CLIENT PROJECT REPORT CPR798

ERTMS Level 3 Risks and Benefits to UK Railways
Final Report

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Abstract

The project investigated the potential benefits and risks of ERTMS (European Rail Traffic Management System) Level 3 to the UK railway. Capacity benefits were investigated using the Parsons’ Railway Integrated Modelling Environment (PRIME); cost benefits were investigated using a spreadsheet analysis of the cost delta for Signalling Equivalent Units (SEU) between Multiple Aspect Signalling (MAS), ERTMS Level 2 and extended to Level 3; carbon emission benefits were considered not to be attributable to ERTMS Level 3 directly and could only be delivered through a suitable traffic management layer. Of these benefits potential infrastructure cost savings (above those achievable with Level 2) were identified as the primary driver for a Level 3 business case. The project considered multiple possible system architectures and application scenarios to represent the range of possible implementation options for the UK railways. Stakeholder consultation identified issues and enabled the development of a route map and risk log to ERTMS Level 3 adoption. ERTMS Level 3 can play a role in delivering the aspirations of the UK railway industry, provided these aspirations are well defined and appropriate technology choices are made from the outset. Many of the barriers to ERTMS Level 3 adoption, e.g. an enhanced communication system, from GSM-R (Global System for Mobile Communications – Railway), and a solution to train integrity proving for locomotive drawn passenger and freight trains are solvable. Partnering with suitable European operators in developing ERTMS Level 3 from simulation through to pilot and trial routes could prove advantageous.

Executive summary

The Department for Transport (DfT), acting on behalf of the cross-industry Technical Strategy Advisory Group (TSAG), commissioned TRL and Parsons to investigate the potential benefits and risks of ERTMS Level 3 to the UK railway and to assess the deliverability of the benefits. This summary provides a brief overview of the work and its conclusions.

ERTMS Level 3 is a development beyond Level 2 which has existed in concept for fifteen years. It extends the use of the onboard train location function which is a basic feature of ERTMS Levels 1 and 2. In Level 3 the train location data is used by the Radio Block Centre (RBC) to track trains through the system, in place of infrastructure based information used by Level 2. Conceptually this allows elimination of the majority of track circuits and axle counters, with benefits in terms of cost, capacity and flexibility of the system.

The generic capacity and cost benefits of ERTMS Level 3 were predicted using appropriate modelling tools. The likely practical benefits were then assessed in a set of application scenarios ranging from rural through to high density urban routes. Risks were identified from the analysis and also through stakeholder consultation, internal review and brainstorming.

It became clear during the study that the Rail Industry has much wider aspirations for future train control, extending to improvements in energy efficiency, recovery from perturbation and flexibility of driver resources which are beyond the capability of the current ERTMS product set. As requested by stakeholders, this report identifies qualitatively the elements of a new train control system based on ERTMS Level 3 which would be capable of supporting these aspirations and includes relevant aspects in the recommendations.

Level 3 is capable of delivering further infrastructure cost reductions of around 25% on top of the 40% already identified by the ERTMS Programme Team as available for Level 2 without lineside signals. Both figures use Network Rail’s SEU-based cost model to compare ERTMS with modern multiple aspect signalling. The additional cost savings offered by Level 3 would be offset to some extent by an increase in the cost of radio communications equipment, if carried out as an upgrade to the current GSM-R rollout, and by an increase in the train-borne equipment cost to provide for a train integrity
function. It was not possible within the scope of the study to quantify these increases, but the communications costs could be avoided by building the Level 3 requirements into the industry’s future plans for communications upgrade beyond GSM-R, and the train integrity costs should be relatively small for new passenger trains.

The work on capacity concludes that the reduction in technical headway compared with Level 2 is between 10 and 20% depending on circumstances, without significant change to the internal parameters of ETCS. The Level 3 capacity can be approached by optimising the Level 2 block layouts in line with infrastructure capability. However, in a Level 2 environment costs increase significantly as a result of adding track circuits or axle counters, whereas in a Level 3 environment additional capacity requires no additional trackside hardware. The cost benefit of Level 3 therefore improves with increasing capacity. It should be emphasised that a deliverable increase in train paths for most practical routes is constrained by factors other than signalling, so the real world capacity benefit from either Level 2 or Level 3 taken in isolation, is usually small. However, Level 3 is capable of delivering major capacity increases on regional routes which are constrained by long sections of absolute block. The business justification for such applications would depend on the demand take-up, and on the number of additional trains to be fitted specifically for the scheme. The capability of Level 3 could be further enhanced to equal CBTC systems for “metro” railways operating at relatively low speed and very high capacity by changing some parameters in the ETCS product.

A major benefit of Level 3 is the improvement in flexibility that it gives. Compared with conventional signalling, the design process gets very much simpler because there is no need to design every route with block layouts tailored to infrastructure characteristics, train performance and length mix, signal sighting requirements and intended service. A modular approach to signalling therefore becomes much more realistic. Modification also becomes easier for similar reasons. The maintenance of a Level 3 fitted route should also be cheaper, both because there is less to maintain and because the train based tracking can operate through planned outages of infrastructure equipment.

Although the Level 3 concept is clearly laid out in the ERTMS/ETCS Functional Requirements Specification (FRS), there are several different ways in which it can be applied within the overall signalling system architecture and each of these has a different balance of benefit and risk. Three candidate architectures were considered in the review. The “simple” architecture eliminated all track based train detection. The “median” architecture retained track based train detection at switches and crossings and the “complex” architecture applied Level 3 as an overlay, on top of a full multiple aspect signalling implementation with a fifth aspect for fitted trains. The “complex” architecture, whilst allowing for mixed fleet operation, increased complexity for little or no practical benefit over and above a Level 2 overlay implementation, and was not considered further. The “simple” L3 architecture provides lowest cost, but has some performance disbenefit at junctions compared with Level 2 and did not allow for failed and unfitted trains to operate (other than under procedure). More importantly, the absence of track based train detection at points means that the deadlocking function would have to be implemented via the EVC (European Vital Computer) and RBC and this was not considered acceptable when a local interlock could be retained at relatively modest cost. The conclusions of this report are therefore based on the “median” architecture.

A further important decision on architecture and functional allocation has to be made at a more detailed level. Level 3 can either be implemented as a fully integrated system based on the RBC, within which the primary means of train tracking is train based, or alternatively as a system in which an interlocking carries out its usual role, tracking trains through notional fixed block sections, and the RBC receives train tracking information, delivers virtual block occupancy to the interlocking and acts as a virtual aspect controller. From a railway operator perspective the second approach is perceived to be less risky, but the history of Communication-Based Train Control (CBTC) systems suggests that the first presents less development risk. It is not yet clear which
architecture would be the best, but in any case it is important that the Level 3 infrastructure is developed as an integrated whole.

Stakeholders, particularly in signal engineering, were concerned about the implementation of a moving block system, which was perceived as a major operational risk. However, as set out in the report in more detail, exploration of the risks with operators and drivers failed to identify any fundamental operational problems with moving block. Nevertheless the concerns could be overcome by implementing Level 3 as a “virtual block” system, in which form it would be indistinguishable from a Level 2 system from the driver perspective. Although this review concludes that stakeholder preference is likely to drive a “virtual block” solution, this is an important decision which needs to be carefully considered as there will be some loss of potential cost and flexibility benefit.

The reduction in track based train detection could improve reliability significantly, provided the ETCS equipment is itself highly reliable. Service experience with Levels 1 and 2 suggests that this may be achievable, but Level 3 increases dependency on both the onboard systems and the communications system. An essential and high priority next step for Level 3 is to carry out a full RAMS (Reliability, Availability, Maintainability, Safety) analysis based on the selected system architecture. Network Rail should be in a position to lead this.

Level 3, whilst delivering full Automatic Train Protection (ATP), does affect the balance of safety across the train control system. On the positive side, dependence on track circuits is reduced. This has benefits in principle which can also be delivered by axle counters, but the inherent risk of single point failure associated with track circuits has long been mitigated and discounted within the railway. The benefit would emerge as a cost saving as devices such as track circuit assisters and heavy line filters on board trains are eliminated. On the negative side, dependence on the accuracy of the train length information held by the EVC and (in Level 2) input by the train driver is increased. A way of validating this will be needed for Level 3 and this is a key issue to be resolved.

Train integrity, in the absence of track based train detection, is an issue which produced many conflicting views from stakeholders. A direct acting solution using a hardwired train line for confirmation of integrity would be relatively easy to implement for multiple unit passenger trains. For freight trains there is no off-the-shelf solution, but the use of an “electronic tail lamp” with a complementary unit on the locomotive to measure train length continuously appears feasible. This would need to be designed as an explicit part of the Level 3 system, with an appropriate reaction from the RBC in case of loss of the integrity signal.

There are several successful CBTC systems around the world which are very similar conceptually to Level 3, so there is no doubt that the concept is fundamentally feasible. However, the only ERTMS based system without track based detection which has passed the concept stage is the Swedish "Regional ERTMS", being developed by Bombardier. This is due to enter service in 2010 and should be carefully tracked by the UK industry. It is designed for low capacity rural lines but embodies most of the principles of Level 3. The development risks for a main line Level 3 lie primarily in the need for higher dependability of the onboard equipment and in the train location based tracking system and its relationship with the interlocking functionality. Suppliers consulted as part of this work perceive no fundamental problem in developing Level 3 and see the highest risk as residing in the agreement of an operational concept and system architecture.

There are several European railways interested in developing Level 3 beyond the "Regional ERTMS" stage, and the UK should consider helping to create a “Level 3 club” which should focus initially on agreeing a cost metric to drive the business case for L3 implementation. This can then be used to develop an economically led operational concept and architecture capable of delivering a defined level of service reliability, leading to a pilot to demonstrate proof of concept for main line deployment. The UK
should be clear what it wants out of such an arrangement in terms of cost and service reliability and the report suggests some preliminary work to establish this.

There is a consistent view from suppliers and other European railways that Level 3 will be ready for main line rollout in 10 years as a minimum, with 15 years as a more likely timescale. Given the length of time needed to organise and implement a pilot project at European level this seems realistic, but to achieve it work needs to start now. A more rapid deployment for a regional product based on the Swedish approach may be feasible. This will become clearer once Regional ERTMS is in service.

Level 3 is an incremental development on Level 2, and rollout of Level 2 needs to continue until Level 3 is ready. Only in that way will the system achieve the levels of maturity needed to support Level 3. A major risk to the delivery of the potential benefits of Level 2 is that the high cost of train fitment, in particular retrofit, may drive the widespread use of an “overlay” solution. Level 3 deployment cannot realistically proceed until all trains are fitted, so this problem represents a risk to Level 3 timescales. Technologies that can substantially reduce retrofit cost already exist, but are not consistent with the detailed requirements of the TSI. It is suggested that a set of “minimum requirements for interoperability” for domestic rolling stock should be established – ideally at European level - freeing designers from the need to use the ETCS product set as it currently stands, and allowing learning from a wide range of European and north American projects to inform a cost-engineered approach to onboard equipment design.

The industry’s energy efficiency aspirations do not need to be addressed within the ETCS domain as Network Rail’s traffic management programme already envisages closed loop train control using Commercial off the Shelf (COTS) products to provide continuous train location tracking, with advisory timing or speed information fed to the driver from an intelligent traffic management system. Agreement of the system functionality and communication interfaces and protocols could be done immediately and rollout commenced within 1-2 years.

Aspirations for increasing driver flexibility by reducing dependence on route knowledge were also expressed by the stakeholders. These can be addressed initially outside the technical scope of ERTMS. A commercial satellite navigation system could easily be adapted for railway use, with route information including station and junction locations, access points etc. built into a route map. An initial implementation without ERTMS would have some value, but the combination of such a system with ERTMS (Level 2 or 3) would deliver a major impact.

Changes in the driver role are seen by stakeholders as a step towards Supervised Automatic Train Operation (ATO), which would be technically feasible using any ERTMS Level as a base. It is very important that any initiative aimed in this direction starts with a realistic and rational human factors assessment of the future main line driver role. An engineering led transfer of metro concepts and technology is unlikely to succeed.

Key to all of these initiatives is the availability of dependable bidirectional communications between track and train. General Packet Radio Service (GPRS) on GSM-R would be a way of providing this at very low cost in the short term. Alternatively the industry may decide to wait until the next generation of communications technology is available.

Two route maps have been developed. The first, (Appendix F) takes a wide view and places the recommendations of this study within a time-based framework which shows how and when the wider benefits can be delivered. The second, (Appendix H) focuses on the work necessary to deliver the ETCS Level 3 subsystem.
1 Introduction

DfT commissioned TRL and Parsons to undertake a project to determine whether, and to what extent, the European Rail Traffic Management System (ERTMS) Level 3 could be expected to deliver the expectations set out for the UK main line railway and what migration route could be used to deploy it economically:

- Increased capacity
- Reduced cost
- Reduced Carbon
- Improved flexibility
- Increased reliability
- Reduced lineside equipment

The study analysed the changes in functionality between ERTMS Level 2 and Level 3 and how these might be applied in a number of possible system architectures and application scenarios. Estimates of the benefits of Level 3 were estimated using the Parsons’ Railway Integrated Modelling Environment (PRIME) for capacity and a spreadsheet based analysis for cost.

The study team also engaged with a cross-section of industry stakeholders to develop a broader understanding of the implications to the industry of implementing ERTMS Level 3 and their perceptions of the risks this might entail.

This report sets out the findings from the study and incorporates its recommendations in a ‘route map’ for the delivery of ERTMS Level 3 benefits in the UK.

ERTMS Level 3 is made up of ETCS Level 3 plus a communications carrier – currently GSM-R. This report uses the term “ERTMS Level 3” except where the reference is specifically to the train control subsystem ETCS.

1.1 Document Structure

The document is divided into the following key sections:

1. Introduction – This section
2. Background – A brief description of ERTMS; the project objectives and scope.
3. Methodology – A description of the methodology adopted for the study; the study questions and the project programme.
4. Results and Discussion – Study results including a description of the system architectures considered and the application scenarios used to produce the cost and capacity deltas from Multiple Aspect Signalling (MAS) to ERTMS Level 3 and from ERTMS Level 2 to Level 3.
5. Implementation – Discussion of the migration strategy to ERTMS Level 3.
6. Conclusions
7. Recommendations
2 Background

The concept of ERTMS was developed by the Union Internationale des Chemins de Fer (UIC) with the financial and regulatory support of the European Commission (EC) in order to improve cross-border interoperability, cost efficiency, safety and railway capacity within European railways. ERTMS Level 1 and Level 2 are now being widely deployed within a large number of Member States and on a number of key trans-European corridors. ERTMS technology is also being deployed in a number of countries outside Europe. The UK is committed to the deployment of ERTMS through the UK National Implementation Plan, submitted to the European Commission in September 2007.

2.1 Project objectives

This project had the following objectives:

- provide an independent and informed analysis of the potential benefits and risks to the UK railways of moving to ERTMS Level 3 as a basis for train control.
- inform DfT policy on the deployment of ERTMS.
- support the DfT’s long-term strategy on ERTMS Level 3 deployment.
- enable an informed view to be taken on where technology research and development resources should be targeted.
- support the DfT’s assessments on whether to move forward with an accelerated development of ERTMS Level 3.

2.2 Project scope

It was agreed at project inception that a formal commitment to deploy ERTMS Level 3 would require a full business case and this would not be feasible within the timeframe and available resources of this project. A business case would also require a clear specification of ERTMS Level 3 and an agreed system architecture which do not yet exist.

The initial scope of the project was to focus specifically on the potential cost, capacity and carbon (emissions) benefits associated with ERTMS Level 3. However, it rapidly became clear that the industry has wider aspirations for future train control which cover all aspects of operating costs. The scope of the study was therefore widened by agreement and outline recommendations for other aspects of the future train movement control system are presented in the Report.

The project scope did not include an investigation of the lessons from the ongoing Cambrian ERTMS Level 2 implementation, although some information was becoming available towards the end of the study. The Cambrian line was nevertheless used as a point of reference by many of the stakeholders in discussion.

Although the main focus of this study is ERTMS Level 3, the potential benefits of ERTMS Level 2 are still some way from being realised on conventional railways, and these are also discussed, if only as a baseline against which Level 3 can be compared. The same applies also to risks.
3 Methodology

3.1 Project Questions
For the project the following questions were developed:
- Can ERTMS Level 3 deliver real cost and capacity benefits?
- Are these benefits more easily realised than for Level 2?
- What are the risks associated with ERTMS Level 3?
- What kinds of route would benefit most?
- Does an approach to ERTMS Level 3 look feasible now?
- What next steps should the industry take?
- Where should resources be targeted?

These study questions were used as a framework for conducting interviews with stakeholders and formed the basis of the workshop at the end of Phase I of the study. All of the activities undertaken throughout the study were aimed at answering one or more of the study questions.

3.2 Project Activities
The project was divided into two phases as shown in Figure 1.

![Figure 1. Project Approach](image_url)

3.2.1 Phase 1
The main activities of Phase 1 are illustrated in Figure 1. Stakeholder liaison was a significant element throughout the study and phase 1 culminated in a workshop involving a key selection of industry representatives. The key Phase I activities that provided the input to the workshop were as follows:
- Development of an outline functional description of ERTMS Level 3 and mapping this to a representative System Architecture –
The ETCS Level 2 specification was examined and the key functional differences between ETCS Level 2 and Level 3 were identified. In parallel with this three representative system architectures were developed for Level 3 implementation. The representative architectures included interfaces with other key railway functions which are outside the scope of the ETCS specification. The ETCS Level 3 functions were then mapped onto the representative architectures to provide a range of possible allocations of the ETCS and signalling related functions.

- **Development of UK application scenarios** –
  From knowledge of the UK rail network and discussions with Network Rail, Train operators and others a selection of potential ERTMS application locations were selected and the key characteristics relevant to the study identified and recorded. The purpose of developing the potential UK application scenarios was to provide a basis for analysis of how the Level 3 functions identified in the previous step can be delivered in a number of specific UK application scenarios; including analysis of migration stages, both overlay and stand alone applications.

- **Assessment of suppliers experience and capability to deliver** –
  A questionnaire was developed to provide a structured means of eliciting information relevant to the study. The questionnaire was distributed to a range of ERTMS suppliers and in several cases meetings were held with the suppliers to facilitate the collection of relevant input.

- **Review of International experience and plans** –
  From knowledge of international ERTMS and CBTC applications a number of potential information sources were identified mainly consisting of European railway administrations and train operators. A structured set of issues and questions were developed to support engagement with the information sources and to ensure consistent recording of relevant information. The purpose of this part of the study was to identify relevant experience and plans from application of ERTMS and CBTC systems in Europe and elsewhere.

- **ERTMS Level 3 capability modelling** –
  High level performance modelling was performed using judgement and the Parsons PRIME tool using representative building blocks representing typical generic railway layouts to identify any weaknesses and constraints for ERTMS Level 3 in various application scenarios.

- **ERTMS Level 3 deliverability, risks, benefits** –
  A high level review of the key benefits and risks was carried out using input from the other phase 1 activities and applying judgement, experience and input from stakeholder liaison sessions. These high level risks and benefits were presented at the phase 1 workshop to promote discussion and identify the focus for phase 2 of the study. The work plan for phase 2 of the study reflected the output of the phase 1 activities including recommendations made at the workshop.

