engaged in refresher training. (Moloney)
Train Performance Display (TPD)	The train performance display provides supplemental information to the simulator operators and users (drivers and instructors). It provides a number of graphical and textual displays that can be used to assess drivers' performance, e.g., line curvature, in-train forces, gradients and brake applications. (Ward, Tyler, and Wilson and Eichinger)
Train Radio	Train radio systems are permanently installed in the cabs of traction units for communicating with signal boxes. The train radio head can be used in conjunction with hand-held portable communication devices, such as guard-driver and shunter-driver systems. The system used in I.É. is similar to the CSR system used in Britain insofar as it supports discrete communications between parties. (Moloney)
Translational Study	A translational study helps to make findings of basic scientific research useful for practical applications. Such studies are carried out in the medical, behavioural, and social sciences. Translational research fosters a multidirectional, multidisciplinary and seamless integrative approach to achieve research outcomes. The activity

	covers all research between the laboratory and the respective community of practice. There are two areas of research translation. One area involves the application of discoveries generated during research in the laboratory to studies of humans and behaviour; it is action based research. The second area is aimed at enhancing the adoption of best practices in the community. (Moloney)
User (simulator)	This term excludes the simulator operators, i.e., those undergoing training. It includes the railway management, communities of practice, observers, instructors and training managers etc. (Moloney)
Validation	The assurance that a product, service, or process satisfies the criteria of the stakeholders. (Moloney)
Vigilance Device or System	A vigilance device (system) is provided in driving cabs as an aid to maintain drivers' vigilance. Task linked vigilance systems accept direct evidence that the driver is actively controlling the train. Modern vigilance systems are speed linked; higher train speeds require more frequent cycling. (Independent Transport Safety and Reliability Regulator)
Virtual Reality	Virtual reality is characterised by the illusion of participating in a synthetic world through an immersive and multi-sensorial experience, instead of external observation of that environment, i.e., when the user is immersed in a virtual world, he cannot see the real world around him. (Coelho *et al.*)
Wheel Slide Protection (WSP)	Wheel slide occurs during braking when a wheelset loses grip with the rail. Prolonged wheel slide causes wheel flats. Electronic WSP equipment is fitted to modern traction and rolling stock. It detects and controls the rotation of wheels that are sliding when the vehicle is in braking mode. This equipment operates automatically and is customised to optimise the performance on specific vehicles. (Moloney)
Wheel Slip	Wheel slip occurs when a powered wheelset loses grip with the rail during acceleration. (Moloney)

Glossary of Terms (B) - Psychology and Human Factors Domains

Ability	Ability refers to the hypothetical construct that underlies performance in a number of tasks or activities. Ability is usually thought to be a relatively stable characteristic or trait that is innate. (Tendick)
Active Failure	An active failure is an error that could be an immediate and direct cause of an incident, e.g., a SPAD. (HEL)
Affective Domain	The affective domain consists of behaviours corresponding to awareness, interest, attention, concern, responsibility, social skills, ability to listen and respond to others, and the ability to demonstrate those attitudinal characteristics or values that are appropriate to the field of activity. (Moloney)
Attention	The concentration of mental resources on particular physical or mental events. (Palmeri) It is the concentration and focussing of mental effort. (Nichols and Cobb)
Automaticity	The level at which some mental tasks are performed, i.e., effortlessly and with little thought or without the allocation of conscious attention. This is in contrast with deliberate, action-demanding and conscious controlled cognition. (Palmeri)
Behaviourism	Behaviourism is the science of observed behaviour. The science was advanced by John Watson who believed that behaviours could be measured and changed through conditioning using reinforcements and punishment. (Moloney)
Behaviourist (theories)	These are theories of learning that aim to develop cue-response chains through repeated practice of well-defined skills and contexts. (Wallace *et al.*)
Boredom	Boredom is an individual's response to a monotonous situation. (Dunn)
Chance	This is analogous to fate and is defined as risks that have such low probabilities that estimations cannot be assigned. (Arnstein)
Cognitive Tasks	Cognitive tasks are performed in situations that require judgement and decision making. (Allen *et al.*)
Cognitivist	Cognitivism is a theory of learning that espouses the idea that learning is a conscious rational process. People learn by making models, maps and frameworks in their mind. Cognitive theories of learning aim to develop effective responses to well-defined situations. They focus on the cognitive aspects of learning, such as the progression from declarative knowledge about a skill to the procedural knowledge of skill performance. This is what Nonaka and Takeuchi refer to as the process of internalisation. (Wallace *et al.*)
Cognitive Task Analysis	This is a technique that allows the train-driving task to be analysed to identify aspects that place heavy demands on cognitive resources, e.g., attention, simultaneous capacity, alertness and perception. The use of CTA facilitates the identification and circumstances of future error causation mechanisms. (Moloney)
Cognitive Skills	Learned behaviour that allows an individual to operate on information, gained from the environment, in order to guide subsequent physical action. (Shepherd)

Competence	Competence is the ability to undertake responsibilities and to perform activities to a recognised standard on a regular basis. (Hughes)
Constructivism	Proponents of this approach suggest that learning is not just a direct result of listening to a teacher. The students have to organize and develop what they hear and read. Learners use current or past knowledge to construct new ideas or knowledge. A Socratic instructional style is used during which the mentor translates the information to be acquired into a format that is appropriate to the student's present state of understanding. This was a major theme of Bruner (1996). (Moloney)
Crew Resource Management	This is the effective use of all available resources, such as crew members, equipment, systems and supporting facilities, to achieve safe and efficient operation. (Joint Aviation Requirements - Operations) It is a set of teamwork competencies that allow the crew to cope with situational demands that would overwhelm an individual crew member. (Mitsopoulos *et al.*)
Crisis	A crisis is defined as an unexpected event or a potentially life-threatening chain or combination of events that causes uncertainty of action and time pressure. This can range from a hazardous or 'hairy' event to a major crisis. It is a novel, unfamiliar situation. (Catchpole)
Critical Thinking	A thinking process that is characterised by careful and exact evaluation and judgement. (Reader's Digest)
Cues	Cues are events which prompt some actions or responses. (Evans)
Culture	Culture is an aspect of the way things operate in an organisation. It is almost invisible to the people working there. (Hale) It is an organisation's personality. (Moloney)
Distraction	Distraction creates a loss of attentional control. (Anon., undated)
Distributed Cognition	Distributed cognition is based on the idea that cognition is distributed over the person and the person's environment. It is based on the fact that some information is available in the head and other information is extracted from the situation. With the AWS, for example, information on the status of a restrictive signal just passed must be retained in the driver's head. The CAWS, by contrast, is a memory aid which distributes cognition back into the context of the cab environment. (Halliday *et al.* and Moloney)
Error	An error is the failure of planned actions to achieve their desired ends. (Reason *et al.*)
Evaluation	Evaluation is the process of gathering information to ascertain the effectiveness and efficiency of training programmes to make informed improvements to the training process, i.e., is the training process doing what it is supposed to? (Atkins *et al.*)
Experience	Experience is a measure of whether the individual has recently had sufficient exposure to, and practice of, the range of tasks to acquire the skills and knowledge required to complete those tasks to the level noted in competence standards. Specific industries require different criteria against which to measure the appropriate levels of 'sufficient exposure', 'practice' and an appropriate 'range of tasks'. (Wright *et al.*)

Experience (a wry definition)	Experience is something you don't get until just after you need it. (Chambers)
Expert	This is the 5th and final stage of skills learning. Experts can cope with unusual and unanticipated events. (Wallace *et al.*)
Expertise	Expertise is the manifestation of exceptional abilities or skills in some domain. (Palmeri)
Far Transfer	This refers to real life skill application where the context is novel and has not been addressed in training. Principle-based lessons, also called far transfer, are designed to teach tasks that have more than one correct outcome. These tasks require the worker to adapt guidelines to various job situations. Railway training is of the near transfer variety. (Clark and Mayer)
Fatigue	The term includes physical (resulting from heavy protracted physical labour) and neurobiological (biologically determined) sleep-awake rhythm entities. (SWOV)
Feedforward Control	This control mechanism attempts to standardise work practices by using prescriptive rules and procedures, backed up by inspectors who monitor behavioural compliance and impose sanctions on deviants. (Moloney)
Field Dependence	The inability to pick a target out of the environment, e.g., picking a red signal aspect out of the surrounding environment. (Drummond)
Hazard Perception (HP)	Hazard perception includes the process of discovering, recognising and responding to potentially dangerous situations. (Engström *et al.*)
High Workload	In a high workload situation, the demands placed upon an operator, are close to reaching the limitations of human performance. (Anon.)
Human Error	Human error means that an action or a decision made by the human was the cause, or a contributing factor, that led to an accident. This definition also includes the human's failure to make a decision or to take action. (FAA)
Human Factors	Human factors are the environmental, organisational and job factors and human characteristics which influence behaviour at work in a way which can affect health and safety. (HSE)
Incremental Transfer Learning	Incremental transfer learning views skill learning as occurring through task performance in a progression of contrived environments, such that, each task is more complex and demanding than the previous. In this sense, learners are considered to be incrementally transferring to contexts more and more similar to those which will eventually be encountered in real life. (Wallace *et al.*)
Knowing-Doing Gap	A knowing-doing gap is created when individuals know the correct course of action to take but choose to exercise a different one. (Moloney)
Learning	Learning is the process of modifying existing knowledge, skills, habits or action tendencies. It is also knowledge or skill that is acquired by instruction or study. (Gagnè)
Line Oriented Flight Training (LOFT)	Line oriented flight training is a complete training process that utilises a full mission simulation for aircraft pilot training programmes. The simulation includes accurate modelling of the systems of a specific type of aircraft, its handling characteristics, ground facilities, navigational aids and airports. In

	addition to systems' knowledge, handling skills and operating skills, LOFT also includes decision making, leadership, management and resource management training. This training facilitates the transition from flight simulation to operational flying. LOFT consists of entire flights, during which various operational or technical problems are managed by the crew in real time. Full operational documentation, pre-flight planning and normal aircraft operating practices are used throughout. There is no direct instructional input during the actual LOFT session unless negative learning begins to occur. At the end of the LOFT exercise, the instructor acts as the facilitator of a debriefing discussion on how the exercise developed and what lessons could be learned from the experience. [Croft; Moloney]
Miscalibration	The calibration process is characterised as the weighting or balancing of the results of an assessment of task demands and an assessment of one's own skills resulting in the recognition of a balance or an imbalance. Miscalibration occurs when the assessment is inaccurate. [Kuiken and Twisk]
Mistake	A mistake is categorised as doing the wrong thing, believing it to be right (planning error). [Halliday *et al.*]
Monotony	A monotonous environment is one that is lacking in stimuli. An individual's reaction to monotony is called boredom. [Nichols and Cobb] A situation is monotonous if it remains unchanged or if it changes in a repetitive and predictable way. [Dunn]
Multitasking	The term multitasking refers to the performance of a number of tasks concomitantly. Multitasking places demands on the actor's attentional skills, cognitive processing capability and motor responses. In certain cases, the actor must prioritise the sequence and timing to carry out the tasks. [Moloney]
Near Transfer	This term refers to real life skill applications where the context is similar to those encountered in training. It is the transfer of a skill from an instructional environment to one where the conditions have been anticipated during instruction. [Wallace *et al.*]
Negative transfer	This term has two distinctively different meanings. In the aviation domain, it refers to situations where trainees are exposed to training scenarios that have a high likelihood of a negative outcome, i.e., a 'crash' in a simulator. Such learning is regarded as being detrimental to confidence building. [Catchpole *et al.*] The second and more common usage relates to the necessity for simulator behavioural congruence with the real vehicle. It is believed that if the model is inaccurate, inappropriate behaviours are learned. [Moloney]
On-the-Job Training (OTJ)	On-the-job training facilitates performance development that is embedded within the operational context. [Evans]
Parallel Processing	Parallel processing involves the execution of two processes at the same time. [Palmeri]
Perception	Perception is the awareness of the external world or some aspect of it, through human physical sensations, i.e., sight, hearing, smell, taste and touch, and the interpretation of these sensations and cues by the mind. [Moloney]

Positive Transfer	Positive transfer is the degree to which trainees effectively apply the knowledge, skills and attitudes, gained in the training context, to their job. (Ward, Tyler, Wilson and Eichinger)
Psychomotor Skills	Psychomotor skills are concerned with manipulative and motor behaviour. (Schmid) Psychomotor skills require the ability to complete a task using a combination of thinking (cognition) and coordinated muscular movements. (Moloney)
Recall	Recall is the ability to memorise, store, or retrieve data and information accurately. It can be directly useful in passing examinations but is only a prerequisite for success in acquiring and using other faculties. (Schmid)
Rule	A rule is a prescribed guide for conduct or action. Depending on the context of the action, it may not always be capable of application at which stage a derogation or local instruction is applied. (Moloney)
Schemata	Schemata are models that suggest the relationships that exist between objects. They determine how the learner interprets the task to be learned, how the learner structures and understands the information, and what knowledge the learner acquires. Synonyms include scene, scenario, model or theory. (Moloney)
Skill	Skill is the ability to choose and perform the correct techniques, successfully and regularly, with the minimum of effort. We get our natural ability from heredity but we have to learn and use techniques to develop our innate abilities. The term implies some coordinated physical or cognitive activity to achieve a goal. The term also implies a degree of flexible or adoptive performance. (Moloney) Skill is the ability to do specific things without necessarily being able to understand the process by which one does them. Skills can be divided into manual and mental skills. The correct execution of skill-dependent actions is controlled mainly by automatic processors. (Schmid)
Stress	Stress is a cognitive state which is part of a wider process reflecting a person's perception and adaptation of the demands of the environment. (Nichols and Cobb)
System Accident	A system accident must have multiple failures, and these failures are likely to be in reasonably independent units or subsystems. They start with the failure of a component, e.g., failure of a part or operator error. (Perrow)
Technical Skills	Technical skills are those skills that are related to academic courses, e.g., understanding of mathematical principles. (Juhary)
Training	Training is a systematic process of instruction, practice, review and examination. It is single loop learning. Atkins *et al.*
Training Need	The training need is the gap between the training objective and the level of proficiency before training occurs. (Hosman *et al.*)
Training Objective(s)	The level of proficiency that the trainee has to master is referred to as the training objective. (Hosman *et al.*)
Transfer	Transfer relates to the application of knowledge, skills and attitudes that are acquired during training, to the environment in which they are normally used. (Alexander *et al.*)

Understanding	Understanding implies the ability to recognise faulty reasoning, to construct hypotheses which go beyond the evidence available, and to identify the kinds of evidence which will verify, or falsify, the hypothesis. (Newton)
Utility Analysis	A set of statistical procedures is used to assess the financial gain to an organisation resulting from the use or implementation of a specified human resource management intervention, in this particular case, CRM training. (Roop *et al.*)
Vigilance Decrement	Vigilance is a state of readiness to detect stimuli, appreciate context and respond accordingly. It is achieved at the optimum level of arousal. Vigilance decrement is defined as a reduction in the state of vigilance from the optimal level. (Whitlock)
Violation	A violation is a deliberate deviation from safe operating procedures, rules and regulations. (Reason and Free)

List of Acronyms

ADU	Aspect display unit
AHB	Automatic half barrier
ALARP	As low as reasonably practicable
ATC	Automatic train control (also air traffic control)
ATP	Automatic train protection
AWS	Automatic warning system
CAI	Computer aided instruction (frequently used interchangeably with CBT)
CAWS	Continuous automatic warning system
CBT	Computer based training (acronym is frequently used interchangeably with CAI)
CCTV	Closed circuit television
CGI	Computer generated imagery
CRM	Crew resource management
CRR	Commission for Railway Regulation – see RSC[1]
CSD	Classroom scenario demonstrator
CSR	Cab secure radio
CTA	Cognitive task analysis
DAS	Data administration station
DBAG	Deutsche Bahn Aktien Gesellschaft
DFS	Detailed functional specification
DIF	Difficulty, importance and frequency
DMU	Diesel multiple unit
DSD	Driver's Safety Device
DTE	District traction (or traffic) executive
EBAT	Events-based approach to training
EF(s)	Equivalent fatality(ies)
ETS	Electric token system
FAA	Federal Aviation Authority
FOC(s)	Freight operating company(ies)
FOV	Field of view
GSM-R	Global system for mobile communications for railways
HP(T)	Hazard perception (training)
HSE	Health and Safety Executive
HTA	Hierarchical task analysis
IDEFØ	Integrated definition for function modelling

[1] The Railway Safety Commission (RSC) was renamed as the CRR with effect from 29 February 2016.

IRR	Internal rate of return
IS	Instructor(s)' station
IT	Information technology
JRE	Japanese Railways East
LMA	Limit of movement authority
MMI	Man machine interface
NRN	National radio network
NTS(s)	Non-technical skill(s)
NWRM	Network wide risk model
OTW	Out-the-windscreen (view)
PCA	Passenger communications alarm (also passenger call for aid)
PF	Proportion factor
PSR	Permanent speed restriction
PRA	Post run analyser
RBTNA	Risk based training needs analysis
ROI	Return on investment
RPD	Recognition primed decision (making)
RSC	Railway Safety Commission – see CRR
RSP	Railway Safety Programme
SA	Situation(al) awareness
SLW	Single line working
SME	Subject matter expert
SMS	Safety management system
SPAD	Signal passed at danger
SPS	Scenario preparation station
SPT	Signalpost telephone
TBT ™	Track builder tool
TCA	Track circuit assistor
TDMS	Train data management system
TNA	Training needs analysis
TOC(s)	Train operating company(ies)
TPWS	Train protection and warning system
TSR	Temporary speed restriction
VPF	Value of preventing a fatality
WSLP	Working of single line by a pilotman

Research Questions

Railways are complex and generally-safe service delivery mechanisms (Naweed, 2014; Merkert, Nash and Smith, 2008; Lindfeldt, 2008 and Peirone, 2005). They employ multiple defensive layers: engineered defences, people defences, procedures and administrative controls (Reason, 2000a and Reason, 1997). However, railways operate in an aggressive and competitive environment, where commercial success often depending on the exploitation of the benefit derived from operating at the fringes of normal accepted practice (Rasmussen, 1998).

To satisfy the service delivery imperative, operating staff must be able to operate competently in all contexts. They are the most important, and sometimes the only, barrier in the event of a technical malfunction (Kecklund *et al.*, 2001b). Railways are bureaucratic control and command organisations that operate on the basis of feedforward principles (Reason *et al.*, 1998). Consequently, operators and, most relevant to this study, traction drivers, must be trained to apply copious rules and procedures to enable them to carry out a comprehensive variety of tasks, in all operational contexts.

Drivers use learning in the cognitive, psychomotor and affective domains. In addition to learning rules, procedures and technical skills, they also need to learn a range of non-technical skills. Many training and development processes concentrate on the development of the cognitive domain and technical skills. They are delivered using conventional methodologies and are dependent on fortuitous real-world experiences for effective exploitation. Whereas these processes can provide experiential training for normal operations, in general, trainees receive only theoretical instruction to prepare them to cope with the other modes of operation. This reflected the situation in Iarnród Éireann (I.É.) prior to the introduction of its simulator enabled training process.

I.É.'s management was becoming increasingly concerned about the level of safe performance of its drivers. *Train crew error* was the third greatest contributor to I.É.'s primary safety risk and accounted for over 9% of I.É.'s total risk exposure. (Sotera Risk Solutions, 2010). The risks associated with *SPAD* occurrence constituted 96% of this risk subset. The use of driver training simulators to provide experiential training in all operational contexts and to develop all the domains of learning was perceived as affording the best opportunity to affect safety improvement. Training simulators facilitate the modification of trainee behaviours through the receipt of internal feedback, from the external environment and from mentors. However, simulators are expensive to acquire, maintain and operate. Furthermore, acquisition costs and the value that is derived from the systems are highly dependent on their appropriateness for and their application to the stakeholders' goals. Consequently, resource allocators invariably question whether such investments are justified.

When conducting his research on this topic, the writer has drawn on his personal experience as the Operations Training Officer at Iarnród Éireann (I.É.). His research questions are thus: (i) What driver-relevant operational safety benefit, as revealed through an analysis of outputs from its risk model, did I.É.'s stakeholders achieve when the company changed the training delivery process for its 500 drivers from the traditional lecture based process to a simulator enabled one, and (ii) did the financial value of any resultant change to operational risk justify the cost of the change?

1 Introduction

Railways are long and thin, geographically-dispersed physical entities that require relatively complex organisational structures. Management is centralised but those who execute management's policies and procedures are decentralised. The managerial task is simplified somewhat through standardisation (Daft, 1995). Management of operational subordinates is characterised along the 'befehlstaktik' principle, i.e., individual initiative and independent thinking are discouraged (Maury Hill and Associates Inc., 2007; and Reason *et al.*, 1998). Standardised procedures and operational constraints, in the form of prescriptive *rules*, are developed by technical specialists who reside in what Mintzberg (1981) calls the organisation's 'technostructure'. These are disseminated to the operational staff through *training* interventions. The overall *competence* of staff is developed and maintained through expensive competence assurance processes (Frérot, 2011 and RENFE, 2004). The aspiration is that these procedures and rules will be applied appropriately and reliably. Only those persons who have been assessed as being competent are allowed to occupy relevant operational roles (The Stationery Office Limited, 2006 and Office of the Attorney General, 2005a).

Typically, passenger operating companies provide services 18 hours a day, for 363 days a year at least (Halcrow Group Limited, 2002). Freight operating companies operate on an as-required basis and usually at night time. These companies utilise a broad variety of long-life physical assets to produce their service offerings. These assets are characterised by different and costly technologies. Because of the capital intensive nature of the asset base, the associated operating costs and the service delivery commitments, there is an economic imperative to utilise the system at near-full capacity. Similarly, there is a large human content involved in the service delivery process which is characterised by high costs, role demarcation and high levels of responsibility. In 2009 for example, 712,400 people were employed in railway companies in the EU 27 (European Commission, 2012); of this, 133,000 were drivers (Schmitz and Maag, 2008). As might be imagined, there is fluidity in any workforce of this scale, resulting in a requirement to train ca. 11,000 (8·25%) drivers (Danish

Technological Institute, CAS and Lloyds Register, 2007). The training requirement in I.É. was ca. 7·6% during the period 1998-2005 and this rate was incorrectly anticipated to exceed 9% in line with unrealised future business growth (I.É., 2004).

Most European railway organisations are either under direct state control or are dependent on their respective states for subventions. Because of these relationships, they are unable to make key commercial decisions without referral to their benefactors. Whilst these railways are subject to normal commercial pressure, governments want to keep passenger fares at a low level whilst, at the same time, constraining their financial support. Passenger customers want repeated on-time service, good comfort, short journey times and absolute safety (Anon., 2008; Baker *et al*.,2007 and RSSB, 2004b); freight customers want *reliability*, speed, suitable terminal-railway interface and storage facilities (Palšaitis and Ponomariovas, 2011). Furthermore, the demand for the rail service is price-sensitive. Price elasticities in respect of urban and regional passenger travel vary between - 0·4 and - 0·9 (Balcombe *et al*., 2004); price elasticities in respect of journey purpose (business, commuting, shopping or social) vary between - 0·4 and - 1·1 (Harris and Godward, *eds*., 1992). In respect of freight, price elasticities vary between -0·03 and -1·23 depending on the types of freight being conveyed (Oum, Waters and Yong, 1990).

As society progresses, it demands ever greater levels of safety, and organisational safety objectives move continuously towards zero risk. The public perception is that railways are intrinsically safe (Reason, 2000b), so much so, that both I.É.'s Performance Obligations (NTA, 2011) and the focus group's contribution to the Department of the Environment, Transport and the Regions' White Paper (DETR, 1998) fail to declare passenger safety as one of the desirable attributes of rail transport. However, this position is incompatible with the views of learned safety professionals. Of the twelve business sectors that he scrutinised, Reason (1997) ranked railway operations in the seventh highest risk position.

Managers are near to the strategic apex of the organisation, and can access scarce and valuable resources to implement improvement initiatives. Because of their positional responsibilities and role as resource allocators, the burden for managing the safety of the system resides with them (Wright *et al*., 2003). A symbiotic relationship exists between managers and operational staff; managers are responsible for safety through the competence management process but operators are responsible for *accident* avoidance and prevention. ROGS (2006), Office of the Attorney General (2005a), HSE (2003) and HMRI (1996) deem certain rail activities as being safety critical. Train driving is included in this determination. This means that, as part of the licensing arrangements, all staff involved in such work must be assessed regularly and certified as competent against risk-based competence standards. Implementation of effective training strategies and processes underpin the satisfaction of this obligation.

This chapter is divided into six sections, dealing with:

1.1 The Context of the Subject of this Study;
1.2 Managing Risk and Alternative Approaches to Failure;
1.3 The Futility of Retrospective Analyses;
1.4 Writer's Motivation for Thesis; and
1.5 Structure of Thesis.

Concluding remarks are presented in Section 1.6.

1.1 The Context of the Subject of this Study

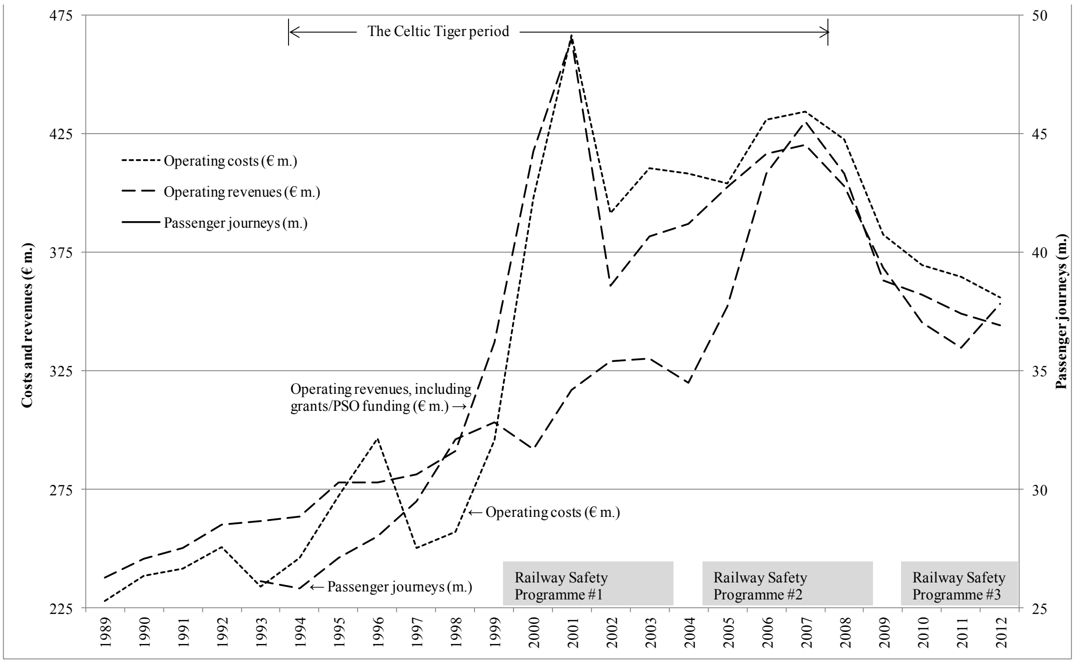
To understand the context of this thesis, it is fruitful to briefly review the historical and financial milieu of I.É, its excellent historical accident record together with the worrying prevalence of accident and incident precursors, the importance of the operational performance of the traction-driver cohort to its risk exposure and the increased emphasis on external regulation (Greiner, 1972).

1.1.1 The Economic Fortunes of I.É.

The rail system in Ireland was ubiquitous in the early 1900s (Stanuell, 1910). Because of the proliferation of road transport, it has consolidated concomitantly in the intervening years into two separate companies; one in the Republic of Ireland and the other in Northern Ireland. The remaining portion of the system in the

Republic was nationalised in 1945 under the designation of Córas Iompair Éireann[2] (O'Rian, 1995). I.É. is the railway subsidiary of this group.

Generally, the demand for rail transport services is derived and strongly correlated with the prevailing macroeconomic climate (Goodbody and AECOM, 2011). The positive changes that occurred in Ireland's macroeconomic environment between 1994 and 2008, commonly referred to as the Celtic Tiger period, helped to facilitate a remarkable reversal in I.É.'s fortunes. I.É.'s own efforts to make rail travel the mode of choice by offering a better, faster and more comprehensive service also contributed to success. The operational and financial results of the combination of the benign market and I.É's efforts are evident in Figure 1.



Source: Annual Reports (Irish Rail, relevant dates)

Figure 1: Operating costs, revenues and passenger patronage (1989 - 2012)

The growth in passenger journeys, achieved up to 2008, was forecasted to continue at an unprecedented rate into the future (I.É., 2004); necessitating an expansion of all components of the system. The training function would have to make its contribution towards meeting this challenge by developing the resultant

[2] Córas Iompair Éireann (C.I.É.) was a fully integrated company between 1945 and 1987. The Transport (Re-organisation of Córas Iompair Éireann) Act (1986) led to the setting up of three operating subsidiaries, i.e., Iarnród Éireann (I.É.), Bus Éireann (B.É.) and Bus Átha Cliath (B.Á.C.). These were incorporated on the 20.01.1987.

enlarged human component. Even though the market conditions were benign, operating incomes[3] had not covered the operating costs since 2000. Not alone was I.É. unable to internally fund the ambitious capital projects that were being considered; it was even unable to maintain the extant system in a satisfactory condition. It was not until after a serious incident[4] had occurred at Knockcroghery that a commitment was made to provide the necessary level of capital investment. This commitment was made on foot of a post-incident review of rail safety by IRMS (1998) who noted that the "... shortfall in investment in recent years… is now impacting on safety" (p.116). As a result of this, and also the Irish Government's acceptance that I.É. could make a significant positive contribution to the nation's economic wellbeing (NTA, 2016), funding for capital projects and for the Railway Safety Programme was provided from the Irish exchequer and from the European Regional Development Fund. The *RSP* is extremely relevant to this thesis as, without it, I.É. may not have been able to fund its simulator system. The phasing, funding and high level output objectives of each phase are presented in Table 1.

Table 1: Objectives of the Three Phases of the RSP

Programme	Operative period	Amount	Main expenditure areas
RSP 1	1999 - 2003	€661 m	Physical infrastructure (€600 m), and safety *culture* and procedures (€61 m)
RSP 2	2004 – 2008	€512 m	Physical infrastructure (€444 m), *SMSs* and human performance (€68 m). Funds for I.É.'s simulator system were provided in this tranche.
RSP 3	2009 - 2014	€513 m	Physical infrastructure (€443 m), SMSs (€31 m) and Human performance (€39 m)
Total		€1,686 m	

Source: Department of Transport, Tourism and Sport, and Risk Solutions (2013)

Spending in all areas of the RSP has been subjected to prospective 'due diligence' reviews and retrospective 'value for money' audits by independent subject matter experts. Auditors' comments, in respect of the manner in which I.É.'s simulator project was managed, are presented elsewhere in this work.

[3] Including state grants or Public Service Obligation (PSO) payments
[4] A broken fishplate caused a derailment of a passenger train on 08th November 1997.

1.1.2 Managing with the Available Resources

Although it fell short of meeting the normally acceptable standard, it would be disingenuous to portray the prevailing situation on the Irish rail system as being shambolic; it was not! IRMS (1998) recognised the past achievements of management and staff, particularly in respect of safe performance during challenging times; noting that "Historically the I.É. network has been a safe railway, with reportable accidents and levels of casualties that are comparable with other European railway networks" (p.116) and, most germane to this thesis, that "... training for staff to undertake their jobs is performed adequately in most functions" (p.74). However, whilst attesting to I.É.'s historical safety performance (see Table 2 for a perspective on the infrequency of multiple fatality train accidents), IRMS and I.É.'s management were concerned about the intrinsic system safety and the prevalence of accident precursors. Perspectives on the frequency of incidents and accidents, and on *signal passed at danger* rates are provided in Table 3 and Figure 2 respectively.

Table 2: Multiple Fatality Train Accidents (1955 - 1997)

Date	Location	Accident type	Fatalities
21.12.1955	Cahir	SPAD resulting in buffer strike and derailment into the River Suir	2
21.10.1974	Gormanstown	Runaway train resulting in primary and secondary collisions	2
31.12.1975	Gorey	Train derailment due to underbridge strike	5
01.08.1980	Buttevant	Train derailment due to the purposeful disarrangement of the signal - points *interlocking* for renewal purposes	18
21.08.1983	Cherryville Junction	SPAD resulting in a rear-end collision	7

Table 3: Historical Incident/Accident Data (1993 - 1997)

Incident type	Number of incidents/accidents	Number of accidents resulting in injuries
Derailments	460	3
Collisions (all types)	90	4
Running into obstructions (all types)	102	5
Train fires	20	0
Unintentional divides	40	0

Source: IRMS (1998)

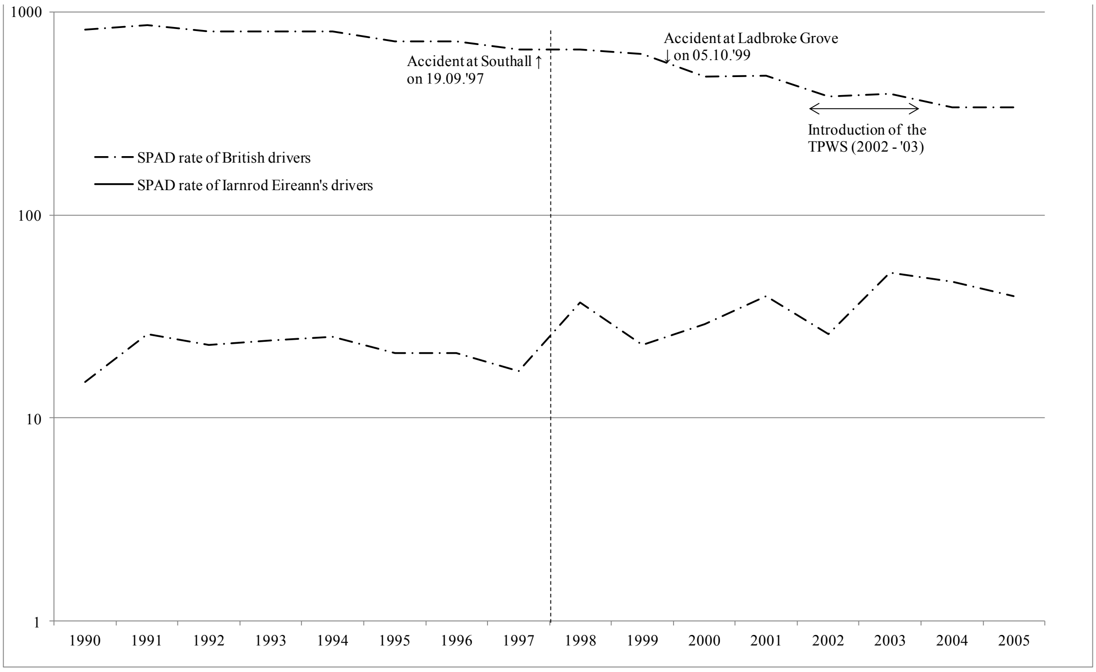


Figure 2: SPAD Performances of I.É.'s and British drivers (1990 - 2005)

Readers should note that when I.É.'s SPAD rate (1990 - '97) is normalised to reflect the relative sizes of the driver populations, its performance was slightly better than the British performance. However, the SPAD rate for I.É.'s drivers continued to rise in the years 1998 - 2005, whereas the rate in Britain declined dramatically following the accidents at Southall and Ladbroke Grove, and the subsequent installation of the *TPWS*.

1.1.3 Criticality of the Driver Subsystem

Signalmen, guards, *shunters* and platform staff, and the range of subsidiary roles, such as pilotmen and secondmen etc., that come into being during periods of *degraded working*, are necessary for the delivery of efficient and effective rail services. Traction drivers are instrumental to the service delivery process; they operate at the concatenation of critical subsystems. The quality of their interactions with the subsystems influences both operational and safety performance (Naweed, 2014; and Leveson, Stringfellow and Thomas, 2012). Occupation of this junctional position is unique. As well as coping with *normal operations*, when the subsystems become faulted or failed the onus is on drivers to operate around the degradation; they are at the coalface (Hughes, 2004). They must possess knowledge of the rules, operating procedures, traction equipment and route features (Tichon, 2007; Kecklund *et al*., 2001b and Hale, 2000). (See also Appendix 1.) On its own, this technical knowledge is insufficient and must be combined with personal abilities, judgemental *skills* and *NTSs* to enable them to operate in a satisfactory manner (RSSB, 2013b; Bonsall and Taylor, 2011; and RSSB, 2009b). As they drive along, drivers are constantly subjected to a range of visual, audible, tactile and, in some cases, olfactory stimuli (Glendon *et al*., 2006). They need to be aware of the prevailing circumstances and must be able to apply suitable learnt and programmed decisions (Tschirner, 2015). They must know, near-instantaneously, which stimulus demands a response, *recall* the appropriate response from memory and apply it with minimal delay. The driving activity, elaborated using the *Integrated Definition for Function Modelling* (level 3) technique, is presented in Appendix 2.

Drivers constitute 10·0% of I.É.'s total workforce (I.É.'s Annual Report, 2005) and about 12·7% of the population of rail workers in the European Union (Commission of the European Communities, 2005); any one of them is capable of inflicting damaging contingencies on his employing organisation (CIMA, 2007). Railway organisations use competence management systems to safeguard against the realisation of this possibility (ORR, 2016). Drivers must be competent in all elements of the role that they perform and be able to demonstrate that initial competence has been established and maintained for as long as they fulfil the role. Definitions of competence abound but the writer favours the one by Bromby *et al*. (2003), namely, "… the *ability* to perform some task or accomplish something… competences reflect the knowledge, skills and the abilities that an individual may or may not have in relation to performing a particular task" (p.14).

1.1.4 The Increased Emphasis on External Regulation

Railway organisations have a duty of care in respect of all people who are affected by every facet of its operation. As a corollary, they must be able to demonstrate compliance with a demanding regulatory framework (Office of the Attorney General, 2005a). The regulation process has become more formal, rigorous and invasive (Little, 2006). In the distant past, there was only one Railway Inspecting Officer in Ireland. More recently, IRMS (1998) recommended that "... the capabilities of the present sole Inspecting Officer [should be strengthened]" (p.123). Presently, the function is carried out by the Railway Safety Commission[5] and the Railway Accident Investigating Unit (RAIU); staffed by 13 personnel in total. Unsurprisingly, the expanded resource base, with its new powers of compellability, led Little (2006) to note that "... I.É. has not previously been subject to the current level of external scrutiny on safety as is being applied now following the enactment of The Railway Safety Act 2005" (p.23).

1.2 Managing Risk and Alternative Approaches to Failure

The hazards associated with railway operation are pervasive. They are mitigated using engineering and administrative controls but they cannot be eliminated entirely (ORR, 2015a). In respect of the train driving task, the engineering controls comprise interlocks (e.g. saloon door interlock), advisory (e.g. *CAWS*) and supervisory systems (e.g. *ATP*), alarms (e.g. *TDMS* displays) and alerters (e.g. *vigilance device*) etc.; the administrative controls comprise standard operating procedures (e.g. in General Appendix), permit to work measures (e.g. certification by traction type and route), provision of appropriate training (e.g. basic, refresher, conversion or remediation) and safety management systems (e.g. standards) etc.

The development, maintenance and assessment of drivers' competence are essential to safe and effective operation (ORR, 2016). However, it is insufficient to ensure absolute safety as, of itself, competence does not ensure that slips and lapses will never occur (RSSB, 2004c). Chambers (2005) believes that while "While audits, reviews and testing play an important role, the baseline competence of the people doing the work is the best defence against system failure" (p.6). This is particularly true during periods of systems' degradation when the engineered defences may be unavailable. In such instances, the continued operation of the railway system is entrusted to the human defence layer. But, it should also be borne in mind that there is a level of human unreliability that is immune to improvement measures (Hughes, 2003; Beaty, 1995 and Smith, 1993).

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[5] The RSC was formally established on 1st January 2006 in accordance with the requirements of the Railway Safety Act (RSA) 2005.

The most distinguishing feature of high reliability organisations is their collective preoccupation with the possibility of failure. They expect their workforces to make errors, train them to recognise their emergence, and prepare them to recover from the errors. Such errors are marginal events that are caused by the same mechanisms that generate correct actions for most of the time (Besnard and Greathead, 2004). Following the occurrence of an incident or accident, the organisation or investigative body may use two perspectives during its inquiry into the cause, i.e., a system approach or a person approach (Leveson, Stringfellow and Thomas, 2012; and Reason, 2000a). The differences between approaches are elaborated in Table 4.

Table 4: A Comparison of the System Approach versus the Person Approach

Dimension	Person approach	System approach
Focus	Unsafe acts, errors and *violations* are perpetrated by individuals.	The defences, barriers and safeguards have failed.
Causes or effect	Forgetfulness, inattention, poor motivation, negligence and recklessness are the causes.	"*Human error* is simply a symptom of the [system] failure, not the cause itself" (Edkins and Pollock, 1996, p.90).
Duration of a remedy	Other operators, even those perceived to be excellent, continue to make the same *mistakes*.	Real causes are identified and remedied; preventing recurrence.
Blame	Individual operators at the front end of the process (drivers, guards or signalmen) are blamed.	Systemic factors are at fault and lessons are learned from the *event* for dissemination to the broader community of practice. Querists should use the substitution test[6] to discern if it was a system failure rather than an individual failure. Dekker (2012) believes that "the aim of safety work is not to judge people for not doing things safely, but to try to understand why it made sense for people to do what they did" (p.13).
Perceived remedy	Blame, shame and retrain the individual. Use the disciplinary process.	Change the prevailing work conditions, e.g., provide access to a confidential incident reporting and analysis system to surface the inadequacies that are apparent to the operator.

[6] Mentally substitute the individual concerned in the incident with one of his peers (of the same background, training, qualifications and experience) and ask "given the circumstances that prevailed at the time, could you be sure that the substitute would not have performed the same unsafe act?" If the answer is 'Yes', then the blame can be attributed justifiably to the individual concerned. If the answer is 'No', the system must be examined for a common cause failure mechanism (Reason, 1998).

Dimension	Person approach	System approach
Other	'Who blundered?' This approach assumes that the individual makes a conscious choice between safe and unsafe behaviour.	'How did the system fail?' Human error is expected to occur but the system must be robust enough to trap the error.
Time horizon	Focus on the immediate lead up to the accident.	'Resident pathogens[7]' have not been designed or managed out of the system and lie dormant until they combine with *active failures*.
Defences	These reside within the individual.	These reside within the system.

Based on Leveson, Stringfellow and Thomas (2012) and Reason (2000a)

Historically, accident investigators leaned towards the person approach but their emphasis has changed gradually to the system approach (Kyriakidis, 2013 and Woods *et al*., 1994). The readjustment of the investigators' gaze, predominantly away from those at the 'sharp end' to envelop all of the systems' actors, has caused personally risk-averse managers and resource allocators to become more attuned to their roles and accountabilities. Wolff and Orr (2009) capture the essence of this shift of attribution from organisational to personal responsibility. They opine that it is necessary to consider "… the 'moral quality' of the source of the hazard, which is a matter of how it is created or sustained, and in particular whether the cause is in some way the culpability of those charged with ensuring our safety" (p.38).

1.3 The Futility of Retrospective Analyses

Some organisations, which operate in hazardous environments or with hazardous technologies, rely on negative process outcomes that are calculated historically in industry-relevant metrics, such as collisions or fatalities per million passenger-kilometres, to inform their safety management strategy. By their nature, so-called high hazard industries, such as railways, encounter a small number of high-potential and a higher number of low-potential adverse events (Statista, 2017 and RSSB, 2013c). Merely counting the number of these events will not provide a reliable indication of the system's intrinsic safety.

Since there is no frequency or severity patterns associated with such accidents, Reason (1997) warns against this retrospective approach because "… the large

[7] This is Reason's (2000) term for the latent triggers that are associated with active failures.

random component in accident causation means that 'safe' organisations can still have bad accidents and 'unsafe' organisations can escape them for long periods" (p.108). Lauber (in Hall, 1997) captures succinctly the weakness of retrospective analyses in his statement that "The absence of accidents does not necessarily indicate the presence of safety" (p.2). Risk modelling provides an alternative analytical technique to assess prospectively the underlying safety of the system (ERA, 2015).

1.4 Writer's Motivation for the Thesis

The writer embarked on this research for vocational as well as academic reasons. He held specific responsibility for the operator training function at I.É. for the nineteen year period to 2012. Under his direction, a group of fourteen Staff Trainers designed and delivered a suite of training programmes. He realised that some of the training and education delivery processes that he had experienced during his own personal development could be applied beneficially to his work situation. Specifically, he came to value practice based *learning*, and to realise that training the basic skills merely was insufficient; *non-technical skills* (NTSs) needed to be developed also. This change in mindset was accentuated by the developments that were occurring in the use of electronic tools for training safety critical staffs in other hazardous industries. He believed that if training effectiveness was to improve in I.É., significant investment would have to be made in the function.

The writer was conscious that, in the past, accident inquiry teams tended to focus on the proximate causes of accidents. In more recent times, their attention has focussed on those substandard conditions that support, unwittingly and unintentionally, the substandard acts which underpin accidents (Heinrich in Leveson, Stringfellow and Thomas 2012). An ineffective training process is one such substandard condition. It was in the writer's self interest to ensure that all training programmes were fit for purpose, that they developed skills in the psychomotor, *cognitive* and *affective domains*, and that they were effectively and efficiently delivered. Conscious of the weighty burden of this personal responsibility[8], the writer persuaded the Board of I.É. to sanction a capital expenditure of €4·9[9] million and associated annual recurrent costs of €150,000 to procure, and operate subsequently, a driver training simulator system. This investment initiative contextualises this study. The questions that were posed by the Board of Iarnród Éireann, which formed part of its due diligence examination of the project, facilitated the framing of the research questions for this thesis.

1.5 Structure of the Thesis

The body of this report is structured into five sections.

The milieu of I.É., and the context and nature of the traction driving task are presented in Section 1 which comprises Chapters 1 and 2.

Section 2 comprises Chapters 3, 4 and 5. Relevant cognitive psychology constructs, and the organisational value and costs that are associated with the provision of training, are examined. The general methods that are used to identify *training needs*, and the specific process that was used to reveal the required *scenarios* for inclusion into I.É.'s lesson plan, are discussed. A key success factor, i.e., a reduction in SPAD occurrence, is furnished. The section culminates with presentations of the simulator enabled lesson plan and associated delivery process. The thesis findings are founded on these.

The manner in which the lesson plan and delivery process were realised is discussed in Section 3, comprising Chapters 6 and 7. A general discussion on training simulators, culminating in an overview of the options that were selected by I.É., is presented. The writer explains the rationale underpinning the key choices exercised by I.É. in its procurement specification and also I.É.'s strategic imperatives for the project.

Section 4 comprises Chapters 8, 9 and 10. The study's constraining context, and the consequentially-necessary methodology that was used to answer the

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[8] This is not a unique stance for people in the writer's position to take. In a survey by Little (2004), 50% of the respondents stated that they would worry about their personal liability if a safety problem arose as a result of their decisions.
[9] At the 'final account' stage of this project, €4·6 million of this amount was spent.

fundamental research question, is outlined. Using the perspective triangulation approach to assess the project's outcomes, the writer provides answers to other aspects of the research questions. Project findings, relevant to others who may be tasked with the introduction of *simulation* within their own organisations, are also presented.

Section 5 comprises Chapter 11. In this, the writer reviews the approach that he used for the study. He also makes suggestions on the possible areas and approaches for further research, aimed at improving the reliability and generalisability of this study's findings, and makes his concluding remarks.

An overview of the thesis, showing the main points contained within each chapter and the associated objectives, is presented in Table 5.

Table 5: Thesis Overview

Chapter	Main issues within chapter	Objectives
Ch 1: Introduction	1) Commercial and safety performances of I.É.; 2) Accident inquiry approaches; 3) Retrospective and prospective analysis of safety performance; 4) Personal motivation.	1) To provide organisational and personal contexts; 2) To propose the use of risk models as a means to differentiate historical safety performance from underlying risk.
Ch 2: The Changing Nature and the Complexity of Train Driving	1) The changed nature of the traction driving task; 2) The concept of socio technical systems.	To show the relatively cognitively complex nature of the driving task.
Ch 3: General Cognitive and Developmental Aspects of Training	1) Relevant cognitive psychology constructs; 2) Constraints around providing experiential training in a live operating environment; 3) The need to provide relevant artefacts in the simulated environment.	To illustrate how simulator enabled training accords with cognitive psychology constructs; thereby facilitating improvement in learning.
Ch 4: Providing Opportunity to Learn	1) The value of training; 2) General and specific costs of providing training; 3) Ensuring safe performance; 4) I.É.'s concern with the extant process; 5) Gaining confidence to transition from the extant process.	To furnish the main reason for changing the extant training process.

Chapter	Main issues within chapter	Objectives
Ch 5: Training Needs Analyses, Scenario Development, the Lesson Plan and Training Delivery Strategy	1) Types of training needs analyses; 2) The approach adopted by I.É. to develop the scenarios; 3) I.É.'s internal standards, and external regulation; 4) Non-technical skills; 5) Furtherance of learning using non-jeopardous means; 6) Contextualisation of operating anomalies; 7) The composite lesson plan.	To present: 1) The reason why the particular study type was adopted; 2) The contextualised lesson plan which is aimed at developing technical and nontechnical skills; 3) The reasons for the overall delivery strategy.
Ch 6: Types of Simulators and Fidelity	1) An overview of the range of simulator equipment available to purchasers; 2) Maintenance and upgrade costs; 3) Insights into egospeed and the concept of presence; 4) Essential realism.	To present: 1) Issues surrounding cost/value trade-offs for the range of simulators and an overview of the type purchased by I.É.; 2) Concerns in respect of speed misperception and psychological fidelity in the context of assessment.
Ch 7: Contribution of Literature Review: description of I.É.'s project	1) Matching system elaborateness with training needs; 2) Identification of features that add or detract from the overall system; 3) Garnering operator acceptance; 4) Strategies used to ensure that the project would succeed at the contract, design and use phases; 5) Systems engineering approaches; 6) Detailed description of the project's scope, deployment and necessary accommodation.	1) To highlight where costs may be incurred and value may be extracted at the specification, procurement and use phases. 2) To show the elegance and scope of the procured system which determine the cost of the project and affect IRR values.
Ch 8: Study Methodology	1) Context of study; 2) Managing operational safety risk; 3) I.É.'s Network Wide Risk Model; 4) What the service user, and the service provider is willing to pay for safety improvement (VPF, and PF times VPF respectively).	To show: 1) The overall methodology used in the study; 2) That the VPF and PF used in this study, and generally used by I.É., is not out of kilter with that used for other project evaluations.
Ch 9: Measurement of Outcomes	The stakeholder constituency approach is used to show the effectiveness of the revised training process as perceived by the public, the operators, the organisation, the regulator and the Government-appointment auditor.	
Ch 10: Other Findings from Project Implementation	What worked well, didn't work or was suboptimal in terms of the commercial aspects, strategic intent, equipment attributes, usability and use cases	To provide guidance on a range of practical issues to railway operations training officers who may be tasked with managing the introduction of simulation
Ch 11: Conclusions	1) Research methods used by the writer; 2) Suggestion of additional areas of inquiry, and alternative approaches for the conduct of further research; 3) Concluding remarks.	

1.6 Conclusion

Railway activities are prescribed and embedded in rules, processes and logical systems. These are given effect by highly trained operators who are dispersed throughout the system. The operators have to rely on their own internal resources and capabilities when the engineered subsystems become faulted. Railway companies hold a duty of care to those parties who are affected by its activities and management needs to be able to demonstrate the discharge of this duty. Proactively enhancing training delivery is an obvious manifestation of the discharge of management's duty of care. However, management's obligations are somewhat counterbalanced by corporate governance responsibilities. Expenditure incurred in the discharge of its obligations must deliver value that is commensurate. The use of risk modelling techniques to assess the extent of the delivered value resulting from investment decisions, most relevantly those relating to driver training, is appropriate.

In spite of the degraded state of its extant asset base, I.É. had a reasonably good safety record but the underlying trend in accident precursors was worrying. After a long period of underinvestment, I.É. received external funding to improve all elements of its system. Without an acceptance that its driver training process required modernisation, I.É. may not have been in a position to procure its simulator system. The investor's munificence was not unconditional and all expenditure was subject to prospective and retrospective audit and critique.

Although, I.É. is absolutely fervent in the discharge of its duty of care through the implementation of its Safety Case, the *RSC* is now well resourced to ensure compliance.

2 The Changing Nature and the Complexity of Train Driving

In the previous chapter, the writer provides organisational context. In this chapter, the writer describes the task and context of the traction driving role; these determine the skills that need to be developed and the necessary content of the training programme.

Trains move with one degree of freedom. Directional control is provided by the fixed properties of the trackwork and by the actions of the controlling *signalman* on the variable route elements (Moray, in TRB, *eds*., 2006b). However, train driving is not just about moving and stopping a train on the tracks; the task is much more complex than this (CRC for Rail Innovation, 2013b) and it has evolved constantly over time. In the early phase of the evolution of the task, it comprised a large physical component. In the latter stage, it has become more complex and "... progressively dominated by cognitive and perceptual skills" (Tichon, 2007, p.177). This perspective on the evolution of the driver's role is endorsed by RSSB (2009a) who perceives it as loosely approximating to that of an aircraft pilot "... knowledgeably monitoring indicators and intervening when systems fail or have to be overridden" (p.62). (See also Naweed and Aitken, 2014; and Balfe, 2017.) The skill development objectives and, hence, the content of the driver training process must reflect the context and content of the task.

This chapter is divided into six sections, dealing with:

- 2.1 The Evolution of the Train Driving Activity;
- 2.2 Task Complexity;
- 2.3 Task Context and its Ramifications;
- 2.4 The Nature and Elements of the Train Driving Task; and
- 2.5 Evolution of the Design of the Job.

Concluding remarks are presented in Section 2.6.

2.1 The Evolution of the Train Driving Activity

The task of train driving is steeped in history and tradition. Custom and practice set the context for train working. There are three discernible phases in the evolution of train driving.

2.1.1 The Steam Era

In the era of steam traction, from 1834 to 1956 in the case of I.É., boys as young as 14 years of age were recruited into the railway. These recruits tended to have a very basic education and performed the function of engine cleaners initially. They also assisted maintenance craftsmen to carry out repairs[10]. After a period of about a year, they were passed out for firing duties, and fired locomotives for short runs and shunting activities. This arrangement created a pool of contingency firemen who could be called upon at short notice. After about 10 years, a cleaner would obtain a full time fireman's appointment. Subsequently, they were passed for limited driving duties. This was a milestone in the individuals' careers. After a long period of satisfactory service at this task and at about 40 years of age, they would become mainline drivers. At this stage, they would have to take their place on the drivers' roster as the most junior men and would work their way through the link structure until becoming top link drivers on express passenger working.

The training process was not as inefficient or backward as it might appear at first glance. Although the training period was long, *trainees* were fulfilling productive roles as part of the two man crew. The foresight, understanding and contribution of the Associated Society of Locomotive Engineers & Firemen (ASLEF) at this early stage of the development of the driver training process deserve special mention. ASLEF recognised the contribution that traction models could make in the training process and, in 1887, set aside £100 for their purchase (RSSB, 2009a, pp.23-24).

The system facilitated staged progression from initial learning through to unrestricted operation by keeping newly qualified drivers out of harm's way by restricting their driving to those times and situations that are known to be lower risk, i.e., by avoiding night time driving, possession working, and complex track layouts and signalling arrangements. It also allowed drivers to gain *experience* on lower speed operations, with attendant lower driver-error frequencies, before

[10] The situation in Britain was different. There, opportunity for personal development was provided through mutual improvement classes. These classes developed basic reading skills which facilitated book learning. They also provided knowledge on traction operation (RSSB, 2009a).

driving higher speed trains. The increased risk, associated with express operation is evident in the human reliability study by RSSB (2004a). The error probabilities for a range of incident precursors, for various types of train operation and associated stages of career progression are shown in Table 6.

Table 6: Driver-error Probabilities by Type of Train

Error	Freight	Commuter	Express
Misread signal	$12X10^{-6}$	$6X10^{-6}$	$44X10^{-6}$
Misjudge braking	$14X10^{-6}$	$32X10^{-6}$	$65X10^{-6}$
Mis-recall signal *aspect*	$40X10^{-6}$	$200X10^{-6}$	$1,170X10^{-6}$
Omit *station* stop	N/A	$20X10^{-6}$	$75X10^{-6}$
Place on I.É.'s drivers' link structure[11]	Freight link	Special link	Top link

Adopted from: RSSB (2004a)

As a driver negotiated his way through the long developmental process, he learned a great deal incrementally, albeit in an informal way, about the task and its context before he was ever placed in the highly responsible position of operating a high speed train. This training process was the epitome of the classic learning by association mechanism, where the 'apprentice' (equivalent to a fireman) learned from the 'master craftsman' (equivalent to the driver). However, the limitation of this type of process comes to the fore when there is an urgent need to train large numbers of drivers, and when limitations are imposed by route availability and rules on *footplate* occupancy. The process of learning to drive steam traction was facilitated by the prevailing technology which necessitated two people to be present on the footplate, one to drive and the other to 'fire'[12] the locomotive. Although a physically demanding process, it had complementary benefits. Reason (in Wallace *et al*., 2000) points out that "… many of the antidotes to *vigilance decrement* were unwittingly present on the footplate of a steam locomotive… the system kept the driver alert through the additional auditory stimulation and the presence of [the secondman] in the cab" (p.11). (See also Lyons, 2005.)