### 3.2.2 Phase 2

Phase 2 of the project included 5 main activities as follows:

- **Capacity Modelling** –
  Capacity benefits were evaluated using domain knowledge coupled with the Parsons tool PRIME. The key parameter of interest was the headway. A generic track layout was devised and its details entered into PRIME. Various rolling stock parameters were modelled and a number of routes were then simulated through the layout. The “Profile” function in PRIME was used to generate speed / distance and time / distance profiles. At the same time “Technical Headways” were
computed for each point on each route through the layout. Sensitivity to various parameters was tested with special consideration given to junctions and a real scenario, Lea Valley, was simulated. The capacity and cost benefits in other scenarios was estimated using judgement based on the generic modelling.

- **Cost Modelling –**
  The approach paralleled that used by Network Rail during 2005/6 to estimate the cost benefits of Level 2. The impact of Level 3 on the cost breakdown within the SEU spreadsheet was assessed and a “delta” for Level 3 estimated. A discussion was held with relevant experts from Network Rail to validate this work. A scenario based evaluation was also carried out to examine the potential for further cost savings for the application of certain types of system architecture.

- **Identification and evaluation of risks and benefits –**
  The high level risks identified during phase 1 were further reviewed and developed along with additional risks and features of ERTMS Level 3 emerging during the detailed cost and capacity modelling. These were used to generate a risk log.

- **Review of wider aspirations –**
  During stakeholder interviews and at the phase 1 Workshop both government and industry experts expressed wider aspirations for the improvement of train movement control. These have been developed further as part of the Industry Route Mapping work. Whilst this study was not intended to establish detailed feasibility of these ideas it was decided that they should be considered as concepts in terms of the benefits that they might bring, and the potential for synergy with ERTMS Level 3.

- **Development of ERTMS level 3 implementation road map and recommendations –**
  Taking into account the benefits, risks and key challenges a route map covering the changes needed to deliver the prospective benefits of the future (ERTMS Level 3 based) train control system was generated along with a series of recommendations to support the proposed tasks. The overall route map includes both core ERTMS related activities and those which relate to the wider aspirations for traffic management. In response to a request from the National ERTMS Sponsor, a more detailed route map for the ETCS Level 3 core was subsequently developed.
4 Results and discussion

4.1 Functional mapping and architectures with options

4.1.1 Functional Changes between ETCS Level 2 and Level 3

4.1.1.1 Specification differences

For the purpose of the study ETCS Level 2 has been assumed as the baseline functionality for UK deployment. Therefore the functional changes of concern are those relating to the difference between ETCS Level 2 and Level 3. The UK specific functionality introduced for Cambrian is not considered at this stage.

ETCS Level 2 and Level 3 are defined in the Class 1 specifications in sections 2.6.6 and 2.6.7 of Chapter 2 of the System Requirement Specification (SRS), Subset 026. Examining these sections the following differences in functionality between Level 2 and Level 3 have been identified.

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<td><strong>Level 2</strong></td>
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<tr>
<td>1. Train detection</td>
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<tr>
<td>For Level 2, 2.6.6.1.4 states</td>
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<td>“Train detection and train integrity supervision are</td>
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<td>performed by the trackside equipment of the underlying</td>
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<td>signalling system (interlocking, track circuits etc.) and</td>
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<td>are outside the scope of ERTMS/ETCS)”</td>
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<tr>
<td>2. Train Integrity</td>
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<td>Provided by underlying trackside equipment</td>
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<td>3. Movement Authority and Route Locking</td>
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<tr>
<td>For Level 2, 2.6.6.2.2 states, inter alia:</td>
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<td>Main ERTMS/ETCS trackside function:</td>
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<td>Determine movement authorities according to the underlying</td>
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<td>signalling system for each train individually</td>
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4.1.1.2 Change Details

In Level 2, the European Vital Computer (EVC) already sends back the calculated train position to the Radio Block Centre (RBC). However, the dependability, accuracy and frequency of passing this data may need to be increased in Level 3 to support the functionality of route locking which now depends on this data rather than on trackside train detection.

A review of the current safe braking model suggests that there are no differences in principle between the brake models for Level 2 and Level 3. The relevant functionality for Level 2 and Level 3 in the ETCS SRS is the same. The safety margin and confidence should be the same for both levels. The behaviour of the train is independent of ETCS level. The requirement for Level 3 is therefore the same as for Level 2: the train must be certain that it will not go beyond the Supervised Location (SvL).

However the processing time assumptions which are used in calculating the start of the brake curve do need to be re-considered for Level 3. The changes will involve extended position processing time and the addition of a train integrity validation time parameter.

Although the safe braking model does not need to change, it is possible that the safety distance (the distance which the SvL is offset behind the closest possible end of train or junction fouling point) may need to be reviewed, given the fact that close following of one train behind another is not restricted by block layout in Level 3, and that adhesion will still be unpredictable in some conditions. If so, this could have a negative performance impact. This was an issue with Train Control System (TCS) on the West Coast Main Line.

Systems based on track based detection (MAS, Level 2) determine train location with low granularity but very high accuracy at train detection boundaries. Train based systems (Level 3) determine where a train is located continuously, but with a higher level of uncertainty (which varies as the train moves over balises). At key junctions track based detection may be needed for performance reasons. This issue is explored further later in the report.

There is an explicit assumption for Level 2 that it may be used with lineside signals and that it can overlay on a relatively conventional interlocking and control centre.

For Level 3, it is stated that “Lineside signals are not foreseen to be used when operating in Level 3”. The specification does not consider degraded modes.

4.1.1.3 Primary Implications for System Architecture

The primary implications of these functional changes, for the ETCS subsystem are:

- Track based detection reduced or eliminated.
- Detection of train integrity becomes an onboard function.
- Train tracking becomes dependent on transmission from train to track of accurate and up to date train location and length information.

There are also a number of key implications outside the ETCS subsystem:

- The interlocking subsystem is no longer required to track the train through the inherent geographic logic of the infrastructure block layout.
- The traffic management subsystem will need to use a different method of referencing when issuing route setting requests to the RBC/interlocking (if a moving block system is adopted).
- Route release by the interlocking becomes subject to positional uncertainty (if track based train detection is eliminated).
The implications outside the ETCS subsystem vary in scope depending on the system architecture that is adopted (see section 4.1.2), and on whether it is decided to retain a level of block-based operation for operational or performance reasons (see sections 4.1.3.3 and 4.1.3.4).

These functionality changes have a direct impact on the way in which the ERTMS Level 3 railway will be operated and the system architecture to support that operation. The operational concept and architecture must be able to support safe operation in both normal and partial failure conditions. Reliability and safety performance requirements are drivers for system design and achievement of acceptable levels of both will ultimately depend on choosing the most appropriate architecture and approach to operation. The architecture also has a direct effect on cost, and the optimum may vary between routes with different traffic mixes and intensities. Each of these issues is discussed in the following sections.

4.1.2 Candidate Architectures

Three candidate system architectures used to provide a basis for discussion and comparison are described.

4.1.2.1 Simple Architecture

The simplest possible Level 3 architecture (Figure 2) eliminates all track based train detection and depends totally on train based train location.

The onboard equipment is very similar to Level 2, with the addition of a train integrity function. The infrastructure equipment consists only of a combined RBC and interlocking and a point controller at each set of points in the area.

The advantages of this architecture are that infrastructure count is minimised, with maximum cost and reliability benefit. The plain line capacity will be enhanced.

The disadvantage is that clearance of a train from the area of a junction has to be confirmed through an analysis by the RBC of the reported train position, train length and train integrity. The RBC must confirm, taking account of the various uncertainties involved, that the tail of the train has exited the junction area so that the junction can be unlocked.

This process may have an impact on junction performance because of the need to allow additional time for the probability of an obstruction to reduce to sufficiently near zero. More significantly, it may simply be unacceptable for the deadlock function to be carried out through a remote loop from train to RBC when it can be carried out by fitting the point with a simple local deadlock. This architecture contains no fallback or provision for unfitted trains, so a failure of the onboard equipment on a single train would result in a reversion to procedural voice control.

This architecture might be suitable for a low density railway where time for junction clearance is not an issue, but the absence of deadlocking is likely to eliminate it from serious consideration.
4.1.2.2 Median Architecture

The median architecture (Figure 4) is conceptually a small increment on the simple architecture described above. Track circuits or axle counters at junctions provide the deadlocking function and the point controller becomes a local controller performing a very simple set of local interlocking functions as a slave to the RBC. The functions can be simple because the underlying assumption is that all normal service trains are ERTMS fitted and will respond correctly to their movement authorities. Functions such as approach locking are therefore redundant at the local level.
This architecture retains most of the benefits of the simple architecture (costs will increase a little) but has some significant operational benefits. Performance will be improved because local train detection can be used for releasing a route. It would be very simple to fit local signals or junction indicators which would allow an unfitted or failed train to move at reduced speed, thus considerably easing the fallback problem.

Complex Architecture

The complex architecture (Figure 5) is needed in a scenario where some trains are fitted and some not, and it is desired to maintain significant capacity with no loss of performance for unfitted trains, whilst achieving the closer headway between fitted trains which Level 3 can provide.

A full fallback MAS system is provided, with track circuit or axle counter based detection for unfitted trains. In order to allow fitted trains to operate at closer headways, an additional aspect will be needed to present to a fitted train which may well be entering a fixed block which already has another fitted train in it.

The RBC and interlocking functions in this scenario would need to be separated if the fixed block, visually signalled railway, was required to continue operating in the event of the failure of the ERTMS system. This very significantly increases the complexity of the system because the train tracking and issuing of movement authorities become split functions carried out by both RBC and interlocking and need to be synchronised between the two.
The benefits of this architecture are the ability to deliver increased capacity for fitted trains whilst continuing to operate with unfitted trains, and the tolerance of complete failure of the ERTMS system. The disbenefits are a substantial increase in cost compared with Multiple Aspect Signalling (MAS) and the likelihood of lower reliability arising from the increase in complexity.

It is difficult to envisage a main line railway scenario in which this architecture is likely to deliver a positive business case.

Figure 5. Candidate Architecture 3 - Complex System

4.1.3 Operational Issues

The operational concept for ERTMS Level 3 must be developed in parallel with the system architecture. It must cater for both full supervision and fallback modes of operation on different types of route. A number of approaches have been taken in this study to consider the operational impact of moving from ERTMS Level 2 to Level 3.

A high level review of the UK ERTMS Level 2 Concept of Operations was carried out. The issues derived from this were discussed with the RSSB staff members who are intimately involved in creating the Level 2 concept of operations.

An extended interview with a driver-qualified member of an open access operator’s staff, was carried out, focusing specifically on the driver perspective. This individual is already involved in standards committee work and gave a perspective on some of the real problems likely to be encountered with Level 3.

Operational issues were also reviewed in the course of more general interviews with Network Rail and Train Operator staff.
The key operational issues to emerge from this process were:

- Data entry;
- Drivability;
- Role of signaller
- Moving or virtual block; and
- Degraded Operation

4.1.3.1 Data Entry

In Level 3, train length data is safety critical, and a combination of data entry by the driver and validation by an onboard system may be needed to provide the appropriate level of integrity. The solution may be different for different train types (e.g. multiple unit, freight). The requirement could also impact the design of other train systems and may be easier to achieve for new designs of train where validation can be in-built. The level of responsibility assigned to the driver and the integrity of any checking system will be of concern to the driving and train owners/operators community.

The impact of this may vary depending on whether infrastructure for train detection is provided at clearance points (e.g. junctions). At any point where a train consists of changes, including splitting and joining, train length will need to be reconfirmed to the same standard. There may be issues with 'shunting' operations on running lines that are carried out in Full Supervision or On Sight modes, particularly making sure that they are protected.

Class 66 freight drivers already enter train length information into “QTRON” which provides an advisory function for PSR and TSR compliance. QTRON lets the driver know that the rear of the train has cleared any speed restriction. It may be considered that ERTMS requirements would be no more onerous on the driver. Multiple Unit passenger trains could calculate their own length or at least perform a credibility check on driver entered data. Validation of driver entered data for freight trains will be more difficult and may require an independent check in the control office. Certain types of train integrity system could provide a degree of onboard checking, but the accuracy and dependability may not be high.

4.1.3.2 Drivability

Drivability has been raised as an issue for Level 3. It appears to cover two different concerns.

The first is that a driver may find it more difficult to drive in a moving block system. In perturbed conditions the end of movement authority may be placed by the system at any point on the route, rather than at a signal or marker board. The Driver Machine Interface (DMI) indications may be harder to interpret in an environment where the driver is dealing with varying MA lengths unrelated to a fixed block pattern. The ‘head up/down’ issue could be perceived as worse for Level 3 than for Level 2. If the information on the DMI is changing more dynamically for a "flexible" block Level 3 system then the driver may need to pay more attention in order to avoid interventions or may drive more defensively.

“Moving block” drivability concerns can be answered by configuring the system so that it operates in “virtual block” mode, with lineside block markers. In this form it should be indistinguishable by the driver from Level 2 without lineside signals. However, operation in “virtual block” mode has other advantages and disadvantages. These are considered more fully in section 4.1.3.4.

The use of head-up displays has been investigated by the industry, but costs are likely to be very high unless automotive (rather than aerospace) technology could be adapted as
an ETCS standard approach. Ultimately, the “head up/head down” question may best be resolved by increasing the level of automated support to the driver. A form of “cruise control” which controls train traction and braking to stay within the ETCS supervision curve has already been in use in Spain for some time.

The second “drivability” concern is that a driver uses line-side signals and marker posts as position references to support route knowledge. If all of these are removed, the driver may find it more difficult to achieve efficient and accurate station stopping (not supervised by ETCS) and also to locate the train when operating in a partial failure mode with ETCS inactive.

The driving representative was firm about the need for drivers to be able to report precise train location in degraded conditions and to be able to receive specific and unambiguous voice commands referenced to physical markers along the track, but suggested that distance markers would be as useful as virtual block stop position boards for this purpose. Stop position boards would be needed at critical locations (junctions and complex track layouts) where precise stopping position is important.

Operation of metro/CBTC driverless systems in manual mode indicates that the moving block drivability issues should not be insurmountable and this view was supported in general by train operators.

Views from the engineering community were more conservative and in most cases perceived a need for physical or virtual blocks for drivability reasons far into the future.

The phase 1 workshop suggested that the provision of supporting information for the driver which would further reduce the dependence on route knowledge might provide significant business benefits in terms of flexibility and reduction in need for training. This was supported by the driving representative. It is understood that currently it takes about 25 supervised trips for an experienced driver to be signed off against a route. Any reduction in this would be a significant benefit to operators. This may have particular value for diversionary routes.

The ETCS safety function (supervising speed within safety limits and stopping at signals) reduces the criticality of route knowledge but does not eliminate it, because drivers will still need to know where to brake to stop at stations. Getting it wrong may result in a train half on-half off the platform which is a safety issue. Route knowledge will also remain important in emergencies and in degraded modes, when train location or the location of an incident needs to be reported quickly and accurately.

It is suggested that the future train movement control architecture should include an independent means of providing route information to the driver. A relatively low grade system similar to road satellite navigation could do this at much lower cost than further development of ETCS functionality. This possibility is considered briefly in section 4.8.3. An important task to be carried out by the industry is to consider the role of the driver in a future railway with higher levels of automation and to build this into future systems planning.

For the immediate future physical infrastructure markers, of which block markers are a subset, will still be required, but it is suggested that drivability may not be a critical factor in determining whether to adopt virtual or moving block. If the non-fixed-block railway has advantages from flexibility or capacity perspectives then the new generation of drivers could be trained to expect it, and current drivers could learn to adapt.

In Level 1 and 2, a driver is given a release speed to enable him to move right up to a block marker, usually in order to clear a route or section behind for another train. Level 3 will still require this capability, to be used at critical locations.

Use of on-sight mode as specified for Level 2 could have an additional use in Level 3 for trains making a permissive “sweep” movement through a section of route which had previously contained a non-communicating train or a train of unknown length and which now needs to be proved clear.
Driver perspective simulation of Level 3 should be used to validate the operational concept. Driver training simulators already exist for Level 2 and have proved very successful in both gaining the confidence of the driving community and feeding back issues for consideration in the system design. Ultimately the simulators provide a useful element of driver training. A particular use for simulators would be in assessing the "drivability" of a fully moving block main line railway. This is well within the capability of current research simulators and could be embarked upon now at modest cost.

4.1.3.3 Role of Signaller

The impact of ERTMS Level 3 on the signaller parallels that of the driver.

On the one hand, Level 3 can be configured to operate continuously as a virtual block system which presents itself virtually identical to Level 2 from a signaller perspective and would apply equally to normal and degraded modes.

This would appear to be an attractive option for many degraded scenarios and has a level of support within the UK railway engineering community. However, imposing virtual fixed blocks may add an unnecessary complexity to the system design. Clearly this is an operational design trade-off.

On the other hand, if Level 3 was configured as a "moving block" system, the presentation to the signaller would inherently be changed. Examination of the control room of Docklands Light Railway (a fully moving block system) shows that the displays, although visually similar to a "conventional" railway have some significant differences. The trains are shown as icons moving along the track, with an indication through colour change of the length of track ahead which has been seized by the Vehicle Control centre (VCC), equivalent to an ETCS RBC, for that train so that it can allocate a movement authority to it. In degraded operation, where an unfit maintenance train or a failed train is being moved under manual control, the system uses its fallback "fixed block" mode which is shown by a different colour to indicate a block occupied by one (or more) non-communicating trains.

The important difference between these two scenarios from the signaller perspective is that in the first case the system has a consistent presentation of track occupancy which replicates current systems. In the second case there are two different presentations, one in normal and one in degraded mode.

It has been suggested that this is not very different from the situation on a piece of automatically signalled conventional railway, but nevertheless the potential for confusion is important and would need to be investigated further, from both human factors and technical perspectives.

4.1.3.4 Moving or Virtual Block

Since the second half of the 19th Century the foundation of railway safety has been the division of the track into physical block sections and the deployment of a signalling system which ensures that only one train at a time can enter a section. Track circuits have been the underpinning technology for the block principle on high capacity railways for more than 100 years. The procedural implications of block working are deeply embedded in the operational culture and supporting technology of the railway, as is acceptance of the constraints that this imposes.

ERTMS Level 3 is intended to eliminate the need for track based train detection, at least on plain line. It makes the block principle redundant from a safety perspective. It allows the safe movement limit of each train to be calculated individually in real time based on the known position of all other trains. The term "moving block" has been used for this kind of system in the past, and the term has been discredited because of project failures on West Coast Main Line and Jubilee Line extension, both in the late 1990s. As a result, there is pressure from industry stakeholders to deploy a system which operates in
a “virtual block” mode – so that the system only issues movement authorities to fixed points on the infrastructure, mimicking the operation of a fixed block system.

Table 2 summarises the impact of “Moving Block” and “Virtual Block” Level 3 systems from a system perspective.

**Table 2. Impact of Moving and Virtual Block Level 3 Systems from a System Perspective**

<table>
<thead>
<tr>
<th></th>
<th>Moving Block</th>
<th>Virtual Block</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Safety</strong></td>
<td>Safety assured by ATP system in all normal circumstances.</td>
<td>Can be configured to approach closely the capacity of a moving block system</td>
</tr>
<tr>
<td></td>
<td>Safety in partial failure conditions unlikely to be affected by difference</td>
<td></td>
</tr>
<tr>
<td></td>
<td>between moving and virtual block configuration, provided a driver referencing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>system (wayside distance markers or navigation system) is provided.</td>
<td></td>
</tr>
<tr>
<td><strong>Capacity</strong></td>
<td>Optimised in all circumstances</td>
<td></td>
</tr>
<tr>
<td><strong>Operational</strong></td>
<td>Manually driven moving block system in perturbed conditions gives driver</td>
<td>Train will always stop at one of a single set of points on route so driver</td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td>a wider range of train motion control problems to solve. Likely to be more of</td>
<td>faces a smaller set of traction/brake control problems.</td>
</tr>
<tr>
<td></td>
<td>an issue with frequent stopping, dense services.</td>
<td></td>
</tr>
<tr>
<td><strong>Migration</strong></td>
<td>Major challenge in switching from current “fixed block” culture, probably</td>
<td>Easy migration from Level 2 with no lineside signals to Level 3 “virtual block”.</td>
</tr>
<tr>
<td></td>
<td>more for signalling engineers than drivers. Different display principles may</td>
<td>Should be virtually indistinguishable from driver and signaller perspectives.</td>
</tr>
<tr>
<td></td>
<td>be a problem for signallers in overlap areas.</td>
<td></td>
</tr>
<tr>
<td><strong>Flexibility</strong></td>
<td>System will be self-optimising. Train related aspects of signalling design</td>
<td>Some flexibility lost – virtual block layout will need to be designed from an</td>
</tr>
<tr>
<td></td>
<td>should be limited to train length and berthing constraints and number of</td>
<td>operational perspective and once fixed in wayside signs will be harder to</td>
</tr>
<tr>
<td></td>
<td>trains in an area (affects RBC layout and communications capacity).</td>
<td>alter.</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Infrastructure costs minimised. Train borne costs include train integrity</td>
<td>Small increase in infrastructure cost.</td>
</tr>
<tr>
<td></td>
<td>subsystem.</td>
<td></td>
</tr>
</tbody>
</table>

A “virtual block” system has the clear advantage that it represents a more limited change from an operational point of view. The driver and signaller perspectives in normal operation will be identical to Level 2 without lineside signals. However “virtual block” also reduces some of the potential benefits. The virtual block boundary locations will need to be optimised for capacity and then marked. The costs of design will be somewhat increased, and there will be a small effect on the costs of implementation. Fixed and marked block boundaries represent a constraint on flexibility because changing them requires a software change in the RBC plus physical work on the ground as well as being a configuration control and driver training issue.
The balance between “virtual” and “moving” block risks and benefits will be different for different types of route. In general the operational performance risks associated with moving block will be lower for a lower density railway because there will be fewer interactions between trains which might cause a train to stop in an unexpected location. However the benefits will be lower also. On a metro-type route with frequent stations and a consistent stopping pattern, the difference between virtual and moving block may be almost imperceptible. The most sensitive types of route are likely to be those where there is a complex interaction between fast and slow trains, with frequent crossing moves. On such routes a moving block system might substantially increase the number of different reactions which a driver has to contend with. It seems likely that the main line railway will opt for a “Virtual Block” system, at least initially. On balance this seems the wisest course of action. This is the route that has been pursued in Sweden with the Regional ERTMS project, although moving block trials are still an option.

4.1.4 **Reliability and System Performance**

4.1.4.1 **ERTMS/ETCS Reliability**

Overall feedback from installed systems across Europe is that after initial bedding-in ETCS components and subsystems are reaching levels of reliability at least as high as conventional signalling. This is being achieved through a programme of extensive testing and in-service improvements of both software and hardware by suppliers in cooperation with infrastructure managers and train operators. RBCs have virtually no failures, in common with electronic interlockings. Object Controllers have presented some problems but these are almost fully resolved as are onboard reliability issues.

At component and subsystem level therefore, ETCS can be considered to have a reliable foundation.

However, problems are still occurring in the internal integration of ERTMS (RBC to GSM-R to EVC; RBC to RBC) and in the integration of ETCS to other railway subsystems – primarily EVC to onboard traction and braking equipment and RBC to interlocking. At this level the problems are not associated with hardware failures, but with integration issues such as data integrity, message timing, traction control and speed supervision and communication system problems. The Spanish Level 1 system has reliability problems due to balise readers failing to read balises. Dual redundant balise readers have been added to overcome this. Many of the problems at this level have been associated with interoperability of different supplier subsystems across the air gap and are now well on the way to being solved. Many are already solved in the current SRS version (2.3.0d).

A major gap in the development of ERTMS is the failure until recently of any of the coordinating bodies to set reliability targets or to collect reliability data. This has been a concern since the initial Swiss Level 2 trials in 2002 to 2003. European user group RAM results are now being collected but have not been released in time to be considered as part of this study. The intention of the ERA is to introduce specific reliability targets into a future version of the ETCS SRS (Index 28), avoiding the need for these to be locally specified. The industry should ensure that the targets set are adequate for Level 3.

Reliability problems with the Cambrian Level 2 implementation are starting to emerge. At the time of finalising this report the principal focus is on problems occurring with the onboard implementation in Level 0. Hard information is not available, but problems are reported to be mainly software rather than hardware related and human factors (driver display related). This tends to reinforce the view that hardware reliability is not the issue. None of the problems currently reported are insoluble given time, and considering the ever-increasing size of the Level 2 user base, it is likely that they will be solved quite rapidly. What is not yet clear is whether the Level 2 onboard reliability will be good enough for Level 3, and this is a key question which needs to be addressed. The UIC is...
due to publish a RAMS analysis associated with the Regional ERTMS project very soon, and this should be studied carefully.

The weakest link in the ERTMS family may turn out to be the use of circuit switched GSM-R, but this is very likely to be solved over the next ten years by transfer to a packet switched carrier (initially GPRS).

The question for this report is then, whether introduction of Level 3 can be done without causing a significant regression in reliability. The view of the suppliers appears to be that it can, because the changes are small, at least in terms of the onboard equipment. This is valid provided that the Level 2 reliability baseline is high enough. For passenger multiple units it should be possible to introduce the train integrity function on the back of existing technology with very little risk. A reliable locomotive hauled train solution may be more of a challenge.

The changes at the infrastructure level are more fundamental and realistically, there are likely to be some integration problems with the new train tracking functions and between the RBC and the local controllers. These should be soluble within a well designed series of pilots, provided that there is agreement on the system architecture to be adopted. The RAMS requirements for a core main line will be different from a regional deployment and the targets for the pilot should be set with care, bearing in mind the assumption that Level 3 can save substantial cost across the network.

4.1.4.2 Railway Performance benefits

Initial work done by the Network Rail System Engineering Team has suggested that there are significant service performance benefits to be gained from ERTMS, provided that the ETCS subsystem is adequately reliable. Level 2 offers some benefits and Level 3 a further increment on top of these.

The benefits derive first, from the reduction in equipment count (track circuits and axle counters) and second, from the impact on service recovery delivered by local improvements in capacity.

Using Multiple Aspect Signalling as a baseline and considering the percentage contribution to delay minutes from infrastructure failures, Table 3 and Table 4 show the potential percentage reductions in delay minutes for ERTMS Level 2 and the further reduction for ERTMS Level 3 respectively, derived from reduction in equipment count.

<table>
<thead>
<tr>
<th>Item</th>
<th>Percentage Reduction in Delay Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signals</td>
<td>5%</td>
</tr>
<tr>
<td>Signal Power supplies</td>
<td>4%</td>
</tr>
<tr>
<td>Other track equipment</td>
<td>3%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>12%</td>
</tr>
</tbody>
</table>
Table 4. Level 3 Additional Potential Reduction in Delay Minutes

<table>
<thead>
<tr>
<th>Item</th>
<th>Percentage Reduction in Delay Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train Detection</td>
<td>10%</td>
</tr>
<tr>
<td>Power for train detection</td>
<td>4%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>14%</td>
</tr>
</tbody>
</table>

Infrastructure represents 28% of all delay minutes. Therefore:

- Level 2 overall reduction in delay minutes for whole railway = 3.4%
- Level 3 further reduction in delay minutes for whole railway = 4%

The potential reliability and performance benefits from reduced infrastructure must be balanced with the potential for increased unreliability of the train due to the addition of ERTMS equipment.

The impact of Level 3 on service recovery will deliver some improvement in PPM performance, where increased local capacity is not used to support additional train paths. The effect of this is localised and has not been modelled in this study, however it may be significant.

Performance modelling is an important part of the next steps for Level 3 and the Network Rail team has suggested that the high level delay minute apportionment already carried out should be updated to include ERTMS Level 3, and that one or more of the RAM models developed for Crossrail, West Coast and Thameslink should be modified to demonstrate the effect of Level 3 on a high density railway. It may also be useful to carry out a more formal comparison of the results from VISION and PRIME.

4.1.4.3 Availability, Failures and Degraded modes

For an ERTMS Level 3 system consideration of reliability and redundancy must go hand in hand with the design of the system architecture, the probability of failure of critical system elements and the availability of redundancy or fallback modes of operation.

Redundancy does not appear to have been considered an important design feature in the UK ERTMS application to date. For example the UK GSM-R system has only 1 MSC for the whole country whereas Spain has 2 and Italy has 7, for both geographic and redundancy reasons. This issue is already being reviewed by Network Rail for the Level 2 Programme. Level 3 will need a substantially more dependable communications system than the current UK GSM-R voice implementation.

The natural tendency is to include fallback systems with which the railway is familiar. CBTC systems similar to Level 3 usually include track based detection to supplement train based detection either as an “underlay” or in areas of critical operational importance. ERTMS applications in Spain and Italy have built in system redundancy, in both cases through fallback to a lower system level.

However there is a balance between complexity and reliability. Less complex systems tend to be more reliable but failures are more severe when they do occur. Availability measures should be carefully chosen to highlight the tradeoffs involved, which may well suggest different architectures on different types of route.

ERTMS Level 3 represents a major shift in railway system architecture compared with MAS, comparable with the change from self powered trains to electrification. It is essential that this system change is fully analysed from a reliability and availability perspective, using the proposed system architectures and expected component
reliabilities to predict the impact on overall railway performance. This is an essential next step, alongside the development of the operational concept.

Design of a practical Level 3 system must take account of failures, both of the ERTMS system itself and of the other elements of the train movement control system. Traditional signalling systems largely rely on operational and procedural fallbacks to overcome failures of infrastructure elements (track circuits, point detection, cable failures). The Level 3 system is not so dependent on infrastructure and has very different failure modes.

The failure modes which need to be considered and the possible system responses to them are summarised in Table 5.

There are important choices to be made in relation to degraded mode operation, which will have a major impact on the cost and complexity of the system. Essentially, the decision would have to be made as to whether to implement a fallback track based system to support fallback operation in a limited number of failure cases (primarily those affecting the EVC) or to implement redundancy (duplication with the same functionality). A decision of this magnitude needs to be supported by a full RAMS analysis and consideration of the operational implications of the alternatives, driven by a whole life cost analysis. RAM targets set through the CCS TSI and TOM TSI will need to be taken into account.

The operational considerations include:

- Driver having train location information when ERTMS infrastructure fails.
- Signaller having train location information when ERTMS onboard fails.
- Driver being able to report train location in emergency (accident, obstruction).
- Operation in dark/fog – driver need for train location information.
- Maintaining voice communication.
- Maintaining a reasonable speed through degraded sections.
- Misrouting (happens quite frequently in diversionary situations and the driver has to recognise and respond to it).

Degraded mode follow-up work analysis should be carried out. Proposed activities are:

- Review of proposed degraded mode arrangements for ERTMS Level 2 on the UK main line.
- A detailed analysis of ERTMS Level 3 and associated equipment failure modes (linked to the RAMS work).
- Review of degraded operations on other railways with CBTC not based on track based train detection (e.g. DLR).
- Workshop to agree principles for degraded mode provision for the main line railway.
## Table 5. Summary of failure modes and possible system responses

<table>
<thead>
<tr>
<th>Cause</th>
<th>Train Movement Impact</th>
<th>Impact on Signaller</th>
<th>Work around</th>
<th>Impact on Performance</th>
<th>Possible Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communications System Failure (MSC or double network fault)</td>
<td>Movement Authority fails to update on a large number of trains</td>
<td>Reported train location lost on large number of trains</td>
<td>None practicable</td>
<td>Extreme</td>
<td>Reinforce communications system to reduce probability to extremely low level</td>
</tr>
<tr>
<td>Local Communications Failure (Base Station Fault)</td>
<td>Movement Authority cannot be updated in affected line section</td>
<td>Reported train location lost in affected section</td>
<td>Station to Station operation</td>
<td>High</td>
<td>Reinforce communications system to increase tolerance to single base station outage – or increase communications diversity</td>
</tr>
<tr>
<td>Single train communications failure (GSM-R data radio fault) (Note: radios normally duplicated)</td>
<td>Movement authority cannot be updated for single train</td>
<td>Reported train location lost for affected train</td>
<td>Voice transmission of MA</td>
<td>Moderate</td>
<td>Fallback track based detection system to support workaround; or increase communications diversity</td>
</tr>
<tr>
<td>RBC failure</td>
<td>All trains in area will stop</td>
<td>No information or control in affected area</td>
<td>Voice transmission of MA</td>
<td>High</td>
<td>Increase RBC dependability; or provide fallback track based detection system and interlocking</td>
</tr>
<tr>
<td>EVC failure</td>
<td>Movement authority and position reporting lost for single train</td>
<td>Reported train location lost for affected train</td>
<td>Voice transmission of MA</td>
<td>Moderate</td>
<td>Fallback track based detection system to support workaround.</td>
</tr>
<tr>
<td>Balise reader failure</td>
<td>Movement authority and position reporting lost for single train</td>
<td>Reported train location lost for affected train</td>
<td>Voice transmission of MA</td>
<td>Moderate</td>
<td>Duplicate balise reader – or Fallback track based detection system to support workaround</td>
</tr>
<tr>
<td>Odometry failure</td>
<td>Movement authority and position reporting lost for single train</td>
<td>Reported train location lost for affected train</td>
<td>Voice transmission of MA</td>
<td>Moderate</td>
<td>Increase internal diversity to allow operation with increased effective train length</td>
</tr>
</tbody>
</table>
### 4.1.5 Safety Performance

The implementation of ERTMS Level 3 will be expected to maintain or enhance the level of safety offered by current signalling systems. There is a perception that a “moving block” system where the emphasis is to move trains closer to the train in front without the protection of block sections must fundamentally increase the safety risk.

An analysis of the safety implications of Level 3 will need to start with a consideration of the impact of Level 2.

The National ERTMS Programme Team has carried out a study to consider the effect of implementing ERTMS Level 2 on operational system safety risk. The study assumed steady state operation of a railway controlled by the ERTMS system and did not consider risks during migration from the present day to an ERTMS operated railway.

The base information used for the process was the Safety Risk Model (SRM) managed by RSSB. Information based on empirical, modelled and estimated data is presented in the form of overall safety risk in equivalent fatalities per year arising from various hazardous events and their pre-cursors. It is these hazardous events and their pre-cursors which were used as the starting point in assessing the effect which ERTMS will have on the safety risk of the national rail network. The safety performance analysis focused on hazardous events involving trains and in particular train collisions resulting from a signal passed at danger. The equivalent for an ERTMS controlled railway was assumed to be a collision resulting from a train exceeding its supervised location.

In parallel with the review of predicted safety performance a qualitative evaluation of the potential causes of hazardous occurrences for an ERTMS Level 2 railway has been carried out using a fault tree approach. The output of the Fault Tree analysis presents the highest ranked potential causes of functional safety risk within the ERTMS signalling system. The risk considered is that of trains exceeding the end of their movement authority and straying into sections of the railway over which conflicting train movements may be signalled or authorised.

The Fault Tree report for ERTMS Level 2 concludes that train parameter selection by the train crew for locomotive hauled trains (particularly freight trains which have a big difference in train mass and braking performance between loaded and empty) is the single most important system (as opposed to product) safety issue for applications of ERTMS on a mixed-traffic railway.
This issue is amplified on a Level 3 railway where train length also becomes a safety critical parameter because there is no track based system to provide confirmation of track occupation.

It should in future be possible to combine the results of the safety performance evaluation based on the SRM with the ERTMS based fault tree work to produce an updated safety risk model which presents and predicts the safety performance of a future ERTMS railway for the UK.

An activity should be initiated to re-examine the Safety Risk Model with respect to “Signalling System Failures” to ascertain the likely impact of changes introduced by Level 3, in particular transferring the position tracking system from lineside infrastructure to trainborne equipment.

One of the key considerations for a Level 3 implementation will be the identification of any new or changed safety requirements and implementation of suitable mitigation measures to support a safety case.

The following should be initiated:

- Detailed re-examination of the ERTMS Fault Tree and development to support ERTMS Level 3 operation.
- Review of ERTMS Level 2 safety requirements to identify new or changed safety requirements.

4.2 Prospective benefits – Capacity

Increased capacity and lower cost are the primary drivers for ERTMS Level 3. A major objective of this study was to determine whether and to what extent increased practical capacity can be delivered by Level 3. Assessments of this kind have already been carried out by the UIC and others. This work was intended also to determine the limitations on capacity which exist in the ETCS product set, and the extent to which these might influence system design. The steps in the assessment of the capacity capability were as follows:

- Generic modelling to determine the basic capability of Level 3 and compare with Level 2 and MAS.
- Modelling sensitivities to determine optimum parameters for Level 3.
- Junction modelling to determine impact of alternative architectures.
- Scenario case study using modelling support.
- Appraisal of alternative cases using domain knowledge and judgement.

4.2.1 Modelling Approach

The modelling approach and results are described in detail in Appendix D and are summarised in this sub-section. The modelling tool used was PRIME. PRIME is capable of accurately modelling 3 and 4 aspect MAS, ERTMS Levels 1, 2 or 3 and Communications Based Train Control (CBTC). A more detailed description of PRIME can be found in Appendix C. The basis of comparison for this study was Level 3 with both Level 2 and 4-aspect MAS. The PRIME algorithms predict technical headway by calculating minimum train separation at 1s intervals for two trains running through the route (see Figure 6).
In Level 2 the End of Authority will be at the end of the signal block and the Supervised Location is at the end of the overlap of that block. In Level 3 the Supervised Location is set as the safe rear end of the preceding train, taking account of uncertainty in train position, length etc. A margin is then applied to the rear of the Supervised Location to define the End of Authority. For this study this margin has been set at the standard overlap distance (183m). The closest location of the head of the preceding train is then calculated using the length of the train and (for Level 3) the odometry error plus the time to prove train integrity, plus the average position reporting time. For Level 2 the calculation uses the length of the block plus its overlap plus a time allowance for track circuit or axle counter response.