From a business management perspective, this training process had a very long lead-time and required long term planning to ensure that there were sufficient

[11] Until 2000, the normal sequence of progression for I.É.'s drivers was (1) shed duties, (2) pilot duties, (3) night-time freight trains (the freight link), (4) daytime freight operation and commuter trains (the special link), and (5) high speed trains (the top link).
[12] Ensuring that there was a sufficient amount of traction medium available with respect to the trailing load, schedule and gradients etc.

drivers available to satisfy future business needs. In addition, the amount of productive time on top link duties, as a proportion of a driver's overall career, was relatively small. At the end of the steam era, the physical work element of the drivers' role decreased and, in essence, drivers became information processors. The resultant potential to redeploy resources, from motor to cognitive demands, was seen as a positive development. If less *attention* is given to some elements of the driving task, more attention can be given to attending to stimuli which are crucial to the driving task (Buck, 1963). A 1948 report by the Railway Executive (in RSSB, 2009a) was less positive about the changes that the transition would bring; noting that "Diesel and electric train driving would be 'more monotonous' but healthier and more comfortable than steam locomotives" (p.34).

2.1.2 The Transition Period

In the mid 1950s when diesel or electric traction became the preferred methods of operation, the type of training process outlined above became obsolete. The need to have a secondman on the footplate no longer existed. However, there was a cohort of extant firemen who no longer had productive work but whose knowledge base was not totally redundant. These were reassigned to the grade of 'secondman' or 'driver's assistant' (in Britain). As part of the transition process, credit was given for the knowledge and experience that they already possessed. Accordingly, they undertook a special conversion training programme which lasted about 27 weeks and covered drivers' rules, basic traction and the principles of route learning (RSSB, 2009a). Accounts are frustratingly deficient on the rationale underpinning the design process for the conversion programme. For completely new entrants, the training process lasted over 2 ½ years in Britain (3 years in Ireland); a duration that was seen as exorbitant to management.

2.1.3 The Recent Past

It was not until the late 1960s that an attempt was made by I.É. to formalise and standardise its training process. In Britain, the MP12 programme of 1973 was the first formally structured national driver training programme. Even the logic underpinning the MP12 programme was flawed conceptually. It was developed through negotiation between British Rail and the trades unions; the latter's contribution centred on hygiene factors[13] rather than programme content. It was not based on any standard that had defined objectives and measurable outcomes (RSSB, 2009a, p.40).

It was not only the nature of the driving task, and the structure and duration of the training process that had changed since those early days; the demonstrable standard of care demanded from public transport providers had altered beyond recognition. In the earlier days, the internal workings of the railway were subject to internal scrutiny by and large; external regulation was less invasive and was typically confined to the investigation of fatal accidents.

The range and sophistication of *traction units*, train control systems, on-board traction management systems, contracts of employment and expansion of duties[14], and interactions of the driver within the overall system railway have all changed radically. It should be noted also that variance exists in the scope of the drivers' roles in railways that are structured differently. In disaggregated non-vertically integrated systems, such as prevails presently in Britain, drivers specialise in driving specific types of trains over limited geographic regions. This specialisation by route, traction and rolling stock type does not exist in a vertically integrated railway, such as in Ireland. The only segregation that exists in I.É. is between the inner suburban (DART business unit), and the mainline and outer suburban activities. Other than this exception, I.É. drivers drive a multiplicity of train and traction types over a number of routes. There are ramifications for training providers resulting from differences in operating methodologies, e.g., the scope of training required, the comprehensiveness of the training tools, and the range and maintenance of the operational competencies of the instructors.

2.2 Task Complexity

After an extensive review of the writings of contingency theorists, McKechnie (1990) attempts to distil the characteristics of task systems. He identifies four characteristics that determine their complexity. He uses the terms heterogeneity,

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[13] This term is used in the context of Frederick Herzberg's motivator-hygiene theory.
[14] Duties expanded with the blurring of lines of demarcation and the espousal of *driver only operation*.

interdependence, variability and unanalysability to describe them. Although McKechnie's suggested use of this framework is to determine overall task complexity for the purpose of organisational design, the writer believes that it is insightful to use the framework to analyse tasks generically.

McKechnie (1990) uses the term heterogeneity to define the number of distinct subactivities being performed within an integrated system of tasks. Rasmussen and Lind (1981) suggest that it is not solely about the number of activities; the amount of possible courses of action available when performing them should also be considered. A scenario where there are only one or two responses is less complex and demanding than one where many responses need to be considered prior to making a decision. The number of subtasks and, hence, the number of decision points involved in train driving is substantial but the number of permitted courses of action for any particular decision is limited through the imposition of prescribed rules and procedures.

The term interdependence is used to denote the degree of interrelationship between the sub-activities, or the closeness of coupling as Perrow (1999) calls it. There are three forms of interdependence, i.e. pooled, sequential and reciprocal interdependence. Task complexity increases according to this typology. In the case of pooled interdependency, the tasks contribute to a common pool without any other direct point of contact between task contributors; they are loosely coupled. In the case of sequential interdependence, there is a one-way reliance on prior activities, such that activity 'A' must occur before activity 'B' and both of these must occur before activity 'C'. Sequential interdependence is characteristic of production settings. Railway operations are typified by reciprocal interdependence; they are tightly coupled. Reciprocal interdependence occurs at the technological and human levels. At the technological level for example, a train must be verified as being in a particular location before a signal is replaced to danger and before the route can be altered. Likewise at the human level, the amount of interdependence between the train crew, signalmen, station staff and the traffic regulator is high and is a function of the level of service. More trains equate to more interdependence (Krueger *et al*., 2000). Various grades of railway operators perform tasks that have a direct bearing on each other. These grades have their own culture and mental models. In recognition of the importance and extent of interdependence, joint training interventions are provided in some railways, e.g., for *pilotmen* and safety critical communications. Perrow (1999) highlights the effects of job demarcation, lack of cross functionality and job specialisation, on interdependence particularly during periods of system degradation. He suggests that unanticipated interdependencies are more likely to emerge when the system has developed a fault as "... those operating the system are less likely, because of their specialised roles and knowledge, to predict, note, or be able to diagnose the interdependency before the incident escalates to an accident" (p.87).

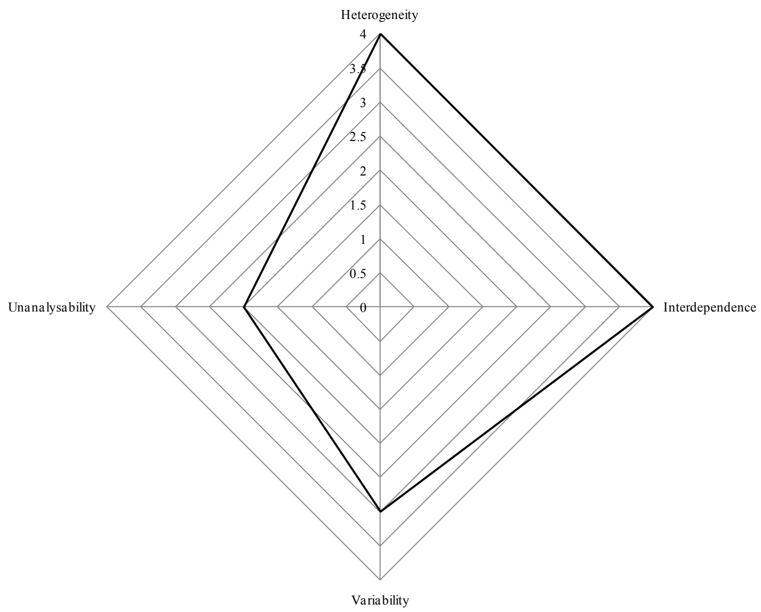
Synonyms for variability include novelty, instability and unpredictability. These terms are used to describe the extent to which the tasks must depart from a constantly recurring pattern. High variability forces the application of new or different forms of task activity. The writer disagrees with McKechnie (1990) that "... this does not necessarily present any serious difficulty" (p.5). On the contrary, the writer concurs with Hughes' (2004) views that "It is clear... from the analysis carried out, that abnormal working [the epitome of variability] is a significant contributor to safety risk on the railway" (p.43). Railway operations suffer from high variability that is brought about by unforeseeable events, degraded asset condition, as well as the actions of internal and external stakeholders. Traditional thinking attributes human unreliability to unwanted variability and attempts are made to eliminate it as much as possible (Reason, 2000a). In more modern thinking, it is accepted that the ability to compensate and adapt to changing events is one of the system's most important safeguards. See Moray (in TRB, *eds*., 2006b); and Prince and Salas (in Endsley and Garland, *eds*., 2000). High reliability organisations are prepared to respond to changed environmental and operating conditions.

Unanalysability refers to incomprehensibility, uncertainty, and difficulty in establishing cause and effect relationships. The entity is absent where the tasks are so well understood that they can be performed by anyone with little or no training.

At one end of the scale, anyone who applies common sense, based on average intelligence and everyday experiences, is well capable of performing the task. At the other end of the scale, special training or experience is necessary. Perrow (1999) highlights the relevance of this construct to the safe operation of complex systems, such as railways, by suggesting that:

> "... as systems grow in size and in the number of diverse functions they serve... increasing their ties with other systems, they experience more and more incomprehensible and unexpected interactions. They become more vulnerable to unavoidable *system accidents*" (p.72).

However, from the driver training perspective, the tasks are well understood and the consequences of underperformance are well known. An amalgam of the four constructs of complexity, as applicable to the system railway, is provided in Figure 3 below.



Source: Schmid *et al*. (2002)

Figure 3: Complexity of the Traction Driving Task

2.3 Task Context and its Ramifications

Being a train driver involves erratic working patterns and the conditions of service vary from one railway company to another. All drivers work to some form of shift pattern. Drivers of passenger services have the most benign pattern which is determined by the times when customers want to travel. In order to maximise the productivity of the assets, freight trains are operated generally at night. Similarly, maintenance of the permanent way is carried out in such a manner as to minimise service disruption. Those depots which provide drivers for freight working and for the maintenance function have a high incidence of night working and weekend working. This work pattern is asynchronous to the body's circadian rhythms and, for social reasons; some people are reluctant to make a career out of such a job. The combination of the job characteristics, shift work, and reducing experience profiles creates risk.

The minimum age for a train driver to operate on Network Rail lines (UK) is 21; London Underground and RailCorp (Australia) employ drivers from 18 years of age. I.É. complies with the stipulations contained in the European Union Directives OJEU (2007) and OJEU (2006)[15]. As the provision of training to drivers is an expensive necessity, understandably, companies want to maximise the return on their investment. In order to recoup the high costs associated with training, it is desirable to recruit a driver at the youngest age possible and retire him at the oldest age possible.

Not everyone holds a romantic view of a train driver's job. It is generally accepted as being boring but very responsible (HEL, 2006; Whitlock, 2002; Kecklund *et al*., 2001a; DERA, 2000; Wallace *et al*., 2000; Edkins and Pollock, 1996; Wilde and Stinson, 1983; and Buck, 1963). Bainbridge (in Rasmussen, Duncan and Leplat, *eds*.1983) is more emphatic in her view; believing that an automated job which requires a lot of monitoring, such as, in a control centre or train driving, is one of the worst types. The potential repercussions of such job characteristics are evident in Smiley's (1990) report into the underlying causes of the railway accident at Hinton[16]. She hypothesised about the effect that the nature of the task had on the accident, noting that "… *monotony* and frequently low task demands

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[15] OJEU C227 E mandates that "Applicants shall be at least 20 years of age. However, Member States may issue licences to applicants from the age of 18 years, the validity of such a licence then being limited to the territory of the issuing Member State" (p.486).

[16] On 08th February 1986, 23 people died in an accident following a SPAD on a single line track in Alberta. The brakes were not applied on either train even though both trains were visible, each to the other, for 20 seconds beforehand. Two crewpersons were on the footplate of each locomotive.

together with adverse organismic and workplace conditions, suggest that lack of vigilance may be an underlying factor" (pp.87-88). The effects of monotony are exacerbated if drivers have to contend with short periods of intense activity in the midst of long periods of low engagement (Dunn, 2011). Moray (in TRB, *eds*., 2006b) describes the situation as "… long hours of *boredom* interrupted by moments of panic" (p.88). HEL (2006), Otterstad (2006), and Edkins and Pollock (1996 and 1997) provide evidence that this work pattern creates attendant risks. Their studies demonstrate the relationship between drivers' loss of attention, and SPAD[17] and accident[18] occurrence.

2.4 The Nature and Elements of the Train Driving Task

Train driving is a dynamic control and decision making task. According to Colford (2004), the activity is characterised as a "... continuous cycle of acquiring information, making decisions based on that information and acting on the decisions" (p.4). A distinction must be made between the information that the driver collects from either the external or internal cab environments, and the explicit, implicit or haptic information which he retains either in his head or in his hands (Nonaka and Takeuchi, 1995). The decision making element is a "... a blend of situation awareness, automated cognitive processes, recognition, working memory limitations and dynamic decision making" (Jansson *et al*. (in Wilson *et al*., *eds*., 2005), p.44).

Typically, the tasks and duties associated with traction driving are set out in the companies' instruction manuals. The contents of Porter's (in Whitlock, 2002) task analysis are presented in the first portion of Appendix 3. In the writer's view, such task analyses are at a basic level of abstraction and provide only limited value as they:

1. Do not address the cognitive or affective elements of task performance in any detail;

[17] Over 47% of those SPADs that were attributable to human factor issues were due to drivers' loss of attention (Otterstad, 2006).
[18] Attentional factors were implicated in almost 70% of train accidents (Edkins and Pollock, 1996 and 1997)

2. Porter's analysis is based on the normal operating mode only and does not include degraded, emergency or *out-of-course working* modes. The potential pervasiveness of system degradation is evident from Appendix 4. Each form of degradation requires specific non-routine operator input.

In addition to the basic requirement of being sufficiently manually dexterous to operate a range of hand and foot controls, drivers also need another set of skills, viz.:

1. The ability to think ahead and anticipate the effects of their intended actions (RAIB, 2007b);
2. Appropriate, not necessarily fast, response time. However, Anon. (2002b) suggests that "... applicants for driving work are able... to react quickly and in compliance with safety requirements to changing situations" (p.11). The view of CAS (2006) is more, but not completely, aligned with the writer's view, suggesting that "... reacting safely is seen as a crucial ability for drivers but speed of reaction is not thought to be so important" (p.17). The writer disapproves of the use of the term 'react' by the two researchers. Instead, he believes that drivers need to respond to *cues* by directing conscious cognitive effort and not merely reacting in an unconscious manner;
3. The ability to maintain vigilance and concentration (Mills and Grimes, 2008);
4. As driving is primarily a visual task, drivers need good observational and perceptual skills (de Winter *et al*., 2007; Glendon *et al*., 2006; Brock (in TRB, *eds*., 2006a); Kwon *et al*., 2006; Luke *et al*., 2005; Pardillo and Troglauer, 2005, Allen *et al*., 2004; Naef, 2002; Harrison, 1999; Drummond, 1989; FRA, 1998); and
5. The ability to integrate information from their environment with information recalled from the short and long term memories, in order to support the decision making process (Kecklund *et al*., 2001a; and Kecklund *et al*., 2001b). Tichon (2007) suggests that the generation of options is an integral part of recognition primed decision making which "... requires retrieval of information from long term memory, such as prior experience of similar conditions" (p.180). Obviously, if the decision maker does not have access to a

comprehensive range of recallable experiences, the most appropriate response may not even be considered and the resultant actions may not be optimised.

In general, the driving task requires the application of a blend of psychomotor, cognitive and affective skills. The psychomotor domain includes physical movement, coordination and motor skills. The cognitive domain concerns knowledge and intellectual capability. It includes the abilities to recall, comprehend, deconstruct, synthesise and evaluate (Bloom, 1956). The affective domain consists of behaviours corresponding to attitudes, awareness, interest, attention, concern, responsibility, and the ability to listen and respond when interacting with others (Morrison, 2003). In Table 7, the writer presents his view on the relative mix of these skills that are necessary for the task of train driving.

Table 7: Different Skill Domain Development Requirements

Ability	Amount required for train driving
Psychomotor	Low
Cognitive	Medium
Affective	High

I.É.'s composite lesson plan, described in Chapter 5, is based on the holistic development of these skills.

2.5 Evolution of the Design of the Job

Job design is the specification of the tasks that role holders must perform to execute their duties. Job redesign can either reduce or increase complexity. Over the years, some job redesign initiatives for traction driving have taken place which have added complexity. Hellreigal *et al*. (1992) identifies five different approaches to job design. These include job rotation, job engineering, job enlargement, job enrichment and a sociotechnical systems approach.

I.É.'s drivers have participated in the job rotation process since the acceptance of a 'one rotating link structure'. In-so-far as their certification permits, they drive different classes of traction and trains, over different routes. The job of the driver is constantly subjected to job engineering principles as management seeks to achieve productivity gains through tighter linking and rostering arrangements. Traditionally, the job of the driver was highly demarcated and narrowly defined;

the driver was responsible for the traction unit, the shunter was responsible for putting the train together, and the guard was responsible for the operation of the train and maintaining the conduct of the passengers. The development of technology blurred some of this delineation of responsibilities. The advent of driver-only operation was facilitated by the features that were incorporated into the design of diesel and electrical multiple units and *push/pull* trains. This obviated the need for shunters and guards, and the drivers' job was enlarged to subsume some of their responsibilities, i.e., marshalling, door operation, train starting procedures, normal and emergency passenger communications, and train *protection* arrangements.

Job enrichment allows employees to assume more responsibility and accountability for planning, organising and controlling their own work. If implemented with sincerity, it can increase operational effectiveness. The underlying principle is that the people who know most about the subtleties of the task are those who perform it routinely. Within I.É., drivers' groups draft operating links, review timetable alterations, participate in focus groups, assist in the anthropometric aspects of new traction unit design (fitting trials), participate on signal sighting committees and, most germane to this thesis, provided valuable advice during the specification and acceptance phases of I.É.'s simulator acquisition.

Social and technical systems need to be designed with respect to each other. The fundamental precept is to get the best possible match between the people, the technology and the organisation. Railways meet the classic criteria for being defined as a sociotechnical system (Wilson *et al*., 2007). Cullen (2001a) recognised the importance of adopting a sociotechnical approach in respect of train driver management and training. On foot of his recommendation, the rail industry commissioned a large amount of high quality railway-specific *human factors* research.

2.6 Conclusion

The job of traction driving has evolved over time. The required skill set has changed from being one with a large physical component to one that has become increasingly cognitive in nature. Coupled with solo footplate occupancy and the fundamentally boring nature of the work, this change has created problems in terms of the maintenance of vigilance and concentration. These problems are additional to those caused by the inherent complexity of the task, most particularly, due to system variability and interdependence with other system actors.

From a training provider's perspective, it is essential to ascertain the full range of subtasks that drivers need to perform the role both routinely, and exceptionally. However, knowing what a driver does and the associated rules is insufficient. It is also necessary to identify the cognitive processes underlying task performance and understand their potential to affect human reliability. An understanding of current risk types, and an acceptance that some risks are imposed by the intrinsic qualities of the job as much as by personal attributes, has resulted in the adoption of the sociotechnical system approach. Railway organisations now take a more human centred and proactive approach to safety management. Training functions have changed their approach accordingly and the training content is now based on the 'soft' issues as well as the 'hard' ones.

Much to their credit, the early proponents of driver training recognised the value of using models for training purposes. However, these were used to provide training in the cognitive domain only. In latter times, modern simulators with their enhanced capabilities replaced these mechanical dioramas which allowed their usage to be extended to develop skills in all domains of learning. As there is such an obvious visual component associated with the driving task, modern simulated environments must cater for this.

3 General Cognitive and Developmental Aspects of Training

Because training is a supporting rather than a primary activity in the organisation's value chain, it is generally beyond the strategic gaze of senior managers. They are interested in the inputs and outputs of the activity and, perhaps because of their backgrounds, they are less concerned about the associated conversion process. More gracious writers might suggest that they entrust this element of the activity to knowledgeable specialists. However, few of the training managers with which the writer is familiar hold a formal qualification in education or have a background in academia; they tend to be subject matter experts or are management generalists. Consequently, it is unsurprising that in their study, McGuffog *et al*. (2006) find that there is a general absence of strategic thinking for the future development of training within the rail industry. Specifically, they highlight the lack of understanding of the difference between training and instructing activities; asking the question as to whether the industry "... needs trainers or just people to instruct" (p.35). Understanding the fundamental differences between these activities is crucial for an organisation that is considering a transition away from traditional training delivery to embrace the alternative facilitative approach that forms the central plank of this thesis.

In the previous chapter, the writer provides insight into the nature of the driving task, and the development requirements. In this chapter he reviews some cognitive psychology theories and constructs that underpinned the transformation of I.É.'s training process. This review serves three complimentary purposes. Using some of the constructs, the extant training delivery process can be assessed and compared with simulator enabled training for appropriateness and adequacy. Other constructs reveal some of the influencers of operator behaviour and, hence, provides insights to aid the effective completion of a training need*s* analysis. Finally, more of the constructs assist in the identification of top level features for inclusion in the specification of a simulator system which will lead to more effective subsequent utilisation. Ten cognitive psychology constructs and topics, relevant to traction driver training, are discussed in this chapter:

3.1 The Difference between Education and Training;

3.2 Experiential, Experimental and Contextual Learning;
3.3 The Nature and the Extent of Necessary Experience;
3.4 Inadequacies in the Extant Process;
3.5 Learning Styles and Training Delivery Strategies;
3.6 Mental Models: the training challenge;
3.7 The Social Dimension of Learning;
3.8 Mastery;
3.9 Distributed Cognition; and
3.10 The Necessary Qualities and Skills of Training Professionals.

Concluding remarks are presented in Section 3.11.

3.1 The Difference between Education and Training

Handy (1989) recalls his early education and concludes, in a tongue-in-cheek fashion, that the objective of the experience was the transfer of 'answers' from the teacher to himself. He perceives himself as being a passive participant in the knowledge acquisition process. Disingenuously, Handy adds that he had learned nothing from the process, choosing for the purpose of his argument, to disregard the fact that he had learned the most fundamental attribute of education; he had learned how to think critically! By contrast, training interventions are not intended to develop logical thinking nor *critical thinking* skills. Depending on the future role of the training recipient, this level of development may be superfluous or even undesirable. Train drivers need to be able to apply pre-formulated rules rather than construct new ones. Critical thinking is not required in those situations where extant explicit rules can be applied; training is the appropriate intervention. However, the training requirement extends beyond preparedness for rules application.

Training and education are not dichotomous entities. On the knowledge acquisition continuum, the relationship is complimentary and synergistic. Education levers off the 'know how' in order to facilitate the development of deeper 'know why' skills and, hence, facilitates the transition from skill and rule based behaviour to knowledge based behaviour. CRC for Rail Innovation (2008) recognises the need for this transition; concluding that "... reliance on rules has the effect of deadening risk awareness… an important competence." (p.10). Wallace *et al*. (2005) highlight the progressive nature of skill acquisition and performance improvement "... as the learner moves from being knowledgeable to prepared, to trained, to skilled, to *expert*" (p.vii). An evaluation of the strengths and weaknesses of simulators for the various stages of skills acquisition and performance enhancement is contained in Appendix 5.

3.2 Experiential, Experimental and Contextual Learning

Kolb (1984) emphasises the value of learning-by-doing in real life situations. His cyclical theory is based on the learner's application of newly developed concepts which have been derived from reviews of previous actions undertaken by him. It is premised on an explorative trial and error principle in order to create a knowledge spiral. The combination of Kolb's model with the taxonomy of Bloom *et al*. (1956) highlights the necessity to provide practice based learning opportunities across the three skill domains. Making mistakes is an inevitable by-product of the learning-by-doing process but this drawback is not entirely wasteful; learning opportunities derive from mistakes (Eichinger, 2004 and Handy, 1993). Although the concept of learning-by-failing may be acceptable when performing non-critical activities, it is unacceptable in the context of live railway operations. Through the use of *virtual reality*, this limitation of Kolb's learning cycle disappears as employees can be provided with the opportunity to make mistakes in a risk free environment.

This view of the benefit, derivable from the use of simulation to learn by failing, is not accepted without qualification. For example, Haworth *et al*. (2000a) opine that the lowered psychological fidelity, present in a simulated environment, together with the absence of attendant consequences, detract from the value of the learning experience. The mode of simulated scenario presentation also influences the extent of learning achieved. Using one presentation mode, scenarios are managed to accept all *operator* inputs; even incorrect ones. The scenarios are allowed to unfold to their logical conclusion whatever that may be. Using the other presentation mode, a simulator is used to provide directed learning, i.e., to train only the desired attributes and behaviours for a task. In this mode, the instructor suspends the scenario prior to the occurrence of a catastrophic event resulting from a trainee's incorrect inputs. (See Croft *et al*., 2000.) In discussing the training process of aircraft pilots, Croft *et al*. (in Catchpole *et al*., 2001) criticise the traditional practice used by instructors of "... lightening the load in *line oriented flight training* scenarios to assure a positive outcome (and thus creating a crew confidence boost)" (p.56). This well-intentioned approach was adopted so as not to put trainees into situations where they were operating outside of their capabilities which would induce under-confidence. It also served to ensure that the training sessions operated to the delivery schedule, and to obviate the need for a simulator reboot[19] following the inevitable 'accident'. The folly of this approach was recognised subsequently and the instructors now present the training scenarios from which trainees are unlikely to recover. Hence, the emphasis of this training has changed from one that discouraged the development of under confidence to one that encourages learning-by-failing. It is the writer's opinion that the second mode of scenario presentation, i.e., providing directed learning only, represents a lost opportunity to learn-by-failing. Pardillo and Troglauer (2005) agree with this position, stating that "... it is better to use more demonstrations and exercises in which novice drivers fail in order to develop a realistic self-evaluation of their capabilities" (p.11). (See also Pardillo, 2008.)

Kolb does not consider the time element or efficacy of the experiential learning process; criteria that are important to those who manage training delivery. The writer agrees with Handy (1993) who notes that learning by experience can be a painful, tedious and inefficient [but effective] process. However, just as it provides a solution to the 'learning-by-failing' challenge, the use of simulation can resolve this issue also by exposing learners to a large number of new experiences within a concentrated timeframe. But this facility to accelerate experience does not come without a financial cost (Wallace *et al*., 2005).

[19] I.É.'s simulator freezes when particular incidents occur, e.g., when trains collide, reach the end of the modelled line or when they derail. The occurrence of such incidents does not require a reboot of the system. Using the instructor station, the instructor merely moves the train away from the location of the incident to restart the system. The process takes a few seconds to complete.

Lave and Wenger (1991) argue that learning is a function of the activity, context and culture within which it occurs. This argument does not describe accurately conventional classroom training delivery which is abstract and which cannot normally be delivered within a realistic context. Situated learning involves learners becoming involved in communities of practice; knowledge being presented in an authentic context that involves social interaction and collaboration. The situated learning approach is centred on the application of the learned content rather than the memorisation of facts. The approach mirrors the subsequent (post classroom) application of the taught material in collaborative workplace settings.

3.3 The Nature and the Extent of Necessary Experience

Guthrie (1938) suggests that all learning occurs as a consequence of the association between a particular stimulus and the response to that stimulus, e.g., a child will retain in his distinctive memory the recollection of a burn that he received by touching a hot surface and will learn, in a single trial, not to do it again.

The amount of trials necessary to achieve learning is influenced by a number of factors. Although learning can take place in a single trial as exemplified above, many trials might be necessary to produce a general response if each stimulus pattern is slightly different (Anon., 2002a and Schmid, 1995). Prior exposure to the general task domain also influences the number of trials necessary to learn a particular additional subtask. In the case of *psychomotor skills* development, Grantcharov *et al*. (2003) found that the learning curve pattern is influenced by prior exposure to similar, but not the same, operative experience. Experienced practitioners needed only one repeat attempt to optimise their performance of the new skill, whereas, novices required between five and seven attempts to achieve the same degree of proficiency.

Skinner (1985), a *behaviourist*, believed that the learning outcome is best when students are drilled and practiced, i.e., ‘practice makes perfect’. As Glendon *et al*. (2006) put it, “An amateur practices until he or she gets it right; a professional practices until he or she can't get it wrong" (p.100). This is the favoured approach for developing appropriate responses to emergency cues (Fletcher and Winfield, 2007; Grantcharov *et al*., 2003; Anon., 2002a; Ford, 2001; RTA, 2001 and Pfeffer and Sutton, 2000). However, this approach may be unsuitable where the skill has to be applied in novel situations or where knowledge-based performance is required.

Skill based training is appropriate for routine operations in stable situations where programmed responses will suffice. It is inappropriate for dealing with novel situations for which a clear response has not been thought out and explicated in advance. For this reason, i.e., being able to deal with both routine and non routine situations, a blended approach is required; *behaviourism* for basic training, and cognitivism and *constructivism* for the further development of the student (Ertmer and Newby 2013). In considering the transition between skill and rule-based behaviour, Tichon (2007), Rushby and Seabrook (2007) and Croft *et al*. (2000) suggest that the number of trials or repetitions required depends on the speed and accuracy necessary for satisfactory performance, task complexity and operator ability.

3.4 Inadequacies in the Extant Process

There was a lack of congruence between I.É.'s then-extant training process and the experiential learning constructs discussed above. With that training process, very limited practice based learning was achieved formally. Affording opportunities to trainees to gain comprehensive experience created difficulties in respect of opportuneness, practicality, cost effectiveness and defensibility. Because of these limitations, it was not possible to provide practical and contextualised training for a great number of events. Inter alia, it was:

1. Inopportune to:
    1.1 Provide non-express paths for training trains which would allow trainees to practice precision stopping at platform markings;

1.2 Introduce abnormal, *reversible*, or *single line* working[20], temporary block working or initiate wrong direction movements. This is an essential requirement as these types of working create risk (Hughes[21], 2004).

2. Impractical to:
   2.1 To ensure that training delivery co-occurred with poor climatic or low rail *adhesion* conditions;
   2.2 Apply fault finding routines[22] that necessitate the driver blocking traffic on both lines.
3. Cost ineffective to:
   3.1 Provide sufficient resources, e.g., paths, traction units and instructors, to allow trainees to practice with sufficient repetition. (See CRC for Rail Innovation (2013a) for an example of the costs associated with providing real equipment for training.);
   3.2 Apply the emergency brakes (recommendation 298 in Cooksey, 1992), as repeated application at speed results in wheel flats;
   3.3 Provide stimulated traction units, for each class, that are capable of responding to a range of instructor initiated faults.
4. Unacceptable to the regulatory authority to:
   4.1 Degrade the train or infrastructure purposely;
   4.2 Make false emergency calls to the controlling signalman, thereby conditioning him in respect of future legitimate emergency calls.

These constraints led to a greater reliance on conventional classroom delivery than was desired. This delivery methodology was based largely on discussion and clarification sessions, the use of powerpoint presentations, basic dioramas and the use of a limited amount of real equipment (typically for part task training). I.É.'s position was not unique; training delivery in other railways was likewise constrained. The inappropriateness of this delivery methodology is widely attested by Balakrishnan *et al*. (2017), CRC for Rail Innovation (2014), Risk Solutions (2013), RSSB (2013a), RSSB (2009c) and CRC for Rail Innovation (2008).

[20] In the UK, the incidence of single line working has been reduced for reasons of time loss and safety; blockade working is introduced instead (RSSB, 2004c).
[21] In Britain 22% of SPADs occur during abnormal working. See also Pěchouček (2007).
[22] See Edkins and Pollock (1996) for an appreciation of the frequency of such events.

3.5 Learning Styles and Training Delivery Strategies

The different ways that learners process information must be considered during the training design process. Specifically, train drivers organise information in a more analytic manner than those in the general population; tending to arrange it in parts rather than in a wholistic manner. However, this tendency is less pronounced in respect of older drivers (Russell, 2006). This may provide a partial explanation of how, when using Riding's Information Processing Index, Russell found that older drivers attained higher scores than their younger counterparts. Although working memory diminishes with age, wholists use it in a frugal and more-compensating manner. They attempt to understand and retain the high level principles that will be used to guide exploration of the detail.

Citing the results of empirical studies by Mayer, and Hegarty and Just; Newton (2000) attests to the value of using dioramas and combinations of text and images to improve the effectiveness and efficiency of training delivery. Using drawings and block diagrams, Mayer demonstrated to his students how automobile brakes work and, using physical models, he demonstrated the atomic structure of chemical compounds. He found that conceptual recall improved by 144%, and creative problem solving improved by as much as 460%. Hegarty and Just found that students took longer to read material that contained text only than when it contained a combination of text and pictures. (See also Curran and Doyle, 2011; Defeyter *et al*., 2009; Cuevas, Fiore and Oser, 2002; and Houston, Childers, and Heckler, 1987.)

Learning is not influenced by presentation techniques alone; learner motivation and application opportunity are essential. Handy (1989) believes that taught material must have relevance for the learner and its delivery must be contextualised. If the material is considered by the learner as being irrelevant, "... it is unlikely that learning will occur 'in spite of himself'" (p.238). He adds that learning takes place in psychological and physical contexts and that the learning is "…put into a frame of reference in our mind… ideas or facts out of context are still there… but studied and learnt in isolation will not readily be used" (p.239). (See also Evans, 2002; Kruse and Keil, 1999; and Rogers, 1969.)

In an idealised world, the foregoing ideas make sense. Application of these ideas in settings where training is delivered to a cohort of learners rather than to individual learners, albeit well motivated learners, as is typical in the railway industry, creates challenges. Newton (2000) believes that the lower efficiency associated with heterogeneous group delivery, because "... providing for a mixed group of learners will usually mean preparing materials which offer the same information in a variety of ways" (p.134), may be compensated by greater effectiveness. Similarly, the delivery of training at a remove from the operational environment or in the absence of operational equipment may prove ineffective.

3.6 Mental Models: the training challenge

Mental models are the basic structure of cognition (Johnson-Laird, 1983). People use them as representations of reality to understand specific phenomena or experiences. They operate below the level of consciousness and frame how we see the world. Most importantly, they influence our actions. Senge *et al*. (1995) liken them "… to a pane of glass that frames and subtly distorts our vision" (p.235). Humans cannot navigate through a complex environment without the use of cognitive mental maps that, by their nature, may be flawed and distorted (Shebilske *et al*. (in Endsley and Garland, *eds*., 2000).

One of the fundamental objectives of training is to alter deeply held inappropriate mental models. To achieve this objective, the inappropriate mental models must first be surfaced and challenged. Air Affairs (2006) suggests that some of the problems associated with mental models can be mitigated by providing training in attention distribution (simultaneous capacity) and self-checking skills ('how do I know I'm right?') (p.3-9). A fundamental objective of training is to ensure that training interventions are structured and presented in such a way to ensure that incorrect models are not created or reinforced.

Besnard and Greathead (2004), Eysenck and Keane (2000), Senge (1999) and Senge *et al*. (1995) provide insights into the features of mental models:

1. Mental models are incomplete and evolve constantly;

2. They are not necessarily accurate representations of a phenomenon and may contain errors. However, such errors "... have to be considered as a side effect of the cost-benefit driven reasoning process that is aimed at getting the maximum level of performance for the minimum mental cost" (Besnard and Greathead, 2004, p.8);
3. They may result in the acceptance of the partial confirmation of a situation that could lead individuals to disregard evidence that does not match the mental model, and that encourages them to search out confirming information only. For example, a driver who is nearing an approach-released signal may mistakenly believe that it is being held at danger to prevent *overspeeding* through a diverging junction (a function that is part of the design philosophy), rather than the possibility that the route has been claimed already by a conflicting movement. (See also Endsley and Robertson (in Endsley and Garland, *eds*., 2000); and Braiker, 1989.);
4. They help to prevent cognitive overload by supplying readymade responses to emerging events. Similar to the recognition primed decision making process, they can be represented by sets of condition-action rules. Woodward *et al*. (1999) believe that high speed train driving forces reliance on them;
5. They contain measures of uncertainty about their validity that allow their usage even when they are incorrect;
6. The probability, that the negative attributes of mental models will surface, increases in situations where two sets of them interact in instances of reciprocal interdependence, e.g., in verbal communication exchanges between drivers and signalmen. (See also Hockey and Carrigan, 2003; Shebilske *et al*. (in Endsley and Garland, *eds*.), 2000; and Schmid and Collis, 1999.) In such cases, the intended meaning of the transmitter of the communication may be misunderstood by the receiver. Specifically in relation to the unintentional promulgation of incorrect mental models, Coplen (1999) warns that "Even rulebooks with identical phraseology could be interpreted and applied differently on different [US] railroads" (p.2). The effect of the difference in stakeholders' mental models is shown humorously in Figure 4.

Source: TRIZ (in Professional Engineering, Vol.21, No.1)

Figure 4: An Example of Stakeholders' Different Mental Models

3.7 The Social Dimension of Learning

Bandura (1977) highlights the social dimension of the learning process as epitomised by the observation and modelling of the behaviours, attitudes and emotional reactions of others. He considers learning as being a situated process, with skill and knowledge acquisition being critically dependent on the social environment and on the learning context. He recognises that learning would be exceedingly laborious, not to mention hazardous, if people had to rely solely on the effects of their own actions to inform them as to what to do. However, the benefits[23] associated with social learning must be offset against the likelihood and extent to which undesired learning may occur. The quality of the social learning is dependent on the attributes of the mentor (Waylen and McKenna, 2002).

The ubiquity of role models during the *on-the-job* portion of traction driver training programmes, in the form of mentor drivers, is reported in DNV Consulting (2004). The importance of the role is recognised, as the selection process for mentor drivers is based on the quality of the applicants' employment records, the calibre of their knowledge and driving skills, the depth of their driving experience and their ability to communicate cogently with trainees.

[23] The benefits of social learning are reported by SWOV (2007). After mandatory accompanied driving was introduced into the Swedish car driver training process, there was a 35% reduction in crash involvement in the first two years post licensure. See also Christie (2001) and Mason (1992).

Attitudinal and personal qualities, such as the exhibition of an aggressive driving style, complacency, overconfidence and anti authoritarianism, are also considered.

In addition to the risks associated with undesired learning occurring due to the poor calibre of mentor drivers, the placement of trainees under their tutelage can lead to situations of deficient role definition, divided responsibility, indifference and *dependency*. These caveats are exemplified in the accidents investigated by ATSB (2013), NTSB (1999) and RAIB (2007a). ATSB (2013) concluded that "... a competing administrative task diverted the co-driver's [mentor driver's] attention away from his primary task of supervising the actions of the train driver, who was a driver-in-training for the route, in the period that the train was approaching signal 135" (p.29). Worse still, the NTSB (1999) investigation into the fatal accident at Butler revealed an appalling lack of interest in the trainee's workplace progress. The NTSB finds that "... during the accident trip, the crewmembers' actions neither promoted compliance with the operating rules nor provided a positive model for the student to emulate" (p.32). In RAIB (2007a), a tram being driven by a trainee driver under the supervision of a driver instructor moved off from the platform when a passenger was trapped in a door. The investigator concludes that "... the perception of a split of responsibility between the driver and the instructor may have contributed to the lack of a final check on the platform before the tram moved off" (p.15). Ergo, when the quality of the role modelling and supervision processes is poor, the value of providing mentor drivers becomes questionable.

Compared to the real world process, the possibility of undesired learning occurring in a simulated scenario is reduced significantly but, depending on the system's configuration and instructor to trainee ratio, it may not be eliminated entirely. By using a channel selector to access any one of the seven scenario management screens (see Appendix 6 and Appendix 7 for a list of the displays and a pictorial overview), it is possible to present the operant scenario and the behaviours of any of the four operators for instructor and peer review. I.É.'s system enables three instructors (one to operate each of the instructor stations and one to take the lead role in the peer review process) to train up to eight trainees[24] at a given time; four operating the simulators and four in an observer role. The overall arrangement of I.É.'s system is shown in Figure 5. Using this span of surveillance, each instructor (#1 and #2) must switch attention between two operators. However, the scenarios are phased to ensure that critical events do not co-occur. The observers switch attention between the activities and scenarios in the four simulators, as controlled by the instructors. This span of surveillance might appear inefficient when juxtaposed with French and American practice. SNCF use an instructor-trainee ratio of 2:6 at its Paris facility, while BNSF use a 2:18[25] ratio at its Salt Lake City facility. However, the writer believes that affording I.É.'s trainees this amount of attention strikes a very good balance between efficiency and effectiveness.

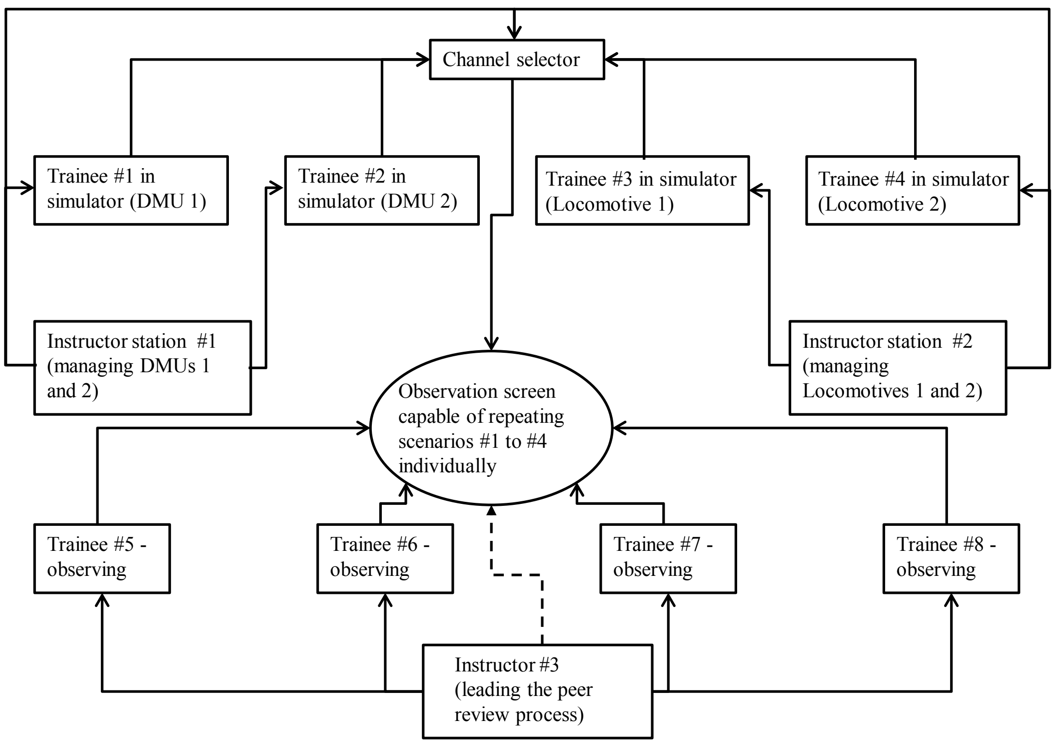


Figure 5: Overview of Simulators, and the Instructor and Observation Stations

[24] This is the maximum class size for ab-initio drivers. The average class size for refresher programmes is 3·15 drivers per session. Refresher programmes are delivered by 2 instructors.
[25] Two instructors use nine networked simulators to train 9 drivers and 9 conductors concurrently.

The discussion above relates to the use of simulators for training purposes. When simulators are used in assessment mode, a use case that is prevalent among British *users*, an instructor to operator ratio of 1:1 is necessary (Anon., 2007).

3.8 Mastery

Carroll's (1963) idea of mastery is particularly relevant to training delivery in commercial settings wherein there is an imperative to reduce the duration of training processes to a minimum, typically, without regard to individual learner abilities. Carroll's theory supports self-paced learning where students are allocated whatever time it takes them to learn the full content of the lesson and to master the subject. With this approach, all of the students should have acquired the same mastery of the subject matter, albeit over differing time horizons. This approach is in contrast with the classical approach to learning which is ability-focussed, whereby all of the students are given the same amount of time to learn the material. Using the classical approach, the amount of learned material differs according to individual ability.

There is a conflict between these two approaches to learning. The first approach is effectiveness driven and is favoured by the trainees. The second approach is efficiency driven and, hence, is favoured by some training managers. The challenge in applying the classical approach is that after the delivery of training, students will demonstrate varying levels of achievement. In the context of the education of engineers, Schmid (1995) suggests that "... for some skills a pass mark of, say, 95% might well be appropriate" (p.213). The writer is inclined to the view that Schmid's approach may be appropriate in cases where students are afforded the opportunity to make up the shortfall of declarative knowledge during their period of further structured professionalisation within a risk free environment. However, it would be very difficult for the manager of a railway training function to defend such a position if an accident occurred and the subsequent investigation into its causation centred on the lack of *understanding* of those rules or procedures that were contained in the 5% where the trainee was unable to demonstrate competence! To avoid such an eventuality, prudent and cautious rail training managers provide supplemental training[26] where assessment deficits have been identified.

3.9 Distributed Cognition

There are two extreme positions in relation to the cognitive process. The traditional view of cognition is that it is a localised phenomenon which is best explained in terms of information processing at the level of the individual. *Cognitivists* claim that all cognition occurs in a person's mind and nowhere else. At the other extreme, situationists claim that cognition happens in a person's environment; knowledge is not assumed to exist but is socially constructed and embedded in different kinds of environmental artefacts. The situationist's perspective supports the concept of contextual learning as discussed in Section 3.2.

Unsurprisingly, most cognitive psychologists hold the view that learning occurs somewhere between of these two extreme positions, and as a result of *distributed cognition*, i.e., at the interaction between the individual, environment and cultural artefacts (Baber *et al*. 2006; McLeod *et al*. (in Wilson *et al*., *eds*., 2005); Hockey and Carrigan, 2003, Anon., 1999 and Lave and Wenger, 1991). Charles (2014) and Wilson *et al*. (2007) add railway relevant insights. In her study into the importance of artefacts to *signallers'* task performance, Charles (2014) concludes that artefacts "... may be used to aid decision-making and planning and enhance the performance as well as the situation awareness of these *cognitive tasks*" (p.44). Whereas, Wilson *et al*. (2007) emphasise the cross functional nature of distributed cognition; spanning the roles of signalmen, controllers and drivers.

Because of the contribution of the environment and cultural artefacts to the distributed nature of cognition, it is essential that simulator systems are sufficiently elegant to be able to present the full range of information sources and cues that the operator exploits when driving in real life. To be effective, such

[26] In the form of repeated exposure to lessons or opportunities for clarification

systems should be able, at a minimum[27], to stimulate the operators' visual, auditory and tactile senses.

3.10 The Necessary Qualities and Skills of Training Professionals

Rogers (1969) and Bruner (1960) are in agreement in respect of the centrality of the teacher in the learning process. The teaching role is to present readily understandable material in a facilitative manner. This approach is predicated on the existence of an adult to adult relationship between the parties. The teacher encourages self-discovery, and the teacher and students engage in Socratic learning. The teacher adopts a non-prescriptive approach and endeavours to educate the student in the fullest meaning of the word 'educate'.

Similar to Gagnè's (1972) focus of enquiry, Bruner addresses the manner in which a body of knowledge can be structured so that it can be understood by the learner most readily. Good methods of structuring knowledge result in simplification of concepts and ideas, the generation of new propositions and an increase in the capability to manipulate the information. Bruner suggests that training material should facilitate extrapolation; a concept synonymous with the projection entity of Endsley's (in Endsley and Garland, *eds*., 2000) situation awareness model.

McGuffog *et al*. (2006) highlight some of the skills which trainers in the rail industry must possess. They need "… to demonstrate effective interpersonal skills and understand how skills are *transferred* from the classroom or simulated environment to the workplace… [and they must also have] a facilitative coaching style" (pp.14-15). The requirement for these skills is additional to strong occupational competence. They are particularly important in those training regimes that are attempting to make the transition from providing lecture-based instruction merely, to providing training. Facilitation skills are also important when the training goal is moving from the development of skill and rule based behaviours merely, to the development of knowledge based behaviours (Hörmann

[27] If, unlike the case of I.É., the development of a response to an onboard fire is a training goal, then it may also be necessary to provide olfactory cues. Training appropriate responses to such events is a goal at the JR East facility at Omiya; smoke is introduced into the 'cab' to simulate a train fire (Abbott *et al*., 2000, p.24).

et al., 2003a). This change imposes particular demands on instructors. For example, the use of simulators for *crisis* training, as distinct from procedural training, is exacting as crisis scenarios are more difficult to generate. Generation of crisis scenarios requires creative thinking to identify those events that could occur but for which there are no predefined procedures already in place. As evidenced by Macdonald (2006), there is a clear need to develop instructional skills in order to exploit the full capability of training simulators.

To attract suitable people to the role of instructor, McGuffog *et al*. (2006) suggest that emphasising the intrinsic elements of the role rather than the hygiene factors "… would be more beneficial in attracting people to the profession for the right reason" (p.33). Their review of the recruitment and selection procedures for trainers indicates that the normal selection process is primarily based on some minimum level of vocational experience while a few recruiters insist on National Vocational Qualification (NVQ) accreditation. It is the writer's belief that this accreditation should be considered merely as a 'stepping stone' in the overall development process which should, ideally, culminate in the attainment of a formal Level 7 qualification in cognitive or developmental psychology. A similar logic applies to the developmental requirements of training managers who carry the ultimate responsibility for the training activity. Training centre managers should possess operational competence in addition to managerial competence. It should be noted that none of the training managers interviewed by McGuffog *et al*. came from training backgrounds; they came from operations and engineering functions within the rail industry instead.

3.11 Conclusion

Safe operation in a dispersed operating environment necessitates rules and process standardisation. However, there is now an accepted need to transition operator training from being exclusively rules and skills focussed, to encompass a knowledge based component. The provision of experiential learning is premised on the priority afforded to the achievement of improvements in training effectiveness rather than efficiency; trainees need to be allowed to learn by failing.

It was difficult for I.É. to provide comprehensive and defensible experiential training formally because of opportuneness, practicality and cost effectiveness. This forced reliance on traditional classroom delivery which was non-contextual, did not promote trainee engagement and was delivered in instructional mode. The focus was on the memorisation of rules, procedures and equipment attributes. Likewise, the delivery process did not accommodate trainees' differing learning styles. Simulator enabled training was perceived as a means to circumvent these challenges.

Mental models are generally cognitively efficient. As they influence actions, the construction of correct ones and the extinction of incorrect ones are central to the training process. Facilitated, open dialogue and frank questioning among trainees in group settings helps to ensure that correct mental models are held. Care must be taken when producing training content, to ensure singular correct interpretation.

Social learning is beneficial insofar as it may help to prevent repeating the mistakes of others. However, realisation of the benefits depends on the personal attributes of the mentor, role definition and division of responsibilities. In railway workplace settings, trainees typically interact with a number of mentors; each with varying abilities, knowledge, experience and motivations.

Because of scheduling constraints and cost considerations, railway training programmes are typically ability focussed. However, to safeguard the investment already incurred, individualised training interventions are provided to make up any identified knowledge or performance deficiencies.

Environmental artefacts facilitate the construction of knowledge and guide actions. When operating traction units in the real environment, drivers depend on the accuracy, efficiency, reliability, informative ability and malleability of the cab artefacts. Consequently, the internal and external simulator environments must contain and present artefacts that possess these qualities.

The attributes of the trainers, in terms of their ability to structure the training material, and their presentation and facilitation skills, are particularly important when using a simulator develop all the domains of learning. The means that the various features of a simulator enabled training process can capitalise on the cognitive psychology constructs are summarised in Table 8.

Table 8: Means by which Simulator Enabled Training can Capitalises on Constructs

Theory or issue	Enabling features of the simulator system or of the training process	How simulator enabled training satisfies the theory or concept
The difference between education and training	Simulator operation *CSD* video presentations	a) The visualisation capability facilitates trainees' development from knowing 'what' to knowing 'why'. b) It facilitates progressive skill acquisition.
The learning cycle (Kolb 1984)	Extensiveness of the range of realistic scenarios available in the simulator library The observation and peer review processes	a) The learning cycle can be applied off line for training in safety critical tasks. b) Risk free mistakes can be made; even encouraged. c) It supports *positive transfer* from the training environment to the workplace. d) The reflective element of the cycle is facilitated by the provision of internal and external feedback. e) It approximates to situated learning.
The three domains of learning (Bloom *et al*., 1956, and Leave and Wenger, 1991)	Contextualised lessons delivered through simulator operation. CSD video presentations The observation and peer review processes	a) It facilitates development of the affective, cognitive and psychomotor domains. It also facilitates the combinative exploitation of the theories of Kolb and Bloom, i.e., practice based learning in the 3 domains. b) It is not abstract and is delivered within a realistic context. c) It partly circumvents the limitations of providing real world experiential training.
The nature and extent of experience (Gutherie, 1938 and Skinner, 1985)	The ability of the simulator to provide realistic cues Archived scenarios can be re-presented faithfully	a) It can provide learners with range of stimuli to elicit pertinent and acceptable responses. b) Depending on the learner's experience, single trial learning may occur. Each qualified operator will experience the specific event on at least on one occasion and also to experience a variation of the event on another occasion. Ab-initio operators are afforded opportunity to experience events many times.
Facilitating different learning styles	The variety of formats available to deliver the lessons	The use of simulation in conjunction with other presentation methodologies, e.g., lectures, CSD videos, images and quizzes, facilitates the differing learning styles of trainees.
Mental models (Senge, 1995 and Johnson-Laird, 1983)	CSD video presentations Those simulated scenarios that involve other actors	a) The visualisation capabilities of these tools assist in the development of appropriate mental models. b) The simulator provides a mechanism for trial and error learning to surface the validity of mental models. c) As part of awareness training, simulator operators can be subjected to inadequate or incomplete information as well as a range of distractors. d) Joint training interventions can be scripted to illustrate the potential for dichotomy of understanding between interacting parties.

Theory or issue	Enabling features of the simulator system or of the training process	How simulator enabled training satisfies the theory or concept
The social dimension of learning (Bandura, 1977)	The situational capability of the simulator	a) Lessons are contextualised and involve a range of actors, e.g., the controlling signalman, regulator, passengers etc. b) The classroom and peer review elements promote group learning. c) More reliable extrinsic feedback is provided from more sources than in the real world.
Mastery (Carroll, 1963)	Organisation of the lesson plan	Trainees can be facilitated by providing repeated exposure to the lesson until the behaviours exhibited by them are congruent with lesson content.
Distributed Cognition	Comprehensive range of artefacts in the internal and external driving environments	Depending on the type and elegance of the system, an extensive range of visual, auditory, tactile and olfactory cues are available. Theses artefacts can be faithful replications of those available for exploitation in the real world.
Necessary qualities and skills of training professionals	Management's commitment to the overall change initiative	a) Provides opportunity for self actualisation of the training professionals. b) Perception that trainees have of the trainers is improved.

4 Providing Opportunity to Learn

The management consultant and educationalist Peter Drucker is attributed with the maxim that ‘If you think training is expensive, try ignorance’ (House of Commons Public Administration Select Committee, 2012; and HMIC, 2003). Although alluding to the problems caused by knowledge deficiency, the underlying sentiment creates a bipolar inference that the provision of training should not be commercially constrained. The capabilities of a workforce can be directed towards the creation of organisational wealth by enabling the satisfaction of valued customer criteria. But the reality is that the development of organisational capability, through the provision of staff training initiatives, impacts financial performance in respect of costs as well as benefits. Training is not provided out of a sense of altruism; it must deliver value.

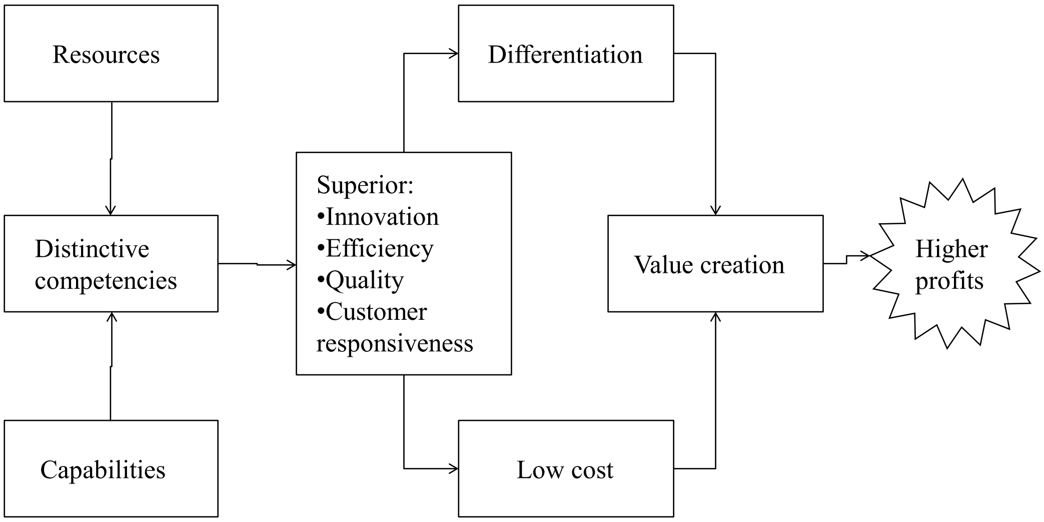
In the previous chapter, the writer showed how simulator enabled training satisfies a range of theoretical cognitive psychology constructs that conventional training processes cannot. In this chapter, the writer discusses the business dimension of training and presents the reasons underpinning I.É.’s migration from its extant driver training delivery system. This chapter is divided into seven sections, dealing with:

- 4.1 Organisational Capability and Value Creation;
- 4.2 The Contribution of Training to Organisational Capability;
- 4.3 Safety: a seeming compromise of stakeholder value;
- 4.4 Investment in Training to Create Organisational Capability;
- 4.5 Dissatisfaction with the Outcome of the Extant Process; and
- 4.6 The Confidence-building Value of Other Studies.

Concluding remarks are presented in Section 4.7.

4.1 Organisational Capability and Value Creation

Distinctive competence is the business feature that an organisation is exceptionally capable at achieving. It enables the organisation to achieve higher levels of customer responsiveness, quality, product innovation and efficiency over its competitors and, hence, secure success in the market place. Distinctive competence is achieved by combining resources and capabilities (Hill and Jones, 1998). Whereas, an organisation needs a resource base comprising tangible and intangible resources, it also needs the capability to put the resource base to productive use. The model, illustrating the pathway between capabilities and higher profits, is presented in Figure 6.



Source: Hill and Jones (1998)

Figure 6: The Roots of Competitive Advantage

Bontis *et al*. (1999) believe that the wealth-creating ability of an enterprise is based on the knowledge and capabilities of its people. More recent contributions in business and management literature suggest that knowledge and information provide increasing returns whereas the yield from fixed assets is diminishing. As a corollary, a company may not need unique and costly physical resources to succeed. In the case of the rail network in Britain, train operating companies do not own substantial physical resources. Network Rail provides and maintains the infrastructure, station buildings and structures etc. By and large, rolling stock companies (RoSCos) provide and maintain the traction and rolling stock through leasing agreements. The value created by the *TOCs* derives from their capabilities both at managerial and operational levels. Organisational capability is achieved by focusing on the internal processes and systems that lead to customer satisfaction, and by ensuring that employee skills and efforts are directed towards this end. These skills are created, developed and maintained through the provision of employee training.

4.2 The Contribution of Training to Organisational Capability

Accounting for the costs of training is relatively easy; putting a value on the realised benefits is more difficult (Bonsall and Taylor, 2011). Leveraging knowledge is the key reason attributed to corporate success stories, such as the tremendous over-valuation of high-tech and internet companies (Bontis, 2000). In respect of train driver knowledge and capability, a fundamental business question must be asked, i.e., do customers value the observable outputs of driver training? In respect of the value proposition of rail travel, a wide range of factors influence passenger perceptions and, thus, their willingness to make rail travel their preferred mode of transport. The service attributes, identified and ranked by three research groups, are juxtaposed and presented in Table 9. The declared preferences that are enabled by driver training are marked thus (*).

Table 9: Rail Customers' Declared Preferences

Declared preferences	Anon.'s (2008) ranking	Baker *et al.'s* (2007) ranking	RSSB (2004b) ranking
Level of crowding on train	1	1	N/A
Punctuality of trains (*)	N/A	2	N/A
Train cancellations/delays (*)	N/A	3	2
Cost/value for money	N/A	4	3
Frequency of services	N/A	5	N/A
Provision of information (*)	N/A	6	N/A
Safety on the train (*) and at stations	2	7	1
Cleanliness on train and at station	3 J	8	N/A
Toilet facilities on train and at station	5	9	N/A
Staff (*)	N/A	10	N/A
Ticketing services	N/A	11	N/A
Accessibility	N/A	12	N/A
Cycle facilities	N/A	13	N/A
Catering on train and at stations	N/A	14	N/A
Quality of trains	3 J	N/A	N/A
How relaxing the journey is (*)	6	N/A	N/A
Heating, lighting and ventilation on board	7	N/A	N/A
Integration	N/A	N/A	4 J
Disabled provision	N/A	N/A	4 J
Environment	N/A	N/A	6

Sources: Anon. (2008); Baker *et al*. (2007) and RSSB (2004b)

It is clear from Table 9 that driver capability is an enabler of the higher valued customer satisfaction criteria. The writer conjectures that the rankings assigned to ‘safety on the train’ (2, 7, and 1 respectively) may be influenced by the customers’ view that 'safety is a given', and the recency and scale of the last recollective rail accident (Chilton *et al.*, 2006; Fischhoff *et al.*, Alhakami and Slovic, and Slovic *et al.* (all in Hiselius, 2003), and Reason, 1997). However, the perception of system safety is fickle and it is reappraised in the event of an accident; Reason (2000b) noting that "Safety is defined and measured more by its absence than by its presence" (p.4).

4.3 Safety: a seeming compromise of stakeholder value

The raison d'être of a commercial organisation is to maximise profits through the creation of stakeholder value. Preoccupation with safety could be seen by some, particularly those who are operating on tight margins, in loosely regulated industries and within particular geographic regions, as a dissipation of stakeholder value. The commercial imperative brings the tensile, and sometimes conflicting, relationship between safety and production into sharp focus (Tichon, 2007; HEL, 2006; Wilson and Norris (in Wilson *et al*., *eds*., 2005); Chambers, 2005; Hobbs *et al*., 2004; Hughes, 2003; Hale *et al*., 2003; van Vollenhoven, 2002; McInerney, 2001; Greenstreet Berman, 2001; Kecklund *et al*., 2001a; Bushell and Dalgleish, 1999; Perrow, 1999; Reason *et al*., 1998; Free, 1994 and Mason, 1992). Reason (1997) recognises the reality of the situation and the necessity for safety and production to coexist, albeit inequitably as "... the partnership between production and protection is rarely equal and... since production creates the resources that make protection possible, its needs will generally have priority" (p.4).

The pursuit of the 'safety objective' may involve the adoption of seemingly inefficient practices, e.g., regulated hours of drivers' work, the appointment of lookouts, pilotmen, secondmen, flagmen, or track safety coordinators, during periods of system degradation or maintenance. However, the benefits of safe operation are significant to an organisation, e.g., the discharge of moral and ethical responsibilities, compliance with legal and regulatory requirements, and maintenance of reputation capital. On the other hand, unsafe operation will be personally costly to management and staff, and financially costly to the organisation. Reason (1997) provides worrying insights into the cost of safety failures in hazardous industries and cites a *HSE* study that reveals that "... for every £1 of costs recoverable through insurance, another £5 to £50 [of non-recoverable costs] are added to the final bill through a wide variety of other financial losses" (p.238). Similarly-damaging contingencies will be inflicted on railway organisations. It is extremely difficult to accurately and reliably ascertain the costs associated with railway accidents because of confidentiality agreements, the apportionment of liability among stakeholders and the timescale of claims' settlement. However, in respect of the accident at Ladbroke Grove on 5th October 1999, the writer extrapolates that the amount paid out in compensation alone was in excess of £73 m[28]. In addition, the cost of holding the ensuing inquiry was £8·7 m (Cuypers *et al*., 2006), and fines of £2 m (Thames Trains) and £4·225 m including costs (Network Rail) were incurred. In addition, there were also the costs associated with damage to equipment and loss of process. Disregarding the moral and regulatory imperatives, improving safety is not a zero sum game and the benefits of adopting a proactive safety strategy outweigh the apparent costs (Chan, 2012; and OSHA, 2005).

4.4 Investment in Training to Create Organisational Capability

There is an almost insatiable appetite for training; it is seen as an elixir that is capable of addressing many types of staff competence improvement areas. Overall, $164.2 bn (2012 prices), constituting 3·6% of payroll costs, was spent on training and development by US Companies (Anon., 2013). The proportion of payroll costs spent by larger Irish companies on training was 3·2% (IBEC, 2013). Of this global amount, mandatory and compliance training accounted for 10·8%, and training in processes and procedures accounted for 9·9% (Anon., 2013).

Specifically in the rail transport domain, I.É. spent 3·94% of payroll costs (€9·6 m, 2006 prices) to train its staff. By comparison, Veolia spent 2·08% (Frérot, 2011), RENFE spent 1·75% (RENFE, 2004) and *JRE* spent 2% (Watanabe, 1997)

[28] This estimate is based on average compensation amounts of £200,000 per fatality and £128,570 per injury in respect each of the 31 fatalities and the 520 injured parties. From (1) Laville, Sandra (2001) £4m paid to relatives of Paddington rail victims. The Telegraph, 11 Aug 2001. Available online: http://www.telegraph.co.uk/news/uknews/1337063/4m-paid-to-relatives-of-Paddington-rail-victims.html; (2) the revelations of one legal representative who acted on behalf of the family of one fatality, and 49 injured parties. Available online: https://www.leighday.co.uk/News/Archive/2004/April-2004/In-the-aftermath-of-Paddington (both of the above accounts were accessed on 19.06.'16; and (3) IRSE Proceedings 2014/2015.

of the respective organisations' payroll costs to provide employee training. Superficially, I.É.'s costs may appear excessive but cognisance must be taken of the differences in national cost structures. The analysis by Monaghan (2006) shows that I.É.'s expenditure is not out of kilter with Irish norms as "... the level of investment by Irish firms in training rose 25 per cent to 3·91 per cent of payroll between 2004 and 2006" (p.9).

A disproportionate amount of I.É.'s overall training costs is incurred in providing training to its cohort of drivers. Reflecting the responsibility of the role, the scope of training and the regulatory requirements, 30% of its overall training costs are attributable to training the 9% of employees in that grade. As it costs €73,000 and €30,000[29] to train mainline and DART drivers respectively (2009 prices), a total investment of ca. €33 m has been made to establish the competence of its 500 extant drivers[30] and another €300,000 is spent annually to maintain it. Invariably, expenditure of this magnitude prompts questions in relation to the achieved realisation of the training outcomes and also possible methods to improve delivery.

4.5 Dissatisfaction with the Outcome of the Extant Process

SPAD precursor events are significant contributors to overall railway safety risk. For example, Andersen (1999) calculated that, during the period between 1970 and 1997, 30% of accidents on British railways were attributable to SPADs. Before the development of I.É.'s Network Wide Risk Model, it was common for I.É.'s management, just as it was in other jurisdictions (ORR, 2015b), to benchmark its SPAD performance against that of other railways. An overview of the SPAD performances of British and Irish drivers, based purely on the number of such occurrences between 1990 and 2005, has been presented in Figure 2 above. I.É.'s SPAD performance, which had deteriorated in the period 1998 to 2005, was all the more disconcerting when the relative contexts of the driving tasks were considered, i.e., system usage, traffic density, and the different features

[29] It cost between £40,000 (converted to €56,641 at 2009 prices) (Walker and Bailey, 2002) and £60,000 (converted to €90,444 at 2009 prices) (Uff, 2000) to train a driver in Britain. Based on calculations from http://inflation.stephenmorley.org/

[30] The number of drivers in I.É. fluctuates to reflect business needs.

of the *AWS* and CAWS (see Connor and Schmid[31]). Benchmarking performance against other railway jurisdictions, using SPADs per million train-kilometres or SPADS per driver as criteria (in Table 10), provided little solace either. Of the 7 organisations compared, I.É. ranked either 5th or 6th depending on the criterion.

Table 10: Comparison of I.É.'s SPAD Performance

Company/Association	No. drivers	MTkm	No. SPADs	SPADs/ driver	SPADs/ MTkm	Rank[32]/ Rank[33]
Association of Train Operating Companies (ATOC)	13,085	463·2	321	0·025	0·693	1/2
Swiss Federal Railways (SBB)	3,000	157	138[34]	0·046	0·879	2/3
Nederlandse Spoorwegen (NS)	3,500	220	214	0·061	0·973	3/4
Norges Statsbaner AS (NSB) - Norwegian Railways	2,500	27·95	53	0·021	1·896	4/1
Iarnród Éireann (I.É.)	490	18·24	40[35]	0·082	2·193	5/6
London Underground	4,334	70·6[36]	609	0·141	8·626	6/7
Queensland Rail	625[37]	36·70	109	0·1744	2·97	7/5

Sources: Chief Safety and Security Officer, I.É., van der Flier (in Andersen, 1999), UIC (2006; Table 41), Fischer (2007), RSSB (2008a), Otterstad (2006), Queensland Rail (2008) and Flack (2009).

Furthermore, as the available human reliability rates vary by an order of magnitude, attempts to make meaningfully comparison of them are unenlightening. For example, the respective reliability rates for drivers in Queensland Rail and Britain are 1 SPAD for every 12,100 and 1 SPAD for every 50,000 successful stops (QR, 2008 and RSSB, 2015). In respect of the relationship between human reliability and the distance travelled beyond the limit of movement authority, Anderson (2007) presents error rates of 2·00E-4 for *LMA* exceedences, and 2·00E-5 for LMA exceedences in excess of 50 m. Data in respect of the reliability of Irish drivers are not available. Even if available, the validity of comparing driver reliability rates is questionable; Nikandros and

[31] Train Protection. Available online: www.railway-technical.com/signalling/train-protection.html. Accessed: 03.08.'17.
[32] SPADS/driver
[33] SPADS/MTkm (Million train kilometres)
[34] Extrapolated from SPAD occurrences during the period January 2007 to October 2007 inclusive
[35] 2005
[36] TFL (2009) London Underground named best metro in Europe as passenger numbers hit record high. Available online: http://www.tfl.gov.uk/corporate/media/newscentre/archive/11579.aspx. Accessed 24.08.'09.
[37] Annual Report 2014-15, Queensland Rail (5,778 employees of which 10·8% are drivers)

Tombs (2007) cautioning that "... data and tasks from one system may not apply to a different system" (p.1).

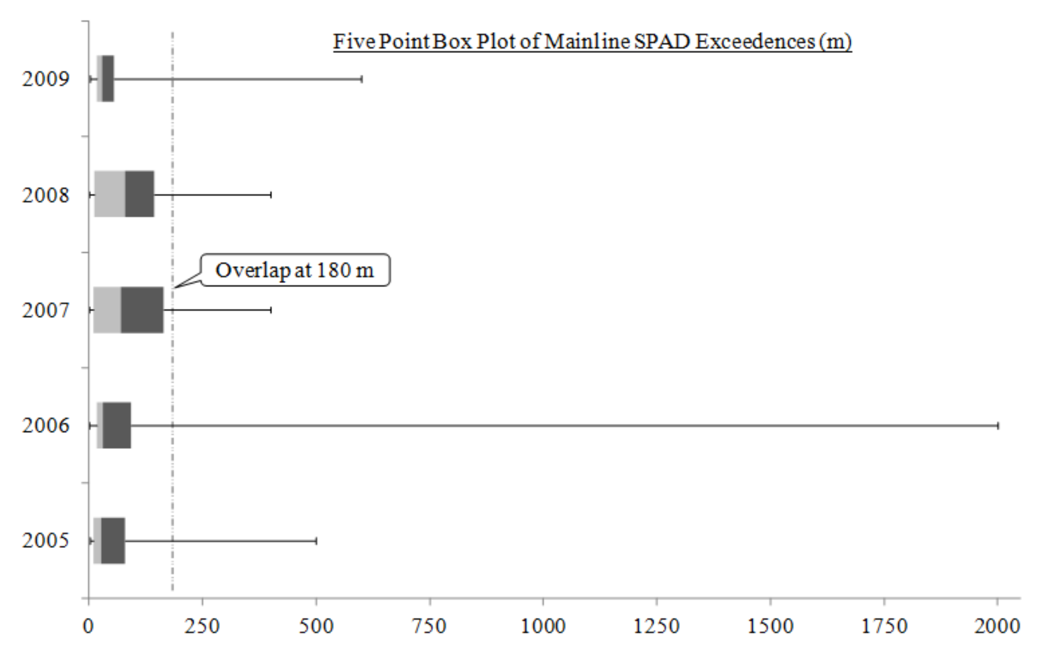
To ensure relevance, reliability and to mitigate statistical noise, the writer presents a time series approach; comparing I.É.'s SPAD performance between 2005 and 2009 and not against an external comparator. It shows, most saliently, that eighty three per cent of I.É.'s SPADs at *running signals* were contained within the signal *overlap*. Exceedences beyond this inbuilt safety margin are particularly worrisome. A five point box plot is included within the table to illustrate the extent of the dispersion and skewness of the exceedences, and also to show the outliers. The changing profile of I.É.'s SPAD data set is shown in Table 11.

Table 11: Probability of Overlap Exceedence

	2005	2006	2007	2008	2009
Total SPADs involving I.É.'s drivers	40	36	30	22	21
SPADs at shunting discs/signals	7	9	7	7	5
Shunting SPADs as a proportion of total	17·5%	25%	23·3%	31·8%	23·8%
Proportion of SPADs at shunting signals	23·5%				
Number of overruns ≥ 180 m at shunting signals	1	0	0	1	0
SPADs at running signals	33	27	23	15	16
Number of SPADs at running signals for which data is available	32	23	22	15	16
Number of overruns ≥ 180 m at running signals	5	4	5	3	2
Proportion of SPADs at running signals where the overrun was ≥ 180 m	17·6%[38]				
Mean exceedence of the LMAs for running signals (m)	70	189	116	119	82
Standard deviation of exceedences of LMAs for running signals (m)	108·6	466·5	124·3	139·9	148·9
Probability of a SPAD exceeding the overlap (180 m) of a running signal	15·6%	17·4%	22·7%	20·0%	12·5%

[38] This is ca. 3% higher than the rate reported in European Union Agency for Railways (2016).

	2005	2006	2007	2008	2009



Source: Chief Safety and Security Officer, I.É.

By any measure, I.É.'s SPAD rate was a justifiable cause for concern. Dissatisfaction with it was a key reason to change its training process.

4.6 The Confidence-building Value of Other Studies

Training Centre management believed that the training process and its outcomes could be improved using simulators. However, the fact that other railways were using them was not, in itself, sufficient reason for I.É. to follow suit. The bioethical maxim 'primum non nocere'[39] was a fundamental principle when deciding to migrate to a different training process. The results of the writer's research provided confidence that simulators could be used to effect improvement. These results are presented in Appendix 8 and Appendix 9. They provide evidence that simulators are effective training tools for a range of outcomes.

4.7 Conclusion

Railways are like any other business type; they must provide value to the end user, or else they will lose their legitimacy and support base. The creation of value is determined more by staff capability than the availability of physical resources.

[39] First, do no harm. Accepting that there is a problem, it may be better to do nothing, rather than risk exacerbating the situation by changing it.

Staff competence enables the delivery of valued customer satisfaction criteria. The provision of training does more than satisfying regulatory requirements; it enables safe operation, reduces risk exposure and creates shareholder value. Staff competence is the most important, and sometimes the only, barrier against adverse consequences after the system has suffered a technical malfunction.

It is costly to provide training but I.É.'s costs are in line with those of other businesses in Ireland. Differences, if any, between I.É.'s training costs and those of foreign railway undertakings are attributable to the high underlying cost base in Ireland rather than inefficiencies in training delivery. In spite of incurring high training costs, and management's unrelenting focus on SPADs, I.É.'s relative and absolute SPAD performance was unsatisfactory. The position had deteriorated in line with the erosion of the experiential profile of its driver population which was brought about by business expansion, and legislative, organisational and social change. It was also clear that the capability of the extant training process was challenged when juxtaposed with other delivery approaches. The purchase of a simulator system was perceived as a means to improve training outcomes generally but, most particularly, SPAD performance.

5 Training Needs Analyses, Scenario Development, Lesson Plan and Delivery Strategy

In the previous chapter, the writer highlighted the potential for staff training to create organisational value and also showed that I.É.'s extant process was not achieving a key safety objective.

In respect of simulator enabled training, it is axiomatic that if the training objectives and the associated scenarios, and the delivery methodologies are not identified at the equipment specification stage, it will be serendipitous whether or not a simulator project will create value and realise its goal. The link between these entities should be established prior to system specification. Such a strategic approach is not evident in all cases where simulators have been acquired (Russell, 2006; Macdonald, 2006; and Pennant Training Systems, 2004).

In this chapter the writer discusses two types of processes that are generally used, at respective units of analysis, to determine training needs. The first process is used at the organisational level, inter alia, to determine the quantum of the resources that are required to satisfy the organisation's training requirements. The second process is used at the role holder level to reveal all necessary training requirements. Poor identification of these will result in a suboptimal outcome, irrespective of delivery methodology. This process comprises three methods of varying degrees of elaboration that are used to elicit the training content, delivery methods and programme durations for each particular role under analysis. The specific process that was used to generate the scenarios for incorporation into the lesson plan for I.É.'s drivers is also described. In recognition of their importance to the achievement of I.É.'s training objectives, the five NTSs that comprise the awareness training element of its lesson plan are discussed.

Part task training is appropriate when the individual elements, contained within the overall task structure, are complex and when the relationship between them is straightforward (Tendick, 2002). On the other hand, whole task training is most appropriate when the sub tasks are relatively straightforward but the interrelationship between them is complex. This is the case of traction operation.

An events-based approach to training (EBAT) was used by I.É. to guide the design of lessons; thereby introducing particular events and sub tasks into general training contexts. This approach provides opportunities to observe behaviours of particular and general interest concomitantly; most particularly, the exhibition of NTSs during the performance of *technical skills* (Fowlkes *et al*., 1998). *EBATs* comprise purposely engineered scenarios to facilitate the accumulation of *schemata*. The EBAT process does not depend on *chance* interactions and encounters; it creates the requirement to act by purposely embedding trigger events and cues within training scenarios. Fletcher and Winfield (2007) capture the essence of the goal of this approach, suggesting that "... instead of getting drivers to just recall newly learnt rules [and procedures], give them real life scenarios where they have to apply the rules and make the right decision, under pressure, because this is what they will have to do in practice" (p.19). In addition to describing the development of the content element of the revised training programme, key principles of the training delivery process are also presented.

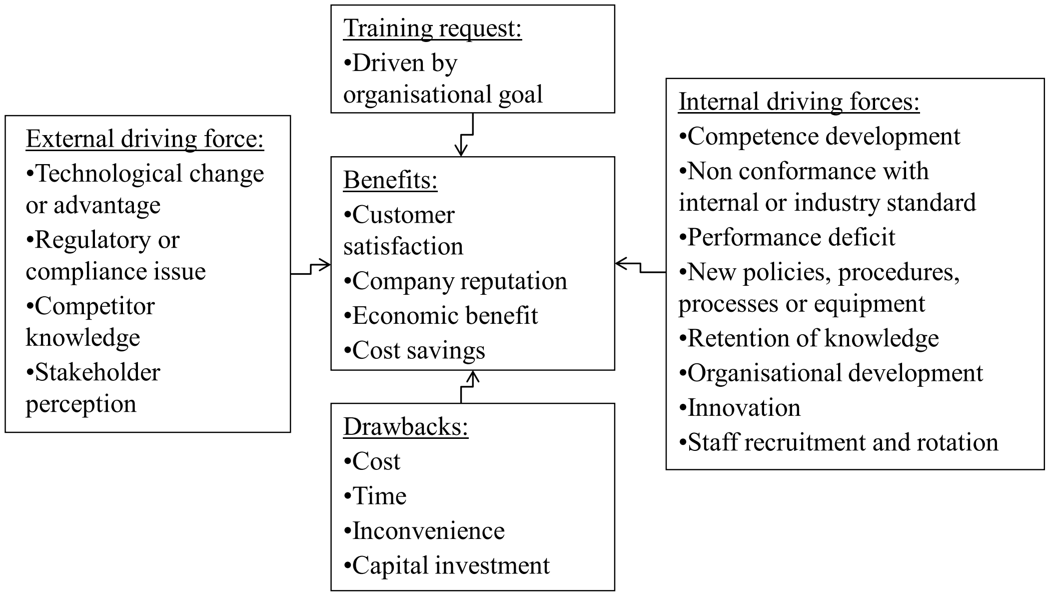
This chapter is divided into ten sections, dealing with:

- 5.1 Training Needs Analysis at the Business Level;
- 5.2 Training Needs Analysis at the Role-centric Level;
- 5.3 Effects of Standards and Regulation on Training;
- 5.4 How the Content of I.É.'s Lesson Plan was Developed;
- 5.5 The Strategic Objective of Developing Non-technical Skills;
- 5.6 Fostering Intrinsic Motivation to Enhance Learning Outcomes;
- 5.7 Serious Gaming - a loose-tight delivery approach;
- 5.8 Contextualised Development of Driving Skills; and
- 5.9 The Composite Lesson Plan.

Concluding remarks are presented in Section 5.10.

5.1 Training Needs Analysis at the Business Level

The objective of a training department is to timely deliver sufficient competent personnel into the workplace to allow the organisation to function effectively (Evans, 2002). The primary objective for conducting an annual *TNA*, at the business level, is to align the training function with the organisation's business's plans and strategic imperatives. The consequential objective is to plan the provision of training resources to achieve this alignment. Determination of training content or delivery methods is not the output objective of this particular process. Figure 7 is a representation of a framework that is useful to identify an organisation's training needs.



Adapted from Furjanic and Trotman (2000)

Figure 7: The Driving Forces of Training

Use of this model facilitates the identification of the range and scope of training requirements in respect of new, extant and recurrent programmes. It is particularly useful in those situations when there is a non-recurrent pattern to the annual requirements. Most germane to this thesis, the process is also used to evaluate the additional requirements, and consequential training resources, resulting from identified operational performance deficits. The type of training and the numbers of employees requiring each type are revealed by the TNA. The overall training requirement is calculated and courses are scheduled having regard to the constraints of all of the stakeholder groups, e.g., staff availability and operational requirements. The output of the TNA constitutes the annual training plan. It is the responsibility of the training function's management to identify and acquire the human, physical and financial resources that are needed to execute the plan. The output of this type of analysis was used to determine the scope of I.É.'s simulator system, i.e., the number of driving desks that were required and their deployment.

The long term plan of I.É. was to grow the business into one requiring 900 drivers to operate. In conjunction with the natural attrition rate, this overall requirement translated into an annual requirement to train 48 ab-initio drivers. In addition, its competence management process mandated the provision of biennial refresher training to its ca. 500 extant drivers and remediation training on an as-required basis to incident-involved drivers. The business level TNA revealed that there was a necessity for I.É. to provide 8 simulator driving desks and 1 extra instructor to support the new training delivery system.

5.2 Training Needs Analysis at the Role-centric Level

A hierarchical task analysis is a structured method that is used to identify all of the task components, the conditions under which they are performed and the performance sequence (Shepherd, 1998). It is a multilayer process that starts with the identification of high level tasks. Each task is incrementally decomposed in terms of sub-tasks and sub-goals until it is fully described. A fundamental flaw with using the *HTA* process alone is that it decomposes what needs to be trained into isolated knowledge, skills and attitudes (KSAs). However, the KSAs in which complex cognitive competence exists are interdependent entities. KSAs are often utilised in clusters, and require *parallel processing* and *multitasking* (Lodge *et al*., 2002; Hörmann *et al*., 2002; Croft *et al*., 2000; Shirts, 1992 and Drummond, 1989). Fowlkes *et al*. (1998) suggest the adoption of an events-based approach to training as a way of developing integrations of KSAs. I.É.'s utilisation of the EBAT approach in its training programme is discussed in Section 5.8.

Behaviour based task analyses do not provide adequate information on the training requirements to enable performance of more cognitively complex jobs, such as train driving (Emmanuel, 2013; and Clark and Estes, 1996). The identification of these training needs can only be comprehensively ascertained by using two complimentary approaches. HTAs provide the framework for conducting *cognitive task analyses*. Shepherd (1998) makes a succinct distinction between the two approaches. The goal of a HTA is to establish "... an accurate description of the steps that are required in order to complete a task; whereas the focus of *CTA* is to capture some representation of the knowledge that people have, or need to have, in order to complete the task" (p.1544). There are over 100 techniques available to evaluate and describe the cognitive aspects of task performance but these can be categorised into three principle approaches: (1) analysing the domain in terms of the goals and functions, (2) computer modelling, and (3) observation and interview methods (Stanton *et al*., 2005). On the basis of its intuitive usability, the writer favours the critical decision method proposed by Klein and Armstrong (in Stanton *et al*., 2005). When I.É.'s training scenarios were being developed, the writer did not have access to cognitive ergonomic competence to perform a professional CTA in accordance with the process set out in Stanton *et al*. (2005, p.102). Accordingly, he used the resources that were available to him, i.e., the strong operational competence and personal experiences of the instructors in managing *critical incidents* and a limited understanding of the CTA principles, to elicit the cognitive elements of the tasks and situations that would comprise the training scenarios.

The TNA, performed at the role holder level, is aptly described by Anon. (2002b) as being "… an auditable series of processes used to determine the performance needs of personnel acting in the role(s) being analysed, the training and assessment objectives required to be met to ensure competent performance in the role(s) and the training media best suited to support training" (p.8). Based on this common sense approach, the more difficult it is to perform a task, the more important a task is in terms of safety risk and the less frequently the task is performed; the more effort and time is expended to train it. Because subjective evaluations are used, the *DIF* process has been perceived by some as being suboptimal and liable to *SME* biases, e.g., recency, availability of information, detectability or representativeness. Such perceptions are exacerbated by Cullen's (2001b) general comments on the quality of risk assessments, suggesting that they can be "… superficial, too restrictive or poorly scoped, too generic, overly mechanistic, and with an insufficient appreciation of human factors" (p.209). (See also Darling *et al*., 2004.)

In more recent times, attempts have been made to introduce formality, objectivity, mathematical rigour and auditability into the TNA process. RSSB (2013b) defines a risk based training needs analysis as “An approach to developing skills, experience and knowledge that results in the performance of activities to the standards required in order to reduce the likelihood of an accident and the harm that could arise” (p.3). The *RBTNA* process may have application in the UK where the Safety Risk Model is populated with data in respect of some 2,000[40] accident precursors relating to 131 hazardous event types (RSSB, 2014b, Table C1). Objectification of the TNA process, to transform it to a RBTNA process, may be less productive in the case of I.É. where its *NWRM* is populated with objective data for 64 precursors. The writer believes that it is impossible to conduct a meaningful RBTNA on the basis that the number of safety critical tasks performed by drivers far surpasses this number. Perhaps reflecting the concerns raised in RSSB (2013b) about the courage needed to change established training processes, adoption of the RBTNA method has generally been slow. Bonsall and Taylor (2011) note that “… although several companies were involved with the development of the RBTNA methodology, only one company was able to pilot the RBTNA template” (p.10). A somewhat similarly cautious approach was taken by the participants in the study by CRC for Rail Innovation (2010), only one company out of eight performed a “... detailed risk-based training needs assessment, most appear to rely on the nationally approved training packages” (p.16).

The overarching output objectives of both the DIF and RBTNA processes are the same, i.e., the minimisation of risk and the allocation of time, effort and resources to where they will achieve the most desirous results. The perceived quality of the decision making inputs, and the inherent defensibility achieved through using the respective processes are the only differences.

5.3 Effects of Standards and Regulation on Training

I.É. functions in accordance with its 200 standards. Ten Company Standards contain the fundamental principles upon which its SMS is founded. Forty three

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[40] About four hundred and sixty of these relate to SPADs.

Railway Safety Standards underpinning the Company Standards. In turn, each department has formulated its own domain-specific standards; demonstrating how it complies with the Company and Railway Safety Standards (RSC, 2010). The detail and granularity of the standards varies with hierarchical position. Relevant to this thesis, very detailed standards exist in respect of ab-initio and recurrent driver training, assessment, and retraining. Accordingly, changes to these processes, such as those required because of the introduction of simulator enabled training, require formal *validation* by I.É.'s Safety Validation Panel.

OJEU (2007) provides direction on the training and certification of European train drivers. As the legislation is in the form of a directive, it sets out the overall goals only and is non prescriptive in respect of the strategy necessary to achieve them. Specifically in relation to training methods, OJEU (2007) suggest that "... although not obligatory, [simulators] may be useful for the effective training of drivers" (p.70). However, Member States are free to adopt a customised strategy that reflects local conditions better. The RSC is the 'Competent Authority' in Ireland and it has provided guidance (RSC, 2012) in respect of the transposition and implementation requirements for the directive. As the competent authority, the RSC has the overall responsibility, and matching powers of compellability, for the driver certification and licensing process. The RSC audit regime ensures "… that duty holders' compliance with their respective SMS is supervised in accordance with the common safety method specified in Commission Regulation (EU) No.1077/2012" (p.3).

5.4 How the Content of I.É.'s Lesson Plan was Developed

Simulator equipment must be specified with respect to the scenarios that are intended to be used in the lesson plan, and the system must also be configured to suit the intended training delivery processes. As I.É.'s project advanced from the feasibility stage to the operational stage, a number of approaches were used to ensure that the equipment would be fit for the immediate purpose and would have the capability to satisfy future requirements. Initially, an expansive range of training scenarios was identified and these were funnelled down to what ultimately became the lesson content. This approach was strategic. Over-specification was not a case of directionless extravagance; the possibility of a future need to revert to the supplier, requesting 'out of scope' items or functionality, was mitigated.

I.É.'s overall output objective was well defined. It was not the intention to use the equipment to provide training on ergonomic issues, such as managing the effects of circadian rhythms, the effects of driver comfort or *fatigue* on performance, or the recognition of olfactory cues[41] etc. Rather, the system would be used to provide procedural and NTSs training in the three operating modes, i.e., normal, degraded and emergency modes. A comprehensive list of emergency and degraded operating situations is presented in Appendix 4. This list was modified to make it context specific and relevant, and to incorporate normal operating scenarios. The modified list (Appendix 10) formed part of I.É.'s system's outline specification. An inclusive approach was used in these developmental activities which were performed by staff at I.É.'s Training Centre, *District Traction Executives* and drivers from its operating core. The development and prioritisation of content was based on:

1. The outcome of a combination of TNAs:
    1.1. A HTA which formed part of an earlier competence assurance process;
    1.2. An amateurish, limited but valuable, CTA which was conducted by a subset of Staff Trainers. This process disclosed cognitive requirements associated with particular operations that occur within specific locations[42]. Consequently, specially chosen artefacts[43] and hazardous locations were included in the scope of supply of the computer generated imagery.

    The experience of I.É.'s team led to a comprehensive, but subjective, revelation of operational risks. A formal RBTNA was not completed because the assessment of training priority (Step 2 of the RBTNA process, in RSSB, 2013b) requires the incorporation of objective NWRM data. I.É.'s NWRM was in its early stages of development and was not

[41] Resulting from an onboard fire
[42] Hazardous operations being performed in specific locations, e.g., driving into a maintenance shed or starting a train on a curved platform
[43] Permanent way road vehicles and the locomotive shed at Connolly Station for example

available for general use (see Section 8.4). A RBTNA would have added value as it would have brought the risk at the platform-train interface into sharper focus. This would have resulted in steps being taken at the specification phase to ensure that the training, suggested in Section 11.2 (Table 36), could be delivered without simulator modification.

2. A review of accident and incident inquiry reports from railways around the world. Particular attention was paid to the querists' recommendations in respect of simulator enabled training and the attribution of human error;
3. The integration of I.É.'s extant safety improvement initiatives:
   3.1. SPAD awareness;
   3.2. *Defensive driving* policy;
   3.3. Structured safety critical communications programme;
4. Research-disclosed possibilities and limitations of simulator capability;
5. The completion of a 'gap analysis'. The purpose of this was to identify any unjustified omission of content from the extant programme;
6. Discussions with users[44] about the capability of simulators to meet training requirements.

It was not practical to simulate, nor considered fruitful to provide training in each of the identified scenarios. It was also necessary to structure the lesson plan by prioritising those scenarios which were capable of addressing the identified inadequacies in the extant process and which were considered most meritorious and urgent, and those that were congruous with I.É.'s other safety initiatives. The store of scenarios which was assigned a lower priority remains available to broaden the lesson plan and to introduce novelty into its delivery in the future.

5.5 The Strategic Objective of Developing Non-technical Skills

While fully accepting that staff needs to be technically competent, technical competence on its own is insufficient to ensure effective task performance (RSSB, 2009b). In recognition of the contribution that NTSs play in safe operation, I.É.

[44] Connex South Eastern, EWS, GNER, JRE, Login, London Underground Limited, Óglaigh na hÉireann (Irish Army), Royal College of Surgeons in Ireland, Scotrail, Translink, Virgin Trains and the Simulator User Group

placed appropriate emphasis on their development. As the simulator system is extremely flexible, productive use of its open architecture for this task is constrained only by the creativity and experience of the scenario designers. The challenge for training designers lays in the identification of scenarios that promote skill development. Contextualisation of the use of NTSs within appropriate and realistic training scenarios requires a combination of blue skies thinking, critical incident recall and, ideally, professional ergonomist input.

5.5.1 Developing Role Appreciation through Joint Training

From the perspective of developing a system's understanding, and unifying drivers' and signallers' mental models, Cullen's (2001a) recommendation (#42) that "… that signallers and drivers obtain a full appreciation of the nature and demands of each other's work" makes sense. Two different approaches can be taken to satisfy this recommendation. The first approach is based on the physical integration of separate signalling and driving simulator systems. Gutiérrez *et al.* (2005) describe the integrated system that is used to train signalling, driving and engineering personnel at the metro in Madrid. The procurement of an integrated system had been considered by I.É. but this option was not pursued because of the same concerns as expressed by Gutiérrez *et al*. (2005). They recognise the engineering difficulty of integrating such systems, question the cost-benefit advantage, and conclude by asking "… it's obvious that the new simulators are full of new possibilities for training, but are all these options necessary?" (p.13).

I.É. uses an alternative approach; one that is based on joint simulations. These are designed to engage other operational roles with the simulator users; using the driver simulator only. Very mindful of the difficulty in justifying the ignoring of Cullen's (2001a) Recommendation #19 in any post-accident public sworn inquiry, the writer decided to provide joint training using this approach despite the negative findings of the qualitative study by Atkins *et al*. (2005). Their study indicates that mixed group training is not highly valued by 49% of recipients Forty six percent of these believed that "… mixed group training took time away from gaining skills specific to their role and 3% reported mixed group training was not useful at all" (p.4). This finding is disconfirmed in this study by the unprompted ex post facto comments, made by I.É.'s drivers in respect of joint training. None of I.É.'s drivers expressed dissatisfaction with joint training. To the contrary, when providing unprompted end-of-course feedback, 8% of the respondents welcomed the concept (see Table 30).

5.5.2 Developing Hazard Perception Skills

If a hazard is not perceived; evasive action will not be taken. There are two elements associated with the skill of *hazard perception*. The first is a process and content based element relating to the methods that are used to detect and perceive the hazard, and the mechanism used to rate its hazardousness. The second element is performance-based and relates to the time taken to mount a response. There is a symbiotic relationship between situation awareness and *HP*; the necessity to perceive an important cue is a common thread in the two constructs. Although the evidence emanates from a different domain, Table 12 illustrates the predominant relationship between perception and overall *SA*.

Table 12: Proportion of Air Accidents Caused by the Constituents of SA

Type of error: (level 1)	Proportion	Type of error: level 2 (constituents of level 1 errors)
Perception	80·2%	Failure to monitor or observe data (37·2%); Information unavailable because it was not actively sought out (11·6%); Information hard to discriminate or detect in the environment (11·6%); Memory loss, e.g., due to *distraction*, (11·1%); Confusing available information with that sought (8·7%).
Comprehension	16·9%	Use of incorrect mental model (6·4%); Incorrect expectation of system behaviours (4·7%); Lack of, or poor, mental model (3·5%); Other, e.g., momentary loss of [aircraft] position (2·3%).
Projection	2·9%	Projections of future actions of the aircraft systems were missing. Examples include misjudging or mistiming the amount of time necessary to complete actions by self or other crew members (2·9%).

The competencies linked to HP include effective scanning and anticipation. Personal attributes, such as *field dependence*, boredom thresholds and willingness to accept risk, play an important role in the manner in which individuals identify and respond to risk (Dumbuya *et al*., in Dorn, *ed*., 2005). HP skill is also affected by experience. By taking in more information from peripheral and distant views, experienced drivers detect more hazards, and quicker, than their inexperienced counterparts (RTA, 2003 and Crundall *et al*., 2002). They also make more holistic assessments of hazardousness whereas the less experienced ones operate at a more detailed level and appear less able to integrate diverse stimuli into an overall assessment of the situation (Killion, 2000 and Zsambock, 1993). Furthermore, the evaluation of the hazardousness of a situation by an inexperienced driver is overly influenced by past experiences of similar events (Nicholls and Cobb, 1996). The reliance on past experience has shown to be a significant contributory factor in SPAD occurrences at *approach released* junction signals.

The link between the extent of HP skill development and accident avoidance has been firmly established (Whelan *et al*., 2004; McKenna (in Kuiken and Twisk, 2001); Leadbeatter and Catchpole, 2001 and Gregersen, 1998). Studies by Watts and Quimby, and Hughes and Cole (both in Mills *et al*., 1998) indicate that simulators are valid training tools for *HPT*; there is a strong correlation between subjects' ratings of hazards when in a simulator and when driving on a real road.

5.5.3 Developing Crew Resource Management Skills

A 1997 experiment, into the performance of air crews during a simulated flight, exposed various operational problems and crew errors which were "... a result of breakdown in crew co-operation or poor co-ordination, and not a result of lack of technical skills or knowledge" (Beaty, 1995, p.39). The *crew resource management* training initiative was developed to address the matter. Although normally associated with the airline industry, the skills are generic and *CRM*[45] training can be applied in any setting that involves collaborative or teamwork activity. In the railway operating context, such collaborative activity takes place within and between the driver, signaller, guard, *pilotman*, shunter, platform dispatch, regulator and secondman roles. The importance of interdisciplinary team training is evident in the recommendations ensuing from high profile railway accident inquiry reports and studies, e.g.:

1. Recommendation 3 d in McInerney (2004);
2. Recommendation 2 vi in McInerney (2001);

[45] Variously referred to as railroad crew resource management (US) or rail resource management (Australia)

3. Recommendation 42 in Cullen (2001a);
4. Recommendation R-99-12[46] in NTSB (1999).

CRM training is designed to develop knowledge, skills and attitudes and includes modules on communications, situational awareness, problem solving, decision making, teamwork and workload management. From the mid 1980s, CRM training in the aviation sector has "… proved to be very successful in improving flight deck performance, particularly with regard to better sharing of situational awareness, improved communications and enhanced leadership skills" (Reason, 1997, p.130). Mitsopoulos *et al*. (2005) cite the findings of two studies which indicate that CRM training improves teamwork skills by 8% to 20% (Salas *et al.*) and by 8% to 13% (Stout *et al.*). The provision of CRM training in the airline industry has been mandatory since March 1998.

Embracement of the concept has proven slower in the rail domain even though studies show that the skills are amenable to training. RSSB (2012) conducted a before-after study (N = 16 train drivers). A comparison of evaluations, using the behavioural marker system, revealed positive transfer of the skills as perceived by both managers and the drivers themselves. From an economic perspective alone, it is unsurprising that interest in the concept of CRM is starting to grow within the rail sector. A *utility analysis*[47] by Roop *et al*. (2007) reveals that, when assessed on the basis of its potential to reduce accidents alone[48], CRM training yields a utility between -$2 m and +$11 m per annum[49]. Although these potential gains are not as large as those obtained for the airline industry[50], the analysis indicates that "… the benefits of CRM training to the railroad industry generally outweigh its costs" (p.20). (See also O'Connor *et al*., 2008.)

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[46] Amtrak employees who have been involved in critical incidents now attend CRM training that addresses the incident-specific issues (Savidge, in Madden and Boursier, *eds*., 2005). This training is usually attended by the entire train crew that was involved in the incident.
[47] Based on a typical Class 1 railroad in the US, employing about 11,000 traincrew members
[48] The analysis is ultraconservative. It does not include (a) the financial benefits of those cases where poor CRM was a secondary cause of an accident, (b) the ensuing increase in the efficiency of operations, (c) the cost of accident clean up, or (d) the remediation costs.
[49] These values are based on a sensitivity analysis using the (a) number of accidents attributable to human error, (b) cost per accident avoided, (c) duration of training effect, and (d) cost of providing the training.
[50] Training 1,200 maintenance staff at Continental Airline in CRM principles reduced ground damage costs by 66% and occupational injuries by 27% (Roop *et al*., 2007).

5.5.4 Developing Situation Awareness Skills

Definitions of the situation awareness (SA) construct abound. The authoritative definition is proffered by Endsley (1995). She defines SA as "... the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (p.36). It is a meta skill that works over and above the existing skills, and enables the effective management of cognitive abilities. Hence, it is difficult to disambiguate it from other human factor constructs (Anon., undated). The writer considers the definition provided by Dominguez (in Croft *et al*., 2000, p.38) to be more suited to the train driver role in-so-far as it includes the integration of information emanating from different sources. She suggests that SA involves the extraction of information from the external environment and the integration of this with relevant internal knowledge to create a mental picture of the current situation. This picture is used to continue exploration in a cyclical manner to anticipate future events.

The construct of SA is especially compelling in settings that involve the operation of complicated systems within dynamic environments. In these, the operator has to integrate widely disparate and, sometimes inconsistent inter-sensory inputs, with elaborate cognitive models of the vehicle and operating environment in order to achieve a successful outcome. The construct is particularly relevant in situations where (i) the environment is dynamic and information-rich, (ii) the operator may experience *high workload*, (iii) extensive training is required, (iv) the problem is ill-structured or novel, and (v) there are time constraints (Uhlarik and Comerford, 2002). This description typifies the task of a train driver when operating in the emergency mode.

Catchpole *et al*. (2001) identifies five factors that are thought to affect the acquisition and maintenance of situational awareness:

1. Attention management, i.e., an individual's ability to multitask;
2. Information management, i.e., an individual's ability to acquire appropriate information and make rational decisions;
3. Cognitive efficiency, i.e., an individual's ability to ignore distractions;

4. *Automaticity*, i.e., an individual's experience of performing routine tasks in an overly practiced and automatic way;
5. Interpersonal dynamics, i.e., an individual's understanding of the dynamics of non-verbal communications and team membership.

Air Affairs (2006) suggest the inclusion of the following topics during train driver training in order to improve their SA (pp.5.5-5.6):

1. Attention management to include attention control, time sharing and attention monitoring;
2. Environmental scanning to promote a systematic way of monitoring the environment. Trainees are taught where to look, what to look for, and when and in what sequence to look;
3. Self-checking skills to encourage individuals to check their own assumptions about the state of the environment against the information presented. Drivers should be trained to treat the projection phase of the SA process as a hypothesis which must be tested for correctness against the environmental evidence. For example, when nearing an approach released signal, drivers should question themselves as to why the signal is at danger;
4. Workload management to provide knowledge about the effects of high and low workloads on SA and to provide guidance on effective coping strategies;
5. Fatigue management to include information on the relationship between fatigue and performance, and on fatigue management strategies;
6. Task management advice to provide trainees with the skills and knowledge to be able to prioritise tasks efficiently and effectively, rather than using event or interruption strategies where each interruption is dealt with as it occurs.

Generally, losses in SA occur during periods of high workload, when multi-tasking, when preoccupied with other tasks or issues, when there is inadequate feedback from crewmembers, during periods of *stress* and when interacting with automated systems (Hörmann *et al*., 2003b). The effect of the breakdown of train drivers' SA is evident from the accident investigations conducted by NTSB (2006), NTSB (2003) and Walsh (1995). The value of SA maintenance is evidenced in the reports by Reilly (2008) and RAIB (2007b) of successful incident handling.

5.5.5 Developing Decision Making Skills

In dynamic operational settings, good decision making is crucial to the avoidance of accidents and precursors. A study of human error in aircraft accidents found that 26·6% of accidents involved situations where there was poor decision making even though there was adequate understanding of the situation (Endsley, in Endsley and Garland, 2000). Effective decision making is also a fundamental requirement of train drivers; ca. 10·6% of SPADS are attributable to poor decision making (Appendix 11).

Decision making effectiveness is influenced by many factors, e.g., the dynamism of the environment, psychological stress to make the right decision, availability of information, time constraints and conflicting goals. In some contexts, drivers may not be afforded the time or information to engage in either the rational or bounded rational decision making processes, and may revert to intuitive decision making or to the *RPD* making process. However, there are inherent dangers in their use in-so-far as their application may be influenced by biases (commission, omission or confirmation biases, or the non-rational escalation of commitment) or the lack of experience. The situation can be ameliorated through awareness training and through enhancement of the decision maker's experience profile. Simulator enabled training allows operators to be immersed into scenarios that compel them to make decisions at critical junctures.

5.6 Fostering Intrinsic Motivation to Enhance Learning Outcomes

Rogers (1969) believes that human beings have a natural propensity to learn; the role of the training professionals is to facilitate the process. (See also McGuffog *et al*., 2006; Juhary, 2006; Evans, 2002; Schmid, 1995; and Leave and Wenger, 1991.) Olson (in Williams and Williams, 2011) opines that learner motivation "... is probably the most important factor that educators can target in order to improve learning" (p.2).

In the case of the transition of I.É.'s training process, it was essential to create an environment that would maximise learners' motivation; any possible hindrance of this goal was not countenanced. No element of the training delivery process was allowed to detract from the intrinsically motivating features of the system. The ethos of the delivery process was defined by the professionalism of the operators, the culturing of an adult-to-adult relationship between the participants, an acceptance that it was okay - even encouraged to make errors, and the free availability of the knowledge and experience of the trainers. Above all, there was a desire to accentuate the learning experience and make it enjoyable.

5.6.1 Non-use of Simulators for Formal Competence Assessment

The initial establishment of competence and its subsequent maintenance are key components in satisfying the railway undertaking's obligations contained within its Safety Case. It must be demonstrable that safety critical employees, such as traction drivers, understand and apply standard operating procedures. However, train drivers, who are assessed as being competent under the competence management arrangements, make avoidable errors which compromise safety. This implies that either an element of driver error is acceptable and/or irreducible[51], that the assessees know the correct procedures but opt to exercise alternative courses of action[52] (the *knowing-doing gap*), or that current assessment processes are inadequate. (See also de Winter *et al*., 2009; RAIB, 2006; Peck (in TRB, *eds*., 2006a); McCarquodale, 2002; and Mason, 1992.)

The traditional process used for assessing driver competence has been the subject of criticism by rail accident investigators (McInerney, 2001; Neal, 2001 and Uff, 2000). For Uff (2000), the main issue that emerged from the Southall crash was that the training system failed in its most fundamental task of "... weeding out drivers who are unsuitable for the heavy task which they have to bear, by attitude or temperament" (p.199). Howells (2000) believes that the reasons why the extant

[51] Nikandros and Tombs (2007) believe that train driver error rates are low and may be approaching the limits of human reliability.
[52] An analysis of train dispatch incident reports by Hughes (2003) reveals that "... mistakes which have occurred have not done so because individuals failed to understand the applicable rules or procedures, but because, on the days in question, the individuals failed to comply with the procedures" (p.8).

assessment process was so unreliable was "... due primarily to testing being performed in the classroom or on a scheduled train service, neither of which permits adequate, controlled complex skills development or assessment" (p.4-4). It is intuitively appealing to suggest the use of simulators for qualification assessment purposes; 12 of the 18 railway organisations in the study by Schmitz and Maag (2008) use them for this purpose.

The perceived benefits of simulator enabled assessments are:

1) If based on a combination of data from the simulator's log files and subjective assessor judgement, simulators can provide an "... impartial, transparent, and detailed assessment" (Maag and Schmitz, 2012, p.1);
2) They promote standardisation and reliability (Schmitz and Maag, 2009, p.51);
3) The assessor's attention is not divided by concomitantly monitoring the safe passage of the train on which the assessment is taking place (Endres, 2005). If an automated process is used, the assessor can further confine his attention to those elements that require human input, i.e., the human factor components. See Schmitz and Maag (2009) for a comprehensive discussion on the merits and challenges of automating the assessment process;
4) High fidelity simulators can provide "A more predictive assessment of the candidate's behaviour because the same operating pressures can be placed upon them that they would undertake within the work place" (Anon., 2007, p.15);
5) There are obvious limitations to the validity of any real world test or assessment. It is unethical to include task demands that expose test subjects to personal risk (McGuffog *et al*., 2006);
6) A more comprehensive range of tasks can be assessed practically, including driving performance during periods of system degradation (Uff, 2000);
7) The reporting and recording of trainees' actions and reactions is almost indisputable, and is unbiased by sympathy or prejudice (Scott, 1998).

The detractive argument for such assessments is based on:

1) The absence of high physical and psychological simulator fidelities. SQA (2014) asserts that "To be effective [for assessment purposes], simulations

must succeed in recreating the atmosphere, conditions and pressures of the real situation" (p.28). (See also RSSB, 2009b.);

2) The concerns of assesses. Schmitz and Maag (2009) found that "As far as the storage of the results [e.g. maximum speed and reaction time] in the AssDB is concerned, the trainees are sceptical due to the comprehensive character of such a database" (p.58);
3) The requirement for an instructor, to candidate, to simulator ratio of 1:1:1 when used as a assessment tool for certification; a use case that is prevalent among British users (Anon., 2007 and the Simulator User Group[53]);
4) The process blurs the demarcation line between the training and certification processes and roles. "Formal competence assessment should be performed by a competent assessor who has not been directly involved in training the person being assessed" (Evans, 2002, p.26);
5) A deconstruction of Uff's (2000) comments. He did not specify that simulators should be used for jeopardous assessment; merely that "Simulators should be introduced for driver training and for the observance of driver behaviour" (p.212). Likewise, he did not specify a change in responsibility for conducting assessments, i.e., from DSMs to instructors[54]. The integration of training and jeopardy assessments discourages drivers from 'declaring their hand' in respect of any lack of knowledge, or seeking clarification on a rule or procedure;
6) The preclusion of accepted peer review by respected others.

5.6.2 Non-jeopardy Training

In many railway jurisdictions, operators' performance is formally assessed as an integral part of simulator enabled training processes (Appendix 12). Non-jeopardy training is an alternative approach that is used in the airline sector and is, after consideration of the arguments in Section 5.6.1, the approach that was adopted by the writer. (See also Bonsall and Taylor, 2011 for supporting commentary.) The provision of non-jeopardy training is not incongruous with Uff's (2000) recommendation #17.5 (3). The term 'non-jeopardy' implies that the operators' licenses will not be subject to revocation in the event of underperformance during

[53] Meeting of 9th October 2007 at Crewe
[54] From DTEs to Staff Trainers in the case of I.É.

training. The rationale underpinning non-jeopardy training is that operators "... can manifest attitudes that are as close as possible to those that would be demonstrated in unmonitored conditions... reserve or defensiveness because of concern for failure must not inhibit participation" (ICAO, 1998, 2.2.16 and 2.5.22). The assignment of this status acknowledges the primacy of the purpose of the event, i.e., the promotion of learning.

A fundamental premise of this philosophy is that the instructor does not issue pass or fail accreditations to course attendees. Except to prevent *negative transfer* of training, each training scenario is allowed to progress without interference or interruption by the instructor; the operators learn by experiencing the results of their own decisions and actions. The instructor is 'not present' within the training event except when role playing. Decisions and actions which produce unwanted results do not indicate a training failure; they serve as a developmental opportunity instead.

The apparent benignity of this approach should not be misunderstood; it is not a 'soft option'. Non-jeopardy does not mean that the training event is treated frivolously. Before the trainee is allowed to return to the operating core, performance deficiencies are corrected through the provision of additional training and coaching. At the end of the training session and after debriefing has taken place, the instructor certifies merely that the training has been completed. It is implicit that, upon exiting the process, all performance deficiencies have been corrected. (This approach does not lend itself to the conduct of Level 2 evaluations, and as there is no auditable paper trail, this deprived the writer of an opportunity to present the results of a full suite of evaluations. The results of Level 1, 3 and 4 evaluations are provided in Sections 9.2, 9.1 and 9.3 respectively.)

There are practical as well as philosophical arguments why a non-jeopardous approach is favoured. The appropriateness of conducting jeopardy assessments that are based on responses, made in an environment lacking full psychological fidelity, to events occurring within an environment that comprise some inaccurate cues, i.e., the misperception of speed, is questionable. At best, it could lead to false positive results which would result in the dissipation of the training investment made in assesses up to that point. Furthermore, the potential to revoke a licence unjustifiably would be unacceptable to the operators and could create disharmony that would detract from the overall initiative. In its study, RSSB (2009b) highlights a range of reasons why a driver might make an error while operating a simulator; only one of which is a skill deficiency. Furthermore, RSSB (2009b) finds that "… there have been some occasions where errors in the simulator have been noted [unjustifiably] as a formal incident on the driver's record, and in some circumstances this has led to the removal of the driver from driving duties" (Point 1.1.3). Most importantly, the introduction of jeopardy assessment would fundamentally change the instructor-driver relationship which is based on frankness, collegiality, altruism, and confidentiality. McKenney (2011) opines that worsened relationships could be generated without any gain, as "Jeopardy assessment… may result in crews producing acceptable behaviour in the simulator but have little real impact on the safety culture" (p.15).

5.7 Serious Gaming - a loose-tight delivery approach

Disparagingly, some critics view simulation merely as a game and suggest that the lack of imminent danger gives rise to ambiguous cues that reduce learning transfer. Blana (1996b) notes that "... the penalty and reward structure that motivates driver behaviour is substantially altered in the simulator" (p.10). The writer contends that the assignment of gaming status to a training simulation is, if implemented properly, a positive attribution.

Serious gaming is currently used in a range of training contexts, e.g., for military personnel and first responders. The essence of the process is captured by Abt (1987) who states that "The oxymoron of serious games unites the seriousness of thought and problems that require it with the experimental and emotional freedom of active play" (p.11). Serious gaming offers "… a playful environment that provides serious content, topics, narratives, rules and goals to foster a specific purposeful learning outcome" (Mitgutsch and Alvarad, 2015, p.2). The results of Sitzmann's (2011) meta analysis attest the synergistic effects of the gaming aspect on the seriousness of the process as:

> "… the intrinsically motivating features… increase self-determination because trainees… find it interesting and enjoyable… When trainees participate in traditional learning activities, they rarely display the level of effort and motivation that is typical of simulation games, thereby limiting the learning potential" (pp.15-17).

Using this loose-tight delivery approach, trainees' brains are stimulated to such a degree that almost all cognitive function is focused on the game, leading to increased interest and, consequently, learning (Cordova and Lepper; and Parker and Lepper (both in Sitzmann, 2011). In respect of its potential to enhance learning of NTSs, Gamberini *et al*. (2008) believe that serious gaming "... could represent an ideal tool for attitude and behavioral changes" (p.133).

5.8 Contextualised Development of Driving Skills

Although the main foci of the constituents in the lesson plan are well defined, e.g., passing a signal at danger or single line working, such events do not happen in isolation in the real world. Degraded and emergency conditions are encountered in the midst of normal operations. To reflect this, the lessons in I.É.'s lesson plan are contextualised within overall training scenarios and are experienced by simulator operators as anomalies. General driving skills that comprise of a blend of technical and NTSs, such as, defensive driving skills, train control skills, adherence to *permanent speed restrictions* and *temporary speed restrictions*, SPAD awareness, communication skills, and the detection of anomalies and discrepancies within the driving environment, constitute this contextualisation. The writer refers (in Column 2 of Table 27) to these general aspects of the lessons as overarching lessons. (More expansive lists of these skill sets are provided in Appendix 3.) Even though these general lessons are not mentioned specifically in the lesson plan, by their very nature they represent a crucial and intrinsic part of the overall process.

5.9 The Composite Lesson Plan

I.É.'s lesson plan is presented in Table 14. Many of the lessons contain a preview element which is sometimes presented in lecture format. This format is often criticised, particularly by those who have been absent from formal learning settings for long periods. However, the value and overall suitability of this delivery approach is dependent on the delivery context, the lecturer and participant qualities, and the availability of suitable alternatives. Some decry lectures on the basis that, when poorly executed, they devolve into disengaging and unidirectional methods of delivery. The use of quizzes, games, videos and computer based training tools, such as the classroom scenario demonstrator[55] feature of I.É.'s simulator system, ameliorates the situation.