A generic infrastructure model was created first and used to assess the effect of Level 3 impact on headway in various operational scenarios, using rolling stock performance parameters as follows:

<table>
<thead>
<tr>
<th>Train Type</th>
<th>Length</th>
<th>Acceleration</th>
<th>Brake Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMU</td>
<td>160m</td>
<td>0.68m/s²*</td>
<td>0.9 m/s²</td>
</tr>
<tr>
<td>Freight</td>
<td>775m</td>
<td>0.12m/s²*</td>
<td>0.4 m/s²</td>
</tr>
</tbody>
</table>

*initial acceleration – power limit applies as speed increases
The generic model was designed to allow the effect of varying ETCS parameters to be demonstrated directly. The model allows for driver reaction and brake build-up times and makes realistic allowances for internal ETCS and GSM-R delays and cycle times and odometry error. The model output used for this study was operational headway, calculated as minimum train headway plus a fixed 30s operating margin.

4.2.2 **Generic benefits of Level 3 – Plain Line Headway**

Figure 7 shows the generic plain line headway curve for Level 2, plotted alongside the maximum plain line capacity of Level 3, subject to the assumptions detailed in Appendix D. Level 2 capacity increases with reducing block size and can exceed that obtained with Level 3 at short block lengths. Whether there is a crossover in capacity depends critically on the difference between the time required for block occupation change recognition compared with Level 3 position report frequency and latency.

![Graph showing trains per hour against block length](image)

**Figure 7. Trains per Hour against Block Length**

4.2.3 **Sensitivities**

Figure 8 shows the effects of varying the various ETCS parameters on Level 3 capacity from a “Nominal” value to either Better or Worse values, i.e. improving or worsening capacity. Each radial axis in the diagram shows the effect of that parameter change when all other parameters are at their “Nominal” values. The parameter values used to obtain the above results are tabulated in Table 6.
The results show that the biggest impacts on headway capacity in Level 3 are by reducing the position report and MA update cycle times. A reduction in cycle time from 5s to 1s gives a 10% reduction in headway. Changing these parameters is entirely feasible in principle (the improvements are typical of CBTC system parameters) but would increase the EVC processor and communications carrier load significantly.

Reducing the balise spacing has very little effect on capacity, because the contribution of odometry error over the assumed 500m normal spacing is small compared with the length of the train. Conversely, increasing the balise spacing to 5 km would give a 6% capacity penalty which may well be acceptable in many applications. However the effect of misreading or faulty balises would need be taken into account.

Odometry error has little impact on headway capacity, but it becomes significant when features such as Automatic Train Operation (ATO), controlled station stopping and platform screen doors are considered.
4.2.4 Junctions

The impact of Level 3 on junction throughput is an important factor in considering overall route capacity, and the choice of architecture for Level 3 may affect throughput, depending on whether or not track based train detection is applied.

Junctions come in an enormous number of configurations and the capacity impact of Level 3 will be different in each case. The modelling work carried out has investigated the impact of Level 3 on a simple converging junction, varying a number of key parameters in order to determine sensitivity. Diverging junctions have a lesser impact on capacity. More complex junctions will be affected differently, but the order of benefit or disbenefit should be similar to the simple case.

The modelling shows that there is a significant benefit of Level 3 over Level 2. The benefit increases with increasing speed differential between the main and converging lines. This is because the model uses a fixed block length for Level 2 on both lines, which is sub-optimal for the reduced approach speed, so the train behind is more affected in Level 2 than it is in Level 3. This apparent benefit of Level 3 could be normalised (at extra cost) by reducing the Level 2 block length to match the reduced speed of approach.

However, at the approach to a diverging junction the Level 2 block layout cannot be optimised for both the main and diverging routes, whereas Level 3 will deliver the optimum for both. This appears to be a benefit of Level 3 which Level 2 cannot match. Both Level 2 and Level 3 have the advantage of not requiring approach locking because of their inherent speed supervision function.

A further improvement can be achieved by using a “hybrid” Level 3, which uses track based train detection to release the route when the tail of a train has cleared it, rather than depending on the reported position from the train, which has to allow for uncertainty. This “hybrid” version is equivalent to the “Median” architecture described in section 4.1.2.2. The benefit is highest for short junctions with high throughput.

These benefits have a wide range depending on the assumptions made on speed through the points in reverse, the “length” of the junction (from the point beyond which the movement authority cannot be advanced without setting and locking the junction, to the clearance point downstream) and the route setting time.

A series of modelling runs were carried out to illustrate the difference in technical headway between converging junctions with various geometries, in Level 2, Level 3 “pure” and Level 3 “hybrid”. Table 7 summarises the results.

In every case the speed limit through normal position is 120 km/h and the route setting time is 10 seconds.

<table>
<thead>
<tr>
<th>Turnout speed</th>
<th>Junction Length</th>
<th>Technical Capacity – Trains per Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Level 2</td>
</tr>
<tr>
<td>40 km/h</td>
<td>102m</td>
<td>26.0</td>
</tr>
<tr>
<td>80 km/h</td>
<td>148m</td>
<td>31.0</td>
</tr>
<tr>
<td>120 km/h</td>
<td>187m</td>
<td>36.8</td>
</tr>
</tbody>
</table>

The conclusion of this work is that Level 3 has specific benefits for junctions. These may be of value in the overall context of a route, but this will have to be considered on a case by case basis. The improvement in capacity is enhanced if a “hybrid” system with track.
based train detection is used to release the route after the tail of a train has left the junction. This is equivalent to the “Median” architecture proposed in section 4.1.2.2, but with the important rider that the RBC will need to respond to the track based train detection in preference to the train derived location data in this specific case. Care will be needed in writing the functional specification in this area.

4.2.5 **Scenario Case Study**

Practical capacity on a real route is measured in train paths per hour (TPPH) rather than in terms of headway on a section of line or through a junction. The time required for a train path, for a defined railway layout and signalling system, depends on a number of factors including:

- The run time from entry to exit of the railway section.
- The characteristics of the preceding train including performance, length and stopping pattern.
- The characteristics of the following train including performance, length and stopping pattern.

The most effective use of the railway capacity is obtained when all train paths are identical. If the Train paths are different then an addition is required depending on the preceding train type.

Practical capacity is delivered by train paths over a complete route. Unfortunately modelling of a complete route is beyond the scope of this study. Practical capacity has therefore been assessed by modelling a key route section and then extrapolating the results to route level using judgement based on domain knowledge.

The application case study is based on the Lea Valley Main Line as depicted in Figure 9.

![Figure 9. Lea Valley Main Line](image-url)

The modelling used three types of service – a non-stop Stansted to Liverpool Street comprised of a modern electric high speed trainset, a semi-fast service with modern
outer EMU characteristics stopping at Cheshunt and Broxbourne and a 775m freight train hauled by a Class 90. The detailed results of this modelling are provided in Appendix D.

As expected, the actual capacity varies considerably with the service pattern. An assessment of the impact of Level 3 on the practical capacity of this route section has been made by taking the following theoretical model timetable for a 2-hour period:

- Allow 1 freight train path preceded and followed by commuter trains.
- Fill the remaining capacity with sequences of one through path followed by 2 commuter paths.
- Derive the total number of train paths within the two hour period.

For this example we get:

- 4 aspect signalling allows 24 train paths in the 2 hour period.
- ERTMS Level 2 signalling allows 28 train paths in the 2 hour period.
- ERTMS Level 3 signalling allows 31 train paths in the 2 hour period.

This suggests that Level 3 can be a valuable tool for enhancing practical capacity through this kind of route section. However, it should noted that the real route capacity for the Lea Valley Main Line is constrained primarily by the variability of train stopping patterns on the twin track section between Cheshunt Junction and Hackney Downs and the need for all trains to stop at Tottenham Hale. It is unlikely that Level 3 would deliver a significant increase in train paths for this route overall, because the current timetable is not constrained by signalling.

4.2.6 Other Application Scenarios

The study also reviewed a number of other application scenarios on a qualitative basis. Diagrams for each scenario considered are included at Appendix E. Table 8 sets out the results of the reviews.

The capacity comparisons are based on an ERTMS Level 2 application using existing block lengths. The capacity of ERTMS Level 2 applications can be increased by reducing block lengths at the expense of increased trackside location equipment (axle counters or track circuits with associated interlocking equipment).
### Table 8. Scenarios - Capacity Implications for ERTMS Level 3
*(compared with ERTMS Level 2 with existing block lengths)*

<table>
<thead>
<tr>
<th>Route Type</th>
<th>Generic Level 3 Headway</th>
<th>Application Scenario</th>
<th>Practical Capacity Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Capacity Urban</td>
<td>ERTMS Level 3, moving block, has potential for an improvement of between 10% and 20% for passenger trains depending on the application specifics.</td>
<td>SW Main Line, Wimbledon – Esher</td>
<td>Route capacity would be significantly improved. Major constraints likely to be turnback and platforming at Waterloo, flat junction at Woking.</td>
</tr>
<tr>
<td>Fast(200 kph), Highly Utilised 4-track Main Line</td>
<td>In this application, the headway benefit of ERTMS Level 3, moving block, is about 20%. Introduction of freight train paths reduces this margin by 5% to 10% for each freight path.</td>
<td>WCML, Kings Langley to Tring</td>
<td>Route capacity may be marginally improved but infrastructure constraints remain.</td>
</tr>
<tr>
<td>Fast(200 kph), Highly Utilised 2-track Main Line</td>
<td>In this application, the headway benefit of ERTMS Level 3, moving block, is about 20%. Introduction of freight train paths reduces this margin by 5% to 10% for each freight path.</td>
<td>WCML, Preston to Lancaster</td>
<td>Route capacity may be marginally improved. Train performance differences and need to loop freight trains likely to be key drivers.</td>
</tr>
<tr>
<td>Regional Main Line</td>
<td>The impact of ERTMS Level 3 will be similar to that for high capacity urban lines as outlined above.</td>
<td>Fen Line, Manea to Peterborough</td>
<td>Route capacity does not appear to constrain timetable currently. Upgrade of the Felixstowe – Peterborough freight corridor may provide an opportunity.</td>
</tr>
<tr>
<td>Rural Route</td>
<td>Level 3 gives little or nothing on single track sections unless directional flighting is feasible. On two track sections the improvement over absolute block is very large.</td>
<td>Cumbrian Coast Line, Bootle to Workington</td>
<td>Capacity constrained by single track sections. Flighting may be of value in some cases. Theoretical increase on twin track sections unlikely to be of commercial value in this specific application but would be elsewhere (e.g. East Anglia)</td>
</tr>
</tbody>
</table>

#### 4.2.7 Comparison with UIC capacity evaluations

A study with broadly similar objectives has been carried out for the UIC [Reference "Compendium on ERTMS"]). This evaluated Level 1, Level 2 and Level 3 in three scenarios. The first was a high speed (300 km/h) main line, not covered in this work. The second ("Conventional Main Line") was a double track main line with 160 km/h operation, 3km block sections which corresponded approximately to the "Fast 2 track main line" scenario described above and the third ("Regional Line") was a single track main line with 80 km/h operation and crossing points at 20km intervals corresponding approximately to the "Rural route" scenario describe above. All three were modelled using an adaptation of the UIC 406 blocking time model. ETCS internal timing assumptions are not discussed.
The conclusions for the conventional main line are broadly parallel to those of this study. A 30% capacity gain for Level 3 over Level 2 is demonstrated. The figure is higher than that predicted in this study because of the long (3km) block sections used for Level 2. Optimising Level 2 block sections brings the Level 2 capacity within 4% of Level 3.

The conclusions for the Regional Line are superficially different from this study. A 60% increase in capacity is demonstrated by Level 3 compared with conventional signalling or Level 2. This is because the service pattern assumes random departures from either end, so that trains frequently follow each other through the single track sections, which they can do in Level 3 but not in Level 2. The scale of increase is clearly unrealistic for a real route (and implied as such in the study) but this is nevertheless a real effect which could be used for “flighting” trains in real circumstances – for example a stopping passenger train following a freight. This point has been included in the summary above.

The UIC study does not consider high capacity or absolute block scenarios.

### 4.2.8 Conclusions on Capacity

- With typical internal processing parameters drawn from current practice, and using moving block principles, ERTMS Level 3 can reduce technical headways compared with Level 2 (or MAS).
- Optimising block lengths can further increase ERTMS Level 2 capacity possibly to approach that obtainable by ERTMS Level 3, but at additional cost.
- ERTMS Level 3 performance can be enhanced by updating position report and movement authority update frequency.
- Odometry accuracy has little impact at main line speeds.
- GSM-R latency is critical.
- The highest capacity is delivered by a “hybrid” system which uses track based train detection at junctions to achieve route release, but train based location on approach.
- Level 3 can give practical capacity benefit in some urban high density applications and in some regional applications as a replacement for absolute block signalling. In most other scenarios route capacity is constrained by other factors and conventional signalling has already been optimised to match these constraints.
- Level 3 (in common with all other ERTMS Levels) could provide a basis for ATO, which has a further capacity-enhancing effect on high density routes.

### 4.3 Prospective benefits – Cost

#### 4.3.1 Cost Background

The costs of conventional signalling are driven by the extensive and complex infrastructure equipment fitted to the trackside and the fact that each implementation has to be tailored to the route section. Every signalling installation has very high “one-off” design costs. The interlocking and its technology is a very small part of the total. Network Rail employs a “Signalling Equivalent Unit“ method of estimating signalling costs, which is based on the historic costs of conventional signalling, described in document BP001 Issue 4 “Definition of Signalling Equivalent Units (SEU) and Volume Reporting”.

ERTMS Level 2 offers the prospect of a significant reduction in these costs. The prediction made by the National ERTMS Programme is that the infrastructure cost element may fall by around 40% through elimination of lineside signals and their
associated infrastructure. This estimate was summarised in a spreadsheet which was kindly made available by network Rail for this study. The Level 2 costs had been arrived at by examining the cost breakdown for an SEU for conventional signalling and estimating how each component of the SEU would change for a Level 2 implementation.

### 4.3.2 Cost Benefits of Level 3 - Generic

Level 3 deploys significantly less trackside equipment than Level 2 and can thus be expected to deliver an increased cost saving. It must be emphasised that, with no experience of Level 3 and very limited UK experience of Level 2 so far, any estimate of this saving is tentative. More information on Level 2 costs across Europe should be available within the next few months, when the UIC completes its work on the subject.

The cost saving achieved by Level 3 will depend on the system architecture adopted, which in turn drives the residual amount of trackside equipment. As set out elsewhere in this report, it is possible to envisage a system in which trackside equipment was reduced to point motors and detection only. The estimates in this section have been arrived at assuming a conservative approach, in which track based train detection is retained for junctions and crossings, with simplified signals at junctions and key stations retained to control movement of unfitted and failed trains.

To get an idea of the order of magnitude of cost savings that could arise, the work done by Network Rail for Level 2 costs was reviewed and a delta for Level 3 estimated. A discussion was held with the relevant experts from Network Rail to understand this work and the project team then undertook an exercise to estimate the further reduction in cost for an SEU between Level 2 and Level 3.

The work showed that a saving of around 25% could be tentatively expected over Level 2 costs and of around 50% over the cost for conventional MAS. The savings come mainly from the removal of train detection and the associated power, cabling, design and installation works that go with it.

### 4.3.3 Scenario Based Approach

The SEU based approach assumes that the fundamental cost drivers for a signalling installation remain the same, but the balance between the various cost elements changes. The number of SEUs in any particular installation is assumed to remain the same. In fact, Level 3 will reduce the number of SEUs substantially because a large number of physical block sections on the ground are eliminated. In order to provide a check on the SEU-based approach, one of the application scenarios (Cheshunt – Broxbourne) was reviewed and an estimate derived for the number of SEUs eliminated completely by Level 3, assuming the "median" architecture described in section 4.1.2.2 (retaining track based detection and simplified junction signals at crossovers and junctions). This suggested a saving of around 35% of the original number of SEUs, for a reasonably complex area. The remaining SEUs would, of course, be reduced in scope to roughly the same extent as Level 2 because of the elimination of visual signals. An overall reduction in cost in the order of 50% appears approximately correct for this area. Extending the limits of the review to the boundaries of the signalling information available increased the saving substantially, because very much more plain line was included. A saving of over 50% of the original SEU count appeared to be achievable. This suggests that the 50% cost saving arrived at through the SEU estimating process may be conservative for many routes.

The savings to be expected will depend first, on the amount of plain line and the signalled headway of that plain line, with higher capacity routes having a higher saving, and second, on the number of point ends per kilometre of line. High capacity double track main lines with long plain line sections and few level crossings will show the highest saving, and low capacity rural and regional routes the least. In this context the
Swedish Regional ERTMS project has published an estimate of costs which it claims are 50% of the costs of conventional signalling, on a rural/regional route.

### 4.3.4 Cost Increases for Level 3

The above cost savings are for the wayside signalling infrastructure only. Level 3 will involve some increases in cost which will offset these.

The most expensive addition for Level 3 is likely to be high dependability communications. If implemented in GSM-R this would almost certainly need major additions to the network which is just being rolled out. However, it is suggested that within the timescales for Level 3, it is likely that a new communications infrastructure will be rolled out on the GSM-R masts and cell structure, and it may be that Level 3 could be accommodated on this with little extra cost.

The addition of a train integrity subsystem has to be allowed for. The cost of this on new trains should be small – no more than 5% extra on top of the Level 2 equipment. The cost on retrofit multiple unit trains should be similar in percentage terms. On locomotive hauled passenger trains it may be significantly more, if it involves fitting all vehicles with a train wired system. For freight trains train wired systems are impractical and a new onboard subsystem will be needed. End of train devices on sale in North America cost in the order of $5K to $15K, but a system to support safe train separation is likely to be considerably more expensive.

### 4.3.5 Cost – Next Steps

Although Level 3 is a direct development from Level 2, the effect on the railway system is transformational. Level 3 takes the railway from a distributed infrastructure based control system, tailored in every application to the track layout and to the trains that use it, to a software based system based on intelligence on the trains. This transformation makes it feasible to develop a much more modular approach to signalling design. The system will be self adapting to layout and to varying loads and services and offers the opportunity for further efficiencies in design, construction, commissioning and modification. It is therefore likely that the infrastructure cost estimates presented are conservative. A fresh bottom up costing exercise should be carried out once time and supply industry involvement allow.

### 4.4 Other Benefits

In addition to cost and capacity, ERTMS Level 3 has a number of other potential benefits which should be considered in any business based justification for its deployment.

#### 4.4.1 Flexibility

ERTMS Level 3 has a number of benefits in the area of flexibility. Level 2 (without lineside signals) decouples block design from train performance and signal sighting constraints, and to that extent makes the design of the signalling system less application specific. Level 3 goes further, and is capable of eliminating block design altogether.

The design of the signalling for a specific application area using ERTMS Level 3 would need to consider only the maximum number of trains in an area, which influences the number of RBCs needed, and geographic matching of track based train detection at junctions to the RBC route map. All other route characteristics (gradient, line speed, speed limits) are set as application parameters in the route database. In similar CBTC systems, "un-allowed zones" are coded into the software to create areas within which a train is not stopped, avoiding blocking of junctions, level crossings etc.

This flexibility supports a modular approach to signalling and the increased use of automation in signalling design, both of which should emerge as reduced costs of
application and both of which are already objectives of Network Rail’s “modular signalling” initiative.