By its nature, the traditional lecture process cannot provide an experiential, situated or active learning opportunity. However, it can make a valuable contribution when it is well executed in a communal setting. Engaging and penetrating lecturers can capitalise on the delivery setting to surface incorrect mental models. To lever off of the best attributes of each approach, a combination of lectures and simulator enabled training is delivered. The information is presented in lecture format for subsequent application in the simulator setting.

In respect of the designation of the subject matter of the scenarios, the presentation of fault finding scenarios, and their purpose and scope, it should be noted that:

1. The designations of the subject matter of the scenarios, shown in Table 13, is not linked intentionally to similarly numbered sections of I.É.'s Rule Book;
2. Fault finding scenarios, relative to the traction types that attendees are passed competent to drive, are presented to them. For example, if a course attendee operates 201 class locomotives, faults are presented on this class;
3. The use of the description of 'fault finding' to the process belies its comprehensiveness; it is more embracing than merely rectifying the fault. The training reflects the totality of the activity and is designed to improve technical and NTSs. In many cases the origination of a fault is presented to the driver by means of the presentation of an alarm on the train's TDMS[56]; creating a task

[55] Described in Section 6.3 (Point 3.1)

[56] On earlier, less elegant stock, awareness of the anomaly is less straightforward. For example, the driver may have to piece together tactile information on train performance with information on the gauges to become aware of a fault on the brake system.

interruption. Depending on whether it is an immediate or negotiated alarm, the driver will:

3.1. Manage the distraction and his workload;

3.2. Identify the location of the fault;

3.3. Effect a remedy;

3.4. Apply the associated rules and processes to the scenario;

3.5. Resume the original task.

Table 13: Coding of Lessons in Lesson Plan

Subject	Designation	Lesson type: focussed and/or general lesson	Subject	Designation	Lesson type: focussed and/or general lesson
Low adhesion driving	A	Focussed and general lesson	Opposite line fouled	G	Focussed lesson
Defensive driving and SPAD awareness	B	General lesson	Train operation	H	General lesson
Communications	C	Focussed and general lesson	Possessions T3	I	Focussed lesson
Passing signals at danger (with permission)	D	Focussed lesson	Shunting	J	Dependent on attendees' work location
SLW	E	Focussed lesson	Degraded on board systems	K	Focussed lesson
Working of a single line by pilotman	F	Dependent on attendees' work locations[57]	Providing and seeking assistance during train failure	L	Adjunct to fault finding lessons

Table 14: Simulator Enabled Refresher Lesson Plan for Qualified Drivers

Time slot	Activity	Procedural training and technical skills under development	Non-technical skills under development
Day 1: 09:30-09:40	Sign in; Housekeeping procedures.	Advise the attendees of the safety protocols. Provide attendees with an overview of the facility and features, and inform them of the logistical arrangements.	
09:40-10:00	Hazard free exploration of equipment and discussion on the: Equipment and how to fault find in 2D; Scenarios to be presented; Purpose of repeating operating performance in observation room and role of observers; Types of instructor interactions and interventions.	The output objectives are to provide: An appreciation of equipment functionality and configuration; Experience of touch screen operation; An understanding of the roles of the instructors and peers; A bespoke simulated Weekly Circular, showing the locations of *TSRs*, T3 possessions, train headcodes and warnings of low rail adhesion etc.; and To state the rules of conduct [58] associated with providing peer reviews	
10:00–10:30	Half of the drivers operate the simulator for a duration of 15 minutes to become familiar with it; the balance remains in the observation area. Operant drivers and observers switch roles. The trial is not complicated by the presentation of train faults or operating anomalies.	Collectively, the two trial periods include starting, stopping, running on restricted signals, obeying TSRs (communicated through the bespoke simulated Weekly Circular) and *PSRs*, using the verbal communication protocols, stopping to serve stations, pre-advised low rail adhesion conditions, driving into a dead end platform and through gate crossings. Activities are performed in a range of environmental conditions.	
10:30- 10:45	Operators are provided an opportunity to comment on the simulator equipment and to ask questions about the process they are about to engage in.	To ensure participants are confident in the use of the equipment.	N/A
10:45- 11:00	Break		
11:00–12:00 (Lesson 1)	A preview of the session, using a training video[59] is provided. Trainees take part in a quiz using a SMART Board ™ interactive whiteboard. They answer the questions anonymously using an electronic voting facility. Half of the drivers operate the simulator and the remainder observe for a period of ca. 15 minutes. Then, they switch roles. The review session comprises discussion, self appraisal of performance, and reviews from instructors and peers.	Scenario type D: Passing signals at danger with (a) authority of the signalman and (b) with the authority of a person in charge of possession. Each group of attendees experience variety.	Hazard perception; Simultaneous capacity
12:00-12:40 (Lesson 2)	Half of the drivers engage in fault finding simulations; the balance observes. The drivers and observers switch roles. Two faults are presented. The review session comprises discussion, and performance reviews from instructors and peers.	Saloon door system failure and inability to either open the doors, or to restore traction after subsequent closing. Drivers initiate bespoke 'open' and 'lock-off' procedures. See note 2 above regarding the presentation of scenarios on relevant classes of traction.	Emotional intelligence (remaining calm in stressful situations).
12:40-13:40	Break		
13:40-14:40 (Lesson 3)	A preview of the session, using a PowerPoint presentation, is provided. Half of the drivers operate the simulator for a period of ca. 15 minutes while the balance observes. Then, they switch roles. The review session comprises discussion, self appraisal of performance, and reviews from instructors and peers.	Scenario type G: Opposite line fouled. Each group is presented with the scenario while operating over different track typographies, i.e., on two, three or four track layouts.	
14:40-15:20 (Lesson 4)	Half of the drivers engage in fault finding simulations; the balance observes. The drivers and observers switch roles. Two faults are presented. The review session comprises discussion, and performance reviews from instructors and peers.	A range of brake problems are displayed on the train's TDMS, e.g., emergency brake application, brake electronic control unit circuit breaker tripped, parking brakes not releasing or service brakes sticking.	Problem solving.
15:20-15:30	Break		

[57] Many drivers do not operate over single line routes.
[58] Peer reviews are provided with the intention of assisting fellow simulator operators. Honest constructive comment, rather than phoney praise, is provided within a framework of order and decorum.
[59] The use of the term 'video' includes the audio video interleaved (.avi) files that have been generated using the scenario classroom demonstrator (CSD) facility of the simulator.

Time slot	Activity	Procedural training and technical skills under development	Non-technical skills under development
15:30-16:30 (Lesson 5)	A preview of the session, using a training video, I.É.'s communications handbook and a case study is provided. Half of the drivers operate the simulator for a period of ca. 15 minutes while the balance observes. Then, they switch roles. The review session comprises discussion, self appraisal of performance, and reviews from instructors and peers.	Scenario type C: The communications process is initiated verbally, e.g., a request to examine the line or visually by telegram message, e.g., 'Stop and Examine' (after activation of hot axle box detector) on the *train radio*. Operators communicate as either transmitters or receivers over the train radio or signal post telephone. Communication exchanges are rated by peers. Each group experiences a variation in the simulation.	Communications; Managing performance of others in the exchange; Workload management; Reflective and active listening.
Day 2: 09:30-09:45	Sign In	Review of activities from Day 1 Short question and answer session	
09:45-10:45 (Lesson 6)	A preview of the session, using a PowerPoint presentation, is provided. Half of the drivers operate the simulator for a period of ca. 15 minutes while the balance observes. Then, they switch roles. The review session comprises discussion, self appraisal of performance, and reviews from instructors and peers.	Scenario type A: Low adhesion driving Two variations are selected, e.g., falling gradient, buffer stop approach, sand application, requesting a route through a station. Each group experiences a variation on the theme.	Situational awareness.
10:45- 11:00	Break		
11:00–12:00 (Lesson 7)	A preview of the session, using a PowerPoint presentation, is provided. Half of the drivers operate the simulator for a period of ca. 15 minutes while the balance observes. Then, they switch roles. The review session comprises discussion, self appraisal of performance, and reviews from instructors and peers.	Scenario type K: Degraded on board systems One group encounters failure of the *safety control equipment* (SCE); the other experiences CAWS failure. The groups need to identify the cause of the failures, isolate the equipment and implement the necessary protocols, e.g., advising the controlling signalman, or the deployment of a secondman.	Awareness of the dangers associated with automaticity and over reliance on safety systems.
12:00-12:40 (Lesson 8)	Half of the drivers engage in fault finding simulations; the balance observes. The drivers and observers switch roles. Two faults are presented. The review session comprises discussion, and performance reviews from instructors and peers.	Failure of the warning device (horn), headlights or *track circuit assistor* (location-specific procedures involved). This lesson is replicated for a range of traction classes. Various 'passenger call for aid' scenarios.	
12:40-13:40	Break		
13:40-14:40 (Lesson 9)	A preview of the session, using a training video is provided. Trainees take part in a 'card game' in which the procedural steps, associated with the task about to be undertaken, must be ordered. Half of the drivers operate the simulator for a period of ca. 15 minutes while the balance observes. Then, they switch roles. The review session comprises discussion, self appraisal of performance, and reviews from instructors and peers	Scenario type I: T3 possessions	
14:40-15:20 (Lesson 10)	Half of the drivers engage in fault finding simulations; the balance observes. The drivers and observers switch roles. Two faults are presented. The review session comprises discussion, and performance reviews from instructors and peers.	Drivers are presented with a range 'General Warnings' on the TDMS., e.g., MCB tripped, motor/trailer bogie fault, couple/uncouple cock in wrong position, fire extinguisher removed, WSP failure, fire on train, passenger/driver interphone, emergency cord alarm or Teloc (event recorder) failure.	Decision making.
15:20-15:30	Break		
15:30-16:30 (Lesson 11)	A preview of the session, using a training video and a PowerPoint presentation, is provided. Half of the drivers operate the simulator for a period of ca. 15 minutes while the balance observes. Then, they switch roles. The review session comprises discussion, self appraisal of performance, and reviews from instructors and peers.	Scenario type E: SLW Half of the drivers operate in the right direction; the other half operate in the wrong direction.	

Specific events, aimed at developing awareness of NTSs, are contained within the lessons. Some NTSs are practiced in a number of the lessons. Opportunity to practice and exhibit these may occur in advance of the formal bespoke lesson. For example, communications skills are practiced extensively in Lesson 1 but the focussed 'Communications' lesson is Lesson 6. Feedback on communication performance is delivered at the end of Lesson 1 as well as in Lesson 6. The contexts, used to develop awareness on NTSs within the lessons are:

1) Hazard perception skills are developed by placing objects and avatars in the visual environment. A commercial road vehicle, modelled on those used by the infrastructure department, is placed in the environment to provide a cue to the driver; prompting him to be on the lookout for permanent way workers who may be 'on or about the line';
2) Communication skills are developed by the application of I.É.'s structured communication protocols during all of the interactions between the driver and the signaller[60]. The driver also manages the authority gradient in cases where the signaller deviates from the standard protocols that are set down for such interactions;
3) Workload management skills are developed during training for normal operations, e.g., non critical communication is initiated by the train regulator[61] over the train radio at a critical juncture. The driver answers the call only after the critical tasks have been attended to;
4) Emotional intelligence (remaining calm in stressful situations) is developed during train failure situations. The train regulator and a passenger[62] enquire impatiently, over the train radio and passenger communication systems, into the reason for the stoppage and the estimated time of journey resumption;
5) Simultaneous capacity is developed by creating situations that are designed to divide the driver's attention. An avatar or a trackside fire is positioned in close proximity to a *section signal*. The signal is at danger;

[60] Role played by the instructor, or by a signalman when used for joint training interventions. It should be noted that to prevent negative learning it is the instructor, role playing the signalman, who is involved in cases where the driver is required to deal with a deviation in communication procedures.
[61] Role played by the instructor.
[62] Role played by the instructor

6) Problem solving skills are developed by placing a shopping trolley, which has been discarded by vandals, on the line. As the train passes the trolley, an emergency brake application is initiated. The process involves the establishment of a causal link between the detection of the trolley and the application of the train brakes;
7) Decision making skills are developed by presenting a mediated[63] alarm to the driver. The driver will decide when to deal with the situation having regard to the tasks at hand, the risks that are known to exist at the particular location and the criticality of the alarm, and the relevant operating procedures;
8) Situational awareness skills are developed using a combination of the CSD[64] and the simulator. Using the CSD, video footage of a train about to start from a curved island platform is shown to attendees. In the video, both lines are occupied by trains. A 'ready to start' handsignal is displayed by platform staff to one of the drivers but is visible to both drivers because of the curve. This creates a *starting against signal* SPAD (SASPAD) trap for the unintended observing driver. Using the simulator in a separate use case, the adhesion at the wheel/rail is reduced. Advice of low rail adhesion (LRA) locations is provided in the bespoke simulated Weekly Circular;
9) The danger associated with automaticity, the potential over reliance on safety systems, and the necessity to respond rather than to react to displays on the aspect display unit of the *continuous automatic warning system* are discussed in Lesson 7.

The readers' attention is drawn to the relevance of the numbering of the lessons in Table 14. The reference numbers of the scenarios (from Appendix 10), together with the locations of these scenarios within the numbered lessons (from 1st column of Table 14), are show in Column 2 of Table 27. Relevant changes to I.É.'s operational risk, achieved through the use of the simulator system, are presented in Column 5 of Table 27.

63 Passenger communication alarm
64 Simulated occurrence presented in video format

5.10 Conclusion

The completion of a TNA at the business level unit of analysis is necessary in order to determine the scope of the system to be acquired. The completion of a TNA at the role centric unit of analysis is necessary to determine the training content for the role and, by extension, the training scenarios and the capability of the system. The intended use cases determine the requirements specification for the system.

Under the influence of emerging technologies, train driving is becoming an increasingly complex process and drivers must receive appropriate training in all the domains of learning. Training requirements must be determined with respect to the task components and, as importantly, to the cognitive processes which determine performance. A combination of hierarchical and cognitive task analyses is necessary to elicit both sets of determinants. To maximise the effectiveness and efficiency of the training process, it makes intuitive sense to adopt a risk and value based approach during the content elicitation, scenario development and training delivery phases. However, this approach has not garnered wide acceptance even in those jurisdictions where there is an abundance of data available on risk exposure.

I.É.'s training programme was developed having regard to its internal standards and validation process whilst, at the same time, respecting the regulatory requirements. Although I.É. did not have access to internal professional ergonomic competence, it utilised the extensive knowledge and capability of its Staff Trainers to reveal the cognitive requirements associated with the operating scenarios.

Non-technical skills compliment technical skills and contribute to safe traction driving. Accordingly, I.É. integrated NTSs awareness training within some of the lessons. This training was delivered in respect of SA, HPT and CRM. I.É. adopted an EBAT approach when designing the lessons. Using this approach, trainees encounter anomalous situations in the midst of routine operations. This approach enables the concomitant training of technical and non-technical skills. Prior to undertaking the simulator component of each lesson, enabling content is delivered in lecture format using a range of engaging techniques. At the end of the simulator component of each lesson, instructor and peer feedback on performance is provided.

Choosing the wrong training delivery approach would have hindered value creation. The writer wished to create an acceptable, non-threatening and engaging learning environment wherein attendees could devote their all of their efforts to the task of learning. It was decided not to make jeopardous assessments part of I.É.'s training process. Instead, the mastery approach was used and operators receive whatever repeat training is necessary until they have mastered the lesson content. Confidence in the competence of the operators is maintained through the precept that operators have been deemed to be competent at the end of the training session. An individual may have made one or more unsuccessful attempts before succeeding but this is unimportant; what is important is that, at the end of the training process, he is competent in task performance.

6 Types of Simulators and Fidelity

In the context of the overall railway system, simulation is used in a full range of engineering, planning and operations applications, e.g., modelling vehicle suspension characteristics (Vampire ™), modelling wheel behaviour with hardware in-the-loop simulations (roller rig), modelling the effects of dynamic loads on trackwork (Adams/Rail-MEDYNA ™), modelling the effects of dynamic loads on structures (LUSAS ™), and modelling train running paths (Voyager ™). There is a fundamental difference between these types of simulations and the type that forms the central plank of this thesis. With the former types of simulation, the operators exist outside of the simulation; with the latter type, the operators exist within the simulation. This is referred to as human-in-the-loop simulation.

Effective training for all of the identified training needs cannot be provided in the real world, so a surrogate mechanism is required to satisfy any identified insufficiency. Training simulators constitute the mechanism to abridge this shortfall. There is a wide variety of simulator equipment, with similarly wide ranging costs, available in the market. Each type is capable of bestowing particular benefits but each type also has specific drawbacks. In the previous chapter, the writer presents I.É.'s simulator enabled lesson plan, discusses the process that was used to develop it and provides insights into training delivery considerations. In this chapter, he discusses the means by which the lesson plan would be delivered. He addresses general issues around simulators, reveals the high level options that were selected by I.É., and introduces the concepts of egospeed and presence; both of which are particularly relevant in the context of performance assessment.

At the feasibility stage of the project, the writer was in the fortunate position of not being overly constrained by cost implications; costs represented ca. 0·31% of the overall cost of the RSP (see Table 1). Because of the perceived transformational effects that simulation would have on training outcomes, there was an ephemeral inclination to procure an extremely elaborate system. Using the research contained herein, such inclinations were quickly aligned with the key commercial principle, i.e., unproductive costs must not be incurred.

This chapter is divided into eight sections, dealing with:

6.1 What is a Simulator?;

6.2 The Proliferation and Development of Simulators;

6.3 Simulator Components;

6.4 The Market for Simulators;

6.5 Overview of the Product Range;

6.6 Egospeed in the Simulated Environment; and

6.7 Simulator Presence.

Concluding remarks are presented in Section 6.8.

6.1 What is a Simulator?

A distinction must be made between the terms 'simulation' and 'simulator'. A characteristic difference is that the former relates to a process and the latter refers to the tool or technology involved in creating the simulation.

Juhary's (2006) explanation of the simulation process is most agreeable to the writer insofar as it encompasses its main output objective, i.e., "... the context should place the student in a situation similar to the one in which he is going to apply the knowledge where understanding is much more important than memorising the facts" (p.3). Simulation is about practice-based contextualised learning which facilitates the development of a comprehensive suite of mental models, most relevantly, the probabilistic ones. Simulation permits the inclusion of probabilistic events into the more predictable aspects of the task environment. The occurrence of possible but improbable operational events epitomises the task context of train drivers. Although there is a lot of predictability associated with the job, it is the ability to cope successfully with the combination of predictable and unpredictable events that defines true competence and *expertise*.

A simulator is always an imitation of reality and, as such, it is never perfect insofar as it reproduces the behaviours, states and perceptions of the real world to a limited degree. Because of this lack of congruence between the virtual and real worlds, Juhary (2006) advises that a simulation should resemble the real world closely as the use of a low level simulation could, conceivably, lead to the formation of two separate mental models; one of the simulation and one of the real world. The approach taken by I.É. at the specification and use phases of its project, to prevent negative learning, is discussed in Sections 7.6 and 5.6.2 respectively.

The description of a simulator by Eichinger and Geraghty (2004) builds upon Juhary's by including the notion of user experimentation. It promotes the concept of non-jeopardy training which is predicated on the concept of learning by failing which, in turn, supports the concept of mental model development. They describe training simulators as "... tools that allow users to experiment with alternative options... [and] predict the results of... operational decisions or actions" (p.1).

6.2 The Proliferation and Development of Simulators

Whilst the preponderance of simulation technology was developed to satisfy the needs of the aviation industry, this technology is now being used for skills training and assessment in many other industries and contexts.

Simulators have been used since 1903[65] to train pilots in aircraft rudder movements (Perrow, 1999), between 1914 and 1918 to train cavalry men, since the 1950s to teach basic car control skills to drivers in Sweden and, since 1996, to train Japanese motorcyclists[66] (Haworth *et al*., 2000a). Although dioramas had been used in Britain since 1887 to train traction drivers, the earliest recorded use of the human-in-the-loop simulators was associated with the electrification of the West Coast Mainline in the early 1960's (Scott, 1998); they have been gaining widespread acceptance ever since. The Canadian National Railway has been using them since the early 1970s and Queensland Rail has been using them since the mid 1980s. More locally, Translink, the railway operating company in Northern Ireland, acquired a simulator in 2004.

[65] However, the purchase of six simulators (Edwin Link Trainers) in 1934 by the US Army Air Force is widely accepted as being the precursor of modern flight simulation.
[66] The task of motorcycle riding is particularly challenging to simulate as it includes *proprioceptive* and tactile components, and balance ability, in addition to the psychomotor, cognitive and affective skills that are required for car driving.

Early traction simulators were constructed using real cab components and controls. The out-the-windscreen view comprised video footage of a real route. Recordings of actual in-cab sounds were used to provide aural cues. A computer simulation of the train behaviours integrated the audiovisual environment and the train control. Although the first generation of simulators created a very realistic training environment, they had limitations. It was not possible to change the state of the environmental artefacts, or to manipulate the weather or time of day etc. The quality of the *OTW* view deteriorated when the route video was played at different speeds than that at which it was recorded. Computational power was limited and the models of train behaviour were simple. Sometimes, the limited capability to alter signal aspects was circumvented by placing a hardware replication of a signal head adjacent to the projection screen. These simulators were used to develop basic driving skills, limited fault finding capability and route knowledge. No consideration was given to training the NTSs. The business case for making the financial investment in them was that they could substitute for a real train and that they were cheaper to purchase and operate.

Technological improvements facilitated higher quality graphics and provided much larger computer memory storage. More accurate and detailed train models, more complex train configurations and more complicated train faults can be modelled which increase the functional fidelity. The second generation of simulators can replicate the virtual environment and train performance characteristics accurately, store and manage data to facilitate multiple comparative runs for each trainee and can calculate train performance data, i.e., in-train forces, energy efficiency, brake performance and trip times etc. Developments in computer graphics have also meant that *CGI* has replaced video footage[67]. States of infrastructure elements, climatic conditions and time of day can be altered at will. The audiovisual environment can be whatever the *user* wants to include in the simulation; not what was available on the day that the recordings were made. Modern simulators can create "... not a rendering of a place in time but of that

[67] CGI was first applied, in primitive form, to aerospace and scientific engineering in the mid 1960s. However, the 1982 movie 'Tron' was the first example of its widespread use to replicate realistic imagery digitally (Hahn, 2010).

place here and now" (Coelho *et al*., 2006, p.26). A three-dimensional model of the navigable space is generated using CGI. As the train is routed through this virtual space, the computer almost instantaneously generates the OTW view based on the exact location of the train, its speed and the objects that are placed in the scenery by the instructor as part of a scenario.

However, the creation of this realism by artificial means comes at a cost. It is difficult to capture the data with sufficient accuracy to construct a high fidelity simulator and also to create the virtual environment for the OTW view. Gutiérrez *et al*. (2005) believe that accurate data capture is even more difficult to achieve than the process of engineering the simulator. The behaviours of the trains and the geographical parameters have to be accurately defined in the algorithms. The construction of a *geo-specific* visual database requires a detailed survey[68] so that all of the topographical details are presented as they appear on the real route.

6.3 Simulator Components

There are seven principal components of a human-in-the loop simulator:

1. A mock up control station or driver's desk. There is much discussion around the required accuracy and realism of this component and whether it needs to be faithfully replicated in hardware or software. This choice is not a dichotomous one; some elements can be modelled in hardware while others can be modelled in software;
2. A vehicle model. This is an accurate representation of the train's systems and behaviours. It ensures that the driving experience is realistic and convincing:
   2.1. The physical properties of motion are calculated in real time;
   2.2. The physical movement of the cab as it responds to changes in the alignment of the trackwork and the elasticities in the formation also forms part of the vehicle model. Depending on the importance

[68] The creation of a geo-specific database has been made much easier. Manufacturers have recently commercialised laser technology and use a software programme (MATRIX ™) to develop routes accurately and effortlessly. The landscape is traversed by a rail mounted scanner and digitised scans are manipulated so that the states of the artefacts on the route can be reconfigured at will.

assigned to recreating cab movement, some simulator systems incorporate expensive motion platforms;

3. A display. The complexity of the display arrangement varies along a continuum from single to multiple monitors; to single channel projectors. The most sophisticated display arrangements utilise multiple channel projectors with edge blending to present a wide field of view seamlessly. Choosing the appropriate *FOV* and the method of its presentation is most important as it influences the presentation of redundant operator cues[69], speed misperception[70] and proneness to sickness[71];
   3.1. In contrast to video, CGI can be used to provide environmentally rich training scenarios that can be designed and modified readily to meet fluid training objectives. CGI allows the user to define the training environment, e.g., the same scenario can be played in conditions of daylight, night, fog, rain, snow, increased environmental traffic and altered character behaviour. It also allows almost unlimited generation of interactive scenarios. Additionally, when using the CSD feature, the 'camera' or eye point can be positioned anywhere in the CGI to provide bird's-eye views of emerging scenarios. In I.É., this feature is used to illustrate the visual and cognitive traps that confront drivers in situations when artefacts and actors are occluded in one viewpoint but are visible in another, e.g., other operational staff are occluded from the driver's view by environmental features or when drivers are presented with 'ready to start' handsignals that are intended for drivers of trains on adjacent platforms. The need for flexibility to alter the visual environment becomes evident when the broad range of scenarios, contained in Appendix 10, is considered;
   3.2. The use of the track builder tool allows users to extend the product's capability. From their desks, users can update the databases of extant

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[69] Excluding the shunting activity, drivers have limited need for wide FOVs of the route ahead.
[70] Research by Wallis, Tichon and Mildred (2007) reveals that the field of view, presented to simulator users, is a determinant of the misperception of speed.
[71] FAA (2003) found that when there is a visual reference to the horizon or ground, the sensory system in the inner ear of the vestibular system becomes more reliable and the operator becomes less disoriented.

modelled routes to cater for infrastructure changes, or alternatively when fully proficient, users can develop new routes;

4. A traffic model. This model includes the other traffic in the environment, e.g., controlled and automatically generated approaching trains, road traffic at grade crossings and trackside workers. Some of the model's components are dynamic and others are placeables, i.e. 'cut and paste' static objects, and avatars;
5. The scenarios. Training scenarios can be pre-scripted using the scenario preparation station. Alternatively, they can be constructed in real time using the instructor station. However, the latter informal approach does not provide opportunity to debug them or to validate them against defined objectives prior to deployment;
6. An instructor station. The instructor manages the simulation and observes trainee performance through this interface. The instructor station also incorporates a communications computer which interfaces with the train radios on the drivers' desks. Using this feature, instructors assume the roles of other actors, e.g., signalmen, other crew members, traffic regulators and passengers in the myriad of inter-party verbal exchanges that can occur, in a variety of contexts, over the train radio, crew phone and passenger communication systems;
7. A *SPS*. The instructor pre-scripts scenarios on this computer. He defines the type of traction, the route, the environmental conditions, the event and any anomalies, prior to launching the scenarios onto the simulators.

The above decomposition of a simulator system is generic and only presents a high level view of the basic components. Simulators are engineered to customer requirements and the specification of many of the components necessitates choices that are influenced by appropriateness to goal achievement, cost-benefit tradeoffs and acceptability to the user groups. As the typical life of a simulator is fifteen years, the choices exercised in respect of each component and attribute should be based on informed inquiry. The options selected by I.É. are presented in Table 15.

Table 15: Option Selection

Simulator Component	Option Selected by I.É.
Mock up driver's desk	i) Desks would be based on nine classes of traction. In respect of engineering and modelling compromises, priority was afforded to the most recent traction fleets with the greater populations. ii) Productivity of desks would be maximised by the use of interchangeable handle boxes. iii) Operator interfaces would comprise a combination of hardware and software elements. iv) Artefacts on the desk that facilitate the achievement of training objectives would be modelled functionally. Ancillary artefacts, e.g., cab heater and saloon light switches, would be modelled non-functionally.
Vehicle model	i) Accurate train models were specified. ii) Motion devices were actively avoided.
Display	i) To assist the creation of presence, 330 kilometres of strategically selected, geo-specific track database would be provided. Presence would be augmented by the inclusion of a number of lifelike prominent buildings on each route. ii) A small FOV would be presented to operators by means of projectors. The result of adopting this approach is presented in Section 10.3.
Traffic model	The supplier's standard offering of controlled and automatic trains, and passenger activity on the platforms was accepted. Although this was adequate to address the extant needs, it may require modification in the event of the use cases being extended as proposed in Section 11.2.
Scenarios	An 'open' platform was specified to enable scripting of a comprehensive range of realistic and relevant scenarios. See Appendix 10.
Instructor station	This would be configured to reflect: i) The extant AEG 90 train radio; ii) A span of surveillance of two operators per instructor; iii) The use of an observation station.
Scenario preparation station	The supplier's standard offering was accepted.

6.4 The Market for Simulators

The market for driver training simulators is highly fragmented. It has passed the growth phase and is now mature. Manufacturers are now trying to gain market share from each other. As it becomes saturated and commences the decline phase, many suppliers will be forced to exit and some users will be left with costly equipment without manufacturers' after sales support. However, support is usually available from remaining players in the market and these can provide maintenance and refurbishment support for equipment that was provided by extinct competitors. It should be noted that there is a vibrant market for the provision of half life equipment rebuilds. Even though the life expectancy of simulators is generally regarded as being fifteen years, there is a need to update them at half life due to lowered reliability of the computer hardware, unsupported operating systems, the requirement to model modifications to stock or new fault remedies etc. Annual maintenance and half life rebuild costs amount to about 1·4% and 25% respectively of the initial purchase price and have a significant effect on the internal rate of return of a simulator project. Over the lifetime of the project this product extension amounts to nearly 50% of the initial capital cost and it is unsurprising that simulator manufacturers are desirous to build and harvest long term customer relationships.

6.5 Overview of the Product Range

There is a full simulator product line-up. The degrees of fidelity and elegance of the various simulator types are evident from the photographic montage, presented in Appendix 13. Within each product segment, there is a great deal of variance in terms of sophistication and, hence, the proffered costs are indicative only. The part task trainer segment occupies the least expensive end of the continuum. It costs about £29,000 to develop the initial prototype and £21,000 per trainer thereafter (2015 prices). Full cab simulators occupy the other end of the continuum. These replicate all of the vehicle's functionality and physical features and, depending on the specification, cost between €650,000 and €1,440,000 for each desk (Actuate Consortium, 2015). It should be noted especially that the scope of supply of full cab simulators in this price range is typically limited to about 30 kilometres[72] of visual database and motion is provided by a shaker seat instead of a costly[73] motion platform.

However, 'expensive' is not synonymous with 'better'. The value that is derived from the various types is dependent on their ability to satisfy the defined output objectives that constitute the customer requirements specification. For example, on the one hand DERA (2000) were able to productively use a part task rail simulator to study the effects of shift pattern and route type on safe performance whereas, on the other hand, the simulator in use by Amtrak has to be a *full cab*

[72] Double line track data base costs about €900/km in excess of this minimum economic order quantity.
[73] The cost of a 6DOF motion platform, including modelling, is about €275,000 (2015 prices).

replica that is mounted on a motion platform. Because of Amtrak's output objective, i.e., to use it for performance skills testing, there is a requirement to faithfully mimic the cab layout and functionality, handling characteristics, and draft and compression forces etc. of the HHP8 Bombardier–Alstom locomotive (Luczak, 2000 and GPO, 1999).

Rail regulatory authorities, in Ireland (RSC, 2012) or elsewhere in Europe, do not prescribe the type of simulators that should be used for training; it is left entirely up to individual railway undertakings to decide the type and degree of elegance of the equipment to be used. The US regulatory authorities are more prescriptive. Although FRA (2012) states that it "… takes no exception to the use of simulators as a training tool… [it] does not consider the use of simulators to be an acceptable substitute for practical experience in the initial training of persons" (p.16-16). Sheridan *et al*. (1999) presents the reasoning underlying the FRA's philosophy on the suitability of particular types of simulators to satisfy particular use cases. In respect of the use of Type II and III simulators, Sheridan *et al.* state that their use "... for initial training of persons... may improperly prepare them for the task of actual operation... [as] in the real world, drivers gain experiences which are tactile... and kinaesthetic" (p.19). See Appendix 14 for an elaboration of simulator taxonomy.

The FRA is even more prescriptive when the simulators are to be used for certification. GPO (1999) mandates[74] that, as a criterion of the assessment of performance skills, the testing procedure "...shall be of sufficient length and… conducted when the person is at the controls of the type of train, or Type I or Type II simulator to be normally operated" (§ 240.127). It should be noted that a performance skills test is more comprehensive than a monitoring check ride and is performed once every three years whereas the check ride is performed annually.

6.5.1 Part Task Simulators

Part task simulators comprise of software and, depending on their application, a visual display system. When used for ab-initio driver training, they include a basic

[74] Regulations valid at 04.04.2016.

OTW display system (see Appendix 13). They also incorporate a meagre hardware interface comprising dummy panels, and a selection of real switches and buttons to represent the principal hardware cab elements. As the term suggests, functionality is designed around a subset of specific tasks and they are usually employed to supplement or fill critical training gaps within an overall training or assessment programme.

They are used to provide non-contextual, general training rather than holistic traction-specific training. Part task training is more appropriate when the individual elements contained within the task are complex, and when the relationship and organisation between them is straightforward and there is no problem integrating the elements (Tendick, 2002). However, as discussed in Section 5.2, skills are often clustered together, so there comes a point in time when learning in those subtasks has to be integrated into a whole piece. Stand alone part task trainers are available to provide training for route learning, basic control skills, eco-driving, passenger information system operation, global system for mobile communications for railways, *automatic train protection*, ATO and *ATC* systems.

Their frugality belies their utility and cost effectiveness. They are particularly useful as complimentary training devices as:

1) They are relatively cheap;
2) For particular outcomes, they can be substituted for other training devices. If procured as part of an overall strategy, trainees' in-seat time on more elaborate and expensive simulators can be curtailed; reducing the number required;
3) They can be used to cope with equipment changes, e.g., when UK operators were transitioning from the cab secure radio to the *GSM-R* system;
4) There may be cost advantages ensuing from their generic nature. For example, the large quantity of them that were purchased to support the implementation of the GSM-R project in the UK, led to a reduction in the unit price.

6.5.2 Desk Simulators

The system purchased by I.É. comprises *desk simulators*. Desk simulators incorporate comprehensive sets of necessary controls, such as door controls, safety control equipment, train radio, train data management system, master switch and the power/brake controller, in hardware format. They are not contained within replica driving cabs but are accommodated either in enclosed spaces or within bespoke booths. As could be expected, they do not create the ambience of real traction units. They are situated mid way on the product continuum. Depending on their design and functionality, desk simulators cost anything from €150,000 to €350,000. Features, such as, the control instruments (speedometer, air and vacuum gauges), circuit breaker panels and isolation switches, and faultfinding artefacts are presented through the medium of touch screens. Images of the route, much smaller than those used in a *full mission* simulator, are presented either on a projection system or on a monitor.

One advantage of this type of simulator is that a number of simulator workstations can be networked and operated using the same set of communications computers, and modelling and development tools through a local area network. This type of system provides a number of efficiencies:

1. There is an economy of scale. A number of workstations can be incorporated into a small space and can share the physical infrastructure as well as the software;
2. A number of trainees can receive training at once, thus speeding up the training process;
3. Very favourable instructor/trainee ratios can be achieved. However, the danger with a large class size is that slower learners may not be able to keep pace and an overburdened instructor may not notice this.

6.5.3 Full Cab Simulators

A full cab simulator looks and behaves like the traction unit upon which it is based. It is designed to provide operators with the greatest immersive experience possible; one that replicates the experience in the working environment. To achieve this goal, all of the equipment contained within the cab itself is fully functional whilst the layout, features and functionality of the cab's exterior, e.g., the engine room or car body side, is simulated using either an integrated touch screen arrangement or a part task trainer.

Depending on the activity under training, e.g., driving a locomotive(s) hauling a long and heavy train or driving a tilting train, it may be considered necessary to develop the drivers' kinaesthetic skills, or 'knowledge in the hands' as Nonaka and Takeuchi (1995) call it. To train such skills, full cab simulators are mounted on motion platforms. This approach increases the sense of presence experienced by the operator and improves egospeed.

Accepting that full cab motion simulators abet the maximisation of presence, they were precluded by the writer for practical considerations:

1) I.É. could have purchased only two full cab simulators for the same cost as eight desk simulators. This would have been inadequate to satisfy the anticipated training workload and to cater for its driver deployment;
2) The value proposition is poor. I.É. would be paying for a facility to train a non-essential skill;
3) A simulator system, based on full replication of a particular traction unit, has low functional and physical fidelity in respect of another type of traction, and nearness of training transfer is diminished.

Irrespective of simulator type, there is a requirement to keep train models and visual databases up to date. This challenge becomes more expansive and expensive in line with simulator complexity. EWS utilised a novel approach to keep its simulator current with the modelled locomotive. EWS assigned a 'total operations processing system' number to it, thus ensuring that any modifications that were carried out on the Class 66 locomotives would be carried out on the simulator as a matter of course Maintaining the visual database to reflect infrastructural changes poses a similar challenge but this was not a concern for EWS who had only included a geo typical database in the scope of supply. As well as affecting training effectiveness negatively, failure to update the system is likely to draw criticism from accident inquiry chairmen and simulator operators (Mackie, 2005; Neal, 2001; McInerney, 2001 and NTSB, 1999).

6.5.4 Simulator Fidelity

There are three dimensions of simulator fidelity and each plays a part in the contribution that simulators make to the didactic outcomes:

1) Physical fidelity is the degree to which the simulated environment looks like the real environment (Eichinger, 2004). To ensure high physical fidelity, a high proportion of original equipment manufacturer parts are used in construction. For example, when General Motors constructed 250 Class 66 locomotives for EWS, they produced an extra cab which was used by IITRI[75] to construct EWS' full cab simulator;
2) Functional fidelity is the degree to which the simulated environment behaves like the real environment (Eichinger, 2004). A simulator with high functional fidelity provides a comprehensive set of stimuli in order to elicit the correct response from the range of possibilities. Such a simulator accepts either correct or incorrect inputs with veridical resultant outcomes;
3) Psychological fidelity is the degree to which the simulation replicates the associated psychological factors, such as stress or fear. (Alexander *et al.*, 2005). High psychological fidelity is achieved by means of the equipment features, ambience and training scenario. For example, an operator who is participating in a scenario of high psychological fidelity and can project forward the outcome of his ineffective inputs, e.g., when encountering wheel slide on the approach to a buffer stop, will become stressed. If dealing with stressful situations effectively is one of the goals of the training intervention, this attribute is essential. The effect of stress on an individual's performance is well recognised (Tichon *et al.*, 2006). Drivers need enhanced skills, particularly *cognitive skills*, such as, decision making, problem solving and critical thinking, to deal with emergencies but these skills degrade in stressful situations. (See also Haworth *et al.*, 2000b.) Virtual reality "... has been demonstrated to enhance the development of quality decision making skills, particularly under the stress imposed by time limitations" (Tichon *et al.*, 2006, p.2).

[75] Illinois Institute of Technology (IIT) now trades under the style of Alion after a management buy out in 2002

It is clear that not all of the systems discussed in Sections 6.5.1 to 6.5.3 are capable of providing high fidelity, and also that a simulator specifier may not wish to incorporate the highest fidelity within each of the classifications. The simulators purchased by I.É. provide a high degree of functional fidelity, a medium degree of physical fidelity and a low degree of psychological fidelity.

6.6 Egospeed in the Simulated Environment

Egospeed is the internal estimation of self-motion (Kim, 2015). The correct estimation of speed is of paramount importance to successfully completing the driving task (see Section 2.4). Humans are adept at estimating their speed even when travelling at speeds that are well beyond those for which evolution has equipped them. Wallis and Tichon (2013) believe that this ability has possibly developed "… through the training gained by observation of a speedometer in fast moving land-based vehicles, [and that]… in order to make speed estimates, the brain relies on integrating a range of sensory cues" (p.71). Kim (2015) points out that "… there is a tendency for individuals to rely far more on external cues to indicate their speed rather than the speedometer, especially on stretches of [the route] that the driver is familiar with" (p.15). (See also Recarte and Nunes, 2002.)

An underestimation of vehicular speed and an observed overproduction of speed can be considered equivalent behaviours and vice versa (Kim, 2015; Pretto *et al.* 2012; Diels and Parkes, 2010; Rakauskas, 2009; and Pardillo, 2008). It should be noted that an underestimation of 16% in vehicular speed, as found in the study by Wallis, Tichon and Mildred (2007) equates to an underestimation of 35% in braking distance requirement[76]. Perceptual judgments are often different between simulated and real world environments. Thus, driving speed tends to be significantly underestimated in simulated environments (Fischer, Eriksson and Oeltze, 2012; and Diels and Parkes, 2010). There is a great deal of empirical evidence concerning the perception of speed in a simulator. Some of this evidence relates to very specific qualities of the visual imagery presented, e.g., modifications to contrast or luminescence. Unsurprisingly, there is variation and conflict in respect of the direction of misperception (whether speed was under- or over-estimated), the

[76] Because of the squared speed-energy relationship

extent of misperception, and the correlation between the extent of (mis)perception and the FOVs used to present the scenery. However, the preponderant finding is that egospeed is underestimated consistently when driving in a simulated environment and when compared with the real world driving. The findings of 5 research groups are presented in Table 16.

Table 16: Perception of Speed in a Simulator

<table>
<tr><th>Researchers</th><th colspan="3">Findings</th></tr>
<tr><td>Kemeny and Panerai (2016)</td><td colspan="3">Contrary to the findings of Wallis, Tichon and Mildred (2007), Kemeny and Panerai found that "… in driving simulators with a large field of view, longitudinal speed can be estimated correctly from visual information… [but] a horizontal field of view of at least 120^{o} is needed" (pp.31-32).</td></tr>
<tr><td>Diels and Parkes (2010)</td><td colspan="3">When using a normal display configuration (a Geometric FOV[77] to observer's FOV ratio of 1:1), visual speed was consistently underestimated resulting in speed overproduction of 10% on average (in the range 13·0% to 7·3% for speeds of 20, 30, 50, and 70mph with higher overspeeding associated with the lower speeds) (p.59).</td></tr>
<tr><td rowspan="6">Wallis, Tichon and Mildred (2007)</td><td colspan="3">Drivers, using the wide-screen simulator, consistently underestimated their true speed by up to - 16%[78] when travelling at 80 km/h. A variance of ca. 11% (from + 5% to – 6%) was noted in respect of the cab simulator.</td></tr>
<tr><td>Variance in wide screen simulator (FOV = 160^{o}X40^{o})</td><td>Target speeds</td><td>Variance in cab simulator (FOV = 50^{o}X40^{o})</td></tr>
<tr><td>- 15%</td><td>20 (km/h)</td><td>+ 1%</td></tr>
<tr><td>- 7.5%</td><td>40 (km/h)</td><td>+ 5%</td></tr>
<tr><td>- 10%</td><td>60 (km/h)</td><td>+ 2%</td></tr>
<tr><td>- 16%</td><td>80 (km/h)</td><td>- 6%</td></tr>
<tr><td>Brünger-Koch, Briest and Vollrath (2006)</td><td colspan="3">Average speed was significantly lower in real driving and faster in the simulation. On straight sections of road, the difference was ca. 9%, i.e., from 63·6 km/h in the real world to 69·2 km/h in the virtual world.</td></tr>
<tr><td>Hurwitz, Knodler and Dulaski (2005)</td><td colspan="3">Based on 320 unique data points, the underestimation of speed was in the range 14·44 mph to 0·50 mph (average 6 mph) when the actual speeds were in the range 17mph to 45 mph.</td></tr>
</table>

The findings of Diels and Parkes (2010) does not concur entirely with the experience of the writer nor of I.É.'s Staff Trainers (N = 10) who found that speed underestimation was associated with higher operating speeds.

As Wallis and Tichon (2013), and Recarte and Nunes (2002) point out, there is a range of devices and cues (visual, vestibular, proprioceptive and acoustic)

[77] GFOV:FOV ratios in excess of 1:1 result in the content of the scenery appearing to be further away from the observer. The effect of changing the GFOV, while holding the size of the FOV (viewport) constant, is to change the displayed image between a wide angle view and a telephoto view. With a GFOV greater than the FOV, the visible scene is larger than in the real world. It alters the amount of visual information (object density) in the visual periphery, as well as the proximity of objects to the observer (Diels and Parkes, 2010, p.54).

[78] The negative sign denotes underestimation; positive sign denotes an overestimation

available to drivers to assist accurate speed deduction. The most obvious defence against speed misperception is speedometer observation which, because its output is determined by a simulator's 'physics engine' tends to be very accurate. However, this defence mechanism is predicated on its observation, but as Recarte and Nunes (2002) point out "… speedometer inspection is a very vulnerable process, perhaps because it is very demanding in visual terms" and, additionally, that engaging "… attention with mental tasks causes drivers to neglect speedometer inspection, which practically reaches null levels" (pp.120-121).

Most of the other cues that aid accurate speed perception, identified by Wallis and Tichon (2013), as well Recarte and Nunes (2002), are not available to the operators of I.É.'s simulator system:

1. As motion platforms are not incorporated, the operator does not receive accurate vestibular cues;
2. As the simulated trains operate over continuously welded rail, the aural cue associated with jointed track is not available to the operator. Similarly, the cue associated with 'road noise' is largely absent.

6.7 Simulator Presence

The task of a simulator is to mislead the operator's senses to elicit naturalistic behaviours. Operators must suspend belief in the real world and must be complicit in the process by allowing themselves to be misled. The deceit is facilitated by the creation of an artificial presence. Witmer and Singer (1998) define presence as "… the subjective experience of being in one place or environment, even when one is physically situated in another" (p.1). The more immersive that an experience is in the virtual world, the greater is the sense of being part of that experience. The extent of immersion achieved is a function of the quality of the stimuli that are derived from the simulator fidelity. As Coelho *et al*. (2006) suggest, the feeling of presence or immersion that is experienced depends "... on the meaning that the operator gives to the stimuli that are presented to him" (p.32).

The creation of a sense of presence influences the training effectiveness of simulators (Tichon *et al*., 2006, and Witmer and Singer, 1998). Tichon *et al*. (2006) propose a set of presence causal factors, i.e., involvement[79], sensory fidelity[80], interface quality[81], and adaptation or immersion[82]. The results of their self report study (N = 12 RailCorp drivers) reveals that the adaptation or immersion dimension was perceived to be the most influential factor in determining the level of presence experienced by the participants. Specifically in relation to the presentation of visual information, Alexander *et al*. (2005) believe that immersion is "… based on the extent to which the visual displays support an illusion of reality that is inclusive[83],… extensive[84],… surrounding[85],… and vivid[86]" (p.6). Simulator sickness detracts from presence, and any effort expended to create presence will be fruitless unless successful mitigation measures are taken at the design and use phases to prevent its occurrence (Tichon *et al*., 2006; Coelho *et al*., 2006; and Witmer and Singer, 1998).

Train drivers need to access a large amount of visual information at any given time. Information on the state of the internal environment is provided to the driver by means of TDMS displays, gauges, lamps, annunciator displays, general warning and incident panels etc. Information on the external environment is available from views through the windscreen and droplights. Internal information requirements are provided through the artefacts on the simulator desks, and the choice whether or not to include specific artefacts in the design is straightforward. Information on the external environment is provided through the presentation of CGI imagery. However, the choices concerning its provision are less straightforward. On the one hand, Tichon (2007), Allen *et al*. (2004), Emery *et al*.

[79] Involvement is the extent to which the user is induced to focus attention on a coherent set of stimuli. It increases when the interface feels natural, and when the user can exercise control.
[80] The more that sensory information engages the operator and makes sense to him, the more likely he will be able to ignore external distractions to his feeling of presence.
[81] Interface quality affects the time taken to adapt to the setting and the resultant performance.
[82] Factors that affect immersion include isolation from the physical environment (by placing driving desks inside individual booths), perception of self inclusion in the virtual environment (the subject allows himself to be immersed), natural modes of interaction and control (provision of a realistic operator interface) and perception of self movement (a moving visual database).
[83] The extent to which physical reality is shut out
[84] The range of sensory modalities that are accommodated
[85] The size of the field of view
[86] The resolution, richness, and quality of the display

(1999) and Allen *et al*. (2004) suggest that the development of the visual database is of paramount importance. On the other hand, Parkes (2005) cautions that the provision of highly realistic, complex and overly elaborate visual environments may induce simulator operators to attend to elements in the visual environment that are peripheral to the training objective. Kaptein *et al*. (in Blana, 1996a) go so far as to say that complex scenery adds no value to a simulator and may, in fact, detract from it. A further drawback, associated with the presentation of complex CGI, is the distortion in the perceived velocity of the simulated vehicle.

To enhance the sense of presence, Beasley and Burwell (2002) propose that a geo-specific, rather than a geo-typical, visual database should be used as it resembles more closely the real world view with which trainees interact. (See also SWOV, 2009; Waters (*ed*.), 2006; and Allen *et al*., 2004.) Geo-specific visual databases are difficult to construct. Here-to-fore, the development of a good geo-specific database was dependent on the availability of good source data[87], the mathematical rigour used to develop the imagery and the capability of the rendering [88]device. The recent commercialisation of the MATRIX ™ software has reduced the effort required to achieve this outcome.

6.8 Conclusion

Simulation permits the inclusion of probabilistic events into the more predictable aspects of the task environment; facilitating the key objective of training for degraded and emergency working. The development of I.É.'s specification was constrained only by the desire to procure a system that was appropriate to the identified training objectives. From a very extensive product range, I.É. chose to procure a suite of desk simulators.

Having considered the various arguments in respect of the creation of presence, the writer found favour with the predominant view. The creation of a moderate degree of presence was sufficient to facilitate the integration of human factors

[87] Typically, this data is obtained from asset management systems, track charts, architectural drawings, CCTV footage from the front of trains, and physical surveys.
[88] Rendering is a conversion process that transforms 3D objects into 2D images. The process calculates the characteristics of a 3D model, such as colour tone, shades and depths, and projects them into a 2D space. This is achieved by PC graphics cards (Kwon *et al*., 2006).

training with procedural training. Presence would be created by specifying the combination of realistic driving control stations and an extensive geospecific CGI visual database. However, absolute presence was subjugated to value-for-money and practical considerations when full cab motion simulators were being considered. Speed production and egospeed can be considered to be equivalent behaviours. Underestimation of speed, commonly experienced in simulated environments, generally results in overspeeding.

Systems need to be maintained and kept current. Over the life of simulator system, maintenance costs can amount to 50% of the capital cost. This must be included in any IRR calculation that is completed as part of an effectiveness evaluation process.

7 Contribution of Literature Review and Description of I.É.'s Project

The writer conducted a literature review of some seven hundred[89] peer reviewed articles, conference papers, books, trade journals and industry reports. Referenced peer reviewed articles relate to the nature of the train driving task, operational rules, human reliability, the business case for training provision, cognitive aspects of training design, the use of models and images for training, motion cueing, simulator sickness, egospeed, competence assessment and the use of proportion factors[90]. The review was carried out using comprehensive library and internet searches, and the information gained from it was supplemented with information gained from seminar attendance and interviews with knowledgeable others in the training and simulator sectors. The elicited information was used to satisfy the writer's inseparable and mutually supporting, personal and vocational objectives. The personal objective was thesis-based and, hence, was undertaken to inform the writer about the effectiveness of driver training simulators. The vocational objective was centred on the developments of the use cases and a procurement specification for I.É.'s simulator system. The outputs of the inquiry processes informed the writer on each of the many occasions when he reached decision points, initially during the specification and procurement stages of the project and, more latterly, during the implementation and value extraction phases.

In the previous chapter, the writer provides a general discourse on simulators; making mention of specific attributes that can limit their use for assessment purposes. This chapter is presented from two discernible foci. At the general level, the writer discusses the necessity for a robust project management process when procuring a bespoke *IT* based system, the need to establish the necessary fidelity requirements timely, and also specific noteworthy features that can detract or add value to the overall training process. He then focuses attention on I.É.'s system; going on to describe it in detail. The elegance and scope of the system determined the benefits and cost and, hence, the project's IRR.

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[89] About three hundred and seventy five of these are referenced herein.
[90] Proportion factors (PFs) are used in combination with the value of preventing a fatality (VPF) to evaluate what an organisation, rather than a customer, is willing to pay to reduce risk.

To achieve a project's goals, the strategic imperatives must be decided from the start. As Lewis Carroll[91] (in Thompson and Strickland, p.3) put it "If you don't know where you're going, any road'll take you there". All elements of the training system must be designed with respect to each other. However well the system is engineered, if it is used without strategic intent, it will not result in optimised outcomes and goal realisation. Descriptions of the strategies and the systems engineering approaches that were used to achieve I.É.'s project's goals, and details of the bespoke equipment, its scope and the accommodation that was necessary to provide for it, are presented in this section. These descriptions contextualise and give meaning to the achieved outcomes, and also to the findings resulting from project implementation.

This chapter is divided into ten sections, dealing with:

- 7.1 Importance of a Robust Project Management Process;
- 7.2 Establishing the Fidelity Requirements of the Driving Desks;
- 7.3 Identifying the Value Detracting Properties;
- 7.4 The Use of Motion Platforms to Provide Cues;
- 7.5 Simulator Sickness: a jeopardous occurrence;
- 7.6 The Value of an Observer Station;
- 7.7 Strategic Imperatives of the Project;
- 7.8 Deployment and Description of Equipment; and
- 7.9 Salient Features of Simulator Accommodation.

Concluding remarks are presented in Section 7.10.

7.1 Importance of a Robust Project Management Process

The Standish Group (2013) reports[92] that during 2010, 21% of all information technology projects failed[93] and a further 42% were challenged[94]. The worldwide cost of IT project failures was €4·5 trillion, and half of the failures incurred budget overruns in excess of 80% (Fanning, 2011). Irish high profile failures include the abandonment of electronic voting machines which cost over €52 m,

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[91] Alice's Adventures in Wonderland
[92] The report is based on an overall analysis of the outcomes of over 50,000 IT projects.
[93] They were cancelled prior to completion, or they were delivered but never used.
[94] They were late, over budget or did not have the required functionality.

and the curtailment of the Personnel, Payroll and Related Systems (PPARS) project for the Health Service. The original estimate of costs was €9·14 m but it was forecast that costs would rise to €230 m to achieve the specified functionality. Spending on PPARS was halted by the Irish Government when the costs escalated to €116 m.

Because of these notorious IT project failures, it is understandable that resource allocators are cautious when granting approval for such projects. Particularly in those cases where the implementation of such projects is novel within the organisation, it is usual to seek experienced consultants' assistance in order to mitigate risk. An alternative approach is to entrust it to those who are most directly involved in the relevant activity, i.e., Training Officers in the case of simulators. To minimise project risk and to prevent the 'non-rational escalation of commitment', I.É. adopted a two phase procurement process (see Section 7.7.1).

7.2 Establishing the Fidelity Requirements of the Driving Desks

The veridical limitation of simulation is captured succinctly by Shechtman *et al.* (2009) who point out that it is an "… abstraction of reality, transforming the all encompassing world into a more sparse simulation that includes specific aspects of reality but disregards others" (p.380). The necessary degree of simulator fidelity is the subject of constant debate; confounding findings prevail. Findings are based on research criteria such as the congruence between the simulated stimuli and reality (Schmid, 1995); nearness of transfer (Groeger (in SWOV, 2006) and Tichon *et al*., 2006); learning domain under development (Alexander *et al*., 2005); training objectives (Dodshon, 2002; and Anon., 2007); effect on operators' physical wellbeing (de Winter *et al*., 2007; Coelho *et al*., 2006; Pardillo and Troglauer, 2005; Anon., 2007 and Blana, 1996b); stakeholder acceptance (Baker *et al*., and Jentsch and Bowers (both in Mitsopoulos *et al*., 2005); cost-benefit trade-off (Macdonald, 2006; Young, 2003; and Walker and Bailey, 2002) and the stage of operator development (Wallace *et al*., 2005).

At the most extreme position in the debate, Lee (in de Winter *et al*., 2007) suggests that "... low fidelity simulators, or simulators that intentionally distort the driving experience may be more effective than those that strive for veridical representation of the driving environment and vehicle dynamics” (p.3). However, the preponderant findings in the reviewed material suggest that the level of fidelity, to be specified by a purchaser, should be determined by the training requirements and that functional fidelity is more important than physical fidelity in satisfying these requirements (Hahn, 2010; Rushby and Seabrook, 2007; de Winter *et al*., 2007; Vlakveld, 2005; Brock *et al*., 2001; and Blana, 1996a). The writer adopted these findings when specifying I.É.’s equipment.

Wallace *et al*. (2005) present a physical/functional fidelity matrix (Table 17) that proposes the varying degrees of fidelity apt to particular stages of development.

Table 17: Levels of Fidelities Appropriate to the Different Stages of Trainee Development

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="4">Physical fidelity</td></tr>
<tr><td>High</td><td colspan="2">Medium</td><td>Low</td></tr>
<tr><td rowspan="3">Functional fidelity</td><td>High</td><td>Use of a real traction unit in a live environment</td><td>High end full cab simulator</td><td>Desk simulator</td><td>High end desktop PC simulator</td></tr>
<tr><td>Medium</td><td>Use real traction unit in controlled environment</td><td colspan="2">Low end (part task) simulator</td><td>Low end desktop PC simulator</td></tr>
<tr><td>Low</td><td>Static traction unit</td><td colspan="2">Arcade type simulator incorporating the functional fidelity of the Microsoft Train Simulator but within a traction unit-like enclosure</td><td>Classroom lecture or lesson; Written material; Multimedia.</td></tr>
</table>

Adopted from Wallace *et al*. (2005)

Wallace *et al*. state that the training delivery methods in the lower right hand quadrant are typically used in the early stages of training process while those in the upper left are used in the latter stages of development. They believe that the combination of functional and physical fidelity in the upper right quadrant is required when there is a high cognitive element to the training objective and that the combination of fidelities in the lower left quadrant is required when there is a high psychomotor content in the training objective.