Additionally, the application design is not linked either to the type of train planned for the route or to the planned headway, other than as a consideration for the number of RBCs required. Enhancements can therefore be made at low cost. Addition of junctions and connections should also be considerably cheaper than with conventional systems.

A Level 3 system is also more flexible in operation. It is inherently self-optimising and can cater (for example) for slower trains at closer headways in the peak and faster trains at longer headways off-peak, without additional infrastructure cost.

A “virtual block” approach would lose little of the flexibility benefit, provided that the blocks are truly virtual. Coupling the virtual blocks to extensive lineside signs at block boundaries would, however, significantly reduce the benefit by increasing the cost of change.

4.4.2 Maintainability

The reduction in trackside equipment resulting directly from Level 3 will improve in maintainability and reduce operating cost and disruptive possessions of the railway. It has not been possible to quantify this during the study as no baseline operating cost figures were available for UK conventional signalling.

ERTMS Levels 2 and 3 also have indirect benefits to the maintainability of the railway more generally. Level 2 can form the basis of a “virtual possession” regime. Trains are kept out of work areas through application by the signaller of exclusion zones, into which a movement authority cannot be extended. Temporary speed restrictions on lines close to work sites can be enforced by the system. These features should be able to support an increase in efficiency of use of engineering hours, and also possibly to create some new situations where work in partial closure conditions is feasible. Safety should also be enhanced.

The relative independence of Level 3 from infrastructure equipment means that it will be easier to keep the train control system operational to deliver these benefits during partial shutdowns of wayside equipment. For the majority of trackside works the Level 3 system will be available.

The flexibility of Level 3 also helps during partial closures. Trains could be run at lower speed and higher capacity on a single pair of lines during partial closure of a four track railway. Bidirectional operation and flighting of trains through temporary single line sections will be easy to implement. When work is needed on the train control system itself, degraded operation is easier to arrange. For example, the system could continue to operate during planned isolation of track based detection at a junction, using only the onboard train location function with the junction clipped and scotched, effectively turning it back into plain line. A temporary speed restriction could be applied, but there should be little reduction in capacity.

4.4.3 Level Crossings

ERTMS has potential benefits in relation to level crossings. These are not specific to Level 3, but have yet to be implemented in Level 2 so will be covered briefly here.

The essential issue at level crossings is to provide an economic means of safely controlling railway and road traffic without unduly disrupting either. Additional safety features for any crossing, whether provided by ERTMS or not, are subject to risk analysis and economic justification. Level crossings are now the highest single risk factor for railway passengers and employees, but represent a vanishingly small proportion of road safety risk. Almost all investment in level crossing safety is therefore met from railway funds.
In terms of their interaction with the train movement control system, UK level crossings can be categorised into four types:

- User worked crossings with no interaction.
- User worked crossings under telephone control from the signaller.
- Automatic train-activated crossings (AHBs, AOBs etc).
- Fully interlocked crossings (CCTV or directly supervised).

The fully interlocked crossing is the safety ideal, but is very costly and in some circumstances very disruptive to road traffic. Automatic train activated crossings are cheaper, but there is no protection against accidental or deliberate obstruction of the crossing, and the combination of variable train speed with fixed infrastructure based triggering causes variable warning times. The triggering location has to be set as a compromise to provide adequate warning time for fast trains without excessive waiting for slow ones.

Consistent warning times at automatic crossings can be delivered by more sophisticated infrastructure based triggering equipment. However ERTMS Levels 2 and 3 both provide precise train location and speed information to the RBC which could be used as the basis of a constant warning time system for automatic crossings, avoiding the need for any infrastructure based triggering equipment. A backup system for unfitted trains would be needed.

Obstruction detection is another technology which could potentially improve protection at automatic crossings, but a way of transmitting the information to the train needs to be found without linking it into the interlocking, so that the cost and timing benefits of an automatic crossing are preserved. ERTMS Levels 2 and 3 could provide a way of doing this. A conditional speed restriction could be applied at the crossing at a speed calculated to minimise the probability of derailment in the event of a collision, with the speed restriction being cleared once the barriers are down and the crossing proved clear by the obstruction detectors. A combination of the constant warning time and obstruction detection technology would effectively provide a new variety of automatic crossing with reduced risk of road user disobedience to the warning signs and almost complete protection of railway passengers and employees. Neither of these suggestions is specific to Level 3. What is important is that the next generation of ERTMS provides for intelligent control of level crossings.

4.5 Risks

The following section summarises the risks that have been identified, relating to the delivery of the potential business benefits of ERTMS Level 3. Appendix A contains the risk log created during the project from which this summary is derived.

4.5.1 Safety

ERTMS Levels 1 and 2 provide the set of Automatic Train Protection functions which, in combination with the route setting and locking functions associated with the interlocking and the train detection functions associated with track circuits or axle counters, reduce to a very low level the probability of train to train collision or derailment due to overspeeding.

The change to train based train location and train integrity has clear implications for the balance of system safety within the control system design. In Level 3 there is a greater dependence on the integrity of onboard data entered by the driver, primarily train length and (in the case of freight) train loading.

The track based system which Level 3 makes obsolete is very well established both in terms of the technology and the inclusion of mitigating elements (for example, track
circuit actuators) within the system to overcome deficiencies. It is also very deeply embedded within the operating philosophy and rules of the main line railway. Although there is no reason to doubt that the development of Level 3 system technology can fairly rapidly reach a state where it is compliant with the appropriate safety standards, it should not be assumed that this means that there would be no safety risks associated with the transition.

The industry associates these risks primarily with block-less ("moving block") operation and the driver perspective. However discussions with some experienced operations personnel and drivers suggest that these concerns may be overstated. In any case they do not impact safety because in normal operation train movement will be protected by the system.

The signaller perspective however may be more significant. Some further work is needed to determine whether this might cause confusion for signalers used to the conventional arrangement, and whether this might be a source of errors in high stress situations.

It would be entirely possible to configure the system to operate in “virtual block” mode and in normal operation this would be indistinguishable from Level 2.

A further risk is associated with the “simple” system architecture described in section 4.1.2.1. With this architecture, all track based detection is removed and deadlocking of points is achieved through the RBC. Points are locked against the position of the train reported by the onboard equipment, rather than locally by track based detection. Although the RBC and the onboard equipment will all achieve SIL4, this is still a point of weakness and further analysis would be needed to ensure that the approach was acceptable. It is notable that although early, very simple implementations of the most mature and successful blockless metro system, SELTRAC, had deadlocking executed through the VCC (RBC equivalent), later versions including that installed on Docklands Light Railway have local deadlocking carried out by a “station controller”.

An issue which causes considerable concern in North America is the elimination, in Level 3, of the ability of track circuits to detect broken rails. In the UK the main line deployment of axle counters has already accustomed the industry to the mitigating steps needed, primarily based on enhanced inspection from moving trains. These principles may need to be applied to Level 3 routes if (as seems likely) the long block approach proposed uses axle counters.

Further issues from a safety perspective are those associated with the operation of the system in partial failure conditions.

4.5.2 Operational Risk

The operational risk associated with Level 3 should be considered from the perspective of the two parties most involved in train movement control, the driver and the signaller.

The elimination of lineside signals is the first major operational issue. The intention of the UK National Implementation Plan is to achieve this with ERTMS Level 2, and it will therefore not be considered further here, although it is very significant from an operational perspective.

The elimination of track based train detection on plain line means that the Level 3 system is inherently blockless ("moving block"), although a practical system would have a level of granularity in its track data model which will result in the train movement being tracked in fixed minimum increments. In concept, the simplest implementation would not constrain the issuing of a movement authority to any point on the track, as determined by the progress of a preceding train, except at junctions and level crossings, where “Un-allowed zones” within which an end of authority cannot be placed would be needed to avoid trains creating an obstruction at the end of a movement. The RBC would calculate whether a particular train, given its length, would infringe an un-allowed zone if
stopped at the end of its next movement authority. If so then the movement authority would be cut back to short of the junction or crossing – so movement authorities through a junction would only be issued when the train can clear it. This might have some effect on capacity in certain circumstances.

It has been suggested that the elimination of both block markers and signals is in itself a significant risk, in that the driver loses a major set of reference markers which support the route knowledge which is essential to controlling traction and braking so that the train runs to time and stops accurately at stations. Route knowledge is also used in abnormal and degraded conditions to support accurate reporting of the location of incidents. Both of these functions could, however, be supported by distance markers along the route, at regular distance from origin and (if needed) also in motorway exit “countdown” style on the approach to stations.

From the driver perspective, a moving block system differs from fixed block working in that a train may be given a supervised movement authority to any point on the route. This may cause performance problems because the driver may be unfamiliar with stopping the train at that location and starting it again, as compared with a fixed block system where stops occur always at the same points on the line.

This could be overcome by implementing the system as “virtual block”, ensuring that the presentation to the driver would be identical with Level 2.

From the signaler perspective also a “virtual block” system has advantages in that it could be configured to look the same as a Level 2 or MAS system, with virtual block occupancy displayed on a VDU screen as the train moves along, as compared with the “moving block” system where the setting of routes from the control centre and the display of train location is significantly different. Instead of block occupancy being displayed, trains are shown as icons moving along the track, with an indication through colour change of the length of track ahead which has been seized for that train.

The reaction of the system during partial failure also needs to be considered from an operational perspective, and the choice of architecture for the system has significant implications.

A failure of the radio communications system for a significant area would be catastrophic operationally for a railway fitted with the “simple” architecture referred to in section 4.1.2.1. With no track based train detection, trains in the affected area would have to be operated either by flag or by voice control over operational radio (assuming diversity of communications), with a backup tracking system in the control centre.

The “complex” architecture referred to in section 4.1.2.3 provides a backup tracking and signalling system, which would very largely mitigate against such a failure. However, apart from the cost of such duplication, there are also significant operational disadvantages. Drivers would need to be familiar with the route in both normal and backup mode. Fixed block signals with a moving block overlay would cause particular complexity. In order to avoid the driver of a fitted train with a valid movement authority in moving block mode having to pass a fixed block signal at danger, the fixed block signalling might have to be designed to display an additional “pass” aspect when a moving block fitted train approached. Such additional aspects are common in metro systems, although it may be possible to use conventional aspects in an unconventional way, as is planned for the Thameslink Level 2 system.

A less catastrophic scenario is the failure of the onboard equipment or communications system for a single train. The train tracking system would then be uncertain as to its location, although it could be assumed to be between its last reported position and its limit of movement authority. Safe further movement of the train in the “simple” architecture would depend on operational procedure. The “median” architecture would enable the train to be tracked and controlled through the long block system, initially under voice procedure, but then under control of the simplified signalling. From an operational perspective, this would present a substantially lower level of operational risk.
Further consideration needs to be given to the system architecture from an operational risk perspective. The effect of a wide area communications failure with a Level 3 system on an intensively used railway is so dire that communications system redundancy should be seen as essential. In current railway technology this could be done by overlapping GSM-R cells, reducing the risk of common mode failures by duplicating the FTN network (this should already be in place using the ring configuration) and duplicating elements such as the MSC. Future railway communications strategy should consider the use of diverse systems to achieve a better effect, based in all probability on the ability to roam onto commercial networks. In the long term ERTMS will be converted to operate in a packet switched environment and this should offer considerably more freedom in this respect.

The other major operational risk issue which needs to be addressed is dependence on driver route knowledge. ERTMS at any level reduces the criticality of driver route knowledge in terms of compliance with a movement authority. However, route knowledge remains essential to timetable compliance and station stopping. Route knowledge is also essential in degraded and emergency situations, either to report current train location or the location of an incident, and the implementation of Level 3 seems likely to make this more challenging, in that stop locations at the end of a movement authority are less predictable.

In the short term this problem can be overcome by retaining lineside distance and station approach markers. However in the longer term thought should be given to providing a supplementary train location system based on commercial GPS satellite navigation, which can give a reasonably accurate location at all times, and could readily be configured to show key lineside features. The ultimate solution to this problem may lie in Automatic Train Operation (ATO), covered in section 4.8.2.

**4.5.3 Development Risk**

The development risk associated with Level 3 needs to be considered in terms of the incremental risk above and beyond Level 2.

ERTMS Level 2 has a long development history, following its pilot application in Switzerland in 2001-2003 and is approaching stability and maturity in its implementations across Europe. The main development risk remaining is in the application of national operational rules at the boundary with national signalling systems.

The changes to the ETCS subsystem implicit in Level 3 could be presented as fairly minor, particularly in terms of the onboard equipment. However, in order to deliver cost and capacity benefit they may require radical changes to the architecture of the railway train movement control system as a whole. It is in this area that the development risk lies.

A successful Level 3 system application to a mixed traffic main line railway will need to be very clearly thought through in terms of the operational rule-set and control principles that will be used, focusing on the compromises between visionary change (in order to deliver the promised benefits) and current railway rules and principles (in order to achieve a gradual transition). Fudging these compromises at the development stage will result in additional cost, delay and failure to meet expectations. The opportunity to create a consistent ruleset across participating Member States should not be lost.

Freight train integrity and train length validation functions are significant individual development risks and these are covered in section 4.5.6.

The other changes to functionality between Level 2 and Level 3 appear limited and as a result it tends to be assumed that the development risk is small. However, this may not prove to be true. The transition from track based to train based tracking is quite fundamental, as is the increase in dependence on the communications system. In addition, the “standard” ETCS onboard equipment may be inadequate to support the
Level 3 train location requirement in terms of its dependability. Plans for enhancement of the ETCS onboard equipment should take Level 3 into account.

The desire to reduce costs is currently driving ERTMS towards an increase in the modularity of systems and the standardisation of interfaces, with the intention of widening competition. The “Open ETCS” initiative is an example of this, as are the continuing efforts to standardise the RBC to RBC and RBC to interlocking interfaces.

These initiatives are inconsistent with the need for integration implied by Level 3 in one main area. The functional split between RBC and interlocking is a very significant issue, with two very different views emerging. In the more radical view it is seen as desirable to integrate all train tracking functions into the RBC, leaving the interlocking as a “junction controller” which simply sets and locks routes when called upon. In this view any cross-referencing between train based and track derived train location would be resolved in the RBC. In the more conservative view, the RBC is seen (even in Level 3) as a slave to the interlocking, acting as an aspect controller and feeding train location to the interlocking as virtual block occupancy. In this second view it is suggested that the signalling principles and operational rules can stay the same as for Level 2.

The view from suppliers is mixed. Experience from CBTC moving block systems suggests that the radical approach is more successful in terms of development of a base product. Train separation is managed on the basis of direct algebraic processing of absolute position reports rather than through Boolean logic which increases in complexity and processing overhead as capacity increases. However there is also evidence that adaptation of systems of this kind to deliver conventionally derived signalling principles is difficult. Other suppliers have stated openly that they have a very large investment in interlocking products and wish to go on using them as long as possible, but the need to track train position within both RBC and interlocking according to very different principles and keep them in lock-step is a development risk in itself.

It seems that the first view is more likely to deliver the prospective benefits of Level 3 because the system can be simpler. However the second should be easier from the migration perspective. It is not yet clear which is more desirable.

What is clear is that an integrated approach is needed to the development of Level 3 and that the drive for modularity and standardised interfaces might frustrate the need to optimise the system if applied too early. Equally, the imposition of a procurement strategy which separates the interlocking from the RBC too early in the development cycle might prove a major problem.

4.5.4 Industry Structural and Cultural Risks

The structure of the British main line railway industry does not readily support technological innovation and change. This is particularly true where the change is at railway system level, so that the costs and benefits fall on different sides of the track to train interface and even more so where there is a change (or a perceived change) in the balance of safety mitigation.

ERTMS Level 3 represents an extremely difficult change from this perspective, even more so than Level 2. Both deliver benefits primarily in terms of infrastructure cost savings, with prospective capacity benefits which fall to the infrastructure manager and government. Both require the addition of equipment to the train which, whilst it performs a safety function and therefore needs to be carefully controlled and maintained, gives little net safety benefit compared with existing equipment. Level 3, in addition, transfers most of the responsibility for assuring train length and train integrity to the operator. This last will be a particular issue for freight. Operators may resist the transfer of this responsibility unless compensated or incentivised.

The industry has a very poor view of “moving block” systems, derived from the failure of West Coast TCS and the Jubilee Line Extension control system in the 1990s. This may
cause Level 3 to be opposed in principle (although this has not been evident during this study) or more likely to be guided firmly into the “virtual block” path. This may or may not be the optimum way forward, and more work is needed on costs and benefits before this important decision is made.

It is vital that the operational concept for Level 3 is developed very early in the process, driven by business and safety needs in balance and maintained through simulation, pilot and rollout phases. The industry consensus process for standards and rules makes this very difficult. The process is very slow and tends to drive conservative decisions at low levels which are not linked to economic objectives and which tend to cause drift back towards what is well known.

These problems are soluble given sufficient vision and leadership at railway system level, but as currently structured this would require direct co-operation between DfT and Network Rail, with sufficient funding allocated, an operator committed financially and contractually to support a Level 3 project over a period of 5 to 10 years. In order to achieve the scale of change needed to achieve real benefits it would also probably be necessary to “ring fence” a discrete section of railway and allocate to it an independent operations development team reporting directly to a senior level safety group, rather than through the current standards process. All of this will only happen if there is a very clear view of the potential benefits and a stable industry over a lengthy period.

The question of incentives also needs to be considered. Reductions in the cost of infrastructure should in the end result in a reduction in track access charges. In addition, with Level 3 a train which reports its own location and train length rapidly and accurately potentially occupies less track space than one that does not. Incentives to adopt (or at least support) the transition to Level 3 need to be visibly linked to the envisaged benefits and within franchise timescales so that they are considered seriously by operators. This is primarily a matter for ORR.

4.5.5 Low Cost Train Fit

ERTMS Level 2 and Level 3 both suffer from the same problem. Once all trains using a route are fitted, the line can be resignedalled in ERTMS taking full benefit of the opportunity to reduce lineside equipment, enhance capacity and simplify the interlocking logic. Until all trains using a route are fitted, the only way in which ERTMS can be rolled out is using a hybrid system which includes both lineside and cab signalling. This increases cost and complexity and impacts both operability and reliability.

Retrofitting trains with ERTMS is at least double the cost of fitting from new and is increasingly less economic the older the train. Furthermore, the costs of fit from new remain at about three times the industry’s expectations. Unfortunately the usage of the UK main line network means that for any particular route section where ERTMS is in prospect, there is usually a mixed fleet of new and old trains which need to be fitted. Much effort has gone into developing alternative rollout schemes which minimise retrofit whilst maintaining the principle of fitting the infrastructure when the existing signalling needs renewal. The situation is made more complex because of the semi-privatised nature of the industry, where franchisees are (at least in theory) free to select their train fleet on an economic basis from those on offer by the train owners. Any rollout plan is therefore likely to keep changing unless DfT is prepared to be directive in terms of the rolling stock aspects, which has not been the case in the past.

The best way to resolve this conundrum is to make retrofitting trains with ERTMS (and ideally fitting from new as well) very much cheaper. If the costs could be reduced from the order of £500K per train to £50K per train, the economics of ERTMS rollout would be transformed.

Level 3 has only a minor impact in this area. The need to add onboard train integrity will increase rather than reduce the additional costs associated with retrofit, but only to a small extent.
Although a breakdown is not currently available, the Level 2 retrofit costs appear to be high in all areas. The need to fit the DMI into an existing cab and the odometry and balise reader into the underframe and running gear are clearly major issues. The extent of cabling required, the size of the electronics rack and the capacity of power supply required are also very significant.

It seems clear that no account of retrofit difficulty and cost has been taken by suppliers in designing the ETCS onboard equipment. Radical solutions may have to be sought. For the North American Joint PTC initiative, the system architecture was specifically aimed at minimising retrofit cost by reducing the size of equipment, eliminating intervention on the underframe and minimising cabling. Although the ETCS system architecture is not fully consistent with this, some key lessons could be learned.

In order to allow freedom to minimise onboard cost, the current ETCS specification may need to be relaxed or changed in some areas in order to allow alternative ways of delivering interoperability, at least for domestic rolling stock. Retrofit cost information needs to be gathered from all available sources and used to inform a re-engineered onboard solution. Some stakeholders have argued strongly that a standardised approach around the current specifications will ultimately deliver reduced cost, but there is little evidence of this, and the difficulties created by the current industry products are obvious.

A focussed independent feasibility study in this area, perhaps sponsored through the UIC, is a logical next step at European level. Failing this, some useful work could be carried out in the UK by the National ERTMS team, building on preparatory work carried out already.

4.5.6 Train Integrity and Train Length.

One of the key issues identified for ERTMS Level 3 (as for other systems using train based train location) is the need to ensure that a divided train is protected against collision. Track based systems do this as an inherent function based on block occupancy (a detached part of a train continues to occupy a track circuit or axle counter block). Train based systems must ensure that the integrity of a train is reliably detected so that a following train can be stopped if the train in front divides.

Closely associated with this issue is the need to assure train length. Although train length is entered by the driver in Level 2 systems, the criticality in Level 3 is increased because the system uses it to determine the safe location of the rear end of the train, and therefore the acceptable limit of a movement authority for the following train.

New designs of passenger rolling stock, designed for use with Level 3, should be capable of both validating train length information input by the driver and confirming their own train integrity at minimal additional cost, using information either hard wired into the EVC or transmitted from the Train Management System. En route coupling and uncoupling will present some issues, but these should be capable of solution through a combination of careful operational procedure checked by onboard train intelligence. This may require some changes to ETCS to achieve, particularly in validating driver data entry and in transmitting en route changes to the RBC.

Train integrity is much more of an issue for freight and there are widely differing views between various industry stakeholders and suppliers about the scale of the problem and the feasibility of a solution. A train wired solution is not practical for freight, so other ideas must be considered. All modern freight trains have a continuous brake which is automatically applied if the train divides and it has been suggested that this can provide all that is needed. Experience from North America with long freight trains suggests that although an intelligent brake controller which monitors brake pipe pressure and flow can provide a train integrity signal, the dependability and response time is inadequate to support vital train separation. Systems which monitor the brake pressure at the last vehicle in the train are in use, and design work has been carried out on a system which
combines this with a method of measuring the distance from locomotive to rear of train using radio propagation techniques. This solution was considered for the Swedish Regional ERTMS, but not implemented because the low level of freight traffic did not justify it.

Validation of train length for locomotive hauled trains is also a key issue. The West Coast project in the 1990s developed the concept of a fixed train length measuring device based on Doppler radar to carry out this function, to be deployed at entry points into the Level 3 network from terminals and sidings. A trainborne solution would be preferably for cost reasons, preferably combined with the train integrity device. The radio propagation technique described above would be capable of estimating train length. Solutions based on an independent check in the control office, similar in principle to a takeoff weight check for an aircraft, are also feasible.

It is perfectly possible to conceive of a railway which operates at high capacity in Level 3 for passenger trains which can confirm their own length and integrity, and at much lower capacity using Level 2 (or even simplified conventional signalling) for freight or other trains which cannot. Candidate Architecture 2 (see section 4.1.2.2 of this report) could support exactly this kind of operation. This could be suitable for rural passenger and high capacity urban railways where freight is very occasional and often associated only with railway maintenance. Wide scale rollout of Level 3 will require a solution to this problem, and this appears entirely feasible given commitment and development funding. The most economical solution is likely to be one in which overall safety is assured through a combination of a lower integrity (SIL2 or lower) onboard system combined with infrastructure-based protection of the movement of the trailing end of the train. For example, in a radio based onboard system in which the locomotive supervises that the train end is still attached, loss of radio communication would be reported to the RBC, which would freeze the movement authority of a following train based on the last known position of the train rear. Whilst not complex or difficult in principle, a standard operational and reporting protocol would need to be developed to cover this. A prerequisite to getting this right is an analysis to derive the functional and safety requirements for train integrity and length in an ERTMS Level 3 context.

Older designs of passenger rolling stock (including locomotive hauled) could be retrofitted with wired systems similar to new trains. Equally they could be fitted with a lower integrity, supervised system as for freight.

**4.6 Supplier Capability**

The availability of products, or the willingness of suppliers to develop them, is an important factor in developing a picture for the opportunities for Level 3 on the UK railway. The plans of suppliers will respond to the market but equally influence its development.

To get a picture of the current thinking within the railway supply industry, a short questionnaire was sent to a selected sample of suppliers, both from Europe (UNISIG) and elsewhere. This was supplemented with interviews in some cases. In addition, a presentation was made to the Railway Industry Association signalling suppliers group (RIASIG) and feedback sought. As the verbatim results contain some potentially confidential information they are not appended to this report but have been provided separately to DfT.

Input was received from three suppliers who are members of UNISIG, Alstom, Bombardier and Invensys. Hitachi and Lockheed Martin were also included to get some wider input, albeit from companies with an interest in the European sector. The responses were comprehensive and in some cases indicated that considerable thought has gone into Level 3.

Their input can be summarised as follows:
• The availability of products and experience from Metro and CBTC systems very significantly reduces the risk in developing Level 3 products.

• Standards at the European level are needed but this is not perceived as a significant step once the Level 2 baseline is complete as the Level 3 development is mostly with trackside sub systems.

• The choice between virtual blocks and moving block is significant with suppliers generally viewing the former as more straightforward to realise and delivering the capacity improvement.

• The main benefits of Level 3 come from cost saving as Level 2 can, for a price, be engineered to virtually equal the useable capacity benefit.

• Most suppliers have an intention to develop Level 3; some have thought about this in developing their current product range.

• The only ERTMS Level 3 solution at present is the Regional one being implemented in Sweden.

• Fallback systems will greatly complicate matters and reduce or eliminate any cost benefits.

• There could be benefit in simplifying the change by considering using Level 3 in plain line areas and retaining train detection over junction layouts.

• Train integrity is soluble but the requirements need to be carefully worked out before choosing solutions.

• The route to ERTMS Level 3 is through experience with Level 2 followed by regional type Level 3 environments. There is a strong view that real pilot projects are vital to expose all the issues.

• European railways are conservative and the main driver for Level 3 type solutions may well come from outside Europe. Level 3 could be in service in some countries within a decade but one commented that given the slow progress to date in the UK, they doubted it would be in the UK.

• The FRA requirement for fitting of PTC to Class 1 and passenger railroads in the USA by 2015 may have useable technical 'spin off', but as currently planned PTC will be an overlay system similar in concept to Level 2.

• A Japanese pilot of a similar system to an urban Level 3 on an 18km length of line is planned for 2011.

Suppliers were not asked to give any views at this stage about resource and expertise availability to undertake further product and system development beyond the current Level 2 baseline, although it was apparent from the responses that some work has been done. This issue of resource and expertise and the prioritisation of its use apply equally to customer and supplier and need to have further serious consideration before embarking on significant work related to Level 3.

When considering how to take forward any development of ERTMS Level 3, it will be necessary to consider a number of issues related to procurement and supply. The costs and risks involved suggest that a consortium of customers could be desirable; the potential for this is considered in the European section of this report. Common and simple functional requirements from the customer base will reduce supplier development costs and make it more likely that a competitive supply of systems could be obtained.

There is also the opportunity to address again the issue of more open systems, both at the interface between infrastructure sub-systems and more radically in the provision of standard software and target hardware. It is only at the point of significant change that the possibility arises for a different approach to system development and procurement and this could be one of those moments. However, an open systems strategy needs to be very carefully thought through. For example it seems most unlikely that a UK
customer would take the responsibility for integrating software and hardware in a vital system.

The customer may also wish to take this opportunity to make sure that any further developments take ETCS away from dependencies on GSM-R as a bearer and into the realm of Internet Protocol and packet switching, thus future proofing (so far as practical) the use of communications bearers. It may well be worth examining whether other technology lock ins can be designed out at this stage to benefit the long term vision and long term system support and ownership.

Metro CBTC systems are identical in concept to ERTMS Level 3. All are distance to go/ATP systems relying on track to train transmission to convey movement authorities and report train position. The transmission mediums may vary, but the fundamentals are at root the same. The key differentiator for ERTMS is the standardised ETCS air gap interface which is designed to create supplier interoperability (and therefore a non-proprietary solution). This is a key advantage for ERTMS compared with metro CBTC systems which are all proprietary.

The downside of the standardised interface, when considered for application to conventional routes, is that ERTMS product development to date has been focused on safety and performance at high speed rather than high capacity or low cost. Future ERTMS development needs to accommodate both solutions with technical performance characteristics equal to the best CBTC and solutions which deliver low cost (particularly onboard cost). If this can be achieved, interoperability between those parts of the network requiring high performance and those where cost is dominant will be assured. Although this issue is not specific to Level 3, the potential for increased capacity that Level 3 delivers will bring it to the fore.

4.7 International Experience and Co-operation Options

The experience and plans of other railways in Europe are important in developing a picture of the opportunities for Level 3 on the UK railway. These plans will influence the content of international standards, development risk and timescales and the supply market. They also offer the opportunity to learn from others’ experience.

To get a picture of the current thinking within European railways, a short questionnaire was sent to members of the ERTMS Users Group, facilitated by Network Rail. This was supplemented with information already collated in the latest version of the Network Rail ERTMS ‘European Report’ dated 03/03/10 and some informal contacts.

Information has been collated from Netherlands (Prorail), France (RFF), Switzerland (SBB), Italy (RFI), Germany (Deutsche Bahn), Spain (ADIF), Sweden (Banverket) and Denmark (Banedanmark); see Appendix B.1 for a digest of the responses.

The results fall into 3 groups:

1. No interest at all in Level 3 development (Italy and Spain)
2. See the potential for secondary lines applications of Level 3 like systems (Switzerland) and some are actively pursuing (Sweden) or planning (France)
3. See Level 3 as an important future step for dealing with capacity improvement and/or cost reduction on the core network. (Netherlands, Switzerland, probably Germany)

For those interested in regional applications, as the UK now appears to be, the Swedish implementation is considered key to delivering experience and co-operation is through the UIC Regional Project (see Appendix B). Swedish experience so far has been mixed, with the project running later than planned with commissioning now expected in October 2010. Bombardier is currently the sole supplier. Train Integrity is understood to be achieved by procedural methods between driver and signaler.
The Banedanmark Signalling Programme is evaluating whether a simple version of Level 2 offers equally good results as Regional Level 3 in the context of their national Level 2 role out. Their conclusions could be relevant to the UK context and are expected soon.

The railways that see potential on the core network are those with significant high density and high capacity operations very similar to parts of the UK network. They all see solving the issue of train integrity as critical to success but only DB appears to be active in this area. 2020 seems to be the earliest that Level 3 is expected.

There would appear to be a good possibility of finding European partners for the UK railway members to work with to take forward Level 3 development; DB, Prorail and SBB for main line applications and those in the UIC Regional Project for secondary route systems.

An approach to the European Railway Agency or the European Commission was not considered appropriate at this stage. The Commission’s oft stated current focus is on the deployment of ERTMS at Level 1 and 2 on corridors and in keeping with the Member State plans. Development and consolidation of Baseline 3 of the ERTMS/ETCS specifications is set to absorb the ERA’s capacity for the next 2 years after which they can be expected to respond to the wishes of the Commission and Member States. If it is decided to pursue Level 3 development for UK rail it will be necessary to have a key group of other interested member states to get the necessary standards work prioritised and EC support forthcoming.

4.8 Wider Aspirations and Options

ERTMS Level 3 technology has significant potential in terms of cost reduction and capacity enhancement. It does not contribute directly to energy (carbon) efficiency of the railway or to customer facing improvements.

It became clear during stakeholder interviews and at the phase 1 Workshop that both government and industry have wider aspirations for improvement of train movement control. These are set out generically in the Rail Technical Strategy (“simple, flexible, precise control system”) and have been developed further as part of the Industry Route Mapping work. This study is not intended to establish detailed feasibility of these ideas. They are considered as concepts in terms of the benefits that they might bring, and the potential for synergy within the future system architecture within which ERTMS Level 3 would also feature.

4.8.1 Traffic Management and Driver Advice

Conventional signalling systems and ERTMS at all levels have been developed to meet safety objectives. They constrain train movement to prevent train collisions or derailments due to overspeed. In control system terms they form an inner loop which acts between the infrastructure and the train via the movement authority to the driver.

Controlling train movement through the network to optimise efficiency has, for main line railways, always been a second order consideration, achieved either through voice communication between control centre and driver or by an overlay traffic management system which operates through the signalling system. Systems like Automatic Route Setting (ARS) have an efficiency benefit because of their consistent operation compared with a human signaller, but were nevertheless developed primarily to relieve signaller workload and operate entirely through the signalling system.

In a railway which is running precisely to time with a conflict-free timetable, the energy consumption will be driven by rolling stock characteristics and driving style. This can be influenced by training and real time advice on driving style, but not by the traffic management system.
Real railways do not run precisely to time for very long. Even minor perturbations below the threshold of passenger perception cause trains to make unplanned slowings and stops, and these inevitably increase energy consumption and capacity utilisation.

It is clear from experience outside the main line railway domain that significant energy and network utilisation benefits can be achieved through a more sophisticated approach which closes the outer loop between control centre and train, delivering regulation messages which avoid trains stopping unnecessarily, minimise junction occupation and make optimum decisions on routing where options are available.

**Figure 10. System hierarchy, showing where benefits are derived**

The ETCS SRS does not provide for such functionality at any level. However there is no reason why such systems should not operate as an overlay on either ETCS or conventional systems. The main elements of such a system are:

a) A train location subsystem which ascertains with an appropriate level of precision where a train is, at all times.

There is a tendency to assume that train location can and should be derived from the signalling system, as it is currently through TRUST. This is unlikely to be the best solution for the future. Signalling systems are interested in knowing to a high degree of dependability and precision where a train is not located (i.e. not in a block that another train wants to enter). Train location for efficiency purposes needs to know where a train is, to a lower level of precision and dependability but continuously as the train moves along the track.

ERTMS Levels 2 and 3 do offer continuous, precise train location. However for reasons of universal application as well as robustness of the system, it is our view that the “outer loop” train location system should be separate from ERTMS. This is a key decision on future train control system architecture which needs to be considered carefully within the Technical Strategy Group or the relevant System Interface Committee.

There are several projects at both European and UK industry level which have aims in this area. Network Rail developed the “Livetrain” initiative some time ago with the support of the ORR, with the objective of fitting all trains with a GPS based train location system, but the costs of this did not appear to be justified.
Further consideration is now being given to the collection of relevant data for efficiency purposes from a number of sources – track circuits, GPS and/or ETCS. The accuracy, dependability and granularity of this data will be need to be recognised in determining whether such a hybrid system can deliver the prospective benefits. Most modern trains (and an increasing number of older ones) are now fitted with GPS for a variety of purposes and it is very possible that a cross-industry initiative could produce good results at very low cost.

b) A traffic management subsystem

Traditionally, the traffic management layer of train control has operated as a “back office” function, interfacing with trains through the signalling system or through verbal instruction to operator staff. Substantial improvements in on-time performance and energy efficiency are possible if interaction with trains in real time is enabled.

The purpose of a real time traffic management subsystem is to determine the most efficient routing and speed of movement for every train through the system, to deliver the timetable with minimum energy consumption and to manage deviations from the timetable.

In order to achieve this, the traffic management algorithm needs to know precisely where every train is located, and to be able to deliver advice to the driver, asking for changes in train speed and/or timing.

A traffic management subsystem is not currently part of the ERTMS scope. A “European Traffic Management Layer” (ETML) was part of the original ERTMS concept, but the Europtirails project which is active in this area is focused on cross-border issues.

Network Rail has established an operations strategy, which contains plans for a traffic management layer consistent with the recommendations of this report, but which some industry parties appear to be unaware of. It is suggested that the Vehicle – Train Control & Communications SIC should act as coordinator in this area, ensuring that the traffic management initiative is aligned with plans for train location and driver advisory systems.

c) A driver advisory subsystem

The purpose of the driver advisory subsystem is to deliver speed and/or timing advice to the driver which complements (but never contradicts) what he/she receives via the signalling system. Simple systems simply monitor timetable compliance based on train movement through the network and are effective when the system is unperturbed. A more sophisticated system can receive information on the route ahead from the infrastructure.

RSSB has been working for some time on a research project (T724) which aims to establish the business case and principles for this kind of system. It is suggested that priority be given to agreeing the data protocols for infrastructure to train information transmission. Details of the onboard system can be left to individual Train Operators, many of whom are already implementing the simplified version.

Network Rail is progressing research into this area, considering also the need for compatibility with the needs of future ATO systems. However, it is suggested that this is a case where gains can be made by implementing a relatively simple system in the short term. The scope and functionality of a main line ATO system is still some way from being determined and uncertainty in this area should not be allowed to delay the initial closing of the loop using a human driver. Combining the two initiatives may also have significant industrial relations implications.
4.8.2  **Driver Support and Automated Driving**

The issue of drivability in terms of the decision between moving and fixed block is covered in section 4.1.3.2 of this report.

It has become clear during stakeholder interaction that reducing dependence on driver route knowledge is seen as a major source of opportunity for the future. All levels of ERTMS support this objective, but only to a limited extent. ERTMS will ensure that a driver does not overrun a movement authority or exceed safe speeds because of a lack of route knowledge. However ERTMS does not support the driver in controlling the train to achieve efficiency or in stopping at stations. Neither does it provide location information, other than through the implementation of the planning area on the DMI or support the driver in emergency and partial failure conditions.

It is suggested that consideration should be given to providing a simple source of route information, either in the driver’s advisory system or as a stand-alone product. The objective would be to deliver an independent display of useful information related to progress along the route. This could be based on commercial GNSS/GPS technology, adapted only by implementing a rail (rather than road) map, with useful geographic features for the driver (access points, stations, bridges) included. The dependability will be only that achievable by the commercial GPS application, but this should be good enough to be useful in most situations.

Route information (satellite navigation for rail) could both supplement ERTMS in normal operation and support an operational fallback mode in partial failure conditions.

It is important that such a system is clearly distinguished and separated from the vital control aspects of ERTMS. A route information system would be valuable now and could start to deliver benefits alongside current signaling systems.

Automatic Train Operation (ATO) is seen by some stakeholders as the ultimate solution to driver flexibility problems. There is also a widespread view that ERTMS Level 3 is in some way a step towards ATO. This view is captured in the “Flexible, Precise Control System” route map prepared for TSAG.