7.3 Identifying the Value Detracting Properties

Although simulator systems are complex and expensive, they provide value if implemented properly. The opposite is also true; value is lost if implemented poorly. As simulators are merely models of reality, use for assessment purposes requires high verisimilitude and, given the assessment criteria, sufficiently-high fidelity may not be commercially available. For example, it is illogical to assess a driver's response rate on the approach to a restrictive signal if there is a mismatch between perceptible train speed, and that calculated by the simulator's physics engine. RSSB (2007) opine that "… wherever possible, assessment [should be] conducted in the workplace… The method of assessment should be selected to ensure that the conditions under which competence is tested are as close to the actual working environment as is reasonable and safe to achieve" (p.19).

Excluding ethical concerns regarding the possible creation of an unhealthy training environment for the operators, the occurrence of simulator sickness detracts from its acceptance and puts simulator projects at risk. The findings of 14 primary and 20 secondary research studies are presented in Appendix 15. These relate to the effects of motion, the method of image presentation and the FOV, on the likelihood of sickness occurring. In summary, simulator sickness can be mitigated by using single channel projection, a high refresh rate[95] for the projected vista, a FOV of 40° in the vertical and 60° in the horizontal axes, presentation of the OTW view onto a display screen having reference edges, by limiting the exposure time and the use of static desks. Theoretically, motion platforms should ameliorate the problem of simulator sickness.

7.4 The Use of Motion Platforms to Provide Cues

The incorporation of motion platforms is invariably considered by simulator specifiers. To understand the possible need for motion, it is essential to first appreciate the difference between manoeuvring and disturbance cues. Manoeuvring cues are those which are presented as a direct result of the driver's control inputs; disturbance cues are presented as a result of external forces acting upon the train independent of the driver's control inputs. Drivers need to appreciate the connectedness of their inputs with the generation of the manoeuvring cues that they experience. The manoeuvring cues, experienced in one particular operating context, are discussed in Section 7.4.3; more general cues include those that are experienced when driving routinely or when coupling vehicles etc. The

[95] Achieved by the avoidance of very complex, non value-adding scenery

value of experiencing disturbance cues in the context of train driving is not clear cut. Cues experienced because train derailment or poor track structure are disturbance cues. Modelling such cues would present difficulties as they would have to be based on the nature of the permanent way (slab track, sleepered track, plain track, switches or crossings), train speed and the proximity of the derailed vehicle to the driver's desk etc. Furthermore, it is unlikely that empirical evidence would be available to validate such models; leading to the possibility of negative training transfer. Motion cues are perceived visually through the photoreceptors and, non-visually, through the mechanical force receptors in the gravito-inertial-somatosensory system (inner ear, kidneys, skin and muscles). Research shows that the gravito-inertial-somatosensory system detects accelerations quicker than the visual system[96] (Bürki-Cohen *et al*., 2011 and Tydeman, 2004).

To provide training in cue recognition and response, a full mission simulator, referred to as a Type I simulator (FRA notation), is used. A Type I simulator includes the equations appertaining to the physical properties of motion, response algorithms of the train's controls and systems, equations that model environmental factors such as track elasticity, and the characteristics of the locomotive suspension and coupler systems etc. To increase immersion, Type I simulators are mounted on 6 DOF motion platforms that move the simulator workspace in response to operator control inputs, vehicle characteristics and environmental factors.

7.4.1 Working Parameters and Limitations of Motion Platforms

The more elegant hexapod motion platforms provide about 35^0 of pitch, roll and yaw, and about 2 m of linear displacement. Because of operating space constraints, simulator motion cues are attenuated deliberately by means of a 'washout filter'[97], and are usually sustained for no more than 0·3 sec. A limitation of the human internal motion sensory system is that once a constant speed is

[96] The brain processes information from the gravito-inertial-somatosensory system in about 1/100th of a second; processing information from the visual system takes about 1/10th of a second (Bürki-Cohen *et al*., 2011).
[97] Linear and rotational displacements have to be achieved without allowing the simulator to move outside of its workspace. On a functional block diagram, the washout filter (a software component) is positioned between the vehicle's dynamic model and the actuation system.

reached, it stops reacting. The brain now relies on visual cues until another acceleration occurs and the resultant kinaesthetic cues are presented, before the sensory system reactivates. In the interim, the operator thinks that he is moving continuously even though the system is operating in reverse. Imperceptible movement of the platform allows the simulator to return to its neutral position in readiness for the next movement. (See also Falkmer (in Dorn, *ed*., 2005).)

Most germane, motion platform operation is characterised by acceleration limits and time delays. Control input time delays range from 300 ms for older platforms to 20 ms for the most recent servomotor hexapods (de Winter *et al*., 2012). These delays present problems in respect of the integration of the simulator's motion and visual systems. The designer's objective is to make movement of the operator's workspace synchronous with the display. Although tightly coupled motion should reduce the incidence of simulator sickness, non-synchronised or poorly-tuned, motion will exacerbate the situation.

7.4.2 Value of Motion Platforms

The writer was unable to find any empirical evidence concerning the possible contribution of motion cues to rail accident prevention. However, in the directionally unconstrained domain of combat aviation, Gebman (in de Winter *et al*., 2012) found that 15% of US Air Force accidents involved situations in which motion cues were important. He concluded that simulators incorporating motion might prepare pilots better to deal with critical situations. However, confounding experimental study results exist.

In their meta-analytical work, Bürki-Cohen *et al*. (2011) present the findings of several researchers in respect of the inability of motion platforms to increase training effectiveness:

1. de Winter concludes that "... for experienced pilots, the effect of physical motion was calculated to be nil" (p.9);
2. Experiments conducted at Volpe Center "... did not find a relevant benefit of motion" (p.10);

3. During their independent experiments, *FAA*/Volpe, and Lee and Bussolari concealed the motion status of the simulator from their subjects. In most cases, its disablement went unnoticed. See also Go, Bürki-Cohen, Chung, Schroeder, Saillant, Jacobs, and Longridge (all in Bürki-Cohen *et al*., 2011) who conclude that "... for recurrent training, no benefit of the motion provided was found" (p.6).

Even in those studies that revealed a positive relationship between the motion cueing and training effectiveness, the results are marginal:

1. In their true and quasi transfer experiments, Vaden and Hall (in Bürki-Cohen *et al*., 2011) found an insignificant effect in favour of motion;
2. Lee and Bessolari (1989) found "... the absence of any reliable effects of motion… on pilot performance and subjective ratings would tend to support arguments for less complex motion systems" (p.140);
3. Szczepanski and Leland (in Leland *et al*., 2009) reveal that "… motion cueing is [only] necessary when training ab-initio pilots or pilots who have limited or no experience in the particular flying task that is being trained" (p.2).

In respect simulators used to train traction unit and car drivers, de Winter *et al*. (2009), Russell (2006), Greer (in Lockridge, 2006), Parkes (2005), Dodshon (2002) and Howells (2000) opine that the feature is unnecessary. Giving practical effect to this position, Virgin Trains decided not to retain the motion platform on the Pendolino driving desk at its training centre in Crewe as it was believed it did not contribute any significant benefit to competence development (Anon., 2007). A contrary position is held by Young (2003), Scott (1998), Blana (1996a) and Blana (1996b) who believe that the provision of motion cues is important.

7.4.3 Value of Motion Platforms: a particular use case

Train control and the management of in-train forces are crucial skills for the safe and effective operation of particularly-long and very heavy trains. Drivers use the brakes and, in some instances, a combination of brakes and throttle, to decelerate or accelerate a train. These non-intuitive combinative techniques are designed specifically to manage the in-train forces that are generated by slack in the couplings between vehicles. Poor slack management can lead to derailment, broken couplings and time wastage.

Drivers need to know how, and in what circumstances, to make a range of brake applications, i.e., service brake, emergency brake, blended brake, dynamic brake, *independent brake* or power brake applications, using either of the brake handles and/or end-of train (EOT[98]) devices. The circumstances necessitating such applications are multifarious, e.g., a running brake test, routine or emergency stop, holding application, and the need to prevent slack or to create it in the couplings. The situation is compounded when the effects of gradient and its direction are considered; in some instances the driver may need to accelerate the front portion of the train while, at the same time, decelerating the rear portion.

Training this skill set requires theoretical and, most importantly, practical input. If using a simulator to develop these skills, the provision of kinaesthetic cues is essential. The driver needs to feel the effects of his actions on the train's acceleration, deceleration and jerk forces.

I.É.'s largest trains are 1,300 tonnes in weight and 450 metres in length. The trains are not loosely coupled and EOT devices are not used. Furthermore, as the strategy was to use the simulator to develop cognitive and procedural skills rather than kinaesthetic or tactile skills, I.É. would not extract value from a motion system.

7.5 Simulator Sickness: a jeopardous occurrence

Simulator sickness and motion sickness are similar in outcome but they have different causation mechanisms. Simulator sickness is caused by "... inconsistent information about body orientation and motion received by the different senses, known as cue conflict" (Kolasinski, 1995, p.vii). The primary conflict, believed to be at the root of simulator sickness, occurs between the visual and vestibular senses. The vestibular system, situated within the inner ear, sends signals to the

[98] 'Smart' EOT devices send data concerning brake pipe pressure to the locomotive driver using radio-based telemetry. In emergency situations, the brake pipe can be discharged and the brakes applied from the end of the train using an EOT device.

nervous system about the body's rotational and linear translations. Theoretically, the incorporation of motion platforms should solve the problem of simulator sickness that is caused by cue imbalance. However, even if implemented correctly, motion platforms seem to create the separate but related problem of motion sickness. This is induced in susceptible people when they are subjected to movements at a particular, usually low, frequency.

The most common manifestations of simulator sickness include general discomfort, nausea, headache, disorientation, drowsiness and vomiting. Kolasinski (1995) identified forty factors that are associated with simulator sickness and categorised these into three global factors, i.e., subject, simulator and task. Factors, relevant to this thesis, are presented in Table 18.

Table 18: Factors Affecting Simulator Sickness

Global factor	Factor	General comments and relevance to traction unit driving
Subject	Age of subject	The prevalence of simulator sickness decreases rapidly between 12 to 21 years of age and is generally not found in those aged over 50. Contrary to Kolasinski's (1995) findings, Reed *et al*. (2007) found that it was older drivers who were more prone to sickness.
	Concentration on task	High levels of concentration are associated with lower levels of sickness. Hence, it is important to keep drivers engaged for the duration of the time they spend on the simulated driving task.
	Experience of the real world task	Those subjects with more real world operational experience are more susceptible to sickness than those with less experience. Ab-initio drivers are less susceptible than the preponderant cohort of experienced drivers.
	Experience of simulator use	Repeated immersion in a simulator will result in adaptation and a reduction in instances of sickness.
	Gender	Females are more prone than males to simulator sickness due to their relatively larger field of view. Males are the preponderant gender in the driving grade.
	Pre-existing medical condition	Only subjects in good general health should operate simulators. By definition, drivers are in good health.
	Field dependence	Field independent individuals are more susceptible to sickness. Field dependence is one of the criteria of medical examinations that are conducted at driver recruitment.
Simulator	Type of display	Presentation of a stereoscopic display leads to a higher incidence of sickness. (See also de Winters *et al*., 2007.)
	FOV	There is a higher incidence of sickness associated with a wide FOV rather than with a narrow FOV. (See also Allen *et al*., 2003.)

Global factor	Factor	General comments and relevance to traction unit driving
	Motion platform	Motion platforms are sometimes installed into simulators to help reduce simulator sickness by resolving cue conflict. Hörmann *et al*. (2003a) did not report any concern about simulator sickness during their experiment with aircraft pilots even though the key experimental and equipment parameters were extreme[99].
	Scene content	The more detail that is provided in the visual scene, the longer it takes for the graphics card to generate it; resulting in *latency* and cue conflict. Effective simulation depends on low latency between the time an input is made and the time that the operator perceives the effects of the input. To minimise latency, the instructor station computers must be located within 20 m of the simulator desks. (See also the note on the attributes of the *Can-bus* in Appendix 6.)
Task	Degree of control	Simulator systems that provide subjects with a high degree of control are less conducive to sickness than those that provide lesser control.
	Duration of simulation	Longer exposure results in a higher incidence of sickness. Kolasinski (1995) suggests that the propensity for simulation sickness peaks at a scenario length of 20 minutes. Coelho *et al*. (2008), Hoff (2001) and Haworth *et al*. (2000a) suggest limits on the duration of simulator runs of 22, 25 and 15 minutes respectively. In contrast, some SUG[100] members in Britain run scenarios that are 2 hours in duration.

Adopted from Kolasinski (1995)

Some of these factors are managed routinely when candidates are being selected for the driving role or else when they are engaged in the simulation process. Other factors need to be managed by astute system design and usage. Understandably, the occurrence of simulator sickness detracts from the training experience and may lead to a reluctance to using the simulator.

7.6 The Value of an Observer Station

The provision of experiential learning in all its domains has been cited earlier as a key benefit of simulation. This benefit can be extended by applying the principle of social or vicarious learning (Bandura, 1977). In its evaluation of the importance of social learning, TUDO (2013) finds that as much as "... 60-70% of learning takes place not in the simulator but next to the simulator [in an observer station]" (p.20).

[99] They included a simulator session of between 1 and 2 hours duration, a 150° FOV, travel movements between 1·7 and 2·8 metres, a yaw rotation between ±37·50°, and acceleration/deceleration forces between ± 1g (p.34).
[100] The Simulator User Group (SUG) comprises UK users of train simulators. Its goal is to share its considerable experience on all aspects of simulators towards the development of best practice. It provides advice to its membership and to companies considering purchase.

Criticism of the incorporation of observer stations usually centres on the efficiency of training delivery, i.e., trading in-seat time for observation time. Critics believe that the observation process usurps resources and contributes little value as the observers become bored. This may be true if the process is unstructured. In cases where observation facilities are implemented with aforethought, the peer group becomes fully engaged in the process as they conduct reviews of the communications exchanges and operator's overall driving performance, and also identify and rate hazards that are presented within the scenarios. This epitomises the collaborative learning approach espoused by Eichinger (2004), Smith (2003), and Lave and Wenger (1991). Observer engagement in the process is also influenced by the elegance and functionality of the observation facility. In the crudest form, observers stand around the driving desk trying to catch sight of the scenario as they jostle for a vantage point. More engaging and less intrusive facilities have separate observation spaces where the operators' OTW view, cab displays, interactions and performance can be observed. A description of I.É.'s observer station is contained in Appendix 7.

Provision of feedback is important in the learning process as it helps to develop an understanding why some encountered scenarios were resolved satisfactorily while others were not. In the feedback process, "... the driver's own feelings are mirrored against the impressions of the observer. In order to objectify the statements of the observers, the trainer can draw on a number of documented data provided by the system as log data" (TUDO, 2013, p.19). In its field study, CRC for Rail Innovation (2013a) found that "In the driver's opinion, the debrief was where the major learning took place" (p.21). The relative merits attaching to the possible sources of the performance feedback should be considered. Some believe that the operators are more susceptible and amenable to feedback provided by peers rather than by instructors (de Craen *et al*., 2005 and MB, CoE & TS, DoE&PS, 1996.) However, others believe that peer reviews or corrective comments are much more easily accepted if they are relayed through the instructor (TUDO, 2013). In I.É., performance feedback is provided by instructors and peers.

7.7 Strategic Imperatives of the Project

In general, projects of the type which are described in this thesis are not well understood by resource allocators. Typically, they evaluate projects comprised mainly of tangible assets. The equipment described herein comprises an amalgamation of tangible assets (44%) and intellectually embedded assets (56%). There is greater risk associated with a project of this type, e.g., escalating software development costs and the derisory value realised from the disposal of a bespoke asset. From a corporate governance point of view and the desire of a semi-state organisation to avoid public criticism, the Board of I.É. needed to ensure that this particular project attained its goals. The Board's objectives and the writer's personal desire to succeed in his assignment determined the strategic approach that was adopted.

7.7.1 Commercial and Contractual, Process and Strategy

The commercial aspects of the project, contract risk and supplier dependencies were managed proactively to ensure that it would be delivered with the required functionality and within the allocated budget. Accordingly:

1. All elements of the project were subjected to open competitive tendering processes;
2. The procurement process was split into two distinct phases;
   - 2.1 A detailed functional specification was developed and agreed by both contracting parties. The contract allowed for the transfer of the design documents to a third party for implementation if irresolvable challenges arose;
   - 2.2 As no problems became manifest during Phase 1, the *DFS* was implemented by the extant contractor in Phase 2.

   This separation of project phases permitted I.É. to avoid escalating commitment irrationally and to halt the project if it became challenged.
3. Ongoing dependence on the supplier was mitigated. A Track Builder Tool ™ was included in the scope of supply. A fixed price maintenance contract was contracted for also;
4. Project risks were identified and mitigated:

    4.1 As simulators need to be housed in a semi clean room environment, the provision of bespoke accommodation was scheduled into the project's critical path;
    4.2 The matter of purchasing a *distributed interactive simulation* system incorporating integrated simulators for signalman and driver training was considered but was not pursued (see Section 5.5.1);
5. The system was deployed proportionally to driver catchment areas;
6. The number of desks purchased was based on the anticipated annual requirement pattern of the drivers, i.e., 250 drivers attending for a four day biennial refresher programme, plus 40 trainees requiring basic driver training, plus an additional capacity for drivers to attend remediation training on an as-required basis:
    6.1 The anticipated class size was 4 drivers on refresher programmes, 8 drivers on ab-initio programmes, and individual tailor-made remediation interventions;
    6.2 I.É. would acquire eight desk type simulators, none of which would incorporate a motion platform;
7. Not all classes of traction would be modelled. Only those classes that are significantly different and that were considered as having a long term future in I.É.'s fleet would be modelled.

7.7.2 Operant Objectives and Strategy of the Project

After consideration of cognitive constructs, the writer developed a clear set of output objectives for the project. He believed that:

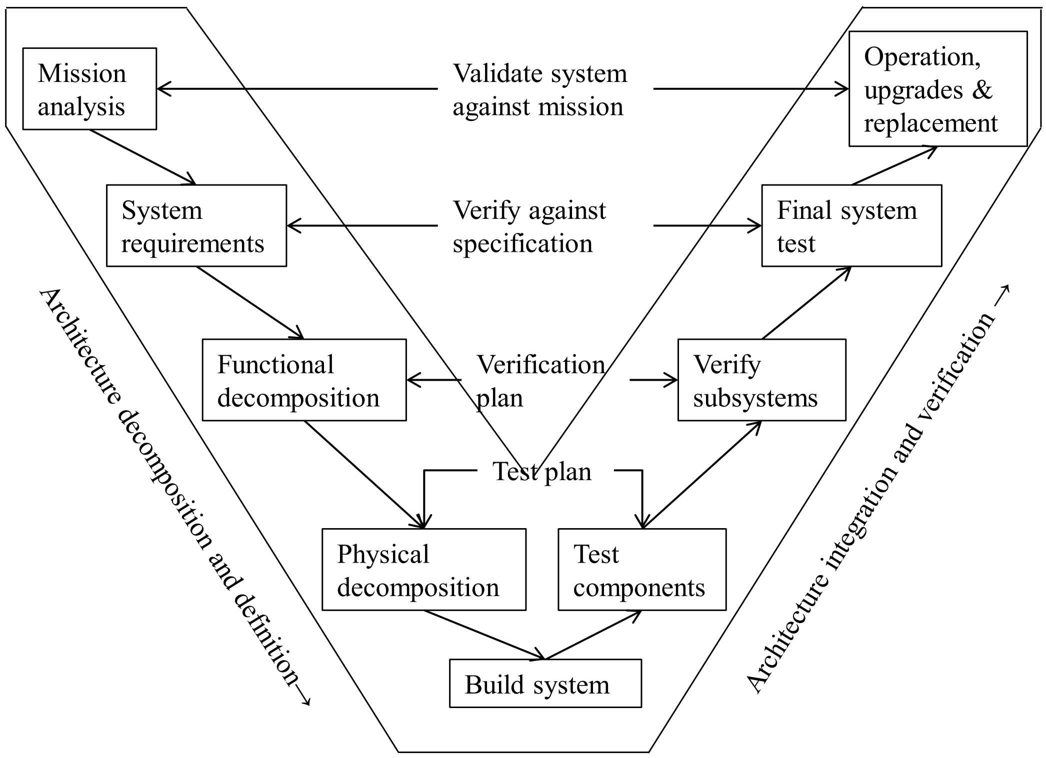
1. Training programmes must be improved; not necessarily shortened. The emphasis was on effectiveness rather than efficiency;
2. The system must support the provision of experiential training in a broad range of normal, degraded and emergency conditions;
3. The system must provide an interactive and collaborative training experience. The ambience within the facility would be relaxed, cordial but business like;

4. The simulator should not be used for the acquisition of route knowledge[101], nor for the acquisition of basic driving skills. It would be used as a procedural training device and to develop NTSs. CRC for Rail Innovation (2013b) concurs with this approach noting that "... it is important to ensure that simulator-based training is conducted from a perspective that recognises that train-driving skills extend well beyond train handling or train control" (p.73);
5. Simulation should be used in an integrated manner and facilitate a blended approach to learning. Operators would receive training in rules and procedures, using a range of training methods, and apply it in the simulated environment;
6. The emphasis should be on driver development rather than on jeopardous assessment. Trainees would be afforded opportunity to learn by failing in a non-threatening environment. Inability to demonstrate competence during training would be seen as a development opportunity. The number of trials taken to achieve mastery of the skills was unimportant. Most importantly, trainees would not be allowed to exit the process before identified performance deficits were remedied;
7. In principle, specific desk types should be located where particular types of traction were used. See point 5 of Section 10.3 for an elaboration of the methodology used to train a particular cohort of drivers who do not have access to a simulator of a specific traction type;
8. The simulator system must be engineered to reduce the likelihood of simulator sickness;
9. Formal and informal communications channels with drivers and their representatives must be used to inform them about the goals, equipment and the intended use cases.

7.7.3 Use of the Systems Engineering Approach

The systems engineering approach, which was used by the simulator supplier and I.É., and which enabled the realisation of the system, is shown diagrammatically in Figure 8.

[101] Only between 13% and 17% of the respondents to the study by Air Affairs (2006) report using simulators to aid route knowledge acquisition of any sort.



Based on: Forsberg and Mooz (1998)

Figure 8: Simulator System Engineering using the Vee Process

The process steps, together with the verification and validation approaches, are presented in Table 19. The contributions of both parties, and the associated documentation that was used in the process, are also shown. The reader's attention is drawn to the use that was made of the DFS when conducting the FAT and SAT verification processes.

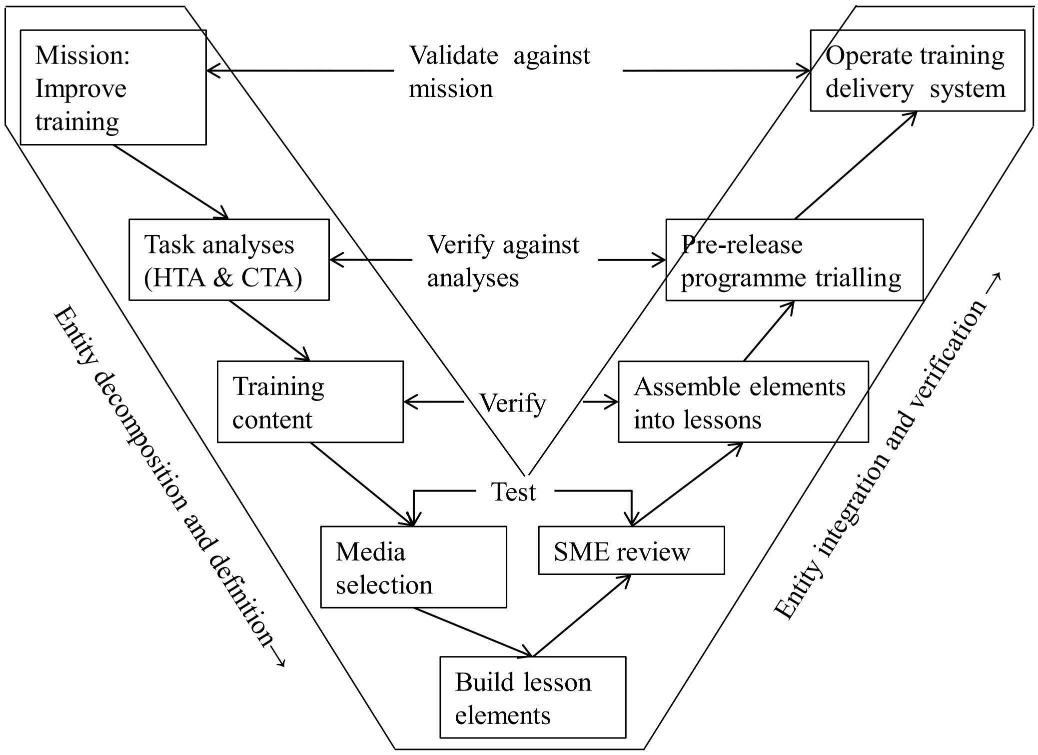
Table 19: Architecture Decomposition, Integration and Verification

Decomposition and definition ↓	Performed by:	Documents	Reviews
Mission analysis. This included the problem definition and output objectives.	The writer in conjunction with I.É.'s stakeholders	The outline functional specification	Internal I.É. reviews and formal 'sign off' of the outline functional specification by senior managers
System requirements. The scope and features of the traction models and routes, and the system's architecture were agreed.	Developed by the suppliers and verified by the writer and I.É.'s Training Centre personnel	The outline functional specification was elaborated into a detailed functional specification (DFS). Test books were developed from the DFS.	Joint system requirements reviews to ensure that the system requirements were comprehensively identified, and that a mutual understanding existed between the contracting parties

Decomposition and definition ↓	Performed by:	Documents	Reviews
Functional decomposition	Suppliers with very limited involvement from I.É. [102]	Suppliers internal documents	Joint design review; the design was evaluated against requirements.
Physical decomposition	Suppliers only	Suppliers internal process	
Build system	Suppliers and subcontractors	Suppliers internal processes	I.É performed quality control checks on hardware components.
Integration and verification ↑	**Performed by**	**Documents**	**Reviews**
Test components	Suppliers with limited I.É. involvement	I.É.'s technical manuals were used to test specific components	Functionality review by I.É. of some train borne systems, e.g., train radio system
Verify subsystems	Suppliers only	Suppliers internal processes	
Final system test comprised: 1) Factory acceptance testing (FAT); 2) Site acceptance testing (SAT)	I.É. personnel at the supplier's premises for FAT, and at I.É.'s Training Centres for SAT[103]. During SAT, the fully-integrated system was tested under full load conditions within its operating environment.	Twelve FAT books[104], which were developed from the DFS, formed the bases of the verification process.	FAT was carried out on the CGI and train models as they were being implemented[105]. The duration of the SAT process was 3 months. The Mantis BT ™ 'bug tracking' tool[106] was used to manage the resolution of the issues revealed through the FAT and SAT processes.
Operation, upgrade and replacement	The writer	1) A documented maintenance contract was put in place. 2) A half life rebuild was provided for.	Validation that the system achieved its mission is performed by the writer in this thesis.

Successful equipment engineering was only one part of the overall mission. The situation is summarised by Hillson's (2009) use of the proverb "A fool with a tool is still a fool" (p.17). Mission success was also dependent on the application of the system. The systems engineering approach, which was used to enable the realisation of the system's mission through the training design process, is shown diagrammatically in Figure 9.

[102] I.É.'s input was confined to anthropometric aspects of the driving desks.
[103] SAT was undertaken to ensure that the system did not deteriorate during shipping, that it was installed correctly, that it interfaced correctly with other on-site systems and features, and that it performed as intended when it was fully integrated and was operated under full load conditions.
[104] One for generic tools (SPS, DAS, TBT etc.); one for system management tools (user interface tools); one for hardware and one for each of the nine train models.
[105] SMEs spent ca. 36 man-weeks at the supplier's premises as part of the FAT process.
[106] Almost 900 observations were recorded on the Mantis BT ™ system for resolution.



Based on: Forsberg and Mooz (1998)

Figure 9: Training System Engineering using the Vee Process

The process steps for developing the training process, together with the validation materials and approaches, are presented in Table 20.

Table 20: Entity Decomposition, Integration and Verification

Stages of decomposition and definition ↓	Performed by:	Documents	Reviews
Mission analysis	The writer in conjunction with I.É.'s stakeholders	The outline functional specification included the list of scenarios to be simulated (see Appendix 10)	Internal I.É. reviews and formal 'sign off' of the outline specification by senior operating managers
Hierarchical and cognitive task analyses	I.É.'s Training Centre personnel	I.É. internal documents	Peer reviews by Training Centre SMEs
Training content (the method of elicitation is described in Section 5.4)	I.É.'s Training Centre personnel	I.É.'s Rule Book, General Appendix and equipment manuals	Reviews by Training Centre SMEs
Media[107] selection	I.É.'s Training Centre personnel		Peer reviews by Training Centre SMEs

[107] Assess suitability of simulator operation, CSD, video clip, game, quiz or lecture for learning points

Stages of decomposition and definition ↓	Performed by:	Documents	Reviews
Build lesson elements: 1) Simulator operation; 2) CSD elements; 3) Lectures, quizzes and games; 4) Communication scripts for actors; 5) 'Weekly circular' etc.	I.É.'s Training Centre personnel	Session plans	Peer reviews by Training Centre SMEs
Integration and verification ↑	**Performed by**	**Documents**	**Reviews**
Review of lesson elements	I.É.'s Training Centre personnel	Session plans	Peer reviews by interdisciplinary Training Centre SMEs
Assemble elements into lessons	I.É.'s Training Centre personnel	New and extant training programmes, and Company Standards	A 'gap analysis' was conducted to ensure correctness and conformance to Company Standards.
Pre-release lesson trialling	I.É.'s Training Centre personnel with *DTEs* and drivers		
Operation			Validation that the system achieved its mission is performed by the writer in this thesis.

The Dual Vee model, which graphically illustrates the system of systems, i.e., the composite training delivery system, is presented in Appendix 16.

7.8 Deployment and Description of Equipment

The scope and deployment of the equipment was determined by I.É. following an analysis of the historic and projected usage requirements. Eight simulator driving desks are located in two centres; Inchicore and Mallow. The deployment of the desks and supporting tools is shown in Table 21.

Table 21: Deployment of System: traction types and classes

Simulator deployment			
Desk	Traction type	Classes incorporated within desk	Location and additional facilities
1	*DMU*	22000, 29000, 2800, 2700	Dublin – master location: 2 observer stations, 1 technical room, 1 CSD, SPS and *TBT* ™ development area
2	Same as desk #1		
3	Locomotive	201, 071	
4	Same as desk #3		
5	EMU	8500, 8100, 8200	
6	Same as desk #5		
7	DMU	22000, 29000, 2800, 2700	Mallow – slave location 1 observer station, 1 technical room
8	Same as desk #7		

The types of driving desks, the models contained within each type and the modelling methodology together with the degree of fidelity compromise are shown in Table 22. Supplementary information on the features, scope and configuration of the system can be found in Appendix 6.

Table 22: Overview of Simulator Desks

	← Traction type - modelled primarily by hardware→ (the number of traction units in each I.É. fleet)			Degree of engineering compromise of the operators' *MMI*[108]↓
	Locomotive type and *consist*	DMU type and consist	EMU type and consist	
← Traction class - modelled primarily by software →	201 (32) hauling a nine piece Mk IV passenger train	22000 in a six car consist (177[109])	8520 in an eight car consist (68[110])	Very little compromise
	071 (18) hauling an eleven piece freight train	29000 in an eight car consist (116)	8100 in a four car consist (76)	More compromise
		2800 in a four car consist (20)	8200 in a four car consist (10)	A great amount
		2700 in a four car consist (27)		Most compromise

1. Scope and features of the train models:
   1.1 Interchangeable handle boxes are used to reconfigure desks types between traction classes, e.g., to change the desk from a 201 class locomotive to a 071 class. The use of a single type of desk to model a number of classes of traction resulted in engineering compromises;
   1.2 There is either a hardware or *software interface* for those elements of the cab equipment that add essential realism to the simulator. Only equipment capable of providing didactic value was modelled;
   1.3 Fault finding stations for each class of traction incorporate, on average, 30 driver-rectifiable faults. These faults are interspersed throughout the train. The effects of faults on the instruments, gauges and systems' behaviours are modelled accurately;
   1.4 Working advisory (CAWS) and supervisory (ATP) systems are incorporated;

[108] Man machine interface
[109] This fleet comprises 15 sets of 6 cars and 29 sets of 3 cars. In addition, a further 57 cars were delivered in 2012.
[110] This fleet comprises three subclasses, i.e. 16 off 8500 (4 sets of 4 cars), 12 off 8510 (3 sets of 4 cars) and 40 off 8520 (10 sets of 4 cars). From a driver's perspective, there are very few minor differences between these subclasses.

- 1.5 The AEG 90 train radio is modelled accurately. *SPTs* are also provided for use when the train radio function is 'unavailable' to operators. Operators learn to adopt an alternative course of defensive action in such cases, i.e. to seek signal protection, to secure their train to prevent a runaway and to wear personal protective equipment when leaving the 'cab' to use an SPT;
- 1.6 All of the elements within the train models are not active, e.g., not all of the circuit breakers have two states and not all of the isolating cocks in the pneumatic system are operable;
- 1.7 A full range of aural cues is presented;

2. Scope and features of the CGI:
   - 2.1 The CGI resembles the actual routes sufficiently realistically to obviate the need for route conducting;
   - 2.2 Four routes are modelled geospecifically. This amounts to 331 km and means that over 98% of I.É.'s drivers can traverse a route without the need of a route conductor;
   - 2.3 The routes include all permanent railway characteristics and artefacts, e.g., gradients, curves, point-work, PSR boards, station locations, crossings, mileposts and signals;
   - 2.4 Train performance is determined by a physics engine which models acceleration, speed and deceleration based on gradients, braking characteristics of traction, braking effort demanded and system delays etc.;
   - 2.5 Track circuits (lengths and codes associated with occupancy) are represented dynamically;
   - 2.6 In general, buildings that are contiguous to the railway line are not modelled accurately. However, notable landmarks are represented accurately to add realism to the OTW view, e.g., the Custom House and the Aviva Stadium etc.;
3. Scope and features of the Instructors' and Observers' Stations:
   - 3.1 The system is managed through the Instructors' Stations. The instructors set the simulation parameters, i.e. route, climatic conditions, train type, faults and events etc., through these workstations;

3.2 Instructors role play other actors through the train radio and passenger communications alarm facility;

3.3 Instructors observe trainees' actions by means of a dynamic desk report and *CCTV* footage. These reports are repeated in the observer stations to facilitate peer and instructor reviews. An image of the desk report of a 22000 class DMU is provided in Appendix 7.

7.9 Salient Features of Simulator Accommodation

Bespoke accommodation is an intrinsic part of the system. It impinges on the layout of the equipment and its performance and, most especially, on the overall experience of the attendees. At a more abstract level, the quality of the accommodation and the ambience that it creates sends a powerful message to stakeholders about the value that an organisation places on the training activity. A comprehensive site specification was developed as part of the DFS to ensure that the accommodation complimented the projects goals and technical requirements. In addition to complying with building regulations, the facilities needed some noteworthy attributes, including:

1. Sound insulation capable of inhibiting 40 dB(a) of inter-booth noise pollution. Trainees need to be isolated from aural cues emanating from contiguous booths;
2. Air conditioning capable of dissipating over 1·5 kW of heat energy, emanating from the display screens and computers, within each booth. Because of the high standard of insulation in the booth, this energy would create operator discomfort very quickly;
3. Air conditioning capable of dissipating the 3·5 kW of heat energy emanating from the computer racks in the technical rooms;
4. Alarmed uninterruptable power supplies (UPSs) to facilitate an orderly shutdown of the equipment in the event of a power supply failure;
5. It was critical to position the instructor station computers close to the driving desks. This spatial constraint was determined by the need to ensure that the video and data transmission cables were less than 20 m in length. This is necessary to minimise the latency of CGI presentation;

6. A ‘reference frame’ would envelop the display screen to help prevent the occurrence of simulator sickness.

7.10 Conclusion

Because of the risk associated with IT projects generally, I.É.’s management was anxious to avoid any commercial problems associated with the acquisition of the simulator. The acquisition process was split into two phases.

Having considered the relevant fidelity criteria in the context of I.É.’s training requirements and output objectives, the writer adopted the preponderant finding of his literature review, i.e., a simulator’s functional fidelity is more important than its physical fidelity. He specified a networked desk type system with high functional fidelity.

Operators’ welfare and concerns were considered at all stages of the project. Simulators will not garner acceptance if they create an unhealthy environment or if they are used unreasonably. Value can be lost because of the occurrence of simulator sickness, but mitigation measures can be taken at the design and use phases. Care needs to be taken if simulators are used for the assessment of performance because of the mismatch between the perceptible and calculated speeds, and the lack of psychological fidelity.

Motion platforms are expensive, they necessitate a great deal of scarce engineering information, and are difficult to implement correctly. The benefits derivable from the provision of motion cues are questionable, and are dependent on particular railway operating methodologies and on the skill under development. In a great many cases, motion cueing provides little or no benefit. Because of its operational context and training goals, I.É. did not acquire motion platforms.

Observer stations promote collaborative learning. However, the observation process needs to be managed and not left to chance. Observers need to undertake specific tasks; the provision of performance feedback in conjunction with the instructor is one key task.

Management of I.É.’s project was characterised by strategic thinking. Foreseeable project risks at the commercial and contractual levels were identified and managed. The equipment was engineered and the training programme developed using systems engineering principles. Project risks pertaining to the operant level were afforded the same importance. To ensure that the revised training process proceeded unhindered, the philosophy underpinning the change, and details of the equipment, the use cases, and the delivery process were communicated timely to the drivers and their representatives. The fundamental output objective was to improve the quality of the training programmes, leading to enhanced operational safety; not to reduce training costs. The emphasis was on effectiveness rather than efficiency.

As well as providing the necessary functionality, the bespoke accommodation also helped to enhance the overall experience of training attendees.

8 Study Methodology

In the preceding chapters, the writer explains the reasons why I.É. wished to change its training process, describes how simulators could conceivably improve training outcomes, details the underlying reasons for specifying particular features when developing I.É.'s procurement specification and describes the actualised system in detail. In this chapter, he presents the overall methodology that he used to evaluate the effectiveness of the simulator enabled training process. There is a range of study designs but because of the regulated nature of the driving activity, the sense of urgency attaching to the project's goals, the live operational environment containing the answers to the research questions and the global nature of the research questions, the use of I.É.'s NWRM is most appropriate. Its appropriateness is all the more justified as the relative value ensuing from the comparison of the ex ante and ex post analyses of driver relevant resident risk is used in the study (Smith, 1993). He also discusses the metrics and approaches that he draws upon for the financial evaluation.

I.É.'s simulator system was purchased on foot of the belief that the extant training delivery process could be proactively improved; resulting in safer driving outcomes. There were professional and business imperatives as well as a moral duty on the writer to ensure that improvements would be made expeditiously. The simulator was not purchased for experimentation, and validation of its effectiveness had to be performed in this context. Furthermore, a main component of one of the research questions of this thesis (an identified reduction in I.É.'s overall driver-relevant operational risk) is global and does not lend itself to decomposition into smaller testable questions. Although the effectiveness criteria of other stakeholders were assessed, the writer set out principally to conduct a Level 3 evaluation of the contribution of the revised training process to safe operational performance. In turn, this facilitated the completion of a Level 4 evaluation. The taxonomy of evaluation methods is presented in Appendix 17.

This chapter is divided into nine sections, dealing with:

8.1 Implications of Context on Study Design Approach;

8.2 Risk Management

8.3 Description of I.É.'s Network Wide Risk Model;
8.4 Network Wide Risk Model: its history and value;
8.5 Value of Preventing a Fatality;
8.6 Investments and Proportionate Returns;
8.7 Choice of Financial Appraisal Methods; and
8.8 Approach Used to Financially Evaluate Benefits.

Concluding remarks are presented in Section 8.9.

8.1 Implications of Context on Study Design Approach

A randomised control study, however desirable from a study design point of view, is inappropriate in this case as:

1. It would create an ethical issue in respect of the untreated group because, as believed, the training that this group would receive would be inferior, and would leave it and the organisation exposed to adversity;
2. Differential treatment would lead to a situation where poor operational performance could be attributed to insufficient training;
3. Control group members would feel professionally exposed in the belief that they did not receive the best available training;
4. I.É.'s training process is standards-based; changes to it must be validated by its Safety Validation Panel. It would be incongruous and indefensible to operate two fundamentally different training processes concurrently;
5. At an individual level of a treated driver, the effects of training transfer relevant to particular precursors culminating in hazardous events, are small and take a long time to manifest themselves. A study by Amalberti (cited by Moray, in TRB, *eds*., 2006b) finds that improvements emanating from safety initiatives, undertaken in what are regarded as 'intrinsically safe' industries, may take many decades before they become manifest. Furthermore, it is difficult to integrate improvements in the range of precursors and accident types (each with particular varying probabilities and consequences) into a single comparable and meaningful entity for a small study cohort.

Although a pre-test and post-test study design, conducted within the simulated environment, could reveal changes to the experimental subjects' recall of knowledge and also to particular behaviours, it would not reveal the true transfer of training to the operational environment and, hence, it would not satisfy the requirements of this study. The limitations of these study designs are obviated by using a risk modelling tool that is populated with comprehensive 'before and after' data to assess the change to the risk profile that was achieved through project implementation. See Taig and Hunt (2012) in respect of the reliability and validity of risk modelling approaches.

8.2 Risk Management

The general safety responsibilities attaching to the operation of a business of any nature in Ireland, are set out in Section 8.1 of the Office of the Attorney General Act (2005b); those that are specific to railways are set out in Section 36 of the Office of the Attorney General Act (2005a). Both acts limit the scope of the responsibility of the employer or railway undertaking to acting in a manner that is reasonably practicable.

The inherent subjectivity of the concept of reasonableness is recognised in George Mitchell (Chesterhall) Ltd v Finney Lock Seeds Ltd [1983] 2 AC 803, [1983] 2 All ER 737. In respect of the malleability of reasonableness, the maxim that 'hindsight is 20/20 vision' (origin unknown) springs to mind: The perception of what is reasonable will, most likely, change after a negative event has occurred. Managers face a conundrum. On the one hand, the management of safety expenditure is "... part of risk management… [and safety expenditure] has an optimal level of activity beyond which there are diminishing returns" (Crowl and Louvar, 2002, pp.4-12). On the other hand, Roth and Meisel (in Eberwine, 2005) confirm that "... what is reasonable in a given situation cannot be determined with scientific precision, and when it is determined by a jury it is always after the harm has been done... reasonableness must be judged without the benefit of hindsight,... [which] cannot easily be put aside[111]" (p. 639). Post accident uncertainty about the perception of the reasonableness of managerial decisions may be one of the

[111] It was not put aside in the case of Kenny v. Southeastern Pennsylvania Transportation Authority. Eberwine finds that "... the transit authority was justified to be nervous that the jurors would 'update' their perception of the reasonableness" (p.646).

reasons why projects with benefit-cost ratios (BCRs) of less than unity are implemented (see Section 8.6).

Decisions to optimise the management of safety are made in the context of a range of criteria, e.g., ethical principles, regulatory compliance, commercial and operational constraints, a desire to avoid organisational and personal culpability, the non-definable concept of reasonableness and possible biases in the conduct of ex post facto accident analyses. However, more-defensible and expansive safety management decisions can be made, much more readily, using risk modelling tools (ERA, 2015).

Railways are complex systems (Merkert, Nash and Smith, 2008; Lindfeldt, 2008 and Peirone, 2005) and, as they become ever more complex, "... risks need to be identified, evaluated and managed in a formal system of control rather than the informal systems which have existed in the past" (Wang and Roush, 2010, p.12). Prospective safety management systems, using risk modelling methods to support decisions, are necessary as "... the practice of learning by mistakes [is] no longer acceptable" (Smith, 1993, p.4). In a diverse and dispersed business, which comprises a variety of activities (each with their own attendant risks), technologies and differing local conditions, risk models are necessary to evaluate the aggregated risk, identify risk contributors and geographic areas, and enable intelligent and focussed spending on risk mitigation measures.

Risk models are in common use within the European railway sector. The European Agency for Railways (ERA, 2015) surveyed the 28 National Safety Authorities (18 responses[112]). ERA finds that risk models are not used in five of the states; five states use them qualitatively and eight states use them quantitatively; and that "… comparatively little use is made of quantitative risk models to support the justification for a safety investment or risk analysis" (p.37). This is not the situation in I.É.; its Network Wide Risk Model (NWRM) is used specifically for these reasons.

[112] Including Switzerland

8.3 *Description of I.É.'s Network Wide Risk Model*

The NWRM was developed as part of the Railway Safety Programme (RSP), to support a defensible and optimised risk based investment strategy for I.É. The tool is used to provide risk estimates covering all stakeholder groups affected by I.É.'s operations, i.e., passengers, members of the public, trespassers and staff. It is predictive and does not rely on past accident or incident data to estimate risk exposure (Risk Solutions, 2008). Instead, the analysis is based on a wide range of precursor events. Fault and event tree methodologies are used to analyse and assesses how each of these precursor events can escalate to become an accident. The predictive ability of the NWRM is particularly valuable for I.É., as there have been few major accidents on its system (see Table 2). Inter-analyses comparison facilitates the identification of changes to I.É.'s risk exposure resulting from financial investment programmes and asset deterioration. A top level representation of I.É.'s NWRM, showing the inputs, process outline and outputs, is presented in Figure 10.

The risk evaluation is based on what Wang and Roush (2000) refer to as the risk triplets, i.e., what can go wrong, the likelihood of failure occurrence, and the associated consequence (pp.4-5):

1. The types of things that can go wrong are elicited by analysts' reference to incident experience, activity data and expert judgement (ERA, 2015);
2. The likelihood of failure occurrence is evaluated using fault and event trees in combination; commonly referred to as the bowtie method. The two types of trees "… are related in that the top [or intermediate[113]] events for fault trees are the initiating events for the event trees. Both are used together to produce a complete picture of an incident, from its initiating causes all the way to its final outcome" (Crowl and Louvar, 2002, p.499).

   Fault and event trees are usually shown diagrammatically, as in Figure 11. This particular example relates to a driver's failure to respond to a *stop signal*. Inputs to and outputs from the model, relevant to this particular event, are also shown. When used as part of a quantitative risk analysis, probabilities (P) are

[113] See Crowl and Louvar (2002) for the suggested approach when choosing the initiating event for the event tree analysis (p.492).

assigned to the various base events which are then aggregated into probabilities for subsequent events using Boolean algebra operations. The simplified diagram, provided to illustrate the aggregation methodologies, indicates that the probability of a driver's failure to react to a stop signal is $PE1 \cup PE2 \cup PE3 \cup PE4 \cup PE5$ (from fault tree) while the probability of the occurrence of an exceedance of the signal overlap is $PTE*Pf1*Pf2*Pf3*Pf4$ (from event tree).

Sixty four precursor categories were modelled using the NWRM (Sotera Risk Solutions, 2010). The scenario exemplified in Figure 11, is particularly insightful as it illustrates the connectedness between the relevant training lessons and this particular risk. In addition to contextualised general skill development, which is discussed in Section 5.8, training content that is relevant to the mitigation of this specific risk (SPAD), is contained in Lesson 5 (promoting the effective use of structured communications and workload management); Lesson 6 (addressing low rail adhesion and situational awareness); and Lesson 7 (addressing CAWS, automaticity, overreliance and train operation in the absence of a functioning system) of the lesson plan. The full lesson plan is presented in Table 14 and the connectedness between changes to the range of relevant risk entities, the lessons delivered and the simulator's scenario capability is presented in Column 2 of Table 27. Other key elements that are modelled in the NWRM and that are contained within the training programme relate to defensive driving (avoiding a derailment or collision, and facilitating smooth ride quality), the correct application of parking brakes (avoiding a runaway), correct vehicle coupling (avoiding an unintentional divide in running), maintaining a sharp lookout when driving to avoid striking objects or persons on the line (avoiding personal injury or derailment), correct use of sanders (avoiding collisions with trains or buffer stops), correct response to hot axle box detections (avoiding derailment) and quick emergency response (avoiding a collision) etc.;

3. Consequences, influenced by the usage of the system, are determined by estimating the impacts on the various stakeholders.

The model also contains an aggregation routine by which minor and major injuries are converted into the statistical equivalence of a fatality. The number of each injury type that is deemed to be statistically equivalent to one fatality is shown in Appendix 18. The weighting process directs "... safety expenditure towards those incidents and accidents that lead to the highest levels of risk without ignoring the types of incident that typically have less severe outcomes" (RSSB, 2013c, p.39).

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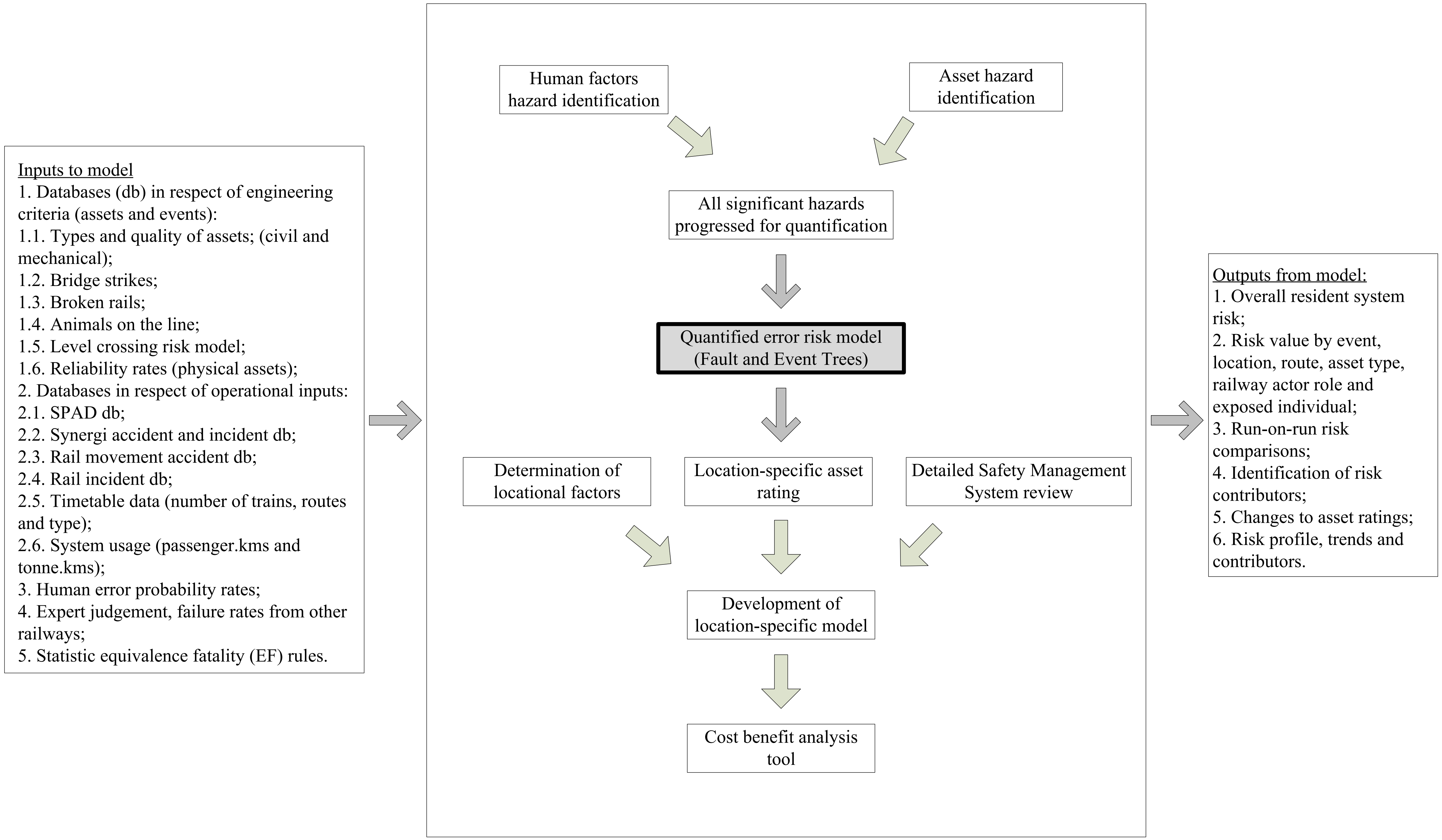
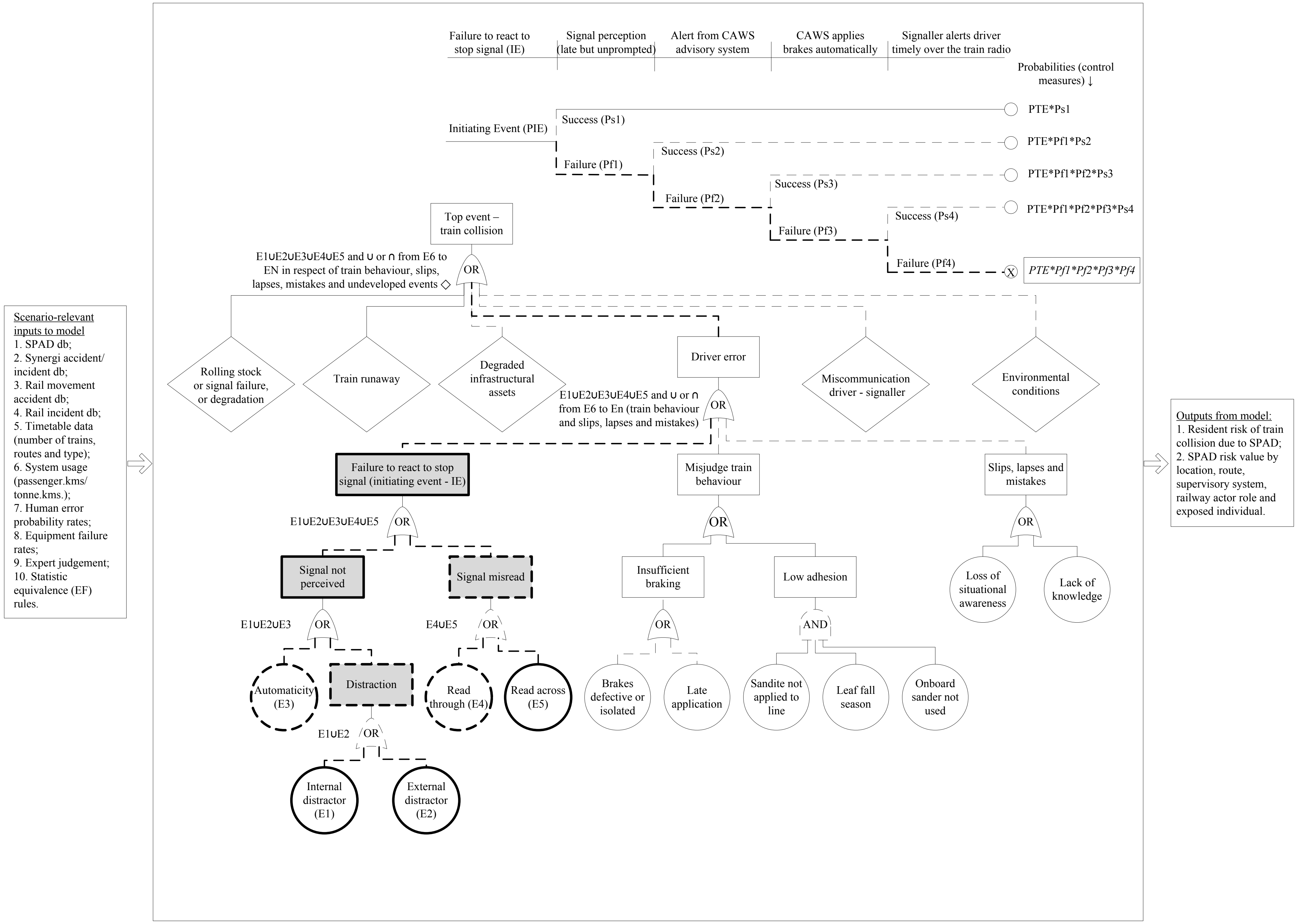


Adapted from: Sotera Risk Solutions (2010)

Figure 10: Overview of NWRM



Based on: Sotera Risk Solutions (2010)

Figure 11: Use of NWRM to Calculate the SPAD Element of Risk

8.4 *Network Wide Risk Model: its history and value*

Before 2003, I.É. maintained a number of accident and incident databases and used their outputs for historic reporting purposes. When used in isolation from other quantitative metrics, their value in the assessment of resident risk and the prediction of future risk could not be exploited fully. (See also Taig and Hunt, 2012.) IRMS (1998) recognised these limitations particularly in respect of infrequent and randomly occurring high-risk events. Accordingly, IRMS recommended that I.É. should "Develop the risk model prepared by the consultants to encompass a wider range of hazards[114]… to include staff error, movement and non movement accidents and occupational safety concerns" (Recommendation 12.6.3 (3)). The NWRM was developed in 2003 by Sotera Risk Solutions and has been maintained and run on a contractual basis ever since.

The output of the NWRM was used to assess retrospectively the effectiveness of Phase 2 of the RSP and prospectively to develop Phase 3. Quantification of the risks that reside within many sectors of the business is achieved through the analysis of precursors, accidents and asset ratings while adjusting for the degree of risk exposure, i.e., changes to the number of train-kms and passenger-kms. Accident precursors are categorised into seven groupings (level crossings, rolling stock, structures, track, Signalling, electrical and telecommunications, interface (trespassers, animals/objects on line), and operations). Nineteen of these relate to operations. There are two hundred incident/accident types; eighteen of these are influenced by traction drivers' actions.