All ATO systems have an ATP system as either an integral part of the package or a separate “underlay”. The ATP carries out vital supervision of the automatic driving function, exactly as it does for a human driver. Earlier work by Parsons demonstrated that ETCS Level 2 is capable of providing the underlying ATP for an automated driving system for a high capacity application, and Level 3 has equal capability and potentially higher capacity. Both are in that sense, therefore, steps in the direction of ATO.

The challenges of developing a main line automated driving function capable of operating over an extensive main line route are considerable. The idea of operating a main line train with no driver at all is implausible in the current generation of technology, so the first challenge would be to agree an operational concept and a functional specification built around a new role, in which the driver, while maintaining overall responsibility for the safety of the train, would use the automated driving function in much the same way as a pilot does the autopilot in an aircraft. The term “Supervised ATO” has been suggested for this function. Such a system is very different operationally from metro “Driverless ATO”. The human factors analysis surrounding such a system is critical, because the driver would presumably need to keep alert and look out for trackside workers, obstructions and incidents. Level crossings would be a particular issue. Automated support for such tasks using image analysis is feasible, but the issues raised are well beyond the scope of this study.

The other major issue for a main line automated driver function would be station stopping. A higher level of intelligence than is currently embodied in metro ATO systems would be needed to cope with the various combinations of train length, platform length and selective door operation that would be seen on a main line route. This is not,
however, beyond the current state of the technology. There may be lessons from “cruise control” systems but these only deliver a small part of the requirements for ATO. If the industry wishes seriously to engage in a main line automated driver project, then the initial work should focus on the development of an operational concept with a linked human factors analysis that demonstrates feasibility at this level. The technology, in comparison, is a secondary issue.

On a broader view, it is clear that technology will change the role of the driver very substantially within the working life of many of those currently employed, on a scale of change comparable with that from steam to diesel in the 1960s. In order to inform the direction of change and avoid wasted investment and conflict, a specific piece of work needs to start now, aimed at establishing a clear and realistic view of the future role of the driver within the train movement control system.

### 4.8.3 Advanced Train Location

A critical issue for ERTMS Levels 2 and 3 is high train retrofit cost, as set out in section 4.5.5 of this document. It has not been possible to ascertain a breakdown of these costs during this study. However a superficial examination of the issue suggests that a large part of the cost is related to train location. Current ERTMS implementations include a balise reader, two tachometers and one or two Doppler radars, all fitted to the train underframe. A major reduction in equipment count in this area would drive very substantial savings in capital cost. Operational (maintenance) cost should also be considered. Current implementations also have a significant maintenance overhead.

A number of modern technologies for this application have been suggested and in some cases trialed in research projects. These include:

- GNSS/GPS/Galileo.
- Inertial Navigation.
- FFCTV image processing.
- Cellular radio.

The levels of dependability needed for a railway vital application are unlikely to be achieved by any single one of the above technologies. For the foreseeable future a solution is more likely to be found by using more than one of these techniques in combination with each other, or one of them in combination with a more conventional approach such as a balise reader.

Approaches such as this have been considered in projects such as GRAIL and LOCOPROL in Europe and by various contenders for the Positive Train Control initiative in the USA. Commercial applications are in use in freight railways in some parts of the world (South America). However, as far as is known, no solution which integrates such an approach into ERTMS is commercially available.

In considering this possibility, two principles need to be borne in mind.

First, the extent of compliance with the CoCoSig TSI will need to be flexible. This should not be a major problem for domestic rolling stock provided that interoperability of the infrastructure is maintained. The [TSI] contains provisions which allow for innovation which could be cited in this case.

Second, the difference between absolute positioning systems (such as GPS/GNSS and cellular radio) and relative positioning systems (such as FFCTV image processing and conventional odometry) needs to be considered. ETCS is based on relative positioning and to be compatible with ETCS an absolute positioning system needs to be combined with an accurate and up to date track map held in a database within the system (usually on the train). A considerable amount of work has gone into the attempt to demonstrate
that absolute positioning systems can be accurate enough to locate a train precisely in a track section. This has yet to be achieved.

The most obvious and widely available technology for absolute location (GPS/GNSS) also has inherent disadvantages. It needs a continuous view of the sky and it is susceptible to interference and deliberate degradation in times of crisis. Cellular radio based positioning, perhaps as a backup, is being actively considered as a possibility.

Relative positioning systems are more directly compatible with ETCS. FFCCTV image processing has impressive capabilities and has been demonstrated on a small scale to be capable of direct readout of train speed in a wide combination of weathers and of reading wayside coded signs containing ETCS fixed balise messages.

A number of onboard architectures could be considered. The most obvious is to replace the conventional odometry but to retain the balise reader. This would save some cost but might not be sufficient to achieve the objective. The next step, eliminating the balise reader, is conceptually possible using an absolute positioning system with an accurate track map, but much more difficult, particularly in terms of achieving a sufficiently dependable “virtual balise”.

Current balise readers can operate up to 300 km/h. It may be worth considering whether a lower power, less intrusive version could be developed for speeds up to (say) 160 km/h. A lower cost “tag reader” technology using commercially available RFID tags is feasible, as is visual reading of a 2D-bar code using FFCCTV, but the domestic interoperability issues raised would have to be solved if different routes were to be fitted with different technologies for providing an infrastructure reference. Dual fitting might overcome the problem if costs were low enough.

It seems likely that a combination of the available technologies could, given commitment and development funding, deliver a practical system within a timescale of 5 years or so. This could be looked at as a supplier problem. However if such a system was considered desirable, the railway industry would need to take a lead both in stating clearly whether and to what degree CoCoSig TSI compliance was required, and in establishing principles and a target architecture for the initiative.

4.8.4 Communications Strategy and Options

ERTMS Level 3 has an inherently higher level of dependence on radio data communications than Level 2 because there is no ground based alternative path for train location data. The dependability requirements for the communications path will therefore be higher, and the current level of GSM-R coverage will need to be increased. The costs of enhancement would offset to some degree the signalling infrastructure savings. However, before considering such an enhancement the industry should consider carefully its future communications strategy in the light of both future train movement control requirements and the likely availability of improved technology.

ERTMS/ETCS is currently configured to use GSM-R as its exclusive data carrier. It uses circuit switching, tying up one GSM-R channel with the equivalent of a continuous telephone call per train. This capacity limiting and wasteful use of spectrum has been recognised by railways and the European Railway Agency and there are moves to adopt packet switching for ERTMS, probably using GPRS initially. There does not appear to be any fundamental problem in doing this, although the ETCS kernel will need adapting to tolerate stochastic rather than deterministic message transmission times. Progress on this issue has been slow – the problem has been evident for at least five years and as yet there is no plan for resolving it.

This is nevertheless a key issue for the future of ERTMS Levels 2 and 3 and the plans must be carefully scrutinised to make sure that the long term is safeguarded and not sacrificed to short term expedient. As an initial consideration, ETCS should be enabled to use any packet switching service in the future and not tied exclusively to GPRS.
GSM technology is already near obsolescence and support for GSM-R may become harder to obtain over the next decade. The long term cost effectiveness of ETCS (and its marketability outside Europe) will be significantly enhanced if it is developed now to be able to utilise a wider range of current and future data networks, both private railway ones and public networks.

Discussions are understood to have begun within the railway telecommunications community and the UIC over the adoption of the next generation technology, LTE (Long Term Evolution). Given the level of applications now being implemented over track to train communications, there is a need for an integrated approach to the evolution of the industry’s use of telecommunications which should include consideration of support of ETCS.

Future railway communications strategy should allow diversity, minimising the risk of operational disruption by providing for alternative pathways. Communications systems may also be able to support alternative methods of train location.

It will be a matter for Government whether radio spectrum should continue to be available exclusively for services such as railway communications and, if not, what regulatory mechanisms are needed to ensure adequate and timely access over networks provided by others.
5 Implementation

5.1 Introduction
Implementation of ERTMS Level 3 is considered within this study at two levels. This section considers in detail the implementation of the Level 3 core technology. Section 7.1 provides an overall “Route Map” for delivery of the industry’s aspirations for future train movement control, of which ERTMS Level 3 can deliver only a part.

5.2 High Level Business Needs
As has been discussed in this report, delivery of the benefits associated with ERTMS Level 3 depends on the implementation of an integrated train movement control system of which ERTMS Level 3 is a part. A set of key high level business needs have been identified for a future train movement control system as presented in Table 9. ERTMS Level 3 will be able to contribute to the delivery of these but will not on its own deliver the full extent of the identified business need. Other initiatives are also needed in concert with ERTMS Level 3 to fully deliver these business needs.

Table 9. Business Needs

<table>
<thead>
<tr>
<th>High Level Business Need</th>
<th>Level 3 contribution</th>
<th>Other initiatives required/Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure cost savings over MAS must be sufficient to support total train fitment costs, pay back the development costs and give a further return.</td>
<td>High</td>
<td>Low cost train fitment. High dependability communications.</td>
</tr>
<tr>
<td>Increased capacity – but only where justified by increased demand.</td>
<td>Medium</td>
<td>Infrastructure changes almost always needed as well. Traffic management and closed loop train control also contribute.</td>
</tr>
<tr>
<td>Improved system flexibility - lower costs of changing services, track layouts etc.</td>
<td>Very high</td>
<td>Flexible traffic management system.</td>
</tr>
<tr>
<td>System reliability and availability make a positive contribution to industry improvement goals.</td>
<td>Medium</td>
<td>High dependability communications as part of a future comms strategy.</td>
</tr>
<tr>
<td>Improved operational flexibility – reduced need for route learning.</td>
<td>Medium</td>
<td>Low cost driver navigation system.</td>
</tr>
<tr>
<td>Energy efficiency improvement.</td>
<td>Low</td>
<td>Traffic management and closed loop train control are the keys.</td>
</tr>
<tr>
<td>Graceful degradation under failure conditions.</td>
<td>Medium</td>
<td>Total design of train movement control system to meet availability targets.</td>
</tr>
<tr>
<td>Flexible migration plans to accommodate changing business imperatives.</td>
<td>Negative</td>
<td>Level 3 precludes overlay operation.</td>
</tr>
<tr>
<td>Compliance with European Standards.</td>
<td>Neutral</td>
<td>Level 3 should deliver equivalent compliance to Level 2.</td>
</tr>
</tbody>
</table>

To deliver these business needs will require a migration from the current technology to ERTMS Level 3 and this migration process is described in section 5.3.
5.3 Migration strategy

The purpose of this section of the report is to consider in principle the optimum migration path from current technologies (Multi-aspect colour light signalling and older, mechanical forms) to ERTMS Level 3.

As well as the migration path for the vital signalling technology, a comprehensive strategy should consider also the other aspects of train movement control, all of which ultimately contribute to the delivery of business benefits.

These ERTMS migration factors and other aspects of train movement control development are brought together in the route map described in section 7.1.

5.3.1 Route Types

The migration path to ERTMS Level 3 is likely to be driven by:

a) Scale of benefits available for a particular route type.

b) Signalling renewal opportunities.

c) Train fitment strategy and opportunities.

d) Availability of the technology.

Maximum benefits would in principle be available for a route where major infrastructure savings are available, where signalling is due to be renewed in a timescale consistent with the availability of Level 3 and where new trains are to be procured with ERTMS capability.

The benefits work carried out as part of this study suggests that the potential infrastructure savings from Level 3 are greater than those from Level 2 without signals by approximately 25% taken on a generic, SEU estimated basis, but that this will be offset to some degree by higher train fitment costs. The capacity benefits are real when taken at a signalled headway level, but are unlikely to translate into a major increase in the number of available train paths on most routes.

The study suggests the relationship between benefits and route type shown in Table 10.

<table>
<thead>
<tr>
<th>Route Type</th>
<th>Likely Capacity Benefit</th>
<th>Infrastructure Cost Benefit</th>
<th>Trains to be fitted</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Capacity Urban</td>
<td>Significant potential. However railways of this type tend to be well optimised with conventional signalling or Level 2</td>
<td>High on plain line. Limited in areas with complex track layout.</td>
<td>Number could be limited in short to medium term. Captive fleets may be acceptable.</td>
</tr>
<tr>
<td>Fast(200 km/h), Highly Utilised Main Line</td>
<td>Some potential. Critical aspect likely to be impact on junction and crossover capacity.</td>
<td>Significant</td>
<td>Hard to avoid fitting very large numbers of trains.</td>
</tr>
<tr>
<td>Regional Main Line</td>
<td>Some potential. Capacity for freight in particular limited by infrastructure layout</td>
<td>Significant</td>
<td>Careful planning may limit number in some cases.</td>
</tr>
</tbody>
</table>

Table 10. Relationship between Benefits and Route Type
The first potential target is high capacity metros, where the need to release additional capacity is the primary driver rather than cost. CBTC systems were largely developed for this kind of railway. However none of the application scenarios looks a promising candidate, primarily because route capacity is not limited by signalled headway and conventional signalling has already been optimised to meet forecast demand. Nevertheless, there are main line targets of this type, where reducing the signalled headway releases extra line capacity for which there is demand available. Thameslink is a prime example and there are likely to be others in the future. Railways of this kind also offer the potential for infrastructure cost savings. Benefit to cost ratio would increase substantially if a line could be segregated in terms of its rolling stock fleet. The parallel work being carried out by RSSB to assess the benefits of segregation is considering a number of targets including Merseyrail and the LTS lines, and it would be worth carrying out further work to estimate the benefits of ERTMS Level 3 on one or more of these.

The results of the study suggest that the infrastructure cost benefits of Level 3 will be highest on routes where there is a low ratio of pointwork to track miles. The two middle types of route fall into this category. For highly utilised main lines the problem is that very large fleets of trains, including both new and old types, will have to be fitted to allow ERTMS to be rolled out without lineside signals. For regional main lines, the number of trains to be fitted may be containable in some cases, but train fitment cost remains an issue.

The rural lines route type appears at first sight to be a promising candidate for Level 3. CBTC systems have been developed for this kind of railway in various parts of the world, primarily driven by safety needs. However the UK context is very different from that of a North or South American “dark territory” freight line. Rural lines vary widely in their signalling type (RETB, mechanical interlocking semaphore and absolute block, token block etc) so the starting position varies widely, but all are fitted with TPWS, so there is no significant safety benefit to justify ERTMS rollout. RETB has the major advantage of portability of on-train kit and of low operating cost for long single track routes, and recent developments suggest that the system life can extended substantially at modest cost. Absolute block routes have almost indefinite equipment life, but have high operating costs. Network Rail’s Modular Signalling programme is intended to realise operating cost savings on this kind of route with a limited capital investment. The combination of ERTMS Level 3 with a modular signalling approach, with which it has strong affinity, offers an opportunity to reduce infrastructure cost yet further. However, train fitment cost still represents a risk. Work by ATOC in support of the National ERTMS Programme promotes a view that this risk is containable on certain routes, provided a planned approach to rolling stock deployment is adopted. These routes are seen as the major potential target for ERTMS Level 3.

### 5.3.2 Migration Steps

In the medium term (over about the next 10 years) the focus of ERTMS implementation should concentrate on Level 2. This will enable the maturity of the product in a UK environment to be established and the experience of the industry in implementing it to be consolidated. Level 2 also allows the overlay option to be used where needed to...
overcome fleet fitment cost problems. Towards the end of this period, if the appropriate steps are taken (see section 5.3.3 and the Route Map), Level 3 should become available as a fully developed product.

The interaction between infrastructure rollout and fleet fitment is precisely the same problem for Level 3 as it is for Level 2 without lineside signals. Considerable effort has been expended in the past to develop a national implementation plan which achieves both a minimum amount of retrofit and a minimum amount of Level 2 overlay. This work is now being repeated within the National ERTMS team using better planning tools and a better informed and more flexible approach to signalling renewal, so the results when they emerge as an update to the National Implementation Plan should be a substantial improvement in terms of the Business Case for Level 2. However, for such a plan to be successfully delivered, the rolling stock and train operations aspects will need to be actively supported by DfT and put into effect through the franchising process, both by including commitments to fit trains in new franchises and by directing the deployment of rolling stock in existing franchises.

Once all trains using a particular route are fitted, a route already fitted with Level 2 infrastructure could in theory be converted to Level 3. Removing track circuits would undoubtedly have some reliability benefits, but it is unlikely that this would pay for a renewal of the interlocking and RBC, so this seems unlikely to happen in practice.

The more likely scenario from a business perspective is that a route fitted with MAS comes up for renewal with either Level 2 or Level 3. Once Level 3 technology is established, the transition from MAS to Level 3 should be easier than to Level 2 without lineside signals. The easier transition arises because the process of “over and backing” where the system is switched over to the new system for trials, and back for service operation, is much more feasible given the smaller number of infrastructure connections involved. Provided that Level 3 has been developed for a main line environment, therefore, and not specifically as a product for rural lines, the ERTMS national programme would be able to switch from Level 2 to Level 3.

It is likely that trains currently being purchased now with ERTMS fitted will operate over Level 3 infrastructure at some time in their service lives. They should therefore be fitted from new with a train integrity subsystem. The cost of this will be very small and will save a large retrofit activity later. The specification for such a system (for fixed formation or multiple unit trains) is very simple and should be given high priority. The development of a train integrity subsystem for freight trains is covered elsewhere in this report.

5.3.3 Technology timeline

The technology timeline for ERTMS Level 3 will almost certainly be driven primarily by demand side, rather than supply side, factors. The history of similar products suggests that any of the suppliers should be capable of delivering a working system within 5 years, given a reasonably clear set of requirements, a target route and a commitment to development funding. Consultation with the railway operators and infrastructure managers and also with suppliers suggests, however, that an overall timescale of 10 to 15 years is more realistic. The reasons for this were not clearly or consistently stated. The following points emerged from discussion:

a) The absence of a clear market demand for Level 3. (Influential national railways and governments do not see it as a priority).

b) The perception that major changes to the operational concept of the railway are needed (this may not be true if Level 3 is applied in “virtual block” mode).

c) The perceived high cost of train fitment (applies to Level 2 almost as much as Level 3).
d) The need perceived by customers to consolidate Level 2 over a period of 10 years or more to deliver product maturity before embarking on Level 3.

e) The probability perceived by suppliers that it will take several years for customers to develop a coherent target and set of requirements.

It may be more helpful to consider what could be done, if a group of railways got together in a “Level 3 consortium”. A very simplistic timeline for such an initiative might look like:

- Creation of consortium, agreement of scope, leadership etc. – 1 year.
- Development of common operational concept, agreement on pilot and procurement strategy – 2 years.
- Specification to contract award – 1 year.
- Development and testing – 2 years.
- Operational trials (pilot) – 2 years.
- Consolidation of operational concept and formalisation of standard spec – 1 year.

This suggests that a timescale of 10 years for a developed concept and formal specification might not be unreasonable, going down the ERTMS path.

One question that should be asked is whether technology is likely to change radically over this timescale and either make the Level 3 concept obsolete or greatly accelerate its likely availability. The following areas of change seem most relevant:

- Telecommunications.
- Availability and precision of GNSS.
- Distributed intelligence with shared data.
- Automated driving.
- Image analysis and recognition.