Full value has not been extracted from the NWRM; prompting Risk Solutions[115] (2013) to comment that "... the NWRM is not directly available to support decision-making processes in IÉ such as setting investment priorities. External support is used to produce periodic results, but the NWRM cannot be used on a more ad-hoc basis to respond to specific management decision issues" (p.47). The lack of ownership of the model by I.É., which results in less accessibility for one-

[114] IRMS had used the outputs of a risk model, which was specifically developed to evaluate the risks associated with infrastructure and equipment failures, to support its recommendations for asset renewals in RSP 1.
[115] Not to be confused with Sotera Risk Solutions

off small project evaluations, such as the project which forms the central plank of this thesis, has been criticised by Risk Solutions (2008) and IRMS (2000). However, restricting its use to the model's developers and maintainers has benefits. These external service providers have a specialism and organisational capacity that the organisation may not have, nor deem cost effective to develop. Confinement of the model's operation to external specialists ensures that the data will be inputted consistently and its outputs will be free from biases and errors.

Sotera Risk Solutions completed a run of the model in 2010, and in 2012 (two years after the introduction of the simulator enabled delivery format) Sotera Risk Solutions facilitated the writer by completing a rerun of the model. The results of the 2012 evaluation were then compared with those of the 2010 evaluation. The changes to the simulator-relevant entities that influence I.É.'s risk have been aggregated with the values of preventing a fatality relative to the 'duty of care' and are presented in Table 27.

8.5 Value of Preventing a Fatality

To ensure the efficient allocation of scarce resources, it is necessary to apply some monetary value on the prevention of a fatality when evaluating safety project investments. Early efforts to assign value to the prevention of a fatality centred on awards handed down in Court judgements while others were centred on net lost economic output[116] and the direct costs associated with accidents, i.e., medical costs and damage. A change in thinking occurred in the early 1970s and efforts were made to estimate the value that people placed on their own safety by considering what they were prepared to pay in order to achieve marginal improvements. In 1982, a stated preference study (N = 1,103 respondents) found that the aggregation of the amounts that each individual was willing to pay was £800,000. This willingness to pay amount was subsequently reduced to £500,000 (1987 prices). (See Jones-Lee and Spackman, 2013 for an exhaustive explanation of the reasons underlying this reduction). The VPF is calculated accordingly: VPF = WTP + NQ + MA where WTP is the willingness to pay component, NQ is the

[116] Output losses were calculated on a net basis, i.e., the victim's future output less the value of consumption.

present value of the saving of net output and MA is the avoided medical cost per statistical fatality (Jones-Lee and Spackman, 2013). The VPF is updated regularly in line with growth in real output per capita, and inflation.

It should be noted that there is a lack of harmonisation of the VPFs that are used in respect of the country of application and also the transport mode concerned. In respect of variance in VPF application on a country-by-country basis, EMSA (2013) provides the VPFs for road transport that are used in 23 countries. These VPFs vary by a factor of ca. 57 times with a median value of €1·2 m. (€1,478,000 at 2012 prices). However, there is little variation in the VPFs used on a country-by-country basis for rail. In 2012, I.É. used a VPF of €2,222,713 for its NWRM[117] calculations which is slightly more conservative than that the amount of €2,264,000[118] that is used in the UK rail sector (RSSB, 2014a).

In respect of variances in VPF application by transport mode, Hiselius (2003) provides theoretical arguments[119] "…for the use of a higher [VPF] within the railway sector than in the road traffic sector" (p.37). But this is not the practice in Ireland where the VPFs used to evaluate road projects[120] are between 4% and 18% higher than the VPF used by I.É. Irish practice accords with the logic put forward by Fischhoff *et al*. and Slovic *et al*. (both in Hiselius, 2003), i.e., that "Road traffic is associated with… more dread than railroads" (p.13).

Jones-Lee and Spackman (2013) considered whether the VPF should be increased to reflect the dread risk[121]. However, they find that the "... considerably lower baseline risk of being involved in a rail accident offsets any effect of dread" (p.38). The regression analysis, conducted by Chilton *et al.* (2006) supports this finding. Chilton *et al.* calculate that the ratios of $\frac{VPF\ (Rail)}{VPF\ (Road)}$, prior to and after the

[117] The VPF, used in I.É.'s NWRM, is very similar to the Implied Cost of Averting a Fatality which is calculated at €2,400,000 (CER, 2013).
[118] Converted from £1,763,000 using the Average Market Mid-Closing Exchange Rate (CBoI).
[119] Railway hazards are involuntary, uncontrollable, induce high degrees of social distrust and moral indignation, and resultant accidents tend to be large-sized (p.17).
[120] TII (2016) and DTTaS (2016), and RSA (2013) utilise VPFs of €2,350,500 and €2,625,000 (2012 prices) respectively, when evaluating road projects
[121] Chilton *et al.* (2006) use 'dread' as a catchall term to include factors, such as, voluntariness, control, responsibility and catastrophic potential etc. (p.22). Jones-Lee and Spackman (2013) uses the term in the context of cause/manner of death and location, e.g., confinement in enclosed space.

rail accident at Ladbroke Grove, had changed from 0·834 to 1·003, i.e., although the ratio had increased to slightly above unity, significantly greater dread was still not associated with a rail accident than with a road accident.

In practice, the VFP is applied universally irrespective of the victims' social class, age, health, personal circumstances, future earning capacity, or type or scale of accident. In most cases, it is discounted to reflect whether the organisation holds a primary or secondary duty of care, or if there was an illegal act involved, e.g., trespass. The adjustments applied by I.É. in such circumstances are juxtaposed with those suggested by other safety professionals in Table 23.

Table 23: VPF Adjustments to Reflect Duty of Care

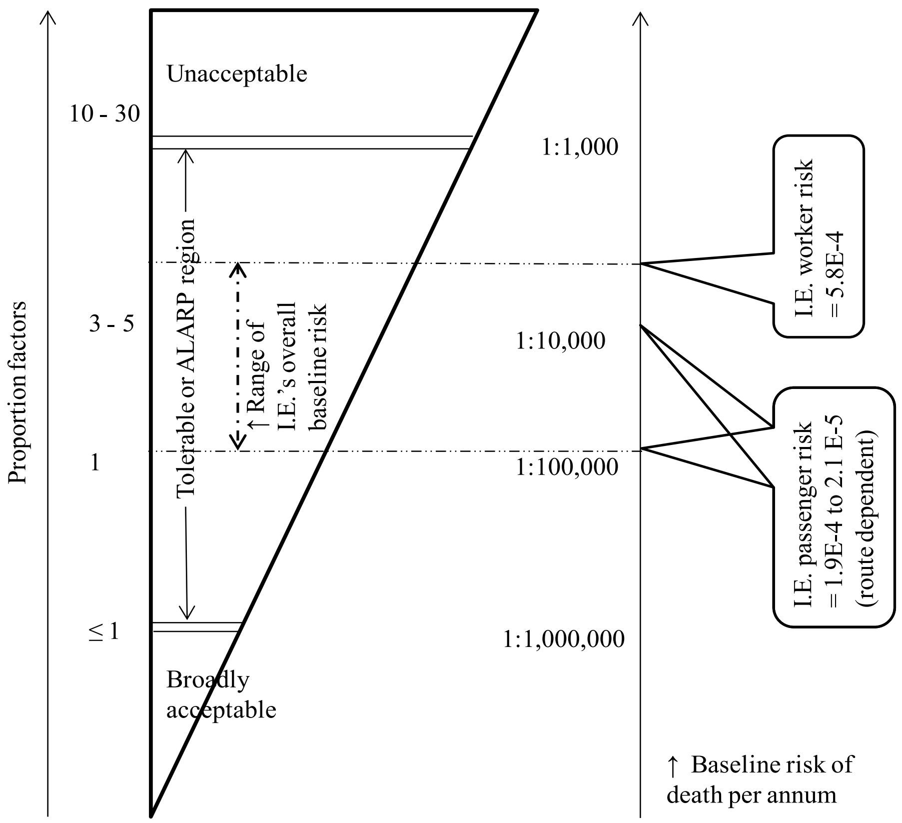
	Primary duty	Shared Duty	Illegal Act
CER (2013)	1·0 VPF	1·0 VPF	1·0 VPF
RSSB (2008b)	1·0 VPF	1·0 VPF	0·4 VPF
IRMS (2008)	1·0 VPF	0·429 VPF	0·215 VPF
I.É. practice	1·0 VPF	0·333 VPF	0·166 VPF

8.6 Investments and Proportionate Returns

Normal commercial investment decisions are made on the basis of their ability to yield a positive financial return, i.e., having a benefit-cost ratio (BCR) in excess of unity. Many railways apply a different rationale to those investment decisions that are aimed at discharging their duty of care. In such cases, investments are made even when the BCR is less than unity. The argument used in support of this rationale is that if a known risk exists and if there is a safety measure available to mitigate it, it should be implemented. Failure to do so implies an acceptance of the risk. This position is laudable but raises the fundamental question of placing an appropriate limit on the BCR of the safety measure. The judgement in the 1949 case of Edwards v The National Coal Board partly answers the question. In that case, Judge Asquith found that if:

> "… the quantum of risk is placed on one scale and the sacrifice involved in the measures necessary for averting the risk… is placed on the other; and that if it be shown that there is a gross disproportion between them - the risk being insignificant in relation to the sacrifice - the Defendants discharge the onus on them" (in Jones-Lee and Loomes, 2006, p.5).

Although Asquith found that it is unnecessary for the duty holder to incur limitless expense, he did not suggest a BCR, commonly referred to as a proportion factor, which would discharge a duty holder's obligation. The matter of proportionality is critical to the safety investment process. If a high BCR is used as the basis for safety project acceptance and the project does not proceed, the duty holder may face severe criticism in the event of an avoidable accident. If a low BCR is accepted, the organisation's investment portfolio will not be optimised as any investment appraisal is almost bound to yield an acceptable result. The HSE has not formulated an algorithm which can be used to determine a PF and suggest that it should be set on a case by case basis. However, H+SAW (2016) provides top level diagrammatic guidance, and positively correlates the PF to the baseline risk of death (see also Hammerton *et al*. and Jones-Lee (both in Hiselius, 2003)). The writer has overlaid I.É.'s passenger risk data for two routes and the staff risk data onto this diagram, and presents the results in Figure 12.



Based on H+SAW (2016)

Figure 12: Relationship of Proportion Factor to Baseline Risk

This illustrates that, in these particular circumstances, the application of values in the range of $1^+ < PF < 3^+$ is appropriate. This finding is useful as a sense check but the range of values is too imprecise and varied for the purpose intended. Supplementary findings are presented in Table 24 below.

Table 24: Proportion Factors: used and suggested for various investments

Proportion factor	Rationale	Source
1) PF of 3:1 for risks to workers; 2) PF of 2:1 for low risks to members of the public; 3) PF of 10:1 for high risks.	"The Nuclear Safety Directorate (NSD) takes as its starting point the HSE submission to the1987 Sizewell B Inquiry". The Hazardous Installations Directorate (HID) uses similar rules of thumb.	HSE (2014)
1) PF of 20:1 2) PF of 5·55:1 3) PF of 8·3:1	1) The PTC system got US Congressional approval in spite of the low BCR; 2) TPWS (UK) 3) ATP (UK) This project was not completed in spite of the fact that "There are often strong institutional, legal and political pressures towards adopting railway safety measures with [this ratio]" (p.146).	Evans (2013)
Possible PF of 3:1		TfL (2013)
PF of 1·5:1	1) Fatalities on LU should be valued 50% greater than those on the roads; 2) Fatalities in large accidents should not attract a specific premium	Jones-Lee and Loomes (in Evans, 2013)
1) PF of 1·28:1 2) PF of 1·12:1	1) For a multiple-fatality accident caused by signal failure; 2) For a multiple-fatality accident involving a fire in a tunnel.	RSSB (2008b)
PF of 4:1	This value was used specifically for the evacuation concept for a long Norwegian railway tunnel.	Reitana and Kalager (2007)
PF of 2·8:1	"[This PF] was adopted… by BRB for risk associated with multi-fatality train accidents… For other types of risk no multiplier was applied. [Afterwards], the industry stopped using this multiplier" (p.6).	Bearfield (2006)
PFs of 3·1. and 2·8 respectively	The installation of ATP between Paddington and Didcot, and Didcot and Oxford respectively did not proceed on these bases.	Cullen (2001a)

It is evident from Table 24 that a wide range of PFs is used by organisations when calculating the worth that they place on risk reduction initiatives. Unsurprisingly, anomalous applications have occurred; lower quality projects with higher PFs have been implemented (TPWS), while higher quality projects with lower PFs have been rejected (specific ATP installations). The average accepted PF of these examples is 4·88:1. Excluding the CBR of 20:1 in the PTC example, which may be an outlier driven by the American culture in respect of uncertainty avoidance[122], the average CBR is 3·37:1. This is in line with the upper value of 3^+ that was extrapolated from the H+SAW diagrammatic guidance in respect of I.É. (see Figure 12), and is slightly above I.É.'s norm of 3:1.

8.7 Choice of Financial Appraisal Methods

The safety benefits accruing from the implementation of the project are enumerated in Section 9.1. Four appraisal methods were considered prior to making the financial evaluation of these safety benefits. Each method has its own limitations and merits:

1. Using the payback period approach, the investment value is reduced by the net periodic income amounts until the expenditure is fully recouped. Time is the unit of measure. The time value of cash, or cash equivalent inflows, and outflows is not considered; nor are the flows after the payback period has been reached.
2. Using the return on investment approach, the annual attributable profit before interest is expressed as a percentage of the investment expenditure. These *ROIs* are averaged over the lifetime of the asset to provide an average ROI value. The time value of inflows and outflows is not considered and it is difficult to evaluate projects with different life spans.

Although the above methods are useful as initial processes for screening out clearly unattractive investment propositions, neither method is suitable for evaluating long life projects.

3. Using the net present value (NPV) approach, all of the future net cash flows are discounted at the company's borrowing rate. They are then netted off against the capital cost and the surplus amount constitutes the project's NPV. The maximum cost of funding that the project is capable of bearing is not revealed using this method.
4. Investment decisions are based on the extent that the cost of funding is exceeded by a project's internal rate of return. The calculation method is explained fully in Section 9.3 where a financial evaluation of I.É.'s project is

[122] The uncertainty avoidance indices (one of the cultural dimensions of Hofstede's model) are 46 and 35 respectively for the USA and the UK; Americans want to avoid uncertainty more than UK residents.

presented. This approach was chosen because it can be used to evaluate the attractiveness of competing alternatives and also of standalone projects; such as this case. Most germane, it is suitable to use for evaluating long life projects where the cost of funding is likely to fluctuate.

8.8 Approach Used to Financially Evaluate Benefits

I.É.'s NWRM was used to evaluate the changes to its driver-relevant risk profile, quantified in terms of the number of equivalent fatalities avoided per annum, over the period 2010 - 2012. Using the concept of the VPF, and adjustments to reflect the relevant duties of care, a financial value was placed on the achieved reduction in risk. In high risk and high profile industries, and in cases where risk owners are anxious to discharge their duty of care assiduously, a PF is used to reflect their aversion to risk. The writer adopted this convention.

Two financial evaluations are presented in Section 9.3. i.e., an IRR evaluation based on a PF of 3 times the VPF which is the PF value normally used by I.É. for project evaluations, and an IRR evaluation based on a PF of 1 times the VPF. A set of scenario based IRR evaluations, showing the minimum PF necessary to yield an IRR equal to +3·42%, which was the prevailing costs of funding at the time of equipment purchase, is presented in Section 10.2.

8.9 Conclusion

The objective of this study was to ascertain the effect of the revised training process on the performance of a global skill set by I.É.'s cohort of drivers. The writer was constrained in the design of study that he could use to test the research questions. A randomised control study could not be carried out because of ethical, business and procedural reasons.

He used the outputs of before-and-after runs of I.É.'s NWRM to assess the change in risk in the two year period immediately following the introduction of the amended training process. I.É.'s complement of 500 drivers had received simulator enabled training in this period. Because of contractual arrangements, this assessment was performed by Sotera Risk Solutions at his behest.

Relevant financial values, based on the VPF and on weightings to reflect I.É.'s duty of care in particular harm categorisations, were assigned to changes to each component of the overall risk. The resultant value was adjusted by a PF to reflect I.É.'s willingness to pay a premium for measures to mitigate known risk. The VPF, adjustments to reflect I.É.'s duty of care and the PF that are used in the calculation are justified by reference to the project evaluation criteria that are used in other organisations and jurisdictions. For investment evaluation purposes, I.É. uses a PF of 3 which is at the lower end of the range of values employed in similar industries. The project's IRR was calculated on these bases.

9 Measurement of Outcomes

In the earlier chapters, the writer describes the task of traction driving and the ways that the training content can be elicited; concluding the description with a presentation of I.É.'s lesson plan. In intermediate chapters he provides a treatise on the range of simulators available to deliver the training content; going on to provide reasoned arguments for the type that he specified. In the previous chapter, he describes the approach that he uses to evaluate the effectiveness of I.É.'s system. He presents the results of his evaluation in this chapter.

The effectiveness of an initiative can only be understood after the organisation's overall goal, or mission statement as it is sometimes called, has been understood. I.É.'s mission is "To provide safe, accessible and integrated rail services that contribute to sustainable economic and regional development in an efficient manner" (I.É., Annual Report 2012, p.4). Railway systems are quintessentially open systems with complex stakeholder dependencies. Operative goals support the overall organisational goals and are realised through operating routines. The degrees to which stakeholders' concerns are satisfied through these routines are measures of their effectiveness.

The use of the stakeholder, or constituency approach as Daft (1995) calls it, to evaluate the change in effectiveness that resulted from the transition of I.É.'s training routine is appropriate. Railway organisations have to satisfy the diverse, and sometimes competing, effectiveness criteria of a range of internal and external stakeholders. It can be seen from I.É.'s mission statement that the provision of safe rail services is its priority. Improvement in operational safety is the criterion of particular interest in this thesis; the satisfaction of other criteria is dependent on this. The effectiveness criteria of the five stakeholder groups, relevant to I.É.'s simulator project are presented in Table 25. These criteria are not mutually exclusive to the respective groups. For example, operational safety is not the concern of the customer and community stakeholder group only, it is the concern of all of the stakeholders and this concern is included with the additional concerns of stakeholders as the hierarchy is ascended. As the focus shifts from the customer and community group towards the Irish Government, stakeholders rate the organisation's effectiveness using multiple criteria.

Table 25: Stakeholders and their Effectiveness Criteria

Stakeholder group	Effectiveness criteria evaluated in thesis
Customers and community	Improved operational safety
Employees (drivers)	Enhanced and valued training experience
Iarnród Éireann	An internal rate of return that exceeds the cost of the capital employed on the investment
Railway Safety Commission	Compliance with regulation
Irish Government	Governments do not wish to be associated with failed expenditure initiatives. Capital expenditure, raised through taxation, must be seen to be spent effectively. Capital projects must satisfy credible independent expert audit.

Based on Daft (1995)

This chapter is divided into six sections, dealing with:

9.1 Improved Operational Safety;

9.2 Enhanced Training Experience;

9.3 Internal Rate of Return on Investment;

9.4 Compliance with Regulation; and

9.5 Independent Expert Audit and Comment.

Concluding remarks are presented in Section 9.6.

9.1 Improved Operational Safety

Passengers and the community, that is contiguous to the railway, are affected directly by its operations and have an inalienable right to be unharmed by them. SPAD occurrence is a key determinant of operational risk. Being in a vehicle or adjacent to one, that has collided or derailed because of a SPAD, is a significant harm causation mechanism for this stakeholder group. In their 'Value for Money' audit of RSP 2, Risk Solutions (2008) notes that "One of the major investments... was the procurement of a train driver simulator... [that was] intended to directly address the risk from SPADs" (p.37).

A review of the Railway Safety Performance reports (RSC, various dates) provides evidence that this goal of the investment was realised. It also supports the findings of the NWRM analysis in respect of SPAD risk (Row 5 of Table 27). The reports indicate that there was a moderate decrease in the number of SPADs at running signals in 2010 followed by a sharp decrease in 2011 and 2012. Readers should note that simulator enabled training commenced on 30th June 2010. (See Table 26 for the coincidence between SPAD occurrence and driver attendance at the new training process.)

Table 26: Recent Trend in SPADs Juxtaposed with Phasing of Driver Attendance

Year	Number of SPADs at running signals	Severity (as determined by I.É.'s 'Risk Ranking Tool'[123])	Proportion and phasing of drivers attending new process
2009	17[124] (sic)	5 potentially significant risk	Simulator unavailable
2010	14	1 potentially severe risk	Simulator unavailable until 30th June. 29% of driver cohort attended in 2010.
2011	7	2 potentially severe risk	51% of driver cohort attended
2012	8	0 potentially significant or severe risk	20% of driver cohort attended (to 29th June)
			2nd biennial refresher cycle commenced 01st July

Sources: Railway Safety Performance reports (RSC, relevant dates) and I.É.'s training attendance records

This reduction in SPADs led Risk Solutions (2013) to conclude that:

> "Evidence of the effectiveness of the Railway Safety Programme as a whole can be sought in lead indicators such as numbers of signals passed at danger (SPADs), and in overall network risk as determined by the network risk model (NWRM)" (p.6).

Prospectively, the NWRM played a significant role during the project evaluation phase when the writer was seeking approval from the Board of I.É. for the project's funding. On the commencement of the revised training process in 2010, and again in 2012 after a period of two years during which I.É.'s complement of 500 drivers were trained, the writer utilised the NWRM as a fundamental part of the effectiveness assessment process. At his behest, Sotera Risk Solutions assessed the changes to the risk profile that were influenced by the change in driver performance during the period 2010 to 2012. It should be noted especially that no relevant operational changes were introduced by I.É. during this period

[123] SPADs with calculated risk rankings in excess of 20 are classified as potentially severe; those ranked between 16 and 19 are classified as potentially significant, and those ranked between 0 and 15 are classified as not posing a significant risk.

[124] There is a difference in the numbers of SPADs at running signals that are shown in Tables 11 and 26 for 2009. This anomaly arises because of the different treatments of a SPAD that occurred on 29th May at a co-sited shunt signal. It was regarded by the RSC as occurring at a running signal.

which could confound these findings. The changes to operational risk and financial value associated with these changes are presented in Table 27.

In this table:

1. The nature of the relevant events or hazards are described;
2. The reference numbers of the training scenarios that have the capacity to alter the risk associated with the events or hazards, and also the locations of these scenarios within the lesson plan are shown;
   2.1. The list of numbered scenarios, categorised by mode[125] of operation, which formed part of the system's outline specification, is presented in Appendix 10;
   2.2. An overview of the content of each individual lesson is presented in Table 14 (Section 5.9). Each lesson is numbered and the term 'overarching lesson' is described;
3. Explanatory comments of the analyst (Sotera Risk Solutions) are presented;
4. The baseline risk values, measured in equivalent fatalities, which were associated with the events or hazards for 2010 are shown. These values were calculated using the NWRM prior to the introduction of the amended training process;
5. The calculated change in risk that occurred in the period 2010 to 2012 is shown (see Smith (1993) in respect of the justifiable level of confidence in relative predictions vis-a-vis absolute predictions. Partly supportive evidence of the reduction in risk is presented in Table 26.);
6. The extent of I.É.'s duty of care in respect of each event or hazard is shown;
7. The adjusted values of preventing a fatality (VPF), based on the extent of I.É.'s duty of care for the events and hazards, are shown;
8. The financial benefit of the reduced risk for each event or hazard is shown. These values are the products of the values in Columns 5 and 7.

This analysis shows that an overall risk reduction of -1·2807E+00 equivalent fatalities was achieved over the two year period 2010 - 2012. The financial benefit of this reduction was €720,878 over the period; equivalent to €360,439 p.a.

[125] Normal, degraded or emergency mode

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Table 27: Changes in Operational Risk (2010 – 2012): attributable to driver performance

1) Description of event or hazard	2) Reference number(s) of scenarios and (their locations in lesson plan)	3) Comment	4) Risk resulting from the event or hazard in 2010 (in *EF*s)	5) Change in risk[126] (EFs) (2010 - '12)	6) Assignment of 'duty of care'	7) VPF relative to 'duty of care'(€)	8) Financial benefit (2010 – '12) (€)
Passenger falls due to poor ride quality	N 3.1; N 15 (overarching lesson)		6·4125E-03	1·0039E-03	Shared	€740,910	€744
Passenger sustains scalding after spilling drink due to poor ride quality	N 3.1; N 15 (overarching lesson)		6·4125E-03	1·0039E-03	Shared	€740,910	€744
Train crew worker falls due to poor ride quality	N 3.1; N 15 (overarching lesson)		1·5775E-03	9·8536E-05	Shared	€740,910	€73
Train crew worker sustains scalding after spilling drink due to poor ride quality	N 3.1; N 15 (overarching lesson)		1·4789E-02	9·8536E-05	Shared	€740,910	€73
Signal passed at danger (running SPAD)	Various (overarching lesson, Introduction and Lesson 1)	Collective change to running and shunting SPADs	1·9697E-01	-1·4176E-01	Prime	€2,222,731	-€315,088
Cat. D SPAD (a runaway)	N 10.1 (Lesson 4)		1·0190E-05	9·0619E-04	Prime	€2,222,731	€2,014
Dispatch staff fails to observe entrapment	N 10.3; N 10.5 (overarching lesson and Lesson 2)		2·2150E-03	0·0000E+00	Shared	€740,910	€0
Hit by train after falling from train onto track	N 10.5 (overarching lesson)		8·1915E-02	0·0000E+00	Shared	€740,910	€0
Train separation occurs (auto coupler)	N 16; E 5 (Lesson 10)		2·3564E-04	-5·3221E-07	Shared	€740,910	€0
Train separation occurs (manual coupler)	N 16; E 5 (Lesson 10)		4·2062E-04	-3·9888E-08	Shared	€740,910	€0
Brakes/brake initiation failure	N 20 (Lesson 4)	The benefit is low as this is an activity which is well practiced and a simulator makes little difference.	5·3948E-03	9·8642E-03	Prime	€2,222,731	€21,925
Object not detected by the driver on an adjacent line	N 22; E 1; E 2 (overarching lesson)		7·2028E-02	0·0000E+00	Prime	€2,222,731	€0
Train driver fails to stop short	N 22; E 11 (Introduction)	The benefit is small as this is a hard area to improve. Often, the train will be going too fast to stop short.	4·5023E-01	0·0000E+00	Prime	€2,222,731	€0
Trespasser/surfer is injured	N 22 (Lesson 5)		3·3403E+00	-1·1495E+00	Illegal	€370,455	-€425,822
Signalman or driver is slow to react, or reacts incorrectly, to an emergency, or an emergency call to stop trains	N 28 (Lesson 5)	Changes in risk profile are less sensitive to driver performance; signalmen play a major part in this scenario.	3·5447E-02	0·0000E+00	Prime	€2,222,731	€0
Overspeeding through speed restriction and derailing	N 30 (overarching lesson and, Introduction)		9·0322E-03	0·0000E+00	Prime	€2,222,731	€0
Collision during permissive working due to driver misjudgement of speed or braking	N 1; N 32 (overarching lesson and Lesson 4)		1·4478E-02	-9·5393E-04	Prime	€2,222,731	-€2,120
Train driver misjudges buffer approach speed	N 1; N 32 (overarching lesson and Introduction)		4·1102E-03	-1·8233E-04	Prime	€2,222,731	-€405
Train unable to stop	N 37; E 1; E 11 (Lesson 4)		1·1690E-01	0·0000E+00	Shared	€740,910	€0
Train driver fails to observe road vehicle in time	N 37; E 1 (Introduction)		1·0036E-04	0·0000E+00	Shared	€740,910	€0
Miscommunication between signalman and train driver results in unsafe movement	D 2; D 11 (Lesson 5)		5·7577E-03	0·0000E+00	Prime	€2,222,731	€0
Poor visibility conditions	D 3; D 4 (Lesson 8)		4·7650E-02	0·0000E+00	Prime	€2,222,731	€0

[126] A negative value indicates a reduction in risk.

1) Description of event or hazard	2) Reference number(s) of scenarios and (their locations in lesson plan)	3) Comment	4) Risk resulting from the event or hazard in 2010 (in *EF*s)	5) Change in risk[126] (EFs) (2010 - '12)	6) Assignment of 'duty of care'	7) VPF relative to 'duty of care'(€)	8) Financial benefit (2010 – '12) (€)
Insufficient time to apply/respond to *detonator* protection	D 7 (Lesson 5)		7·8200E-03	0·0000E+00	Prime	€2,222,731	€0
Wrong side failure of train vigilance device or bypassed	D 9 (Lesson 7)		2·7160E-06	0·0000E+00	Prime	€2,222,731	€0
Train door interlock wrong side failure or bypassed	D 10 (Lesson 2)		1·5212E-02	0·0000E+00	Shared	€740,910	€0
Train driver fails to follow a TSR approaching worksite or SPAD entering possession	D 18 (Introduction and Lesson 1)		2·7417E-03	0·0000E+00	Shared	€740,910	€0
Driver unaware of wrong side failure	E 4 (overarching lesson and Lesson 7)		9·4154E-02	0·0000E+00	Prime	€2,222,731	€0
Driver/guard of train # 1 slow to apply protection after collision	E 6 (Lesson 5)		3·0156E-05	0·0000E+00	Prime	€2,222,731	€0
Driver fails to stop short of a set [reversed], or clipped points - low speed move	E 8 (Introduction)		3·7666E-02	0·0000E+00	Prime	€2,222,731	€0
Fire on train - detected early and communicated to driver	E 9 (Lessons 8 and 10)		2·2488E-03	0·0000E+00	Prime	€2,222,731	€0
Object placed on line by vandals	E 12 (Introduction)	The benefit is small as there is only a small chance of detecting the object in advance.	7·6770E-02	-1·3566E-03	Prime	€2,222,731	-€3,015
Hot axle box not detected by HABD before derailment	E 13 (Lesson 5)	The benefit is small as equipment reliability will, most likely, dominate over staff response errors.	3·3911E-03	0·0000E+00	Prime	€2,222,731	€0
Buffer locking results in a derailment	E 14 (overarching lesson)		3·3224E-02	0·0000E+00	Prime	€2,222,731	€0
				-1·2807E+00	Financial value of risk reduction		-€720,878 or -€360,439 p.a.

Sources: Analyses by Sotera Risk Solutions in 2010 and 2012

9.2 Enhanced Training Experience

Operators were asked to complete end-of-course evaluation questionnaires. A copy of the questionnaire is provided in Appendix 19. The questionnaire comprised three main sections in which attendees were asked to:

1. State their levels of (dis)agreement in respect of global attributes concerning the equipment, the training experience and the achievement of the output objective of the training process. The writer converted the forced Likert scale to an interval scale. Values, ranging from -2 to +2, indicate levels of (dis)agreement from strong disagreement to strong agreement;
2. State the extent to which they (dis)liked each of the four elements of the process. Values, ranging from +1 to +5, indicate weak to strong approval for each activity of the process;
3. Comment openly on any aspect of the process. A 'free text' non-directive section was provided on the course appraisal form for this purpose which elicited 1,905 responses in total.

Details of the results of the survey, in respect of the levels of (dis)agreement with the global and process elements, are presented in Tables 28 and 29, and are shown graphically in Figures 13 and 14. A summary of the most common 'free text' comments is provided in Table 30. These tables and figures show the disclosed beliefs of 397 drivers; a response rate of 80%. Almost unanimously, respondents believe that the use of simulation supports their learning. As importantly, they consider that there were no barriers to learning and that the simulator enabled training process is enjoyable and that the system is easy to use. Furthermore, respondents disclosed that the provision of feedback by the instructor and peers, facilitated by remote observation, is valued. In addition to the high mean values of the responses on each dimension, the readers' attention is drawn to the small margins of error.

Table 28: Summary of Feedback on Global Attributes

Level of agreement with statements → on a forced Likert scale which have been converted to (interval scale)	The simulator equipment is easy to use	Using the simulator was enjoyable	The simulator supported my learning
Strongly disagree (-2)	1	0	1
Disagree (-1)	3	3	2
Agree (+1)	212	205	173
Strongly agree (+2)	181	186	221
Total number of valid responses	397	394	397
Average of values	1.4332	1.4594	1.5390
Standard deviation	0.5674	0.5429	0.5565
Margin of error (95% CI)	0.0558	0.0536	0.0547

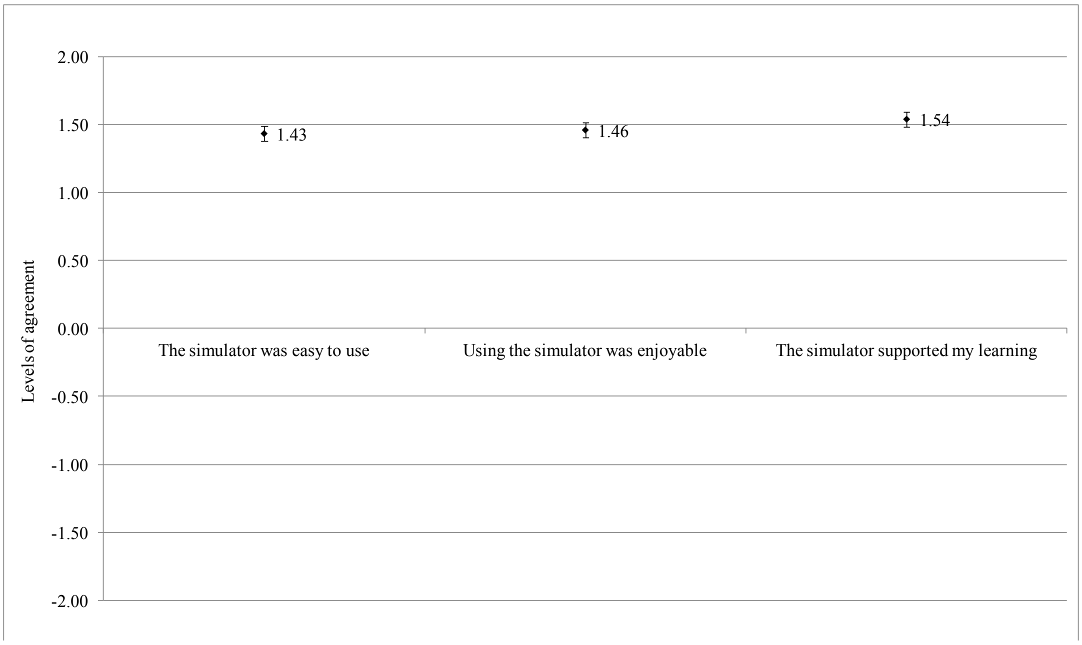

Figure 13: Operators' Views on their Experience and Value of the Simulation

Table 29: Summary of Operators' Liking for Each Element of the Process

Interval scale	The classroom	The driving	The observation	The feedback
Not liked at all (+1)	1	0	2	0
Disliked (+2)	2	4	1	3
Average (+3)	26	18	14	13
Liked (+4)	119	102	114	93
Highly liked (+5)	247	271	261	282
Total number of valid responses	395	395	392	391
Average of values	4.5418	4.6152	4.6097	4.6726
Standard deviation	0.6638	0.6274	0.6212	0.5768
Margin of error (95% CI)	0.0655	0.0619	0.0615	0.0572

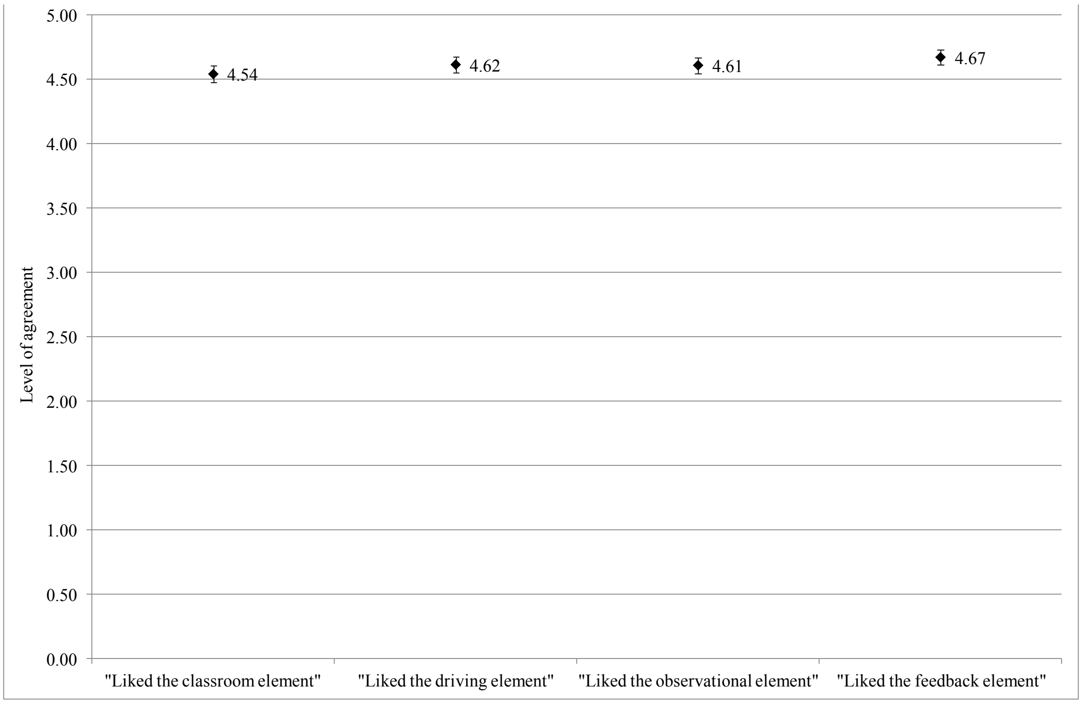

Figure 14: Operators' Views on the Constituents of the Revised Training Process

The writer's view on the value of peer review, performed using the observation facility, is vindicated. The inclusion of an observation facility is sometimes advised against as it is considered wasteful to have non-operant drivers observing the actions of their colleagues.

Table 30: Free Text Comments of Simulator Operators

Essence of respondents' comments	Number of operators who choose to comment on the particular issue (N = 397 possible contributors)
'Opportunity should be provided to allow operators to practice particular skills.'	One hundred and ninety (48%) would like to see more faultfinding included in the training programme.
'Satisfaction with the degree of immersion, and perceived need for motion'	Ninety five (24%) commented on the realism of the simulator and the scenarios. The corollary is that only one commentator (0·25%) "Would like movement or motion, by means of a shaker seat, incorporated into the simulator."
'Simulator scenarios [EBAT] added to the experience'	Seventy seven (19%) concurred with this sentiment.
'It prepares drivers for *emergency situation*s and calls.'	Fifty eight (15%) thought that being practiced in handling emergency situations was beneficial.
'The course is too short.'	Fifty seven (14%) wanted to spend more time on the simulator enabled training course.
'The new training process is better than the old process.'	Fifty two (13%) liked the new delivery format better than the old one.
'The new delivery process is not boring, or as boring, as the old process.'	Forty six (12%) did not think that the new process was boring, or as boring, as the old one.

Essence of respondents' comments	Number of operators who choose to comment on the particular issue (N = 397 possible contributors)
'Gaining an appreciation of the nature and demands of each other's work, i.e., joint training'	Thirty two (8%) welcomed the concept of interactive training with signalmen. No one expressed adverse comment.
'It provides a learning opportunity to train for novel situations.'	Twenty eight (7%) learned how to cope with situations that were novel or that they had no opportunity to practice in the real world. It should be noted that the preponderance of operators had in excess of 5 years driving experience, highlighting the stochastic nature of event exposure in the real world.
'The training allowed me to learn from mistakes.'	Twenty two (5%) believed that the simulator facilitated the learning-by-failing process.
'The relaxed training atmosphere'	Sixteen (3%) appreciated the relaxed atmosphere and thought that it contributed to the intervention.
'Increased confidence in future performance'	Ten (2%) felt more confident that they would perform their duties better after simulator training.
Non-jeopardy training	Five (1%) believed that the facility allowed them to make mistakes in a risk free environment without the fear of recrimination.
'Allowing scenarios to unfold to their logical conclusion'	Four (1%) welcomed the idea of playing out scenarios to the end.
'Professional driving'	Two (1%) felt that the training would add to their professionalism.

The operators' responses, presented in the above table, should be interpreted in accordance with this example. The fact that forty eight percent of the respondents expressed the view that they would like to see a greater faultfinding element in the training programme, should not be taken to imply that 52% would prefer to have the faultfinding content reduced. It simply means that 190 respondents chose to state their preference; the balance chose not to express any view on the matter.

9.3 Internal Rate of Return on Investment

Capital and ongoing costs were, and continue to be, incurred in order to achieve the reduction in the quantum of risk that is shown in Table 27. The internal rate of return (IRR) is the financial calculation that is used by the writer to evaluate the merit of investing in this project. The monetary value of the risk reduction that was realised (from Table 27), other financial savings achieved, and the costs that were incurred because of project implementation are presented in Table 31. The IRR is the discount rate that makes the net present value (NPV) of all cash flows equal to zero. Use of the word 'internal' in the term denotes that external environmental factors, such as interest or inflation rates, are not considered in the calculation. The higher a project's internal rate of return, the more desirable it is as an investment opportunity. The calculation shows that, based on the non-adjusted value of risk reduction (PF = 1), the nett cash flows need to be discounted at a rate of - 19·20% before an NPV of €0 is reached. The IRR for any project can be calculated manually using the formula: $NPV = 0 = \sum_{0}^{N} \frac{C_n}{(1+r)^n}$ where n is a positive integer; N is the total number of periods; C is the cash flow (in or out); r is the IRR and NPV is the net present value which by definition is 0. It can be calculated with ease using the IRR function in Microsoft Excel.

As mentioned in Table 1, the project was funded under the RSP 2 initiative. Even if this was not the case and if I.É. had to fund the project using the normal commercial borrowing facility, because of its prestigious borrowing position of being a semi-state organisation, it was able to borrow money at the ECB AAA lending rate of 3·42% per annum in 2010. As the IRR, based on a PF = 1, falls far short of the cost of funding (-19·20% versus +3·42%), this project would not be countenanced on commercial grounds alone. But this project was not unique in respect of RSP 2 as a whole, Risk Solutions (2008) "… found that in strict cost benefit terms [PF = 1], the safety dividend was less than the cost of the investment" (p. 6).

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Table 31: Cash Flows and Internal Rate of Return Resulting from I.É.'s Project Implementation

	Cash Outflows (all values in €)																
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	
Capital cost	-4,600,000																
Additional staff costs at Training Centre		-168,700	-168,700	-168,700	-168,700	-168,700	-168,700	-168,700	-168,700	-168,700	-168,700	-168,700	-168,700	-168,700	-168,700	-168,700	
Additional insurance		-10,900	-10,900	-10,900	-10,900	-10,900	-10,900	-10,900	-10,900	-10,900	-10,900	-10,900	-10,900	-10,900	-10,900	-10,900	
Electrical energy		-6,500	-6,500	-6,500	-6,500	-6,500	-6,500	-6,500	-6,500	-6,500	-6,500	-6,500	-6,500	-6,500	-6,500	-6,500	
Maintenance of equipment		0	0	-53,350	-53,350	-53,350	-53,350	-53,350	-53,350	-53,350	-53,350	-53,350	-53,350	-53,350	-53,350	-53,350	
Additional costs for maintenance of facilities		-33,667	-33,667	-33,667	-33,667	-33,667	-33,667	-33,667	-33,667	-33,667	-33,667	-33,667	-33,667	-33,667	-33,667	-33,667	
'Half life' rebuild										-902,367							
Total annual outgoings	-4,600,000	-219,767	-219,767	-273,117	-273,117	-273,117	-273,117	-273,117	-273,117	-1,175,484	-273,117	-273,117	-273,117	-273,117	-273,117	-273,117	
	Cash (or cash equivalent) inflows (all values in €)																
Safety benefits			360,439	360,439	360,439	360,439	360,439	360,439	360,439	360,439	360,439	360,439	360,439	360,439	360,439	360,439	
Reduced fuel and maintenance of traction unit[127]		3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	
Ongoing reduction in energy use (eco-driving initiative)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Residual value of buildings																0	
Total annual savings		3,000	363,439	363,439	363,439	363,439	363,439	363,439	363,439	363,439	363,439	363,439	363,439	363,439	363,439	363,439	IRR
Net flows	-4,600,000	-216,767	143,672	90,322	90,322	90,322	90,322	90,322	90,322	-812,045	90,322	90,322	90,322	90,322	90,322	90,322	-19·20%

[127] Used for basic driving and fault-finding courses

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Notes in respect of outflow amounts of project's elements:

1. To facilitate the espousal of the new technology and to provide the extra Staff Trainer resources, which enabled the transition of the training delivery process from broadcasting to narrowcasting, additional staff costs amounting to €168,700 p.a. gross were incurred.
2. Insurance costs of €10,900 have been included in the calculations. These were not incurred as I.É.'s general policy is to carry the risk on facilities and equipment up to a threshold of €5 m. A premium of €10,900 would be paid annually by a company with a different outlook on risk exposure.
3. The system consumes 33kWh of electrical energy at a cost of €6,500 p.a.
4. To ensure whole life reliability, I.É. placed a contract with the supplier to provide preventative and breakdown maintenance services. Defects that occurred during the first two years of service were remedied under warranty arrangements.
5. The cost of additional bespoke accommodation at the two centres (Inchicore and Mallow) was €673,348. In addition, it is customary for I.É. to provide 5% of the capital cost annually to cover building maintenance activities.
6. Although the project has a working life of 15 years, the writer recognises the impact of obsolescence, e.g., computer operating systems go unsupported and user expectations increase. An amount of €902,367 is provided for a 'half life' rebuild. This represents 23% of the initial cost of the simulator equipment.

Notes in respect of inflow amounts of project's elements:

1. Risk reduction has a financial value. Neglecting the practice of applying a PF to the VPF on the basis of reducing the risk to as low as reasonably practicable (*ALARP*), the financial value of the reduction in risk is €360,439 p.a.;
2. Simulator usage reduced the necessity to have a real traction unit made available on the basic driving and faultfinding courses. This has saved €2,000 on fuel costs and a further €1,000 on maintenance costs p.a. Standing charges on the traction unit are excluded from the calculation as they are not an avoidable cost;

3. Evans (2013) highlights the difficulty in evaluating the peripheral benefits that safety related projects can bestow. He notes that "... it is possible that [projects] could provide benefits other than improved safety... such other benefits may be their main justification... identifying and quantifying these benefits more precisely is proving elusive" (p.143). The benefits attributable an enhancement of faultfinding skills, achieved through simulation, could not be ascertained by the writer and, hence, are ignored in the calculations;
4. The matter of training driving techniques to reduce energy consumption (eco-driving) deserves special mention. Ireland's transport sector consumed 32% (4,326 ktoe[128]) of its primary energy demand in 2013. The rail sector consumes 42 ktoe and produces about 138 kt of CO_2 annually (SEAI, 2014). As well as being costly to the environment, it is also costly to the company. The financial cost to provide I.É.'s energy requirements was €31·6 m (8·6% of total costs) (I.É.'s Annual Report, 2011). The use of simulators is seen as a means to develop energy efficient (eco) driving skills, and the savings achievable through this use case are often the main identified advantage in the cost-benefit analysis to justify their purchase (Rushby and Seabrook, 2007). Ironically, when they surveyed ten British operating companies about achieved fuel efficiency through simulator usage, "... only one reported great improvements, one reported a little improvement and five recorded no change. Three [respondents] recorded the question as not applicable" (p.34). The reasons why there was such a mediocre response may be found in the desktop study by RSSB (2011a). Whilst acknowledging the potential to save between 1% and 10% of energy costs, they expressed caution in respect of the possible ensuing safety and operational performance consequences. RSSB finds that distraction caused by eco-driving may result "... in overspeeding or a failure to see a sign or an obstruction on the line" (p.16) but acknowledges that the probabilities attaching to these precursors are either low or very low. The concept of eco-driving is congruent with defensive driving. Both techniques improve the passenger experience by enabling a smoother drive and by reducing the risk associated with LMA exceedence. The results of the studies,

[128] Kilotonnes of oil equivalent

in Appendix 9, show the potential gains of eco-driving. The reason why there is so little take up of eco-driving lies in the principle 'safety over performance and performance over eco-driving'. In an environment that is characterised by the pursuit of adherence to the running schedule, performance wins out. The benefits of eco-driving were not realised in I.É.'s case because of a policy decision not to adopt the initiative;

5. It cost €673,348 to provide bespoke training facilities. Readers should note the non-conventional treatment of this amount. Normally, the buildings would be revalued on foot of a valuation certificate and shown as a cash inflow at the end of the project. However, this inflow is unrealisable as the facilities have niche suitability. The incorporated functionality has no use other than for the accommodation of a simulator system. Perpetual use of simulator equipment is necessary to reap future value from the monies already expended in the facilities. Thus, in this analysis, the facilities are shown as having no residual value. When the system is replaced at some point in the future, the overall capital cost will be lower as the facilities are already in situ and, ceteris paribus, the IRR for that expenditure will be higher than for this project.

In respect of I.É.'s policy decision not to train eco-driving skills, the annual nett savings foregone are calculated at €0 in Year 1, €113,000 in Year 2 and €226,000 for subsequent years. From his research, the writer concludes that it was possible to achieve a minimum gross saving of €316,000 p.a. (1%) on I.É.'s overall annual energy expense. To achieve this saving, it would be necessary to incur additional training costs of €90,000 p.a., based on a burdened training cost of €300 per day training for 300 trainees per annum. The impact of achieving the savings on the project's IRR is evident from rows 1 and 2 of Table 32.

The principle of ALARP, and the appropriateness of assigning PFs to the financial value of a reduction in risk when completing a cost-benefit analysis are discussed in Sections 8.5 and 8.6. To reflect I.É.'s aversion to risk, a PF of three times the financial value of the safety benefits is applied when completing the scenario based IRR calculations. This is the convention that is normally used in I.É. The effect on the project's IRR of using a PF = 3, without implementing the eco driving initiative, is evident by comparing rows 1 and 3. The effect on the project's IRR of delivering eco-driving training and applying a PF of 3 is evident by comparing rows 1 and 4.

Table 32: Scenario Based IRR Values (based on delivered scope)

Scenario	IRR value
1) Actual IRR of I.É.'s project as implemented - based on the application of a PF of 1 times the VPF and training for eco-driving was not delivered	-19·20%
2) Estimated IRR of I.É.'s project as implemented - based on the application of a PF of 1 times the VPF and if training for eco-driving was delivered	-3·13% (est.)
3) Actual IRR of I.É.'s project as implemented - based on the application of a PF of 3 times the VPF and training for eco-driving was not delivered	+10·99%
4) Estimated IRR of I.É.'s project as implemented - based on the application of a PF of 3 times the VPF and if training for eco-driving was delivered	+15·28% (est.)

There are vastly different viewpoints in respect of the application of PFs to the financial value of safety benefits. To achieve an IRR of 3·42%, i.e., the ECB AAA lending rate at the time of the investment, iterative backward calculations show that it is necessary to apply a PF of 2·1675 to the safety benefits. It would have been necessary to apply a PF of only 1·512 times to the safety benefits if these benefits had been supplemented with eco-driving benefits.

9.4 Compliance with Regulation

Although the European Parliament and the Council of Europe (OJEU, 2007) state that simulators may have application in the training and certification process of train drivers, they stop short of mandating their use.

The RSC was set up under 'The Railway Safety Act 2005'. Its mission[129] is to "... advance the safety of railways in Ireland through diligent supervision and enforcement". The commission is far less ambivalent in respect of simulators and considers their use to be:

> "... mandatory for the effective training and continuous training of drivers... every initial training and examination and continuous training and examination [process] shall employ a simulator element on abnormal working conditions and for rules infrequently applied" (RSC, 2012, p.17).

[129] As communicated on its website: http://www.rsc.ie/. (Accessed: 15.01.'15.)

By embedding simulator enabled training into its training processes since 2010, I.É. has surpassed the guidance in OJEU (2007) and has proactively complied with the mandate of the RSC.

9.5 Independent Expert Audit and Comment

History is replete with instances where IT projects did not achieve their intended objectives. Senior office holders, particularly those in government departments, are desirous to avoid negative public criticism in respect of their involvement in ineffective spending. To avoid allegations of misspending and to demonstrate good corporate governance, they frequently obtain 'second opinions' and evidence from independent auditors and reputable industry lead bodies.

I.É.'s simulator project was subjected to a disproportionate level of scrutiny. The Irish Government commissioned two consultations from Risk Solutions[130] to evaluate the effectiveness of Phases 2 and 3 of the RSP. I.É.'s simulator project was an enabler of the human performance component of Phase 2. At the pre-implementation stage of the project, Risk Solutions (2008) made two salient comments:

1. "I.É.'s original intention was to purchase a single simulator in the form of a replica cab mock-up... the requirements were redefined. Instead of a single simulator, the decision was made to procure [PC-based simulators]... is likely to prove better value for money than the original proposal. We commend I.É. for recognising that [a full cab type] was not the best option" (p.37);
2. "Assuming that they are well specified and properly implemented, the simulators should prove an invaluable training aid in the future and be good value for money" (p.37).

At the post implementation review, Risk Solutions (2013) found that "... drivers have embraced [the simulator] with enthusiasm... [it is] in keeping with this adult learning thinking... [and there is] good evidence of a positive change in this indicator (training attendance and influence on SMS outcomes)" (p.93). The authors conclude that that "[I.É.'s] performance [0·44 SPADs per million train-

[130] Trading name of Risksol Consulting Ltd

kms in 2012[131]] compares very favourably with UK figures, where a running 12-month average of 0·68 per million train-kms [was recorded for] July 2012" (p. 7).

Further supportive independent evidence is provided by the UK based industry lead body in RSSB (2013a). Its review is fulsome in its praise, commenting that "[I.É. is] an example of a company that takes a competence-based approach to competence review and assessment rather than just doing it for compliance" (p.48). See also RSSB (2011b, p.68) in respect of the alignment of the training environment created by I.É. and the environment deemed necessary to sustain the purpose of SMSs. RSSB (2013a) also notes that I.É.'s training and competence development activities "...encompass many of the points within this guide" (p.94). The author concludes that:

> "From a business perspective, the investment had to be justified; the simulators [etc.] had driven up the cost of training... However, the training process is more effective. There is value to be added by investing in the technology especially when it is part of an overall strategy to improve training" (p.100).

9.6 Conclusion

The perspective triangulation technique provided an opportunity to address the research questions from multiple perspectives. Most saliently, the project satisfied I.É.'s fundamental goal of improved operational safety performance. The project also improved the training experience of attendees. However, the project did not make financial sense when normal commercial criteria are applied; applying a PF of 1 to the VPF results in an IRR of -19·20%. When a PF of 3 times the VPF is used however, the project's IRR is +10·99%; well in excess of the cost of funding. A 'backward pass' of the IRR calculation reveals that a PF of 2·1675 times the VPF is necessary for the investment to cover the normal cost of funding, i.e., to achieve an IRR of 3·42%.

[131] Eighteen million train kilometres were operated (Annual Report, I.É., 2012) and eight SPADs occurred in 2012 (Table 26)

The project surpasses the requirements of EU directive 2007/59/EC and has proactively satisfied local regulatory requirements. The project drew very favourable comment from government appointed auditors in respect of key implementation decisions, and also outcomes.

10 Other Findings from Project Implementation

Findings in respect of a range of stakeholder criteria, relating to the achieved outcome effectiveness of I.É.'s simulator system, are presented in Chapter 9. These findings are of particular interest to those who are interested in 'what' was achieved. The background narrative in respect of 'how' these outcomes were achieved is contained in this chapter. The achieved outcomes cannot be considered as being mutually exclusive to the strategies and implementation methods that were involved in achieving them. This narrative is intended to provide guidance to those who hold dual organisational roles, i.e., the Operations Training Officers. This cohort is sometimes involved in the specification and delivery phases, but is always involved in the use phase of the equipment. The onus is on them to ensure that the system will be implemented correctly and that it will deliver the intended outcomes. A suggested extension to the use cases that are currently performed, and chosen specifically to create extra value and increase the IRR of the investment, is also proposed.

This chapter is divided into seven sections, dealing with:

- 10.1 Findings in Respect of the Commercial Aspects;
- 10.2 Findings in Respect of the Strategy Employed;
- 10.3 Findings in Respect of the Equipment Attributes;
- 10.4 Findings in Respect of the System Usability;
- 10.5 Findings in Respect of the Unrealised Value-adding Capability; and
- 10.6 Recommendations from Research Activity.

Concluding remarks are presented in Section 10.7.

10.1 Findings in Respect of the Commercial Aspects

The commercial aspects of the project had the potential to influence the initial and recurrent costs and, hence, were determinants of its IRR. The three most significant aspects were:

1. The two unforeseen challenges that were encountered in respect of providing accommodation at the slave site:

1.1 A late managerial decision to redeploy the equipment from Portlaoise to Mallow partly usurped the monetary contingency that had been provided for that element of the project;

1.2 The construction company, engaged to complete the works at Mallow, became insolvent. The necessity to engage another contractor to complete the work, and adverse on-site weather conditions delayed completion.

I.É. incurred a cost of €33,000 to resolve these difficulties. However, the scheduled commencement date for training delivery was not affected.

2. The development of the DFS during Phase 1 of the project was essential to its success. In total, almost 900 observations were made on the behaviours of the train models, on the hardware and on the CGI during the acceptance testing process. Of these, only 5 items (< 0·6%) were outside of the project's scope as defined in the DFS.

   No cost overruns were incurred as a result of out-of-scope items.

3. The users of new technology are instrumental to its successful introduction. Instructors, who constitute the main user group, are the subject matter experts and soon become the simulator experts. In the case of I.É., they were involved in all stages of the project.

   It is not surprising that their remuneration expectations rise and they seek financial recognition for their involvement in such projects.

10.2 Findings in Respect of the Strategy Employed

The elaborateness and scope of the project were determined by I.É.'s strategy in respect of its intended use cases and usage rate. These criteria had a direct bearing on the capital cost. The three most influential issues in respect of the criteria are:

1. As shown in Section 7.8, the project involved ambitious equipment modelling. These modelling objectives were achieved fully but resulted in an over-elaborate system insofar as one of the key objectives is concerned, i.e., training NTSs.

   It would have been sufficient to model just the predominant class within each type of traction, i.e., to develop train models for the 22000, 8520 and 201 classes only.

2. The poor reliability of I.É.'s 8200 class EMU and 2700 class DMU fleets had prevented their continuous use over protracted periods of time since 2010. Several unsuccessful attempts were made to increase their reliability metrics and they were removed from service before value could be extracted. Spending €115,000 to model these fleets proved futile.
3. The number of driving desks exceeds I.É.'s revised requirements. Due to the collapse in I.É.'s business resulting from the general economic recession, the anticipated requirement to train 48 ab-initio drivers per annum did not materialise; it was only necessary to train 8 per annum. The simulator content of ab-initio training programmes is thirteen days; a duration that reflects the novelty of the tasks, the rate of absorption of the material and the necessity to provide opportunity to practice. In addition, qualified drivers of autonomous traction attend refresher training biennially for two days. Under the previous training process, they attended for four days. The duration of the refresher programme for EMU drivers remains unchanged at two days. The capacity of the system was based on an annual throughput of 48 ab-initio drivers, a four-day refresher programme, and the writer's intention to include training to develop eco-driving skills and more comprehensive modules on non-technical skills. In the event, eco-driving skills are not developed and training in NTSs is limited to awareness training. (See Sections 9.3 and 10.5 for an elaboration of the opportunity that was missed because of the non delivery of eco-driving training.) Based on these changes, only 5 driving desks are necessary (see Table 34). A full set of calculations of simulator usage and requirements is provided in Appendix 20; a summary of the design usage and the achieved usage is presented in Table 33.

   It should be noted that I.É.'s position is not unique in respect of achieved utilisation rates. From the limited data available, it appears that the achievement of very high utilisation rates is unusual (CRC for Rail Innovation, 2013a and Hartmann[132], 2011).

[132] Hartmann (2011) indicates that, even by operating a two cycle shift, an average utilisation rate of ca. 43% was achieved by Deutsche Bahn AG in 2010.

Table 33: Effects of Changed Refresher Training Duration and Business Downturn on Usage

Location and type	Type of training intervention	Anticipated usage	Achieved usage
Dublin – autonomous traction	Refresher	63%	40%
	Ab-initio	26%	5%
	Remediation	1%	1%
	Total	90%	46%
Dublin – electric traction	Refresher	16%	11%
	Ab-initio	10%	5%
	Remediation	0%	0%
	Total	26%	16%
Mallow – autonomous traction	Refresher	79%	25%
	Ab-initio	0%	0%
	Remediation	1%	1%
	Total	80%	26%

Table 34: Revised System Scope and Deployment: traction types and classes

Revised simulator deployment strategy			
Desk	Traction type	Classes incorporated within desk	Location and additional facilities
1	DMU	22000	Dublin – master location: 2 observer stations, 1 technical room, 1 CSD, SPS and TBT ™ development area
2	Same as desk #1		
3	Locomotive	201 (required for conversion training)	
4	EMU	8520	
5	DMU	22000	Mallow – slave location 1 observer station, 1 technical room

The reduced modelling requirements from 9 classes to 3 classes, coupled with the reduction in scope from 8 driving desks to 5, would have resulted in a capital cost saving of €315,000. Based on the same calculation process and values, except for the capital cost, upon which Table 31 is based, the effects of reduced scope of supply on the project's IRR are presented in Rows 1 to 4 of Table 35 below. Rows 5 to 8 of this table show the PFs that it is necessary to apply to the benefits in respect of the four conditions, i.e., the actual delivered scope, the reduced scope, if Eco driving benefits were realised and if they were not, before the project would cover the normal cost of funding of +3·42%.

Table 35: Scenario Based IRR Values

Scenario	IRR based on reduced scope	IRR based on delivered scope
1) IRR of I.É.'s project (without delivering eco-driving training and without the application of a PF adjustment to VPF values)	-18·83%	-19·20%
2) Estimated IRR of I.É.'s project if eco-driving training was delivered as part of the implemented project (without the application of a PF adjustment to VPF values)	-2·37%	-3·13%

<table>
<tr><th colspan="2">Scenario</th><th>IRR based on reduced scope</th><th>IRR based on delivered scope</th></tr>
<tr><td colspan="2">3) IRR of I.É.’s project (without delivering eco-driving training) but with a PF adjustment of 3 times the VPF applied</td><td>+12·15%</td><td>+10·99%</td></tr>
<tr><td colspan="2">4) Estimated IRR of I.É.’s project if eco-driving training was delivered and with a PF adjustment of 3 times the VPF applied</td><td>+16·57%</td><td>+15·28%</td></tr>
<tr><td>Scenario</td><td>PF</td><td colspan="2" rowspan="5">+3·42%</td></tr>
<tr><td>5) Delivered scope and ECO driving benefits were not realised (the actual situation)</td><td>2·1675</td></tr>
<tr><td>6) Delivered scope but if ECO driving benefits had been realised</td><td>1·5120</td></tr>
<tr><td>7) Reduced scope and if ECO driving benefits were not realised</td><td>2·0852</td></tr>
<tr><td>8) Reduced scope and if ECO driving benefits were realised</td><td>1·4297</td></tr>
</table>

10.3 Findings in Respect of the Equipment Attributes

Specific attributes were incorporated into the system that increased the productivity of training delivery, supported extant safety improvement initiatives, and facilitated contextualised learning of non-technical skills. Cost effective ways to supplement simulator training, features and usage patterns to prevent simulator sickness, approaches to allay operator concerns and interface issues between the equipment and power supply were also identified and managed successfully.

1. Geo-specific modelling of the strategically identified routes for the CGI, although difficult to achieve, proved worthwhile because of the improved sense of presence that it created. This helped greatly to garner operator acceptance. The quality of the modelled routes is such that route conductors are not required. Although it was costly to produce, it is labour saving from the perspective of the provision of training resources.
2. Modelling the advisory and supervisory systems exactly proved to be a challenging but necessary requirement. The modelled systems are used to train procedures in respect of the ‘running release’[133] feature of ATP, systems’ bypass procedures, operation in areas that are not fitted with the CAWS, and general training in the hierarchy of signal perception, i.e., the priority of actual signal observation over incongruent indications presented on the advisory system.

[133] An override feature that allows a train to move at restricted speed in the absence of a code.

3. Exact modelling of the AEG 90 train radio created a dilemma. It was I.É.'s intention to replace the AEG 90 system by a Global System for Mobile communications for Railways (GSM-R) system but the timeframe for the replacement, and the characteristics and features of the substitute model had not been decided at the time. As safety critical communications training is a facilitative element of many of the training scenarios, the writer opted for the inclusion of a model of the extant train radio. The model has full modality, and a full range of verbal messages and telegrams can be sent to and from the radio by the various actors.
4. Train faults are advised through the simulator's TDMS, and by means of the indications and gauges on the driver's desk. Driver-correctable repairs or resets are executed on a 14" touch sensitive screen that is located on the rear wall of the simulator booth. In addition to learning how to correct a fault, training is also provided on contextual procedures, i.e., the simulation scenarios contain lessons on obtaining signal protection, placing the *track circuit operating device* on the opposite line and keeping customers informed of service delays.
5. It should be noted from Table 21 that a locomotive simulator desk is not provided at the facility in Mallow. However, some drivers from this catchment area drive locomotive hauled Mk IV trains. Because of the lack of redundancy with single point traction, and the imperative to minimise service recovery time, the writer amended the scope of supply of the contract to include an *emulator*. This is used to train the drivers to correct faults on locomotives.
6. I.É.'s system features static simulators, each using projectors to present narrow FOVs for the OTW vistas. Furthermore, the amount of time spent actually driving during the scripted scenarios is purposely kept short. Typically, it is about 15 minutes per hour per driver. These features and the operating methodology were selected to reduce the likelihood of simulator sickness. This strategy has proven to be successful. None of the drivers taking part in simulator enabled training, in the 2 ½ year period between its introduction and the time of writing, became ill during a training session, or experienced illness to the extent that training had either to be suspended or where feelings of nausea

impacted negatively on its receptivity. The mitigation approaches, outlined in Appendix 15 accomplished the objective.

7. A great deal of accurate quantitative material, relating to operators' performance, is available in the post run analyser; a tool that is similar to an event recorder. The *PRA* is included in the simulator manufacturer's standard offering. For railways operating an aggregated training and jeopardy assessment regime, it is attractive to use the PRA. However, its perceived benefit may be illusory as:
   7.1 The simulated driving environment and conditions do not replicate exactly those pertaining to the real world. Performance deficits in the simulated environment could legitimately be attributed to the mismatch of the perception of speed and the calculated speed, sighting distance for signals or the lack of psychological fidelity;
   7.2 The PRA cannot capture some really meaningful results, i.e., the NTSs of the operators. (See Kyriakidis, 2013; and Blickensderfer (in CRC for Rail Innovation, 2013a)). Good, qualitative instructor judgement, followed by facilitative and non-threatening feedback, is more valuable and beneficial than jeopardous use of the PRA (RSSB, 2009b).
8. The design of the electrical circuitry at the training facilities specified the incorporation of 30 mA residual current devices (RCDs) to protect equipment users. However, nuisance tripping can occur anywhere from 15 to 30 mA. In respect of the facility at Inchicore only, the sum of the standing earth leakage current of the fully operational system and the flow from the capacitive touch screens is within this range. This necessitated modification to the protection arrangements.

10.4 Findings in Respect of the System Usability

Some features of the system have the ability to constrain potential use cases, whereas other features provide unanticipated benefit.

Although the physical characteristics of the trains and routes are modelled accurately, there is a mismatch between the perception of the speed of movement at higher speeds, and the speed that is shown on the speedometer. Operators perceive the speed to be lower than that calculated by the physics engine and displayed on the speedometer, and this can influence operator behaviour (Kim, 2015, and Diels and Parkes, 2010). At low speeds there is no perceptible mismatch. Mismatch is attributable to the accuracy of the artefacts in the visual database, and the speed of computation necessary to draw the wireframes of the objects and to render them. Unhappy with the perceived mismatch, the writer conducted a small experiment using the CSD. Based on the finding of Kwon *et al.* (2006), the writer moved the operators' eye point by +8º in the horizontal plane, i.e., he foreshortened the vanishing point of the horizon. A single blind test was performed with the instructors (N = 8). All of them noticed that there was a very slight improvement in speed perception at higher speeds. A further improvement could have been achieved by reducing the dot density for the texture of the permanent way (Kwon *et al.*, 2006). However, this makes the model of the route appear more artificial and less lifelike. As a very high proportion (87·25% - from Table 11) of I.É.'s SPADs occur at low speed and are contained within the overlap distance, i.e., during shunting movements, when entering or exiting engineering possessions, SASPADs or when starting in advance of a signal etc., this mismatch is not problematic in such cases. The speeds of the train movements, involved in the remaining 12·75% of SPADs where the movements exceed the overlap, are not known.

Significant effort and money was expended in creating very detailed train models that can be used to train basic tasks. This may appear wasteful but the approach garnered a high level of operator acceptance and facilitated *near transfer* learning also. As a peripheral benefit, all of the instructors who were engaged in the delivery of ab-initio training programmes (N = 6) found that the simulator experience prepared trainees better for the upcoming 'training train' module. For example when audible alarms sounded on the real traction unit, because of their prior experience in the simulator, the trainees knew where the sounds were emanating from and could cancel them before incurring a time penalty.

10.5 Findings in Respect of the Unrealised Value-adding Capability

The provision of training to develop energy efficient driving has been found to yield financial benefits. Findings from five railway specific studies in respect of the achievable gains are provided in Appendix 9. These indicate that an overall average reduction of 8·4% in energy consumption may be achievable. The writer took an ultra conservative position when calculating the relevant scenario based IRR values that are contained in Table 32 and in Table 35 by basing the calculations on the assumption that a 1% reduction of I.É.'s energy costs could be achieved. Attention is drawn to the significant effect of eco-driving savings on the project's IRR. The IRR improves from -19·20% to -3·13% (PF = 1) and from +10·99% (est.) to +15·28% (est.) (PF = 3). However, this initiative was not pursued because of a perceived negative effect on operational performance.

10.6 Recommendations from Research Activity

Simulators should not be used merely to train technical skills. CRC for Rail Innovation (2013a) suggests that:

> "Merely mimicking aspects of the task, such as applying correct procedures, may not be sufficient to produce the behaviours which will enhance safety and performance… [simulators] need to be treated as sites for simulating the whole job of train driving and the range of skills involved" (p.25).

The value, derived by I.É., was achieved by the concomitant development of technical and non-technical skills. However, the full extent of this value was not realised; I.É. should invest more time and effort in the development of the NTSs. In Australia for example, initial training programmes, dedicated to the subject of rail resource management have durations of two to three days[134] (Rail Safety Regulators' Panel, 2007). In the US, the programme duration is 1 day (Roop, 2007). Increased investment by I.É. would facilitate more extensive training of the NTSs currently under development, and the development of other NTSs that are not being addressed in the extant programme, e.g., risk management, emergency

[134] Recurrent training courses have a duration of one day.

and crisis management, self evaluation of performance and meta situation awareness.

Undoubtedly, instructors are experts in the development of technical skills. This expertise is insufficient in an era where the emphasis has shifted to encompass the development of NTSs. To improve trainees' experience and training outcomes, instructors need:

1. To understand relevant cognitive psychology and ergonomic constructs. They need to be able to utilise this understanding when scripting scenarios in order to elicit specific responses from which desired learning will occur;
2. To be able to provide qualitative and defensible feedback on performance. This is an essential element of the training process as it prevents trainee *miscalibration*. Instructors should receive additional training to develop this skill, most especially, in respect of the use of behavioural marker techniques;
3. To change further from being SMEs merely, to being observers of behaviour and mentors as well.

A training simulator is one tool in the instructor's armoury. The training process should not become means-end inverted by using it in every conceivable instance just because it is available (see Pennant, 2004). The suitability of each training tool in the armoury should be assessed with regard to the training content, the skill under development and the trainees' stage of development.

Training experiences can be enriched by animating some of *placements* that are included in the simulator system. The inclusion of road vehicles traversing a crossing, or a shunter passing between vehicles etc. would improve the sense of presence within these scenarios.

10.7 Conclusion

Although I.É's project was an overall success as defined by the stakeholder criteria, there is no idea that good that cannot be improved on[135]. There were a number of areas at the strategic, implementation and operational levels where

[135] This maxim is attributed to Michael Eisner; a proponent of the Quality and Lean initiatives

excessive costs were incurred and where benefits were not maximised. Most of these costs were incurred because elements of the intended strategy were not realised; lesser additional costs were incurred because of unforeseen challenges. Although the excessive sunk costs can never be recovered, the possibility of maximising the benefits remains. Utilising the system's potential to enhance training in respect of the unrealised value adding capability will increase the IRR beyond the level already achieved.

11 Conclusions

In this chapter, the writer reviews his research approach, makes suggestions for further research to facilitate generalisation of the outcomes that he has presented in Chapter 9, and makes his concluding comments.

11.1 Review of the Approach Used by the Writer

The work undertaken for this thesis is an extension of the writer's MSc dissertation entitled 'Employing New Techniques to Improve the Effectiveness of the Training Process for Traction Drivers' (2003)[136]. In that prospective report, he investigated the merits of introducing simulation tools and techniques into I.É. While it contained a recommendation to procure a number of desk simulators, it did not consider adequately the extent of the achievable outcomes or the functionality, or the engineering and staff issues necessary to achieve them. This report is written retrospectively; the achieved outcomes of the initiative and the challenges that were faced in their realisation are grounded in experience.

The research reported in this thesis supported the realisation of the project from goal elicitation, through the equipment specification, procurement, systems engineering, installation and value extraction phases. The acknowledged success of the project by industry specialists is a testimony to the extent of the research activity and its value.

Four types of research methods were used by the writer:

1. A review of relevant cognitive psychology constructs highlighted weaknesses in the extant training delivery process which the writer believed could be resolved through the use of simulation. The overall literature review, together with field research, also informed him about simulator attributes and implementation approaches that could help to ensure success;
2. A collaborative action research approach was taken. In addition to I.É.'s training practitioners, the external community of practice contributed to the research process. The community shared its experiences and suggested

[136] Available at the University of Sheffield

solutions to issues that members had encountered when implementing similar initiatives;

3. Quantitative studies were carried out by Sotera Risk Solutions which revealed the nature and extent of driver relevant risks. These were used to reveal the change in the risk profile that occurred in the two years period immediately following the introduction of the new training process. On the basis of this change, it was possible to complete a scenario based analysis of the project's IRR;
4. Qualitative studies revealed user satisfaction ratings.

It was appropriate to adopt a combined study approach for a *translational study* such as this as it coalesced of a range of assets and approaches, i.e., a combination of desktop research and field practice coupled with domain specific primary analyses, towards the achievement of the research goal.

11.2 Suggested Further Research to Generalise Outcomes

The output of I.É.'s NWRM and the resultant financial analysis has provided evidence that simulator enabled training has been effectively employed in this case. The increase in training effectiveness was achieved through the exploitation of general cognitive psychology constructs. The findings of this research can be extended and further generalised by using the following five approaches:

1. By conducting a series of repeat biennial analyses over the lifetime of the project. Using this approach, the training programme would not be altered for what would essentially constitute a longitudinal study over the project's life. This approach is not favoured by the writer as:
   - 1.1 The programme would become dated and boring, and the initiative would regress; leading to a deterioration in operator satisfaction ratings;
   - 1.2 Additional identified risks would not be mitigated and associated benefits would not be realised.
2. By conducting a repeat analysis based on an amended training programme. The operational risks to which I.É. is exposed do not remain constant over time. Because I.É. managed specific risks using the simulator enabled training programme, the associated quanta were reduced. As a consequence, other

theretofore lesser-addressed risks come to the fore and need to be similarly managed. Just as I.É.'s risks do not remain constant, so too, I.É.'s simulator enabled training programme should change to reflect the changed risk profile. The risk profile should be recalculated to reflect the amended programme. The project's IRR, based on the altered risk profile and any additional costs incurred in modifying the simulator system to cater for the amended programme, should be reappraised as part of the change process. Expanding the scope of usage in line with emerging risks will demonstrate the generalisability of benefits across a broader skill set. This is the writer's preferred approach.

The four largest risks in descending order, as determined by the NWRM, are accidents involving trespass and surfing; slips, trips and falls on the railway infrastructure; train collisions with road vehicles at level crossings; and accidents at the platform/train interface. Not all of the risk elements within these classifications are influenced by the behaviours of train drivers. For example, train collisions at level crossings represent 12% of I.É.'s overall risk but 95·2% of this type of risk is brought about by user behaviour and, hence, is not reducible by traction driver training (Sotera Risk Solutions, 2010). A greater proportion of accidents that occur at the platform/train interface can be influenced by driver behaviour. An annual average of 80·4 accidents occurred at the platform/train interface over the seven year period 2005 to 2011. This shared risk represents 8% of I.É.'s overall risk (Sotera Risk Solutions, 2010). Simulator enabled training could be provided for about 34% of these accident types (see Table 36). It would be appropriate to redesign I.É.'s training programme to focus on those particular hazards, that can be influenced by driver training and can be accommodated by the simulator system, and to assess the resultant changes to risk. In addition to ascertaining the extensibility of the effectiveness of simulator enabled training, this approach would also provide evidence as to the durability and the permanence of the behaviour modification that has already been achieved by the current training programme.

Table 36: Average Number of Platform/Train Interface Accidents per annum (2005 – 2009)

Type of accident	Number (%) of accidents	Is this amenable to training?	Suitability of simulator for training task	Comments on the suitability of I.É.'s simulator and the required modifications for training the task
Passenger caught in saloon doors	25 (31%)	Yes	Yes but would require modification	Additional value can be created by including dynamic platform CCTV monitors in the OTW view. CCTV images should include the train dispatch operation in crowded environments.
Passenger hit by train door	2 (3%)	No	N/A	
Passenger fall between train and platform	18 (23%)	No	N/A	
Passenger dragged by doors	1 (1%)	Yes	Yes but would require modification	Door operation is controlled by drivers' actions only. The software commands to facilitate an onboard 'passenger' making an 'open door' request are not in the train models. (See RAIB, 2016). The equipment is suitable to train other aspects of door operation, e.g. managing station dwell time.
Passenger fall when boarding or alighting	27 (34%)	No	N/A	
Passenger fall from platform onto track	4 (5%)	Possibly	Possibly	Development and inclusion of some additional dynamic avatars is required to add realism.
Train stopped at incorrect location – fall from doors	1 (1%)	Yes	Yes	Some of the consists of the modelled trains may require to be increased. See Table 22 for a description of the extant consists.
Short platform	1 (1%)	Yes	Yes	
Other	1 (1%)	It is unclear if training can ameliorate this situation		

Source: Sotera Risk Solutions (2010)

3. Improving the effectiveness of training is, undoubtedly, the goal of training mangers in all railway organisations. Affirming the contribution of simulators towards the achievement of this goal has common benefit and is worthy of cross-industry support. To this end, an industry wide analysis, similar to the one conducted in this thesis, should be conducted in other railway operating companies. Almost inevitably, this would entail the use of different simulator systems with varying degrees of elegance, different use cases and different delivery methodologies. However, the operational risk profile of each railway undertaking is particular to it, and is a reflection of its culture, values and state

of organisational development. Acknowledging this caveat and the necessity to avoid study confounds, the design of such a study would require careful consideration. If properly implemented however, it would provide sufficient data to enable the completion of a meta analysis and, thus, enhance the reliability and generalisability of this study.

4. By changing the focus of the study to address non-safety critical training objectives. For example, it is feasible to conduct a randomised control study into the use of simulation to train drivers in the maintenance of sectional running, customer care or the mean time to repair train faults;
5. By conducting a before and after quasi study in which randomly selected subjects would undertake a different and unsanctioned lesson plan, i.e., one that does not form part of I.É.'s competence management system. Such a study would loosely approximate to a Level 3 evaluation and be based on performance evaluations by SMEs. However, the outcome of the study would be dependent on high inter-rater reliability. Furthermore, it would not inform researchers about the durability of the delivered training, nor its transfer to the workplace.

11.3 Concluding Comments

I.É.'s management has always vigorously pursued stringent safety objectives but, by the turn of the millennium, it was becoming increasingly concerned with key safety metrics in respect of traction driving performance. An attempt to redress this situation contextualises the training initiative that is described in this thesis. The context defined the type of study that should and could be undertaken. It was important to the writer to measure the true transfer of the global skill set that affects driver relevant safety risk; not just isolated skills that are used in non-safety critical situations. The highly regulated operational environment determined the type of study that could be undertaken. All of I.É.'s processes, including training, are prescribed in standards and regulation.

It was important to take an organisational perspective on the evaluation of training effectiveness for the constituency of stakeholders, as the satisfaction of criteria that are important to one stakeholder group may have been achieved at the expense of another group, e.g., the provision of a simulator system with high functional fidelity and a good degree of presence was costly to the organisation but was valued by the operators. At the outset of his research, the writer set out to establish what benefits, if any, I.É.'s stakeholders realised when the company changed the training delivery process for its drivers from the traditional lecture based process to a simulator enabled one. He also wished to make a financial evaluation of the resultant change in driver-relevant operational risk, which had been revealed through before and after analyses of the outputs of I.É.'s risk model, to ascertain if the cost of the change was justified.

The writer made five findings in respect of I.É. stakeholder groups:

1) I.É.'s exposure to driver-related risk decreased by -1·2807E+00 equivalent fatalities over the two year period 2010 - 2012;
2) Almost unanimously, the drivers endorsed the change in training process;
3) The answer to the cost justification element of the research question is that the costs were justified in the case of I.É. However, from a financial perspective only, the project would not merit the investment in those organisations that use a PF of 1 for project appraisal. The analysis shows that an organisation must be willing to pay a cost of 2·1675 times the value of the risk reduction before the investment makes financial sense;
4) The Irish 'Competent Authority', the *CRR*, made the guidelines of the European Parliament and the Council of Europe mandatory;
5) The simulator equipment and the training process received positive endorsements at the specification and use phases by auditors who were engaged by the Irish Government. The training process was also endorsed by the UK industry lead body.

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Appendices

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Appendix 1: Operational Safety Rules

Safe systems of working are usually defined by a set of rules and procedures which are written by functional specialists, and communicated to the workforce for implementation. In work situations which involve many actors, they also define areas of responsibility and thereby lessen the probability of an undesired event occurring because of a lack of role clarity. Organisational controls can cover a wide spectrum, from being largely discretionary to being highly prescriptive process controls. Railway safety rules are part of the apparatus to render the behaviour of the system's actors sufficiently predictable that open loop operation can succeed in most of the situations encountered.

Control mechanisms attempt to standardise the work processes by using prescriptive rules and procedures. These are backed up by monitoring and supervision to ensure compliance, and sanctions are imposed on deviants for non-compliance. This type of control process is referred to as feedforward or open loop control. (See Figure 15.) An open loop system can only work with sufficient certainty if predictability is ensured by compliance with the rules. The system achieves an economy of effort by the operators as they do not have to develop responses from first principles. They simply have to remember the responses that have been pre-scripted and to apply them. Free (1994) believes that "... working to rules often requires little understanding of the system" (p.376) and that this can reduce the skill [and the training] necessary to do the job. (See also HSE, 1999.) As a corollary, there is an inverse relationship between the duration of training interventions and the amount of rules; the longer and more intensive an individual's training, the less likely it is that the person will be governed by rigid *feedforward controls* (Reason *et al*., 1998 and Reason, 1997).

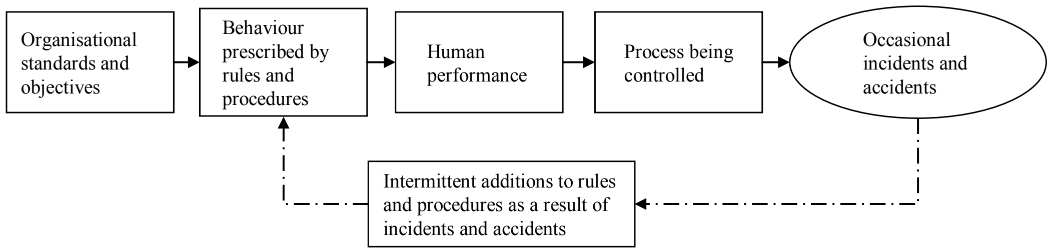

Figure 15: The Feedforward Control Process

Initial training and subsequent refresher training is provided to people in all safety critical roles on the railway to ensure that a common understanding of the company's extant processes is achieved. This common understanding must be maintained in a context where additional rules are generated as a result of accidents and incidents. These restrict further the courses of action that are available to operators. Accidents are analysed up to the point "… where it became clear that someone had broken a rule (at which point discipline was appropriate) or that there was no rule for this eventuality (in which case a new one was made)" (Hale, 2000, p.7).

Tichon (2007) points out that there is a general preference for prescriptive responses but that this has the effect of limiting an individual's development of critical thinking and problem solving skills. Some railway companies are taking a different approach. StateRail, latterly known as RailCorp, has furnished its staff with a new, simplified book of rules and procedures. SGI (2003) report that:

> "To improve safety, the StateRail Authority instituted a dramatic change in its operational structure, switching from a rule-based to a risk-based operating environment. As a result, the former 17 volumes of regulations had been whittled down to one; employees would now be expected to act less according to strict rules and more through the use of critical thinking" (p.1). (See also Kecklund *et al.*[138], 2001b; Coplen, 1999; and Reason *et al.*, 1998.)

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[138] Kecklund *et al*. (2001b) point out that the amount of written material that Swedish drivers receive each year exceeds 20 kilograms (p.27). Their research subjects also "... considered the operational safety rules to be so comprehensive as to be almost incomprehensible" (p.35). The

At an organisational level of analysis, there are disutilities in the imposition of detailed rules (Wilson and Norris, 2005; Hale *et al*., 2003; van Vollenhoven, 2002; Reason *et al*., 1998; Reason, 1997; Free, 1994; and Reason and Free, 1993). Reason *et al*., (1998) suggest that "… all hazardous operations routinely involve a commission of actions that lie outside the prescribed boundaries, yet remain within the limits of what would be judged as acceptable practice by people sharing comparable skills" (p.3).

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excess of written information was regarded as a very serious problem; second only to the concern that drivers have of running over a person on the line.

Appendix 2: Decomposition of the Railway System (IDEFØ technique)

The benefit of using modelling tools, such as the *IDEFØ* approach, is that they facilitate researchers to identify key inter, and intra, interface issues among the system elements at the various levels of analysis by permitting the researcher to change the focus of inquiry (Hockey and Carrigan, 2003). When viewed at level 0, i.e., at the context level, the function of transporting people or goods is a simple input/output process with a feedback control loop (see Figure 16).

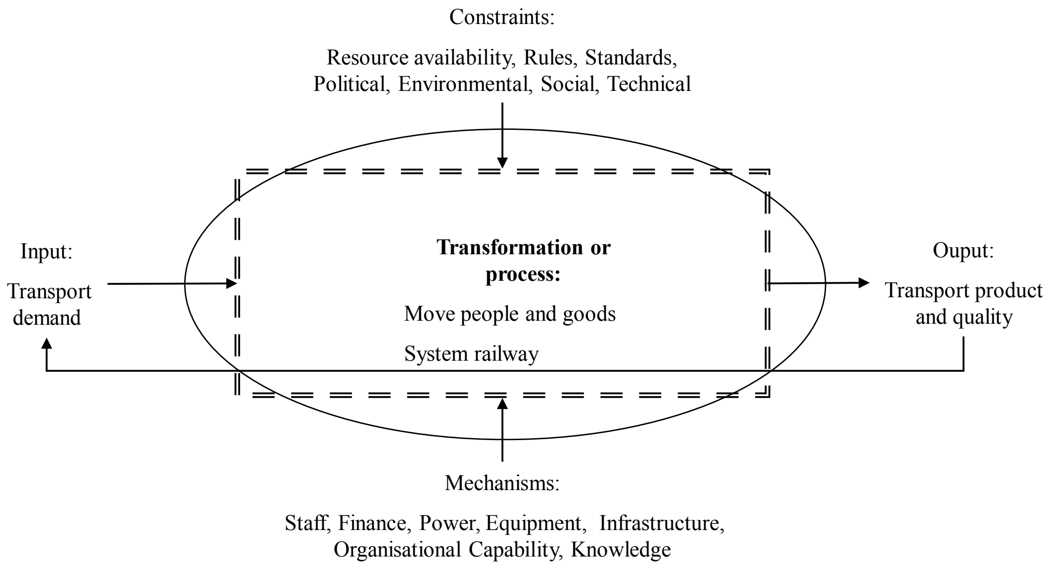

Figure 16: IDEFØ (level 0) representation of the system railway

The value of the tool increases as the system is decomposed to lower levels of abstraction (see Figures 17 to 19). Level 1 depicts the railway system at the concept, development and operational functions. The dependencies that exist between functions start to manifest themselves, e.g., failure to identify and plan the system's requirements correctly will have an effect on its operation.

For the purpose of this thesis, analysis of the level 2 functions is crucial. At this level of abstraction, dependencies and potential conflicts manifest themselves. To fulfil the service obligation, functions must coexist. For example, the system must be maintained and operated concurrently. It would be a simple task to maintain the system if operations could be suspended. The controls to facilitate concomitant maintenance and operational activities are depicted as arrows entering the functional boxes from the top. These controls are imposed to govern or constrain the functions. Quite often, problems arise because of the competing imperatives of the maintenance and operating functions.

The necessity to provide competent crewpersons to satisfy demands for train movements is depicted in the level 3 representation. The scope and content of training becomes clear at this level.

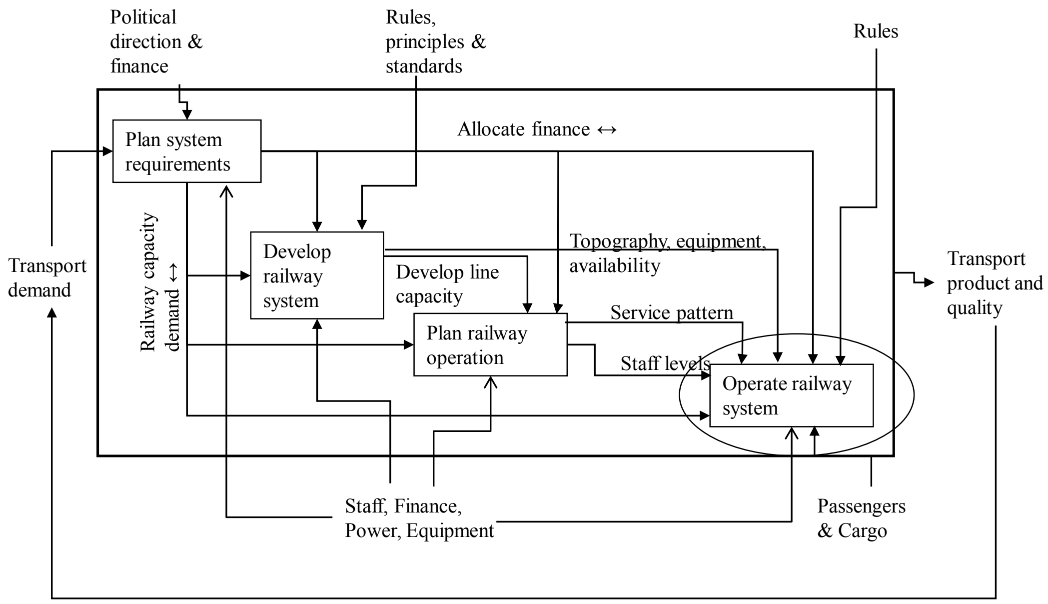

Figure 17: IDEFØ (level 1) first level view of the system railway

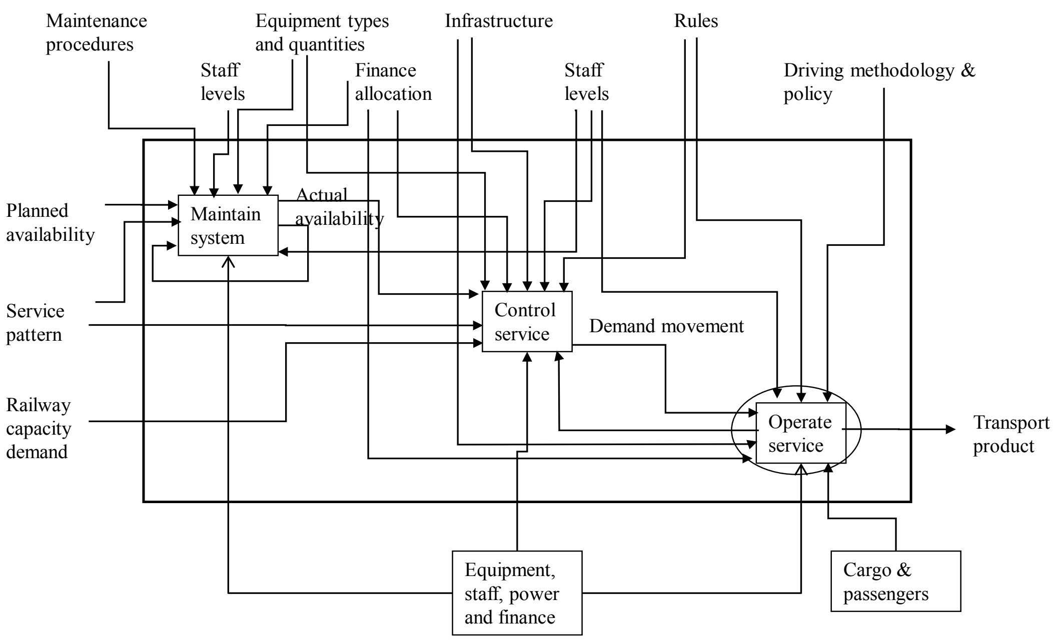

Figure 18: IDEFØ (level 2) second level view of 'operate railway system'

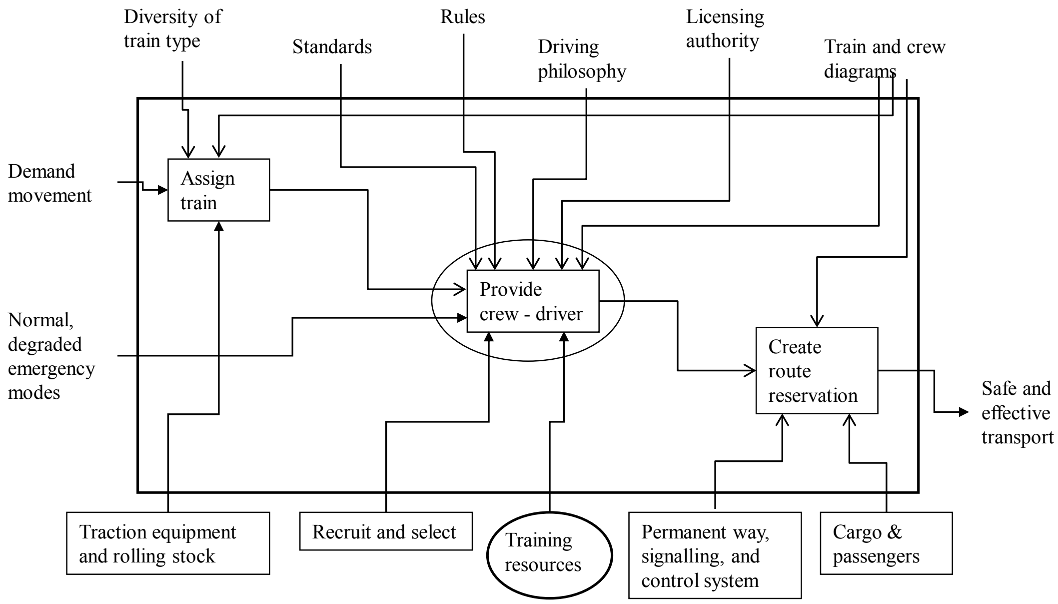

Figure 19: IDEFØ (level 3) third level view of 'operate service'

Appendix 3: Task Analysis

The key technical skills of a driver's job are to:

1. Adhere to signals, trackside signs, boards and indicators. This requires:
    1.1 Vigilance to notice the informational artefacts;
    1.2 Recollection and application of rules and route knowledge;
    1.3 Ability to assimilate information;
    1.4 Decision making skills;
    1.5 Ability to mount a fast response to the information.
2. Monitor the trackside and the track ahead for trackside workers, trespassers and obstructions. The requirements for this task group are:
    2.1 Vigilance;
    2.2 Fast reactions;
    2.3 Decision making skills.
3. Monitor and adjust the speed of the train. This necessitates:
    3.1 Observation of the speedometer, and the assembly of data from late notice cases, weekly circulars and lineside signage into information;
    3.2 Cognisance of train make up, train performance and metrics, *permissible speed* and gradients.
4. Respond to advisory systems. This requires vigilance to ensure that a signal is not missed and that there is correspondence between the displayed aspect on the *ADU* and the lineside signal. This process involves recollection and application of route knowledge;
5. Respond to the SCE. This involves application of traction knowledge;
6. Attendance to informational cues. The requirements for this task group are:
    6.1 Attendance to internal inputs, e.g., TDMS, train radio messages and passenger communications system;
    6.2 Attendance to external cues.

Adapted from: Porter (in Whitlock, 2002)

While accepting that staff needs to be technically competent; on its own, it is insufficient for effective task performance. Complimentary non-technical competence is also required. This skill set includes:

1. Situational awareness:

1.1. Attention to detail;
1.2. Overall awareness;
1.3. Ability to maintain concentration;
1.4. Ability to retain information;
1.5. Ability to anticipate risk;

2. Conscientiousness:
   2.1. Ability to apply a systematic and thorough approach;
   2.2. Constant checking;
   2.3. The display of a positive attitude towards rules and procedures;
3. Communication:
   3.1. Ability to listen and take the intended message out of the verbiage;
   3.2. Ability to communicate clearly and assertively;
   3.3. Willingness to share information;
4. Decision making and action;
   4.1. Ability to make effective and timely decisions;
   4.2. Possession of diagnostic and problem solving skills;
5. Cooperation and working with others:
   5.1. Considers others' needs;
   5.2. Supports others;
   5.3. Treats others with respect;
   5.4. Ability to deal with conflict or aggressive behaviour;
6. Workload management:
   6.1. Ability to multi-task and to selectively attend;
   6.2. Ability to prioritise;
   6.3. Ability to remain calm under pressure;
7. Self-management:
   7.1. Is motivated;
   7.2. Is confident and can take the initiative;
   7.3. Maintains and develops skills and knowledge;
   7.4. Is prepared and organised;
8. Fatigue management:
   8.1. Can identify symptoms of fatigue;

8.2. Recognises effects of fatigue;

8.3. Can implement coping strategies.

Source: RSSB (2012)

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Appendix 4: Degraded Operating Scenarios

Scenario	Possible cause(s) and conditions (examples)
1. The signaller authorises a driver to pass a signal at danger in connection with: 1.1. Movement to, or from, a possession; 1.2. Single Line Working; 1.3. Working of Single Line by Pilotman; 1.4. Passing section signal; 1.5. Train starting ahead of signal; 1.6. Train passing a signal that is protecting an isolation; 1.7. Defective or disconnected signal; 1.8. Failed signalling or level crossing equipment; 1.9. Examination of the line; 1.10. Providing assistance to a failed train; 1.11. Next train after removal of a failed train; 1.12. Train entering section after clearance of a runaway or a divided train; 1.13. Obstruction ahead of next *home signal*; 1.14. Train to pass signal protecting T (II) work.	 1.1. Engineer's train to enter or leave possession; 1.2. SLW is introduced because of line blockage; 1.3. As shown in Rule Book Module P2: 1.4.1. Shunting movement into forward section; 1.4.2. Finding out why next *signal box* is not open; 1.5. Train to continue in reverse direction; 1.6. Movement required towards isolation limit; 1.7. Train to pass defective or disconnected signal; 1.8. Train(s) to proceed through affected area; 1.9. Using next train to check if the line is clear; 1.10. Using next train to remove failed train; 1.11. Checking section clear; 1.12. Checking section clear; 1.13. Train to proceed into section with clearing point ahead obstructed [AB and *ETS* systems]; 1.14. To gain access to station, siding or SLW.
2. Train passes signal at danger on driver's own authority where SPT is defective at: 2.1. An automatic signal; 2.2. Any signal where the signal box is closed.	 2.1. Loss of communication with signaller; 2.2. Loss of communication with signaller.
3. Signaller authorises driver to make unsignalled movement in the wrong direction in connection with: 3.1. Movement to or from a possession; 3.2. Single Line Working; 3.3. Train overrunning platform; 3.4. Train taking a wrong route; 3.5. Line blocked by an accident, failure or obstruction; 3.6. Failed train. (See Cherryville Junction rail accident that occurred on 21.08.1983.); 3.7. Front portion of divided train setting back to rear portion; 3.8. Loco or MU proceeding around a failed train; 3.9. Shunting through ground frame points.	 3.1. Engineer's train to enter or leave possession; 3.2. SLW introduced because of line blockage; 3.3. Need for train to set back; 3.4. Need for train to set back; 3.5. Need for train to set back from or towards blocked line; 3.6. Train to set back because it cannot be driven forward; 3.7. Need to recouple divided train; 3.8. Need for assistance to reach front of failed train; 3.9. Shunting movement needs to set back through ground frame points.
4. Signaller authorises passenger train to proceed on authority of shunting signal(s). This is not considered good signalling practice and is avoided normally.	4. Unable to set route with main aspect(s) and passenger train requires to proceed
5. Signalling of trains after receipt of report of signal failures and irregularities and cautioning following trains as necessary	5. Initial report from a driver of signal failure or irregularity and following trains require to proceed
6. Actions after reports of failures and irregularities with the (C)AWS, TPWS and ATP systems	6. Initial report from a driver of a failure of the (C)AWS, TPWS or ATP systems
7. Train to proceed to an out-of-service location with the (C)AWS isolated	7. Defective on-board (C)AWS equipment (see Southall rail disaster - Case study 2)
8. Temporary Block Working	8. Extensive failure or disconnection of signalling equipment
9. Failure or disconnection of signalling equipment. (See Buttevant rail accident that occurred on 01.08.1980.)	9. Failure or disconnection of signalling equipment for maintenance or renewal
10. Manual operation of power-worked points	10. Points failure or disconnection for maintenance or renewal
11. Handsignalling duties at signals and other protection locations.	11.1. Signal failure or disconnection; 11.2. Temporary block working; 11.3. SLW; 11.4. Protection of engineering work or isolated sections.
12. Driver accompanied by a conductor driver	12. Driver not in possession of route knowledge (normally relates to a diverted train)
13. Guard accompanied by person with route knowledge	13. Guard not in possession of route knowledge (normally relates to a diverted train)
14. Use of emergency call procedure from on-board radio	14. Need to alert signaller to an emergency that is threatening the safety of trains
15. Use of emergency stop message from signaller to driver by radio	15. Need to alert driver to stop immediately
16. Speed restrictions on light locomotives and short formation trains	16. Reduced braking capability
17. Train required to stop in section	17. Engineering or freight train requirements or Officers' Special
18. Assisting locomotive at front (double heading)	18. Train load requires additional locomotive
19. Assisting locomotive at the rear	19.1. Where authorised as a regular arrangement; 19.2. In failure conditions.
20. Guard's advice to passengers when the train not fully accommodated at the platform	20.1. Train too long for platform and is not fitted with selective door enabling controls; 20.2. Driver stops train in incorrect position.
21. Permissive working: 21.1. On platform lines; 21.2. Other lines where authorised.	 21.1. To enable trains to couple up; 21.2. Local arrangements.
22. Hauling of failed traction units	22. Failure of traction unit
23. Advice to drivers and the control of trains where exceptional rail head conditions exist	23.1. Weather alert; 23.2. Leaf fall; 23.3. Contamination.
24. Emergency protection of the line by: 24.1. Person working or walking on or near the line; 24.2. Train crew.	 24.1. Person sees danger to approaching trains: 24.2. Train crew sees danger to other train(s); 24.3. Train derailed.
25. Driver sounds the 'train in distress' warning.	25. The driver cannot control the speed of train.
26. The train explodes detonators.	26. Emergency protection is placed on the line.
27. Train is stopped by *PCA* alarm	27. Passenger communicating with train crew
28. Abnormal brake application	28. Train divided or other loss of brake continuity

Scenario	Possible cause(s) and conditions (examples)
29. Defective, isolated or damaged on-train equipment	29.1. Failure or isolation of the (C)AWS, brakes or driver's vigilance device; 29.2. *Driver's reminder appliance*; 29.3. DSD; 29.4. Electronic brake system; 29.5. Power-operated doors; 29.6. Headlight; 29.7. Speedometer; 29.8. Damage to side window of passenger train; 29.9. Damage to cab windscreen; 29.10. Hot axle box.
30. Special signalling arrangements for certain mobile on- track machines and vehicles with low axle loads	30. Track circuit assistors are provided on on-track machines and DMUs that cannot be relied upon to actuate track circuits. Particular rules and procedures apply when dealing with *TCA* failure; depending on the vehicle's position within the consist.
31. Shunting movements	31.1. Where regular movements take place; 31.2. Unplanned movement.
32. Driver of train is detained at signal and is using the *NRN*[139] radio to contact signaller.	32.1. SPT defective; 32.2. Unsafe to use SPT because of limited clearance.
33. At level crossings: 33.1. Driver cautioned over (*AHB*) crossing; 33.2. Driver told to obtain green handsignal before passing over MCB[140] or AHB crossing; 33.3. Driver to stop before passing over AOCL[141] or ABCL[142] crossing where trains not normally required to stop; 33.4. Driver cautioned over occupation or accommodation crossing; 33.5. Road traffic authorised by Police Officer to pass red flashing lights.	33.1. Equipment failure; 33.2. Crossing under local control; 33.3. White flashing light not showing; 33.4. User has not advised signaller that the crossing is clear; 33.5. Failure of telephone at crossing; 33.6. Failure of equipment.
34. Train crew carry out emergency protection of line(s).	34. Train is stopped by accident, fire or accidental division.
35. Train crew carry out assistance protection.	35. Failed train requires assistance.
36. Single Line Working by Pilotman	36. One line of a double line is blocked by: 36.1. Engineering work; 36.2. Obstruction.
37. Working of Single Line by Pilotman	37. The circumstances are listed in the rule book.
38. Blockage of the line for engineering work under Rule T2	38. Engineering work not requiring use of engineer's trains
39. Blockage of the line for engineering work under Rule T3	39. Engineering work which may require the use of engineer's trains
40. Blockage of siding for engineering work under Rule T3A	40. Engineering work in a siding which requires the stoppage of all train movements
41. Imposition of temporary speed restriction	41. Condition of track or track renewal
42. Imposition of *emergency speed restriction*	42. A temporary speed restriction which is not shown (or not correctly shown) in the Weekly Operating Notice
43. Passing trains over a broken rail	43. Broken rail
44. Passing trains over or under damaged bridges	44. Bridge strike
45. Trains running in severe adverse weather	45. Snow, flood or fog
46. Switching off electric traction current in emergency	46.1. Derailment; 46.2. Fire; 46.3. Person in contact with OLE or conductor rail; 46.4. Damaged OLE or conductor rail; 46.5. Accident.
47. Signaller is signalling trains by bell code or telephone at a TCB box.	47. Unable to use train describers
48. Signaller needs to stop trains in an emergency.	48. Obstruction of the line
49. Signaller requires train to be stopped and examined.	49. Visible defect with train, e.g., door open, hot axle box or fire
50. Signaller needs to deal with a train proceeding without authority.	50. Train running away (includes a SPAD)
51. Signaller needs to establish why the train is delayed in section.	51.1. Train failure; 51.2. Accident; 51.3. No communication from driver.
52. Signaller needs to establish why the train is proceeding without *tail lamps*.	52.1. Tail lamp extinguished; 52.2. Train divided.
53. Signaller requires the line to be examined.	53. Following a previous incident: 53.1. Report of defect; 53.2. Track circuit failure.
54. Signaller needs to admit an assisting train into the section.	54. Failed train
55. Failure of individual track circuit	55.1. Rail defect; 55.2. Signalling equipment defect.
56. Failure of a group of track circuits	56.1. Rail defect; 56.2. Signalling equipment defect.
57. Power failure of the main supply only; the standby system is working	57. Public supply failure
58. Power failure of both the main and standby systems	58.1. Public supply failure; 58.2. Poor maintenance of the uninterruptable power supply.
59. Interlocking remote control failure (but duplicate system working)	
60. Interlocking remote control failure (main transmission path failed but standby path working)	
61. Interlocking remote control failure (but ability to set one route at a time remaining)	
62. Interlocking remote control failure (but ability to set 'through routes' remaining)	
63. Interlocking remote control failure (interlocking not under control)	
64. Signal lamp first filament failure	
65. Signal lamp out but 'lamp or controls' applied	

[139] The NRN is an old British system. It operates on open channel principles and does not provide discrete communications between the transmitter and receiver.
[140] Manually controlled barrier
[141] On an automatic open crossing, there are no physical barriers. The road traffic signals are monitored by the train driver.
[142] Automatic barrier crossing whose operation is monitored by the train driver, i.e., he ensures that the barriers have lowered before he proceeds.

Scenario	Possible cause(s) and conditions (examples)
66. Signal lamp out; signal *in rear* held at red	
67. Loss of points *detection*	67.1. Track geometry out of specification; 67.2. Signalling equipment defect.
68. Loss of points operation	68.1. Track geometry out of specification; 68.2. Signalling equipment defect.
69. The driver is cautioned over CCTV level crossing where the CCTV feature has failed and an attendant has not taken control.	
70. Failure of a trainborne signalling subsystem. For example: 70.1. CAWS or AWS; 70.2. TPWS; 70.3. ATP System; 70.4. European Rail Traffic Management System.	70.1. Trainborne equipment hardware or software fault; 70.2. Track based equipment failure; 70.3. Incorrect data programmed into the subsystem.
71. Failure of tilt or tilt authorisation and speed supervision (TASS) system	71.1. Evident System Faults: 71.2. Trainborne equipment hardware or software fault; 71.3. Track based equipment failure.
72. Hidden system faults	72. Incorrect data programmed into subsystem
73. Failure of the automatic brake	73.1. WSP system fault; 73.2. Brake module fault; 73.3. Brake pipe failure.
74. Loss of brake continuity	74.1. Train divides unintentionally; 74.2. Brake pipe ruptured or lost; 74.3. Control system fault.
75. Failure of an external door	75.1. Door not correctly closed; 75.2. Door control system fails to prove that door is correctly closed; 75.3. Central door locking system failure; 75.4. Selective door operation system failure; 75.5. Door control system failure, e.g., traction interlock and/or door interlock.
76. Failure of the driver's reminder appliance	76. Equipment fault
77. Failure of vigilance or driver's safety device	77. Equipment fault
78. Broken or obscured windscreen	78.1. Vandalism; 78.2. Windscreen wiper failure; 78.3. Windscreen washer failure.
79. Fire detection and/or fire extinguishing system failure	79.1. Equipment fault; 79.2. Fire extinguisher bottle pressure low or bottle empty.
80. Headlamp failure	80.1. Bulb failure; 80.2. Battery discharged.
81. Tail light failure	81.1. Bulb failure; 81.2. Battery discharged.
82. The hot axle box detector (HABD) activates.	82.1. Axle box running hot due to inadequate maintenance; 82.2. Trainborne HABD system failure; 82.3. Trackside HABD system failure.
83. Locked wheels, damaged tread or slipped tyre	83.1. WSP system failure; 83.2. Brake system failure; 83.3. Poor adhesion.
84. NRN or *CSR* failure	84.1. Equipment fault; 84.2. Inadequate radio coverage.
85. *On-train monitoring recorder (OTMR)*	85. Equipment fault
86. Sanders inoperative	86.1. Equipment fault; 86.2. No sand supply in the reservoir.
87. Speedometer inaccurate or inoperative	87. Equipment fault
88. Track circuit assistor ineffective	88. Equipment fault
89. Horn inoperative	89. Equipment fault
90. Partial loss of engines or traction drives	90. Equipment fault
91. Complete loss of brakes	91.1. Equipment fault; 91.2. Loss of supply to electric trains.
92. Defective cab heater or air conditioning system	92. Equipment fault
93. Bodyside saloon window broken	93. Vandalism
94. Loss of saloon heating AC lighting	94. Equipment fault
95. Buffer or coupling failure	95.1. Component failure; 95.2. Couplers not correctly engaged.
96. Pantograph drops or fails	96.1. Overhead line fault damages pantograph head; 96.2. Automatic drop device operates incorrectly; 96.3. Excessively worn pantograph carbons.
97. Monitor operation of interference current monitoring unit (ICMU) to ensure that the 50 Hz component of the traction return current does not interfere with the 50 Hz track circuit and result in a wrong side failure. A circuit breaker opens at currents of 0·5A at 50 Hz and cuts traction power.	97. Equipment fault
98. Automatic power control (APC) system failure	98. Equipment fault
99. Gapped train requires recovery	99.1. Technical defect; 99.2. Driver fault.
100. Loss of auxiliary power	100. Loss of energy source (diesel engine, electrification supply, auxiliary supply equipment)
101. Fire	101.1. Electrical fault; 101.2. Diesel engine fault; 101.3. Vandalism.
102. Suspension failure	102.1. Component failure 102.2. Inadequate maintenance
103. Item or equipment on train out of gauge	103.1. Train incorrectly routed; 103.2. Component failure leads to equipment detaching from train, e.g., traction motor or cardan shaft; 103.3. External door open when leaving station; 103.4. External door opens in traffic; 103.5. Freight wagon has shed its load.

Scenario	Possible cause(s) and conditions (examples)
104.Earth faults	104.1. Cable fault; 104.2. Equipment fault; 104.3. OHL failure and/or vandalism.
105.Excessive axle forces damage rail, bridges or other structures.	105.1. Suspension failure; 105.2. Incorrect train routing (with respect to the route availability number); 105.3. Train carrying an excessive load relative to load restrictions imposed on bridges.
106.Passenger communication is inoperative.	106. Component failure
107.Public address system is inoperative.	107. Component failure
108.Driver to guard signal buzzer is inoperative.	108. Component failure
109.Bodyside light(s) fail.	109. Component failure
110.Passenger saloon lighting is inadequate.	110.1. Component failure; 110.2. Power supply fault.
111.Traction interlock switch fails.	111. Component failure

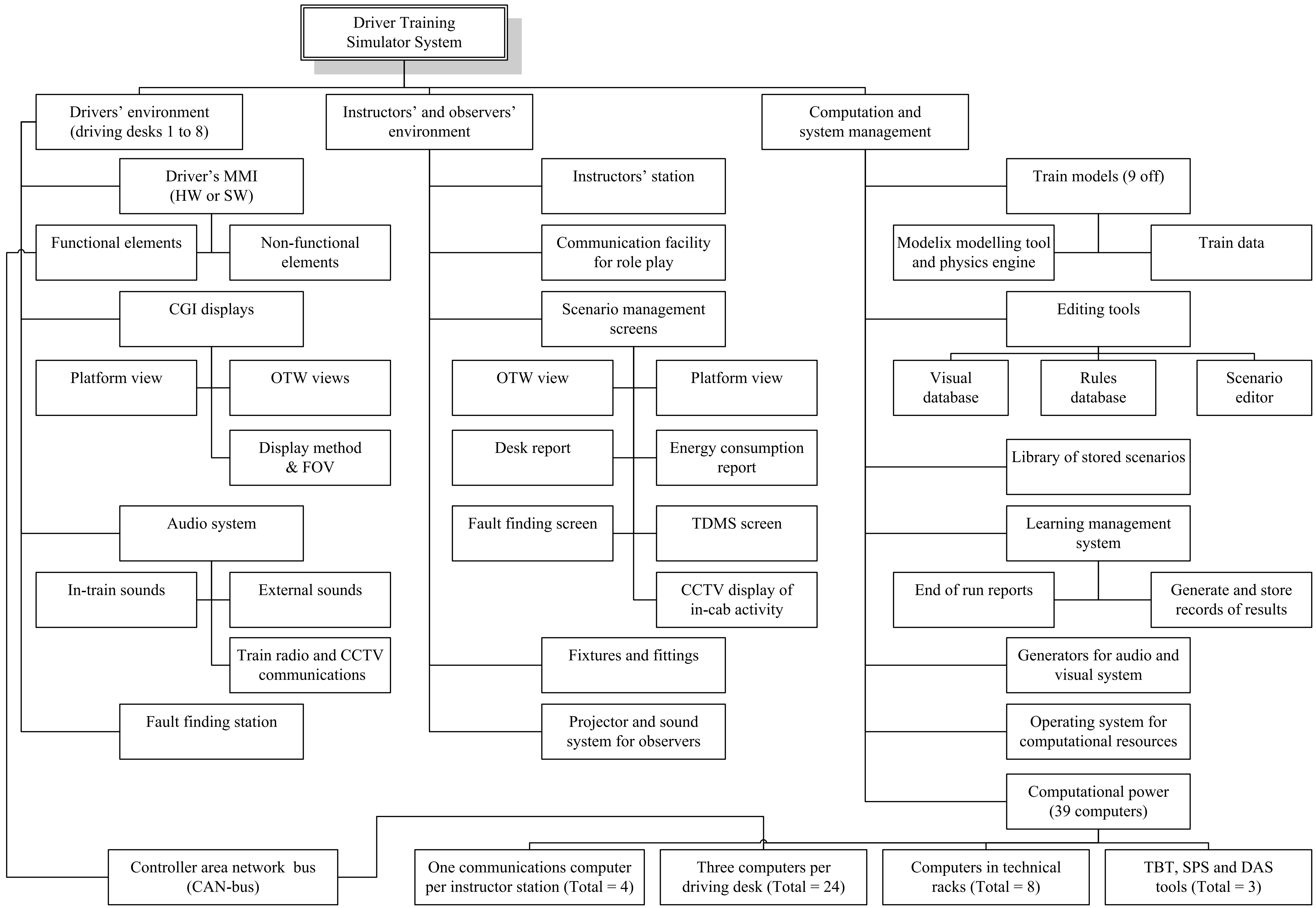
Adapted from: Hughes (2004)

Appendix 5: Assessment of Simulators for Incremental Transfer Learning

Stage of *incremental transfer learning*	Traditional instructional techniques	Strengths of a simulator as a training tool at this stage of development	Weakness of simulator at this stage of development	Cost considerations
Knowledgeable: transfer of prior learning to the skill domain	Self directed, or instructor-led learning, using written multimedia materials and, possibly, static real equipment	Simulators do not add commensurate value to this stage of the learning process; *CBT* or *CAI* is appropriate.		Providing opportunity to practice contextually on a wide range of tasks in the real world requires extensive periods of training. However, this requisite determines the functionality and capital cost of a simulator.
Prepared: formation of mental models	Instructor-led demonstrations dealing with cognitive and psychomotor aspects using classroom and real equipment	Simulators can be used to provide expert demonstrations and visualisations to support rule-based training.	Poor visualisation capability of a system may lead to the development of inappropriate mental models. Each trainee needs in-seat time.	
Trained: initial skill practice	Instructor-guided practice on a real traction unit. Operation is confined to driving within a confined area, or operating out-of-service trains on the mainline under instructor guidance.	They can be used to provide supervised learning with the provision of feedback from trainers and peers, and through self discovery. Depending on the scope of the system, greater opportunity may be provided to gain experience as only one training train is deployed typically.	Accurate modelling of the traction units and routes is essential. Incorrect modelling may lead to negative transfer, i.e., the development of inappropriate skills.	
Skilled: near transfer	Under the tutelage of mentor drivers, trainees gain independent practice by driving in-service trains on the mainline. In these cases, mentor drivers perform two roles, i.e., driving and mentoring, thereby creating a risk of divided attention.	Using a simulator that has full fidelity with the type of traction that will be operated in the real world, a full range of supported learning experiences can be provided. A wide range of performance parameters can be monitored and assessed to provide feedback for remediation. NTSs can be developed in training scenarios.	Instructors must be competent in the use of behavioural marker techniques. Most simulators cannot provide the psychological fidelity of real operations.	
Expert: *far transfer*	Trainees get independent practice by operating solo on the mainline. They review their own performance but are subjected to a series of periodic assessments; the frequency decreasing with experience accumulation.	A simulator can be used to provide knowledge-based training in contrived environments. A wide range of scenarios and contexts, including emergency and crisis conditions, can be implemented.	Simulator based training is provided during relatively short periods in the overall training programme. More practice is achievable, albeit over a smaller range of naturally occurring tasks, in the real world.	

Based on: Wallace *et al*. (2005)

Appendix 6: Functional Block Diagram of Simulator System: integration of the subsystems



Hierarchy and Functionality of Simulator System's Computers

Thirty nine computers are used to operate the system which extends to eight driving desks deployed at two locations. These are deployed as shown below.

Location	Master location: Inchicore (30 computers)			Slave location: Mallow (9 computers)	Total computers (39)
Type of desks	Locomotive	DMU	EMU	DMU	
Number of desks (computers)	2 (three in each desk)	2 (three in each desk)	2 (three in each desk)	2 (three in each desk)	24 computers in 8 desks
Number of technical racks	1		1	1	3
Type of technical rack	Locomotive and DMU computers are combined in a 4 channel rack		Separate 2 channel rack	Separate 2 channel rack	8 computers in 3 racks
Instructor stations (to manage communications)	This is a dual instructor workstation. It incorporates 2 computers (one in each user's MMI).		1 (one computer in user's MMI)	1 (one computer in user's MMI)	4 (one computer in each user's MMI)
Users' tools	Scenario preparation station (SPS)	Track building tool (TBT)	Data administr-ation station (DAS)	SPS, TBT ™ and DAS outputs are deployed by internet	(3 computers for user's tools)

An instructor station for each driving desk is located in the technical rack. All of the data are physically stored in this location. The device on the instructor's desk is merely an interface with the *IS*. The train models and line data are stored on the hard drive of the IS computer. There are three computers located within each driving desk:

1. The 3D computer imports data from the IS and renders it for presentation to the operator in the OTW views;
2. A control computer manages the simulator desk activity. A CAN-bus is used to manage the data flows from all of the input devices to the control computer and to manage the outputs back to the displays, sound matrix and desk illuminations etc. The control computer uses the data that are stored on the hard drive of the IS computer. It computes the train model files to create the physical behaviours;
3. The VCR manipulates the data that are located in the hard drive of the IS computer and the line data to generate the platform views. It records the CCTV footage of the operator's activity in the booth also.

The performance of each operator can be stored on the *DAS* and a report can be burned onto a DVD. If this option is not exercised, the video of operator performance is lost.

The CAN-bus deserves special mention because of the critical role it plays in the information exchange between the simulator artefacts. It is an input/output device that facilitates the communication of vast amounts of information between the subsystems. The train model receives inputs from the driver's controls and from the instructor station[143]. In turn, the CAN-bus sends outputs to the cab indicators and artefacts. It drives the vision and sound systems to create the impression of movement. The inputs are either in digital or in analogue format; the latter are converted into digital approximations. Outputs are in digital format; they are what the driver sees, hears or feels. The rate of information transfer is determined by the length of the bus. A bus of 40 metres long can accommodate a transfer rate of 1 Mbit/second. For this reason, the IS must be accommodated adjacent to the driving desks in the training facility. As simulators are not safety critical pieces of equipment, information on the CAN-bus is not accompanied by a cyclic redundancy check to verify accuracy.

[143] The *controller area network* also receives inputs from other devices. Some of these devices are implemented through touch screens, i.e., fault finding, air pressure gauges, CAWS and door test buttons etc., using the Swing Process ™.

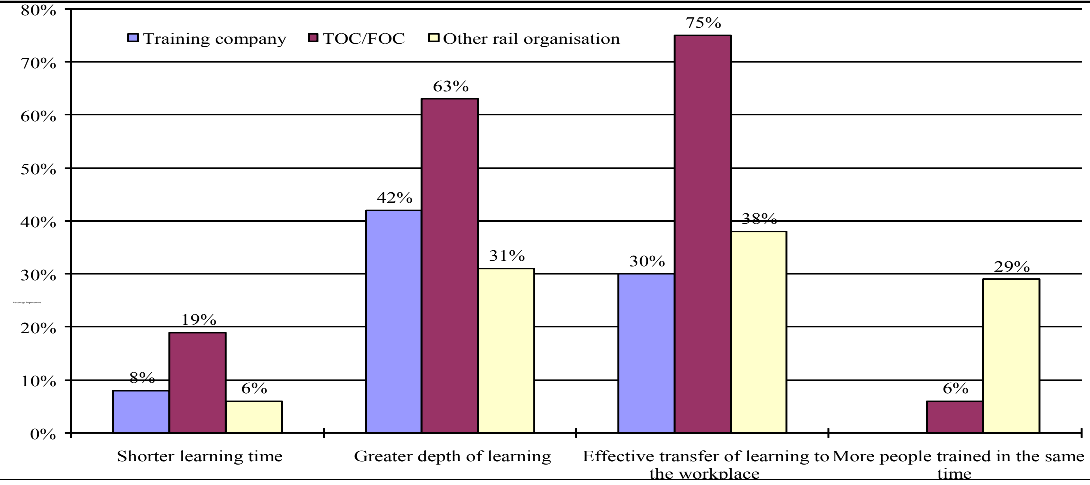
Appendix 7: Observer Station and Dynamic Desk Report

The observer stations are located adjacent to the simulator booths (booth doors are on the RHS in the photograph). The photograph shows the simulator repeat screen on the rear wall (illuminated for illustrative purposes only), while the instructor makes a presentation using a SMART Board ™ interactive whiteboard on the RHS. Training content is previewed using the whiteboard, applied in the simulator, and reviewed using the repeat panel. This layout fosters collaborative learning.

The dynamic desk report, shown below, represents the main artefacts on the driving desk. The desk elements repeat the readings on the instruments, and the control and switch positions in real time. They are presented, in one of the available displays, to the trainees in the observation station who are monitoring the actions of the simulator operators. The range of available views is presented in Appendix 6. Observers critique the driving style of the simulator operators by assessing the speed of approach to a station, the response to abnormal displays in the CAWS ADU, or the use of the traction or brake controls etc.


EMERGENCY BRAKE ELECTRICAL
PRESSURE GAUGE (BC/BP)
PRESSURE GAUGE (MR)
km/h
m.p.h.
BUZZER
DEPARTURE TEST CARRIER
DIMMER
RED DISABLE
CAWS ACKNOWLEDGE
CARRIER
CAB BUZZER
LEFT DOOR ENABLE
LEFT DOOR CLOSE
ALARM CUT-OUT
HORN
LOW
HIGH
MARKER/TAIL LIGHT SHUT DOWN
HEAD LAMP
OFF
DIM
HIGH
F
N
R
OFF
ON
UNCOUPLING
HATCH CLOSE
HATCH OPEN
RUN
EM
RIGHT DOOR ENABLE
DOOR INTERLOCK
PASS BRAKE
OVERIDE
PA
IC
EC
RS
ENGINE START T/L
BATTERY T/L
ON
OFF
SALOON LIGHT T/L
GENERAL WARNING
EMERGENCY BRAKE RESET
EMERGENCY BRAKE PNEUMATIC
DSD PEDAL
CLASS 22000
CAB HVAC MODE
COOL
VENT
OFF
HEAT
CAB AIRCON
WIPER
SALOON HVAC
FOOT WARMER
RIGHT DOOR CLOSE
DOOR TEST

Appendix 8: General Findings on the Effectiveness of Simulator Enabled Training for Traction Drivers

<table>
<tr><th>Researchers</th><th>Type of study, domain and skill type</th><th>Study design</th><th>Main findings and conclusions</th><th>Does the study's findings support the use of simulators?</th></tr>
<tr><td>Rushby and Seabrook (2007)</td><td>A desktop study based on the beliefs of training managers;</td><td>The researchers reviewed the experiences of 24 simulator users in the rail sector (6 training companies, 12 TOCs/FOCs and 6 other types of rail organisations). The participants were asked to evaluate the extent of improvement that they experienced across four commonly accepted improvement areas.
The readers' attention is specifically drawn to the significant degree which simulator training is seen to facilitate learning transfer between the classroom and the workplace.</td><td>
</td><td>Yes</td></tr>
<tr><td>Hawthorne (2006)</td><td>An assessment of learning</td><td>The Norfolk Southern Corporation evaluated (a level 2 evaluation) the improvement in trainees' knowledge achieved through simulator usage.</td><td>An average improvement of 5% in the assessment scores of trainee drivers has been achieved, i.e., an increase from 83% to 88%.</td><td>Yes</td></tr>
<tr><td>Russell (2006)</td><td>Attitudinal study</td><td>Russell conducted an attitudinal study (a level 1 evaluation) (N = 54 drivers) to determine the operators' perceptions of simulators.</td><td><table>
<tr><th>Satisfaction statements ↓</th><th>Number (%) in agreement</th></tr>
<tr><td>The equipment was easy to use.</td><td>46 (85%)</td></tr>
<tr><td>The training experience was enjoyable.</td><td>52 (96%)</td></tr>
<tr><td>I am happy to use it again in the future.</td><td>54 (100%)</td></tr>
<tr><td>The tool supported their learning[144]</td><td>52 (96%)</td></tr>
</table></td><td>Yes</td></tr>
<tr><td>Eichinger and Geraghty (2004)</td><td>A longitudinal study of improvement in psychomotor skills</td><td>Eichinger and Geraghty conducted a level 3 evaluation of a simulator's effectiveness to train drivers in the management of in-train forces. The company (Mackay Sugar) trained 200 drivers on a simulator that was owned by Queensland Rail. It had low physical and functional fidelity relative to Mackay's operation. The simulator did not replicate the terrain, the train models or the driver's desk. Some minor software modifications were made to the simulator's train model to match the performance characteristics of the sugar train better.</td><td>The immediate reduction in major dynamic induced derailments from 10 to 1 per year was attributed wholly to simulator based training.
Although early success was achieved using Queensland Rail's simulator, the most common request from drivers was for a simulation that was based on their (Mackay's) trains and their operating environment. In addition, Mackay's investment in professional driver training sent meta messages to the drivers.</td><td>Yes</td></tr>
<tr><td>Greufe (2004)</td><td>A longitudinal study of safety performance</td><td>Greufe presents the findings of a level 3 evaluation and highlights the success in the reduction of operational incidents at Houston Metro since the introduction of simulation in 2002.</td><td>Houston Metro experienced a 15% drop in accidents overall in 2002; followed by a further drop of 10% in 2003 and another drop of 8% up to June 2004.
Remedial training for existing drivers reduced accident rates by 34%.</td><td>Yes</td></tr>
<tr><td>Naef (2002)</td><td>A quality assurance audit</td><td>Naef describes the efforts that were made by DBAG to improve continuously the quality of its driver training programme, and to implement a quality assurance process by measuring the performance of 24,500 drivers in 15 simulators.</td><td>The drivers "... achieved a great improvement in terms of quality and effectiveness of training and checking" (p.4). Naef received very positive feedback from the drivers who reported that "... [historically] instructors out on real locomotives were not consistently telling them the same things; whereas simulator instructors achieved highest scores in correspondence... [simulator instructors] were highly appreciated as being professionals, trustworthy and informative" (p.12).</td><td>Yes</td></tr>
<tr><td>Bowey et al. (2001)</td><td>A longitudinal study of improvement in psychomotor skills</td><td>The researchers conducted a study of unintentional train divides at BHP Iron Ore railroad in Australia. The solution included an enhanced maintenance regime and engineering modifications. Drivers received simulator training on the management of the power and brake controllers. Training provided guidance on which individual locomotive, of the four in the consist, should be braked dynamically and taken off load, and which locomotive should be developing low power as the train traversed the undulating terrain.</td><td><table>
<tr><th>Damage after train divide</th><th>1994 to 1995</th><th>1999 to 2000</th><th>Improvement attributable to:</th></tr>
<tr><td>The coupler was not damaged</td><td>107</td><td>3</td><td>Modifications to the coupler</td></tr>
<tr><td>Broken coupler</td><td>43</td><td>23</td><td>Improved driving practices</td></tr>
<tr><td>Damaged air hoses (main reservoir and brake pipe)</td><td>86</td><td>2</td><td>Combination of improved coupler design and driving practice</td></tr>
</table></td><td>Yes</td></tr>
<tr><td>Southeastern (undated)</td><td>A study of precursors</td><td>Southeastern report the findings of a level 1 and level 3 evaluations of the operational performance of 994 train drivers.</td><td>Southeastern achieved a reduction in SPADs in 2002/03, and a 35% improvement in safety critical communication partly to simulator usage. In addition, operator satisfaction was rated at over 85%.</td><td>Yes</td></tr>
</table>

[144] This disclosure is supported by the responses that Atkins *et al*. (2005) received in their study; 84% of traction drivers reported that the use of interactive simulation supported them in their role.

Appendix 9: Findings in Relation to Training Energy Efficient Driving Techniques (eco-driving)

<table>
<tr><th>Researcher(s)</th><th>Study design</th><th>Main findings and conclusions</th></tr>
<tr><td>RSSB (2011a)</td><td colspan="2">In this comprehensive and diverse study, the energy consumption of four UK operating companies, in respect of 5 diesel and 2 electric train types, travelling over 15 routes was analysed by the researchers. The potential energy savings identified were between 1% and 12·3% (mean saving of 4·4%) for diesel traction. In the case of electric traction, the energy reductions were between 0·6 and 15·4% over one route (mean saving of 5·2%) and between 0·3% and 6·3% over another route (mean saving of 2·3%). The general conclusion is that "... potential savings of between 1% and 10% could be obtained" (p.103). However, none of the companies installed meters to measure actual energy usage. The analysis was based on estimates derived from a combination of data downloaded from the on-train monitoring and recording facility (showing time spent in each power notch) which was integrated with engine data sheets and engineering calculations.</td></tr>
<tr><td>European Commission (2010)</td><td>The authors undertook a three year long longitudinal study in Greece, Slovenia, Italy, Netherlands and Slovakia. The results of a desktop analysis are presented in the case of the Slovakian railway company ZSSK Cargo; empirical studies were conducted in the other jurisdictions.</td><td>ZSSK CARGO (Slovakia) report an estimated improvement of 0·1% following the delivery of a two hour theoretical training programme to its 1,800 drivers.
Trenitalia (Italy) achieved a 3% reduction in energy consumption on the Milan - Verona route as a result of the provision of simulator enabled training, practical train handling and lectures.
Slovenske Zeleznice (Slovenia) achieved reductions in energy consumption of 10%, 8% and 5% in respect of local, regional and high speed services as a result of the provision of simulator enabled training (using desk type simulators) and conventional lectures.
NS Reizigers (Netherlands) achieved a 30% reduction in energy consumption on The Hague – Venlo route as a result of the provision of simulator enabled training (using full scope simulators) and conventional lectures.
OSE (Greece) achieved reductions in energy consumption of 47% and 35% on the Athens-El. Venizelos airport route. Conventional training, seminar attendance and practical training on operational trains, was delivered to 600 drivers. Training was not the only enabler of this achievement; operational changes were also made. If travel time was increased by 11%, a saving of 47% in electricity consumption was made; if train speed was reduced by 10%, a saving of 35% in electricity consumption was made.</td></tr>
<tr><td>Union Pacific (2006).</td><td>In 2005, UP introduced its successful Fuel Master Programme with the intention of conserving fuel. Train drivers (N = ca. 6,500) receive financial incentives, in addition to simulator training and counselling by mentor drivers, to conserve fuel.</td><td>For FY 2005, the programme saved more than 16 million gallons of diesel and $30 million for UP. Improvements of up to 6% were achieved on specific trips.</td></tr>
<tr><td>CER (2004)</td><td>The Energie Sparen project was introduced in October 2002 by DBAG. The aim of the project was to reduce traction energy consumption by 10% through the adoption of energy efficient driving practices. In the period between October 2002 and November 2004, 14,000 DBAG drivers partook in the training initiative. The programme commenced with a four-hour theoretical lesson on energy the driving techniques. This was followed by one hour of simulator training and subsequently by one hour of practical on-train training and coaching by the trainees' line managers.</td><td>Initial measurements reveal a saving of over €8 million. It is anticipated that the provision of ongoing information and advice will result in full achievement of the goal of a 10% energy saving.</td></tr>
<tr><td>Doucouliagos and Sgro (2000)</td><td>Subjects (N = 60 drivers) from Queensland Rail attended a simulator enabled, 3 day 'Train Dynamics Concept Development' course. It addressed the topics of train running times, fuel consumption, and draft and buff forces. The researchers conducted pre training and post training evaluations of performance on these criteria which enabled them to perform a cost – benefit analysis subsequently.</td><td><table><tr><th>Performance measure</th><th>Pre-training average score</th><th>Post training average score</th><th>Change (%)</th></tr><tr><td>Time</td><td>35·69</td><td>35·75</td><td>+0·17</td></tr><tr><td>Fuel usage (raw)</td><td>132·44</td><td>126·84</td><td>-4·42</td></tr><tr><td>Fuel per load usage</td><td>0·19</td><td>0·178</td><td>-6·42</td></tr><tr><td>Draft forces</td><td>104·78</td><td>71·03</td><td>-47·52</td></tr><tr><td>Buff forces</td><td>119·94</td><td>99·41</td><td>-20·65</td></tr></table>"The training program involved the use of a simulator which has proven to be an effective medium for on-the-job training... the estimated benefit - cost ratio was 130 per cent and the estimated minimum ROI was 30 per cent" (pp.42-43).</td></tr>
</table>

Appendix 10: Typical Operating Scenarios to be Simulated

Appendix 4 provides readers with an understanding of the number of different ways that the railway system can degrade and the types of emergencies that can arise in the operating core. Operators must be trained to respond to these events. Additionally, there is a range of normal operating conditions that cannot be trained adequately during line operations.

Normal operating scenarios

Number	Description of scenario	Other comment
N 1	Spatial perception/judgmental training, e.g., stopping the train with precision	Due to technical limitations, the perception of speed is poor in a simulator. This disparity can be reduced by manipulating the operator's eye point.
N 2	Defensive driving policy guidelines	
N 3	Correct accelerating and decelerating techniques	
N 3.1	Passenger comfort and service (smooth acceleration/deceleration and proper passenger announcements into saloon)	
N 3.2	Efficient energy usage	Using the eco-driving feature of the simulator
N 4	SPAD risks – using actual material from I.É.'s SPAD awareness programme	Complete range of types, e.g., SASPaD, SOYSPaD, entering/exiting possession
N 5	Shunting risks	
N 6	Electric *token* system (ETS), *Absolute Block*, *Track Circuit Block*, bi-directional and reversible working operation	Lines worked under ETS and Absolute Block principles were not modelled because of systems' obsolescence.
N 7	Efficient train operation	
N 7.1	Efficient energy usage	
N 7.2	Minimisation of wear and tear on rolling stock and infrastructure	Trainees are encouraged to drive sympathetically. Peer and instructor observations of the dynamic desk report in the observer station form the basis for a critique of driving style.
N 7.3	Better adherence to the train running schedule (on time or minutes late)	Simulated run using actual timings
N 8	Shorter time to diagnose and rectify faults.	
N 9	Trains running beside one another (3 roads reversibly signalled or quadruple main line) with interactive traffic	
N 10	Starting train	
N 10.1	Train rolling back on a gradient – purpose and effect of holding brake	
N 10.2	Doors open	Using the traction interlock as an engineering safeguard to prevent accidents at the platform/train interface

Number	Description of scenario	Other comment
N 10.3	Look back feature with passenger trapped in the doors of the train	Passenger entrapment is presented (through failure to restore 'blue light' and unavailability of traction and OTW cues) within the simulation as a door obstruction
N 10.4	Door operation	Dwell time management
N 10.5	Making an emergency stop after starting the train, on receipt of a hand danger signal from platform staff	
N 11	Driving onto a dead-end platform when WSP activated	
N 12	Non-verbal messages (aural, tactile and visual cues)	
N 13	Passing rear of train on opposite line with a trespasser on the line immediately behind it	Achieved through the use of the CSD facility
N 14	Road traffic lights competing for attention against railway signals (field dependence)	Can be implemented more realistically in simulators using MATRIX ™ software. May also be implemented using the TBT ™ to develop a fictitious section of line
N 15	Optimising control skills, accelerating, decelerating (minimisation of jerk rate) and coasting	Use simulator, end of run report (the *train performance display*)
N 16	Preventing train division	
N 17	Maintaining sectional running – linked to WTT or running/shed notices	
N 18	Use of cab controls	
N 19	Systems' checks	
N 20	Carry out brake test	In conjunction with another crew member or platform staff
N 21	Person on line (permanent way/member of public with flag)	
N 22	Animals/person on line (trespasser)	
N 23	Prolonged *wheel slip*/slide illumination (aural tone from the engine is out of synchronisation with the line speed and indications are illuminated)	
N 24	Loss of main reservoir and brake pipe pressures	
N 25	Loss of "blue light" in running (visual display of door integrity)	
N 26	Passenger communication applied (emergency brake or audible tone)	
N 27	Air usage because of repeated application (correct braking techniques)	
N 28	Train radio telegrams (to measure the speed and accuracy response of drivers to emergency calls)	
N 29	Working in tunnels	
N 30	Logic of interaction between track and train (effect of running through points and crossings at excessive speed	
N 31	Penalty brake applications	

Number	Description of scenario	Other comment
N 32	Failure of speedometer – (provide drivers with an intuitive sense of speed without reference to instrumentation). The instructor must be made aware of the actual speed of the movement	
N 33	Display of signals from signal box/permanent way personnel (normal and emergency)	
N 34	Routing through a complex junction	
N 35	Setting up the passenger information system while a signaller call comes through on the train radio, all this occurring close to a signal displaying a danger aspect	
N 36	Working in tunnels, the noise and deterioration in lighting conditions must adjust automatically to this location feature	
N 37	Approach to *automatic half barriers* (AHBs) while cars are driving around lowered barriers	

Degraded operating scenarios

Number	Description of scenario	Other comment
D 1	Traction equipment faulted. Range of equipment faults of different traction-specific faults. This includes fault-manifestation, fault effects, and a fault finding menu	Training in fault rectification can be achieved using the fault finding panel in the simulator or on an emulator
D 2	Signal failure and authorised passing signals at danger	
D 3	Driving in conditions of poor visibility and poor adhesion	
D 4	Lineside fires, fog/adverse weather/night driving, glare from sun	
D 5	Abnormal downgrade/upgrade on CAWS	
D 6	Runaway train/out-of-control sensation (demonstrating the effect of the *wheel slide protection* system on stopping distance)	
D 7	Explosion of detonators on line with and without trackside personnel present (to check for drivers' response)	
D 8	Brakes dragging on train (to gauge the tactile response)	Not in delivered scope
D 9	Faulty CAWS, deadmans, vigilance (to test rule compliance)	
D 10	By-pass of traction interlock	
D 11	Temporary block working	
D 12	CAWS – audible and visual outputs, failure/abnormal display –defects & reasons for isolation	
D 13	SCE – audible outputs, failure – defects & reasons for isolation	

Number	Description of scenario	Other comment
D 14	SLW and *WSLP*	The simulator is ideal for joint training interventions with the pilotman, driver and signalman
D 15	Failure of wipers/horn/headlights	
D 16	TCA failure	
D 17	Running signal not visible from usual sighting distance due to lineside vegetation	
D 18	Entering and exiting possessions	

Emergency operating scenarios

Number	Description of scenario	Other comment
E 1	Obstruction on line, e.g., car on crossing, fallen tree, animal on line	Use simulator and CSD
E 2	Opposite line obstructed	Use simulator and CSD
E 3	Signal reversions (Category B SPAD)	
E 4	Lineside and CAWS aspect displays out of correspondence	
E 5	Broken couplings/unintentional divide	
E 6	Collision	
E 7	Emergency handsignal responses	Use simulator and CSD
E 8	Points incorrectly set - shunting operation	
E 9	Fire on train – message from on-board fire system	
E 10	Observation of the passage of a train on the opposite line that has a notifiable defect, such as, fire on train, open door etc.	Use simulator and CSD
E 11	Emergency stop signal delivered from a passing train	
E 12	Person acting suspiciously on or near the line	
E 13	Operation of *hot box detector*	
E 14	Buffer lock	Not in delivered scope
E 15	Incorrect routing	
E 16	Assisting a failed train (passing signal at danger, going to protection point and thence to failed train)	Use simulator. The assistance process is achieved from the perspective of the assisting train only. (Movements to assist can take place in both directions.)

Appendix 11: Percentage of all SPADs by Error Type (1995 - 2003)

	1996/'97	1997/'98	1998/'99	1999/'00	2000/'01	2001/'02	2002/'03	Average	Type of error (based on SA model)
Anticipation of signal clearance	5%	6%	6%	5%	5%	5%	5%	5·29%	Projection
Failure to check signal aspect	18%	18%	17%	20%	16%	20%	17%	18·00%	Perception
Failure to locate signal	10%	7%	9%	8%	12%	12%	7%	9·29%	Perception
Failure to react to caution signal	20%	25%	24%	27%	27%	25%	15%	23·29%	Action
Ignorance of rules or instructions	1%	1%	2%	1%	3%	0%	1%	1·29%	Comprehension
Violation of rules or instructions	5%	4%	6%	7%	8%	7%	5%	6·00%	Model does not apply
Wrong information given	2%	2%	2%	1%	2%	3%	1%	1·86%	Perception (communication)
Ambiguous or incomplete information given	2%	1%	1%	3%	3%	1%	3%	2·00%	Perception (communication)
Information not given	0%	0%	0%	0%	1%	0%	0%	0·14%	Perception (communication)
Correct information given but was misunderstood	1%	1%	1%	1%	1%	2%	1%	1·14%	Perception (communication)
Viewed wrong signal	7%	5%	6%	5%	5%	8%	5%	5·86%	Perception/comprehension
Viewed correct signal but misread aspect	2%	2%	2%	5%	3%	3%	3%	2·86%	Perception/comprehension
Misread previous signal	1%	1%	2%	1%	1%	2%	0%	1·14%	Perception
Misjudged train behaviour	8%	8%	7%	5%	3%	3%	3%	5·29%	Comprehension/decision making
Misjudged environmental conditions	8%	7%	7%	5%	4%	3%	3%	5·29%	Comprehension/decision making
Other reason	5%	6%	3%	4%	2%	1%	0%	3·00%	
Equipment or environment (not the driver)	6%	3%	4%	3%	3%	3%	2%	3·43%	External factors
Not yet categorised	1%	3%	1%	0%	0%	1%	26%	4·57%	

Based on: RSSB (2003)

Appendix 12: Findings in Relation to Usage Patterns, and Acceptance for Training and Assessing Traction Drivers

Researcher(s)	Does simulation and CBT satisfy the requirements of regulatory authorities, industry lead bodies and internal processes?
Schmitz and Maag (2008)	Trenitalia permits the substitution of a simulator drive for one of the quarterly real cab rides that it uses to assess the competence of its mainline and regional drivers.
Hawthorne (2006)	The American Federal Railroad Administration (FRA) accepts simulator certification for driver competence if it (a) uses the same control panel as the locomotive that the driver operates; (b) provides a graphic representation of the forward view from the locomotive; and (c) generates sound.
Endres (2005)	Since 2002, Die Bahn utilise 29 simulators, deployed in twelve locations, to provide basic and refresher training. Each of its 21,500 drivers attends a simulator centre on a yearly basis for a one-hour assessment run. In addition, they use simulation for training drivers on the operation of the LZB, ATP, ATC and supervisory systems.
Savidge (in Madden and Boursier, *eds*., 2005)	According to the FRA, the simulator based performance skills test is a more thorough observational test than is achievable during a monitoring check ride on a locomotive. A performance test for recertification is only required every three years[145] while the check ride is required at least annually.
	Depending on class size, Amtrak provides between 1 and 2 weeks of simulator-based training on its basic training programmes. They also provide 3 days refresher training annually but they do not use simulators during its delivery.
Hansen (2005)	BNSF drivers are required to train on a simulator not just as part of their basic training but when they are qualifying on new routes also. Trainees do not learn the routes on the simulator but learn the specific route risks before they operate a real train over the routes. In addition, experienced drivers who require recertification are able to complete this process on their home computer terminals. The networked simulators are deployed via the corporate intranet from the training centre. Twenty seven system-wide locations have this facility.
Cullen (2001b)	Japanese railway companies make extensive use of technology with a considerable concentration on simulators. These are programmed to help drivers learn about train failures and emergencies. Drivers are expected to demonstrate their capabilities to their supervisors and peers during a two-monthly simulator test.
Abbott *et al*. (2000)	At JR Central, qualified drivers receive 2 hours simulator training per month dealing with systems' failures mostly. Emphasis is placed on peer review, and all of the class attendees do not drive the same scenario serially. Drivers at the Odakyu Electric Railway Company receive 37 hours simulator training as part of the basic training programme.
Luczak (2000)	Norfolk Southern (NS) provides a four-week classroom and simulator training module for its trainee drivers prior to them undertaking an 8 to 10 month on-the-job training module. The simulator training is provided to make them more susceptible to the cues that they will need to recognise during the on-the-job module and also to provide them with train management skills (slack management) that may avert a failure or derailment.
Watanabe (1997)	JRE provides at least 37 hours of simulator training during ab-initio training. This includes 52 scenarios in respect of abnormal and emergency working.

[145] Federal Railroad Administration Regulation No. 49CFR240

Appendix 13: Physical Differences between a Full Scope Replica and a Desk Simulator System

Full cab replica showing views of a fully functioning driving desk. The desk is integrated into a cab which may, or may not, be mounted on a motion platform.

New generation of a desk simulator that incorporates value adding controls only

← Images of the new generation of simulator desk showing (clockwise from top LHS):
1) Screen for platform view, passenger communications handset, engine start panel, TDMS, main desk controls and gauges, safety control equipment, emergency brake plunger, LHS door controls, alarm cut out;
2) OTW view, door test button, incident light, train radio head, RHS door buttons, uncoupling cock, coupler buttons and lamp;
3) Door of technical cabinet, switch panel (non-functioning foot warmer, wiper, saloon heat), radio handset;
4) Faultfinding panel (situated on rear wall of simulator booth). This fully functioning panel shows a navigable train on the bottom, the circuit breaker and cut out panels, pneumatic cut out cocks and deployable safety equipment.

Desk simulator (old generation)

Part task trainer with basic controls

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Appendix 14: Types of Simulators Used for Driver Training

Type I Simulator means a replica of the control compartment of a locomotive with all associated control equipment that:

1. Functions in response to a person's manipulation and causes the gauges associated with such controls to appropriately respond to the consequences of that manipulation;
2. Pictorially, audibly and graphically illustrates the route to be taken;
3. Graphically, audibly, and physically illustrates the consequences of control manipulations in terms of their effect on train speed, braking capacity, and in-train force levels throughout the train; and
4. Is computer enhanced so that it can be programmed for specific train consists and the known physical characteristics of the line illustrated.

Type II Simulator means a replica of the control equipment for a locomotive that:

1. Functions in response to a person's manipulation and causes the gauges associated with such controls to appropriately respond to the consequences of that manipulation;
2. Pictorially, audibly, and graphically illustrates the route to be taken;
3. Graphically and audibly illustrates the consequences of control manipulations in terms of their effect on train speed braking capacity, and in-train force levels throughout the train; and
4. Is computer enhanced so that it can be programmed for specific train consists and the known physical characteristics of the line illustrated.

Type III Simulator means a replica of the control equipment for a locomotive that:

1. Functions in response to a person's manipulation and causes the gauges associated with such controls to appropriately respond to the consequences of that manipulation;
2. Graphically illustrates the route to be taken;
3. Graphically illustrates the consequences of control manipulations in terms of their effect on train speed braking capacity, and in-train force levels throughout the train; and

4. Is computer enhanced so that it can be programmed for specific train consists and the known physical characteristics of the line illustrated.

Source: FRA (2012) and FRA (2010_49 CFR 240.7)

Key differences between Type II and Type I simulators are that Type II simulators do not incorporate a ‘control compartment’ and do not ‘physically illustrate the consequences of control manipulations’.

Key differences between Type III and Type II simulators are that Type III simulators do not ‘pictorially ... and graphically’ illustrate the route to be taken’ nor ‘audibly illustrate the consequences of control manipulations’.

Appendix 15: Prevalence of Simulator Sickness Identified in Research Studies

Table 1/3 - Primary Research

Researcher(s)	Context/study details	Propensity and suggested causation	Recommendations and amelioration methods
Kennedy *et al*. (in Coelho *et al*., 2008.)	This experiment involved the use of head mounted equipment for the treatment of acrophobia (the fear of heights).		Short repeated sessions should be separated by intervals of a few days; Short sharp exposures to the simulator are most effective; Avoid alcohol and sleep normally before each session; Operators should avoid sudden head movements.
Reed *et al*. (2007)	This research study assessed the viability of using simulators to train professional truck drivers in advanced skills, such as energy efficiency, vehicle sympathy and hazard awareness.	24·5% of the subject group (N = 640) were unable to complete the trial. Older operators are more prone to sickness when using both types of display. Analysis reveals that the dropout rates were significantly lower when the motion system was inoperative (a period of 6 months). This suggests that the motion cuing system was not functioning correctly.	Simulator sickness is affected by the type of OTW display system. Subjects using a simulator with the display mounted on the floor had a higher sickness rate than those using a simulator with a 'flying screen', i.e., where the projector moved in unison with the moving cab; The dropout rate decreased to 13·2% by improving the visual database, motion system, by screening out subjects who were pre-disposed to illness and by providing more familiarisation time.
Mitsopoulos *et al*. (2006)	The researchers correlated the participants' intentions of what they would do (the simulator was in automatic mode and they had no control over it) with their actual performance on a subsequent simulator task (when they had control over it). The output objective of this study was to establish the extent of the 'knowing-doing' gap (N = 30 novice and 30 experienced car drivers). The stated intentions of the participants ('I would do this, if I was in control') were compared with their actual behaviours when they were in control of the simulator ('this is what you actually did when you were in control of the simulated run').	7·4% withdrew from the study due to sickness	
Kappé and van Emmerik (in SWOV, 2006)		Subjects who have real word operating experience are more prone to sickness.	
Tichon *et al*. (2006)	The objective of this study was to measure 'presence' in a train simulator, to inoculate drivers against stress and to prepare them for novel events (N = 12 participants).	Attention is diverted away from the driving task to concern over the unpleasant physical symptoms; Some individuals are predisposed towards sickness; 8% became ill during the study.	
Parkes (2005)	This review paper focuses on visual databases that are constructed as a result of an analysis of training needs, i.e., the construction of fictitious locations rather than the recreation of real world scenes.		Motion systems, if required, should be accurate or they will lead to increased levels of sickness; Diminished aspects of colour, tint, texture and object obscuration may result in a loss of face validity but produce a driving environment of high utility.
Allen *et al*. (2003)	During this trial (N = 111 novice car drivers), each driver received 6 trials on a range of OTW presentations (narrow/wide FOV and single/multiple monitors) to assess the effectiveness of the various means to present the graphical images.	91·7% were 'fine', 2·8% were 'a little queasy', 3·2% were 'moderate but could continue' and 2·4% 'would like to stop'; The gender effect was statistically significant, females were more prone to sickness; Simulator configuration was not significant. Data did not support the view that the FOV was a significant factor; Single monitor displays can result in trainees driving at excessive speeds because of lack of peripheral cues.	The feeling of sickness diminished with the number of trials.
FAA (2003)	Aircraft operation		Limit the duration of simulator exposure initially and increase it at a later stage; Subjects should be provided with plenty of fresh air; Medications, like Dramamine, may help but these cause drowsiness.

Researcher(s)	Context/study details	Propensity and suggested causation	Recommendations and amelioration methods
Masciocchi *et al*. (2003)	This study considers the effectiveness of using simulators to provide training to snowplough operators (N = 174). Operators are trained, off road, in road skills and energy consumption. The simulators used three monitors with a combined 180° FOV, and five to ten minutes were spent on the simulated run.	3% felt so ill that they were unable to complete the experiment; Generally, sickness scores were low, equating to below a 'slight' sensation of sickness; Sickness increased with the age of the subject.	Provide time to acclimatise operators.
Smyth (2001)	A field comparison of performance when driving military vehicles using (i) natural OTW views and (ii) indirectly by monitoring CCTV monocular images of the route on monitors in the cab	Most subjects (N = 8) reported symptoms of discomfort associated with motion sickness; Subjects drove faster with natural vision; Workload increased when the FOV was presented by indirect means.	
Durlach and Mavor (in Emery *et al*., 1999)	Literature review	10% of the population are susceptible to simulator sickness; Bright imagery is more likely to induce sickness, rather than night scenes; A wide FOV exacerbates condition; Curve negotiation [high lateral acceleration cue] exacerbates the condition; Older persons are more affected.	Sickness effects can be countered by limiting the duration of simulator exposure and by filtering out persons who are susceptible.
Blana (1996a)	Survey of the state of development of car simulators	Barrett *et al*. (in Blana, 1996a): sickness affected 64% of study group in a car driving simulator; Breda *et al*. (in Blana, 1996a): 7·5% of subjects had to quit the validation process; Blaauw (in Blana, 1996a): None of the subjects in the study experienced sickness; Reed and Green (in Blana, 1996a): 8% of the experiment group experienced sickness.	Experiments in a simulator should not be too long; A motion platform will decrease the likelihood of simulator sickness.
Kennedy *et al*. (in Kolasinski, 1995)	This study examines the potential of simulator sickness to detract from the benefits of equipment usage in the US Navy and Marine Corps.	Between 20% and 40% of military pilots have experienced at least one of the symptoms of the sickness; The symptoms were not prevalent in subjects over 50 years of age; Subjects who have real word operating experience are more prone to sickness.	Symptoms are greatest when the subject is 20 minutes into the simulated run.
Barrett and Thornton (in Drummond, 1989)	Barrett and Thornton (1968) conducted research to establish the relationship between field dependence, i.e., the ability to find target figures embedded in the environment, and accident involvement. They assessed the subjects' ability to detect and identify the onset of an emergency situation, i.e., the emergence of a pedestrian onto the road.	52% of the subjects suspended the trial.	

Table 2/3 - Secondary Research

Study conducted by:	Number of participants and age groupings	Dynamic (D) or Static (S) simulator	Type of scenario	Picture presentation technique	Number of persons with symptoms of sickness or needing to suspend the experiment
Bolstad (2001)	16 young, 16 middle aged and 16 old	S	2 off 5 minute exposures to varying traffic environments	Computer monitor	5 experienced sickness symptoms; 1 suspended the trial.
Catlin, Blouin, Simoneau and Teasdale (2004)	15 young and 25 old	S	16 km route with 26 junctions	19 inch monitor	One in each group had to suspend the trial.
Cox, Quillan, Thorndyke, Kovatchev and Hanna (1998)	29 with Alzheimer's disease and 21 without	S	Varying	Three monitors with 160° FOV	2 suspended the trial (both were sufferers of Alzheimer's disease).
Dymott *et al*. (2003)	12 young, 12 middle age and 12 old	S	Public highway, urban environment and garage	100°X60° projected image	3 young and 1 old subject experienced symptoms in one trial; 1 young subject experienced symptoms in another trial.

Study conducted by:	Number of participants and age groupings	Dynamic (D) or Static (S) simulator	Type of scenario	Picture presentation technique	Number of persons with symptoms of sickness or needing to suspend the experiment
Edwards, Creaser, Caird, Lamsdale and Chisholm (2003)	12 young and 12 old	S	Road junctions	Three projectors with 165° FOV	2 young and 5 old subjects had to suspend the trial.
Freund, Gravenstein, Ferris, Burke and Shaheen (2005)	119 old	S	30 minute simulation in urban environment and vehicle manoeuvring	135°	10 suspended the trial.
Hagenmeyer and Sommer (2004)	13 young and 12 old	S	Urban environment and public highway	Three monitors with 120° FOV	2 young and 10 old suspended the trial.
Hakamies-Blomqvist, Östlund, Henricksson and Heikkinen (2000)	35 old	D	8·6 km of public highway with gradual turns	Arched monitor providing 120° FOV	1 suspended the trial.
Hakamies-Blomqvist, Henricksson, Lundberg and Östlund (2001)	41 old	D	30 and 35 km in summer and winter conditions respectively	Arched monitor providing 120° FOV	2 suspended the trial.
Henricksson (2005)	52 old	D	Urban environment and public highway	Three monitors with 120° FOV	42 suspended the trial.
Lee and Drake (1998)	10 old ex drivers and 23 old active drivers.	S	15 km with 8 staged events	One computer monitor	3 suspended the trial and 7 experienced sickness symptoms.
Lee, Cameron and Lee (2003)	129 old	S	Junctions and lane changing for 45 minutes duration	One computer monitor	11 experienced slight sickness symptoms.
Lee and Lee (2005)	129 old	S	Junctions and lane changing for 45 minutes duration	One computer monitor	9% reported simulator sickness.
Lee, Drake and Cameron (2002)	29 old and 24 very old	S	15 km with 8 staged events	One computer monitor	4 experienced sickness symptoms.
Lundqvist, Geredle and Rönnberg (2000)	24 stroke patients and 29 healthy persons	D	80 km of public highway with off-peak traffic conditions	Arched monitor providing 120° FOV	1 suspended the trial.
Merat, Anttila and Luoma (2005)	24 young and 24 old	S	Public highway	Semi-circular monitor providing 230° X39° FOV	80% of the old population suspended the trial.
Reed and Green (1999)	6 young and 6 old	S	Straight public highway for 40 minutes duration	Monitor 2·5 m X3·7 m	1 experienced sickness symptoms.
Rizzo, Sheffield, Stierman and Dawson (2003)	164 old persons	S	30 minutes on public highway with critical events	One projector with 155° FOV	34 suspended the trial.
Roenkler, Cissell, Ball, Ball, Wadley and Edwards (2003)	3 old groups of 26, 51 and 27 respectively	S	Reacting to stimuli presented	35 mm projection system	Respectively, 3, 2 and 2 persons suspended the trials.
de Waard *et al*. (1999)	21 young and 16 old	D	Junctions in an urban setting (15 minutes duration)	Monitor 2 m X 2·5 m	2 young and 6 old persons suspended the trial.

Source: Henricksson (2007)

Table 3/3 - Summary of Research Findings by Henricksson (2007) and Option Selection by the Writer

Dimension	Total participants in the studies	Number experiencing varying degrees of illness	%	Option selected by I.É.
Dynamic simulator	218	54	24·7	I.É.'s specified a static system
Static simulator	1,014	161	15·9	
OTW view presented on monitor	785	153	19·5	I.É.'s specified projection as the means to present OTW views.
OTW view presented by projector	447	62	13·9	
Wide OTW FOV	659	154	23·4	I.É.'s specified a FOV of 40° vertical by a 60° horizontal
Narrow OTW FOV	469	54	11·5	

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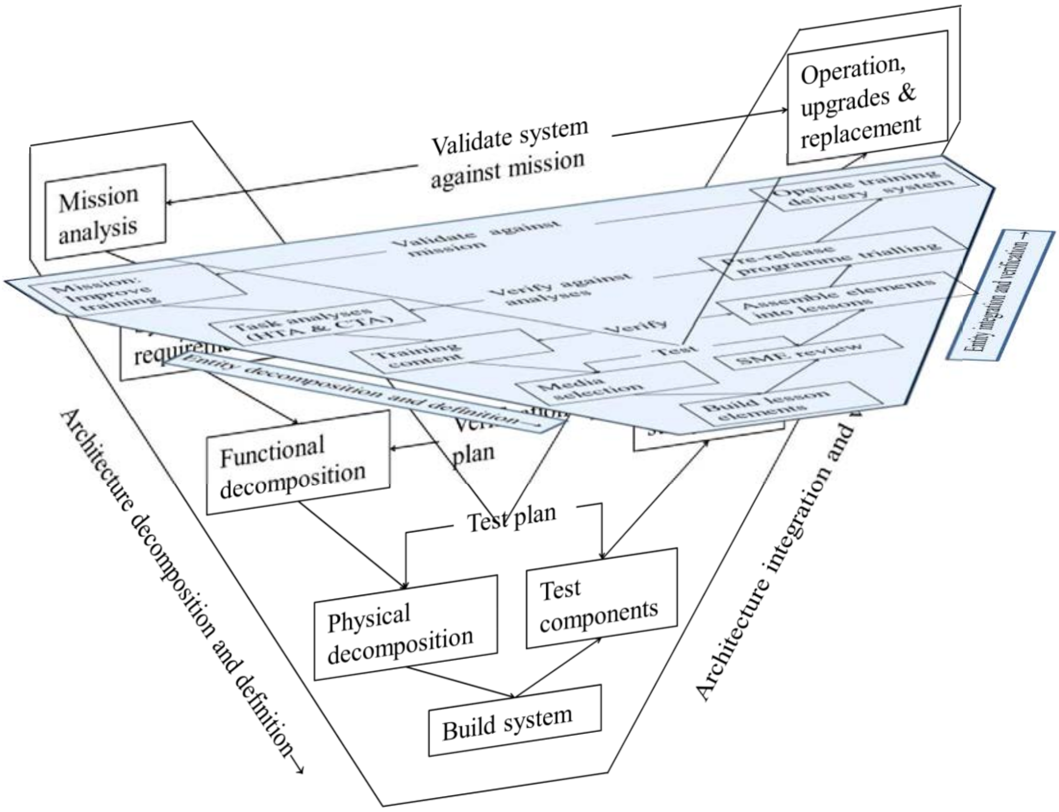
Appendix 16: The Dual Vee Model



Based on Forsberg and Mooz (in Griendling, 2011)

Appendix 17: The Kirkpatrick Model for Measuring Training Effectiveness

The framework, proposed by Kirkpatrick and Kirkpatrick (2005), and referred to in Table 37, is useful when considering the types of effectiveness evaluation studies study that can be undertaken. The value obtained from a particular study increases in proportion with the degree of difficulty to complete it, i.e., as one moves from level 1 to level 4. From a business perspective, a level 4 evaluation is very desirable type but, because of implementation difficulties, it is only achieved in 7% of studies.

Table 37: Types and Methods of Evaluation of Training Effectiveness

Level of evaluation	Focus of evaluation	Evaluation measures	Appropriate method of evaluation for this level	Frequency of use
1	Individual	Reactions of training recipients	Completion of course evaluation forms	78%
2		Changes to participants' learning	Examination or assessment	32%
3	Business	Changes in observable on-the-job behaviour	Observation of behaviour in the work setting; change in performance metrics	9%[146]
4		Changes in resultant financial metrics	Financial appraisal	7%

Source: The Report of the American Society of Training and Development (in Arthur *et al*., 2003)

[146] Typically, behavioural change is assessed by supervisors.

Appendix 18: Fatalities and Weighted Injuries

Injury degree	Definition	Ratio
Fatality	Death occurs within one year of the accident.	1
Major injury	Injuries to passengers, staff or members of the public as defined in schedule 1 to RIDDOR 1995 amended April 2012. This includes losing consciousness, most fractures, major dislocations, loss of sight (temporary or permanent) and other injuries that resulted in hospital attendance for more than 24 hours.	10
Class 1 minor injury	Injuries to passengers staff or members of the public, which are neither fatalities nor major injuries and: - for passengers or public, result in the injured person being taken to hospital from the scene of the accident (as defined as reportable in RIDDOR 1995[147] amended April 2012) - for workforce, result in the injured person being incapacitated for their normal duties for more than three consecutive calendar days, not including the day of the injury.	200
Class 2 minor injury	All other physical injuries.	1000
Class 1 shock/trauma	Shock or trauma resulting from being involved in, or witnessing, events that have serious potential of a fatal outcome, e.g., train accidents such as collisions and derailments, or a person being struck by train.	200
Class 2 shock/trauma	Shock or trauma resulting from other causes, such as verbal abuse and near misses, or personal accidents of a typically non-fatal outcome.	1000

RSSB (2013c)

[147] RIDDOR refers to the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations a set of health and safety regulations that mandates the reporting of, inter alia, work-related accidents. These regulations were published in 1995 and amended in 2012.

Appendix 19: Course Evaluation Questionnaire

Driver Simulator: Attendee Questionnaire

The purpose of this questionnaire is to help in promoting best practice for training design for safety critical roles.

Please take the time to complete this questionnaire and return it to your trainer at the end of the course.

Attendee's name:

Date:

Please tick the box that best describes your opinion.

Q1: The simulator is easy to use			
Strongly disagree	Disagree	Agree	Strongly agree

Q2: Using the simulator was enjoyable			
Strongly disagree	Disagree	Agree	Strongly agree
What in particular was enjoyable?			

Q3: The simulator supported my learning			
Strongly disagree	Disagree	Agree	Strongly agree
Do you think it may help you on the job; if so how?			

Q4: What was the one thing you liked **most** about using the driver simulator today?

Q5: Would you change anything that was done on the course?

Q6: Is there a subject that you would like to see covered?

Q7: Each session is composed of 4 parts:

- The classroom portion;
- The driving of the simulator;
- The observation;
- The feedback.

Please rate **each individually** between 1 and 5, 5 being highly liked ☺ and 1 meaning not liked at all☹.

Rating	1☹	2	3	4	5 ☺
The classroom					
The driving					
The observation					
The feedback					

Q8: Briefly tell us how this refresher compared with the old 4 day refresher.

Appendix 20: Calculation of Simulator Requirements: based on 2-day and 4-day refresher cycles

Bases of calculations:

1. Biennial refresher cycle;
2. Prior to the introduction of simulator enabled training, the refresher programmes for drivers of autonomous and electric traction had durations of four days and three days respectively. The anticipated simulator usage rate is calculated in Table 38. This usage pattern was used to determine the scope of simulator supply;
3. After the introduction of simulator enabled training, the durations of the refresher programmes for drivers of autonomous and electric traction were reduced to two days. The achieved usage rate is calculated in Table 39. A summary of the anticipated and achieved utilisation rates is presented in Table 40.
4. Sufficient equipment must be made available to accommodate drivers' release from the operating core to attend training. The operating core cannot release drivers during the summer holiday period. This creates an unavoidable inefficiency. A 'window' of 7 months is used in the calculations to reflect seasonality.

Table 38: Anticipated Biennial Utilisation

Location	Type of simulated traction	Type of training programme	Number of drivers	Class size	Number of classes	Duration of simulator element of programmes	Class days (simulator element)	No. simulators employed during each training session	No. simulator class days	Simulator resource availability (432[148] days multiplied by simulator availability)	Attendance constraint: Due to annual leave, drivers are available for refresher training during the months of October to April	Usage rate (7 month usage slot)	Usage rate (12 month usage slot)
Dublin	DMU and locomotive	Refresher	320	4	80	4	320	2	640	1728	1008	63%	37%
		Basic	80	8	10	13	130	2	260			26%	15%
		Remediation	6	1	6	1	6	1	6			1%	0%
Total utilisation												90%	52%
Mallow	DMU	Refresher	100	2	50	4	200	2	400	864	504	79%	46%
		Basic	0	8	0	13	0	0	0			0%	0%
		Remediation	1	1	1	1	1	1	1			1%	0%
Total utilisation												80%	46%
Dublin	EMU	Refresher	80	3	27	3	81	1	81	864	504	16%	9%
		Basic	16	8	2	13	26	2	52			10%	6%
		Remediation	0	1	0	1	0	1	0			0%	0%
Total utilisation												26%	15%
Aggregate utilisation with trainee attendance constraints, i.e., trainees available to attend over a seven month period each year									1440		2016	71%	
Aggregate utilisation without trainee attendance constraints, i.e., if trainees were available to attend over a twelve month period each year									1440	3456			42%

[148] 365 days/year less (weekends, annual leave, Public Bank Holidays and illness allowance) = 216 days/year or 432 days/2 year cycle

Table 39: Achieved Biennial Utilisation Rate

Location	Type of simulated traction	Type of training programme	Number of drivers	Class size	Number of classes	Duration of simulator element of programmes	Class days (simulator element)	No. simulators employed during each training session	No. simulator class days	Simulator resource availability (432[149] days multiplied by simulator availability)	Attendance constraint: Due to annual leave, drivers are available for refresher training during the months of October to April	Usage rate (7 month usage slot)	Usage rate (12 month usage slot)
Dublin	DMU and locomotive	Refresher	320	3·185	101	2	202	2	404	1728	1008	40%	23%
		Basic	15	8	2	13	26	2	52			5%	3%
		Remediation	6	1	6	1	6	1	6			1%	0%
Total utilisation												46%	27%
Mallow	DMU	Refresher	100	3·185	32	2	64	2	128	864	504	25%	15%
		Basic	0	8	0	13	0	0	0			0%	0%
		Remediation	1	1	1	1	1	1	1			1%	0%
Total utilisation												26%	15%
Dublin	EMU	Refresher	80	2·875	28	2	56	1	56	864	504	11%	6%
		Basic	5	8	1	13	13	2	26			5%	3%
		Remediation	0	1	0	1	0	1	0			0%	0%
Total utilisation												16%	9%
Aggregate utilisation with trainee attendance constraints, i.e., trainees available to attend over a seven month period each year									673		2016	33%	
Aggregate utilisation without trainee attendance constraints, i.e., if trainees were available to attend over a twelve month period each year									673	3456			19%

Table 40: Global Summary of Anticipated and Actual Biennial Utilisation

Duration of refresher	Annual leave constraint	Global (overall system) usage
Anticipated usage (based on four-day refresher)	Aggregate usage with trainee attendance constraints, i.e., trainees available to attend over a seven month period	71% (ranging from 90% to 26% depending on the type of simulator and location)
	Aggregate usage without trainee attendance constraints, i.e., trainees available to attend over a twelve month period	42% (ranging from 52% to 15% depending on the type of simulator and location)
Actual usage (based on reduced ab-initio requirements and two-day refresher session)	Aggregate usage with trainee attendance constraints, i.e., trainees available to attend over a seven month period	33% (ranging from 46% to 16% depending on the type of simulator and location)
	Aggregate usage without trainee attendance constraints, i.e., trainees available to attend over a twelve month period	19% (ranging from 27% to 9% depending on the type of simulator and location)

Table 41: System Requirements Based on Amended Biennial Usage Pattern

Type of simulated traction	Simulator usage based on 7 month driver availability	No. simulators purchased	Amended requirements based on reduced ab-initio training requirement and shorter refresher programme
Inchicore (autonomous)	46%	4	2 (plus one additional simulator required for locomotive conversion) = 3
Mallow (autonomous)	26%	2	1
Inchicore (DART)	16%	2	1
Total		8	5

[149] 365 days/year less (weekends, annual leave, Public Bank Holidays and illness allowance) = 216 days/year or 432 days/2 year cycle