The fundamental change brought by ERTMS Level 3 is the transfer of responsibility for vital train location from the infrastructure to the train. This can be seen as a step in the process of increasing the intelligence of the train and reducing the complexity of infrastructure (particularly at the lineside). All of the areas of technology change listed above can be seen as supporting this longer term process. The question is, therefore, whether the ERTMS Level 3 technology as currently envisaged will become obsolescent during the development process. This is clearly the case in some areas. The communications industry is forecasting the start of withdrawal of GSM technology in 2015, at about the same time as the UK railway is likely to complete rollout of GSM-R. Train location technology using GNSS and image analysis may also overtake current ETCS train location technology using axle tachometers and radar. Neither of these seems likely to overturn the ETCS Level 3 concept, so can be regarded as welcome areas for inclusion in the development programme, depending on timescales.

The only change which might challenge the concept is if train borne intelligence, location and advanced communication technologies advance to the point where very little infrastructure based intelligence is needed at all. It is already possible to conceive of a system where every train has an accurate onboard track map, knows the location of all other trains in its area and can communicate in real time both with other trains and with a route management centre which carries out high level routing and prioritisation. Each train would be responsible for its own movement authority. Local junction controllers might set and lock routes in response to direct requests from trains, rather than through an infrastructure controller. Although conceptually possible now, the rate of change of railway technology is such that a practical main line implementation must be regarded as many years away. This should not, therefore, be regarded as a constraint on progress towards the Level 3 concept.
5.3.4 **National ERTMS Implementation Plan – implications**

DfT submitted the UK’s National Implementation Plan for ERTMS to the EC in 2007. Work to update it within the National ERTMS team is ongoing, but no revisions have yet been formally published. The changes which were presented to the ERTMS Strategy Group in March 2010 are the deletion of the East Suffolk route from the plan, and the introduction of the Thameslink route, to be commissioned in 2015-2018. These are relatively minor in overall terms.

Until the mid 2020s, the ERTMS National Implementation Plan focuses on Level 2 rollout on the High Speed TENs network (primarily GWML and ECML). Current plans are for GWML to be an overlay, with the intention that visual signals are removed by 2026 and for ERTMS to be fitted to ECML without visual signals, starting in 2018.

Current work by ATOC under the overall remit of the ERTMS team was described in section 5.3.2 and is focused on optimising the balance between infrastructure rollout and fleet fitment, with the objective of avoiding both overlay implementation and train retrofit. The strategy was described to the study as “outside in” – fitting rural and regional routes first, where changes in fleet deployment are less likely to destabilise the overall plan, with the core network following later. It is not clear whether the plans the TENs high speed network are likely to change as a result. This strategy is perceived by the team developing it as offering a major opportunity for ERTMS Level 3 to be deployed early on rural and regional routes.

The conclusions of this study do not justify a change to the national strategy, which should continue to be focused on Level 2 for the next decade, whilst developing Level 3 in parallel. The development of a rural and regional Level 3 product is a major a step on the development path to a system suitable for national rollout, but in terms of cost achieves only a small percentage of the potential prize, so the specification for a pilot needs to be developed with care. It would also be unwise to build the whole Level 3 strategy on the assumption that the developing plans for minimising train retrofit will succeed, unless and until commitment to the necessary directive action is given by DfT. Lowering the cost of retrofit should also, therefore, be given priority.

Until the problem of fleet fitment cost is solved, there remains a significant risk that the rate of ERTMS rollout be dominated by the rate at which new, fitted trains arrive onto the system, and the need to cope with a mixed fleet will drive dual-fitted infrastructure using an ERTMS Level 2 overlay. Introducing Level 3 into this problem set would simply make it more complex, because routes would have differential capacity and a complex mix of fallback modes depending on the mix of fitted and unfitted trains.

Looking beyond 2020, the size of the prospective prize is evident. According to the National Implementation Plan published in 2007, the percentage of national infrastructure fitted rises from around 10% in 2020 to around 60% in 2034. This involves about 40,000 SEUs. If Level 3 saves a conservative 15% per SEU at 2003 values, the total saving could be at least £1.62Bn. The establishment of a target in the mid 2020s for a transition in terms of the technology to be fitted from Level 2 to Level 3 would give an objective to the industry and would not imply any change to rollout strategy in the medium term.

5.3.5 **Industry Structure and Incentivisation**

The history of railway train control over the past fifty years or more has involved the gradual addition of complexity on the train. This is sometimes described as a transfer of responsibility from infrastructure to train, but in reality what has happened is the addition of supervisory and control override functions to reduce the safety impact of driver errors. Over the same period the infrastructure equipment has become more rather than less complex. Costs overall have increased, but in general these are perceived to have been justified by increases in safety. It could be argued that ERTMS Level 2 is a further step along the same path, with the system taking over primary...
responsibility for transferring the movement authority from track to train. However the safety benefit is correctly perceived as small and implementation is justified by prospective reductions in system cost, with some potential for capacity benefit.

Although ERTMS Level 2 offers reductions in infrastructure cost, the cost of the train will rise. The benefits thus fall on one side of the track to train interface and the costs on the other. Capacity benefit within the current structure accrues largely to Government.

In general, the UK industry has found it difficult to manage this situation. Although Network Change offers a mechanism for operator compensation, there is no incentive on the operator to support net system cost reduction. Franchises offer a mechanism for contractually enforcing implementation, but development risk and uncertainty in rollout timing are hard to handle.

ERTMS Level 3 offers more of the same, in that further reduction in infrastructure cost and prospective increases in route capacity are partially offset by further increases in onboard equipment cost. Level 3 adds another factor, in that the responsibility for train location and train integrity are transferred from infrastructure to train. This has implications for both safety and reliability. Both should improve overall, but the contribution required from onboard systems increases, and therefore there is likely to be a perceived increase in risk from the perspectives of the train owner and operator. If no incentive is offered, this is likely to result in cost escalation and delay.

Incentivisation within the industry access agreements is very possible, if the marginal track access charge for a fully fitted train can be made less than an unfitted train. There is logic to this, in that the infrastructure costs should be less, and because the track occupancy of a train fitted with Level 3 would be less than one without train integrity. This is something for DfT to consider with ORR and will be of particular relevance to freight operators.

The agreement of a funding strategy for ERTMS would have another major advantage, in that it would test the commitment of both Network Rail and Train Operators to future change. Only if the organisations are committed at Board level will this change be effectively supported.

**5.3.6  Rolling stock retrofit cost**

The costs of retrofitting rolling stock, as outlined above, are the major barrier to ERTMS Level 2 implementation and will be marginally more so for Level 3.

A solution to this problem should have very high priority within the ERTMS domain. A three-pronged approach to solving this problem is suggested:

a) Determine the primary drivers for high retrofit cost, using experience from Cambrian, Switzerland, Sweden and elsewhere in Europe where significant numbers of older trains have been fitted with ERTMS.

b) Determine the minimum requirements for interoperability of domestic (UK) rolling stock. It is suggested that these should be no more than the capability to run without specific restriction on a route fitted with ERTMS Level 2 (or 3) without lineside signals.

c) Carry out a desk top study followed up by a feasibility assessment and ultimately by a pilot, looking at the available technologies which might reduce retrofit costs whilst maintaining the minimum requirements for interoperability.

Ideally, this work should be sponsored at European level.

See also the “Advanced Train Location section of this report (4.8.3).
5.3.7 **Train Integrity and Train Length Validation**

As described in section 4 of this document, train integrity (particularly for freight) is a significant risk to the Level 3 concept. The way to resolve it may be to design a solution with an acceptable level of integrity at system level – perhaps combining a trainborne subsystem which is capable of detecting loss of train integrity but with a lower level of dependability, with a supervisory subsystem which enforces a safe reaction, if necessary freezing the movement authority of a following train until integrity is reconfirmed. The starting point must be a set of operational requirements, and it is important that these are created at system level, very early in the Level 3 development agenda. Demonstration of feasibility and agreement of a concept should be followed by a pilot, which can be independent of a Level 3 pilot line. This workstream should also cover train length validation.

5.3.8 **Other train movement control subsystems**

This section considers the changes and additions to other train movement control subsystems which are needed in order to deliver the industry’s aspirations. Many of these are independent of ERTMS and can proceed as soon as a business case has been demonstrated. Table 11 suggests the dependencies that these initiatives have on the signalling technology and their benefits and status.

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Signalling Technology Dependence?</th>
<th>Benefits</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous train location</td>
<td>Low (could be provided by ETCS Level 2 or 3, but better independent).</td>
<td>Foundation for better system management (capacity, energy efficiency, customer information, management of disruption).</td>
<td>Already exists to some extent on new trains. Multiple initiatives exist but way forward for UK industry unclear.</td>
</tr>
<tr>
<td>Traffic management</td>
<td>Low (unfeasible with mechanical signalling).</td>
<td>Better system management (see above).</td>
<td>Network Rail operations strategy covers this and more – but implementation plan not yet developed.</td>
</tr>
<tr>
<td>Driver advisory speed/timing</td>
<td>None</td>
<td>Better timetable compliance (PPM), Better system management (capacity, energy efficiency).</td>
<td>Systems being implemented independently by First Group and others. RSSB research project exists – but no interface definitions or rollout plan.</td>
</tr>
<tr>
<td>Drivability (route information)</td>
<td>None</td>
<td>Better management of failure; More flexibility in driver rostering; Reduced training needs.</td>
<td>No initiatives currently known.</td>
</tr>
</tbody>
</table>

It is suggested that the Vehicle – Train Control System Interface Committee, with the support and guidance of TSAG, should act as the coordinator of these initiatives.
6 Conclusions

The Rail Industry's aspirations for a simple, flexible, precise train control system are stated at high level in the Rail Technical Strategy published in July 2007 and have been reinforced in the course of this study. Stakeholders are seeking lower capital cost, lower operating cost, more flexibility in recruiting and assigning drivers, more flexibility in designing and modifying the system and higher capacity together with reductions in energy use and carbon emissions. Technology is already capable of meeting these aspirations, but the natural rate of adoption of innovation within the UK railway suggests a timescale of 30 to 50 years to make the change. By this time (at least in control system terms) the railway will be far behind other modes of transport.

The primary questions for this study were whether ERTMS Level 3 is a step on the way towards this future vision and if so, what risks were associated with adopting it. The secondary question was what other strategic initiatives should be considered in association with it in order to drive forward more rapidly towards the industry's aspirations.

This study has shown that ERTMS Level 3 is theoretically capable of delivering significant benefits for the UK main line railway. Infrastructure capital cost reductions of up to 25% on current costs could be delivered, over and above the 40% reductions forecast for Level 2. However, the infrastructure cost benefits are offset to a certain extent by trainborne ERTMS costs. These will be marginally increased by Level 3.

Maintenance cost reductions should also be realised through the reduction in infrastructure, but this study did not determine the base costs against which such savings could be set. The base costs are stated by Network Rail to be small.

Operator costs, including the implications of driver flexibility and reduced dependence on route knowledge, are unlikely to be changed significantly by Level 3 acting on a standalone basis. However the reduced criticality of route knowledge in terms of safety, which is achieved by ERTMS at any level, could be used as a basis for further improvement. A driver support system based on commercial satellite navigation technology is feasible at low cost now and could deliver significant benefits. ERTMS at any level provides ATP, which is an essential underlay for automatic train operation, seen by many in the industry as the ultimate aspiration. Whether or not ATO is the logical progression from ERTMS, it is clear that the driver role will change substantially in the next 10-20 years.

The reduction in line side equipment possible with Level 3 has the potential to make a significant contribution to reduction in delay minutes. The models used in the study predict a reduction of about 14% in infrastructure delay minutes for a Level 3 system compared with Level 2. However this will depend on both a high level of reliability for the ETCS equipment and a high level of dependability for the GSM-R communications system.

Level 2 is already a step forward in terms of design flexibility compared with conventional signalling. Level 3 improves the situation yet further and should substantially simplify the signalling design process and allow changes to the system (such as the introduction of new crossovers) to be achieved at lower cost. One of the key advantages of ERTMS is the possibility of bidirectional operation. This is even more easily realized in a Level 3 system than Level 2 due to the reduced reliance on track based infrastructure for position and direction reporting.

Blockless systems like Level 3 have been introduced by metro systems for capacity enhancement reasons. Although Level 3 will deliver some increase in spot capacity, the increment compared with an optimised fixed block system is small, and the practical increase on real routes is yet smaller because of the physical route constraints and mixed use associated with the UK main line railway. However the cost benefit of Level 3
increases as capacity rises, because the quantity of infrastructure equipment eliminated increases. The conclusions of this study suggest that the primary reasons for adoption of Level 3 should be reduced cost, not increased capacity.

Carbon emissions will not be significantly reduced by ERTMS Level 3. There may be some benefit from the reduction in the number of signal stops, but this will be small. However, substantial energy consumption benefits could be realised by better traffic management combined with a “closed loop” control system (although this is outside the scope of ERTMS.

The actual benefits to be realised will depend on the route to which Level 3 is applied. The application scenarios considered in this study show qualitatively that these benefits can vary quite widely. In terms of target applications mixed-use main line and high capacity urban lines appear to offer the most opportunity to deliver cost savings and capacity benefits. Further work is required to identify specific lines with these characteristics and to carry out detailed cost and capacity benefit studies. Complex infrastructure areas provide the least opportunity for benefits from Level 3 if track based detection continues to be required at junctions as the study suggests.

Rural and regional railways are often seen as a good target for this kind of system, but capital cost savings would only be substantial where the alternative is a fully track circuited and signalled system. For long single line routes, ERTMS costs would have to fall substantially to compete with a re-engineered RETB until ERTMS onboard comes “for free”. For two track regional routes, the main opportunities lie in reduction in operating cost, facilitated by an electronic interface to a regional signalling control or traffic management system. Network Rail is developing its modular signalling concept for this application and ERTMS Level 3 would be a logical next step, reducing costs yet further provided that numbers of trains to be fitted can be kept small, as currently being planned by the National ERTMS Programme team for Level 2.

Although the benefits summarised above are realisable in principle, their achievement in practice will depend on the way in which ERTMS Level 3 is designed into the railway signalling system. A number of different architectures are possible, depending on the requirements for operation with unfitted trains and the perceived need for a fallback system with track based detection and visual signals. The greater the degree of fallback and unfitted provision, the lower the benefits. The best architectural solution for a rural route may not be optimum for a busy commuter section of track. The representative architectures developed for the study have provided a useful mechanism for identifying generic architecture types for specific routes and this needs to be developed further to support overall system application design.

The risks and challenges facing a wide area deployment of ERTMS Level 3 are considerable.

Experience with Level 2 has shown that a major risk to wide-scale rollout is the high cost of onboard equipment, particularly where a train has to be retrofitted, and the costs of taking a train out of service for a period in order to do so. However, Level 2 can be applied as an overlay, retaining visual signals for a period in order to allow a mixed fleet to operate. This option is not realistically available for Level 3 (except perhaps for the occasional freight or maintenance train on low capacity routes) and low cost onboard equipment should be seen as a necessity for Level 3. This is not within the development horizon of ERTMS at European level.

The study has also shown that Level 3 imposes a greater dependence on the telecoms element of the ERTMS system to provide sufficient availability and integrity of communication between RBC and train to support continuous update of train position. The GSM-R voice network currently being deployed by Network Rail will need substantial reinforcement for both Level 2 and Level 3. Level 3 does not depend on packet switching, but packet switching will be needed to support Level 2 before Level 3 is ready. Level 3 dependability and diversity requirements need to be considered in the strategy
for future railway telecoms systems, remembering that GSM is already seen by the telecoms industry as an obsolescent technology and is likely to be replaced by LTE from 2015 onwards in commercial systems. This may require intervention at government level to ensure that a suitable strategy is adopted to maximize the use of the emerging telecommunications environment.

The need to assure train integrity using onboard equipment is fundamental to the Level 3 concept. Widely diverging opinions are held by different stakeholders as to the feasibility of this. The study concludes that the problem is relatively simple to solve for most UK passenger trains. A system for freight trains also looks feasible using current technology but will need commitment and development funding. It is unlikely that the onboard system on its own will have sufficient dependability, and further levels of protection may be needed through RBC reaction to a loss of the integrity signal. The development process needs to start by developing the requirements at system level, rather than by designing a product in isolation.

Level 3 should not present a safety risk in itself. Indeed, the elimination of track circuits (which have a low level of dependability in isolation) should be seen as a safety benefit. However, the railway community will need to be reassured of the safety of ERTMS Level 3. Elimination of track based train detection, integrity of on-board data and changes in driver interaction with the route are major issues for consideration. This study recommends a full safety review and has identified a key safety issue being the integrity of the onboard data. In particular where this is input by drivers and train preparers and especially for variable consist trains, particularly freight trains.

An important issue for the industry to resolve will be the approach to signalling design, whether to continue to design with pseudo block sections and overlay the “dynamic” train provided position onto the blocks, or to take a fundamentally different approach basing design on the underlying functionality of a flexible (potentially moving) block system. The more fundamental approach will deliver greater benefits but the migration risk will be higher. The system can be readily configured as virtual block but some of the potential flexibility and cost benefit will be lost. Currently the supplier community has no common view on which approach is easier or cheaper to engineer. There is much to learn from CBTC systems in this respect and a discussion is included in this report. These differences within the signal engineering community must be reconciled before embarking on the development of a practical system.

As with Level 2, the potential cost benefits of ERTMS Level 3 will be realised only within an integrated UK deployment plan covering both infrastructure and trainborne aspects. Development work for the Level 2 plan is ongoing. The migration path to Level 3 will be driven by the scale of benefits available for a particular route type, signalling renewal opportunities, train fitment strategy and opportunities and availability of technology. The speed of implementation is likely to be driven by the demand side rather than the supply side.

ERTMS deployment will continue to be dominated by Level 2 systems until Level 3 technology is fully developed and further lessons are expected to be gained from these deployments to inform future Level 3 implementation. Once Level 3 technology is established and assuming all trains in an area are fitted, the transition from MAS to Level 3 should be easier than to Level 2 without lineside signals. The easier transition arises because the process of “over and backing” (i.e. the system is switched over to the new system for trials, and back for service operation), is much more feasible given the small number of infrastructure connections involved. Key issues related to migration and candidate routes are discussed in this report.

The key issue which is outside the immediate remit of ERTMS Level 3 is the development of a holistic future railway operational strategy which encompasses all elements of railway operation with ERTMS as a “sub-system” delivering the train control function.
Cooperative development of ETCS standards on a European level will be essential if the suppliers are to develop ETCS systems. Development of specifications for RBC and interlocking functionality and the implementation of a cooperative pilot/test track are important features of this cooperation. The UK should explore potential European or even non-European partners to develop the specifications and system requirements for a Level 3 system. Sweden and France are planning similar regional applications. The Netherlands, Switzerland and Germany see Level 3 as an important future step in dealing with capacity improvement and/or cost reduction. The potential benefits of developing a European-wide Level 3 specification are sufficient to warrant lobbying for European funding.

CBTC systems have proved the concept and have been in use for over 20 years. Regional ERTMS is the closest approach to the same concept for a main line railway. However this is only a regional product and is yet to be fully commissioned. Responses to the supplier questionnaire indicate that some suppliers have given considerable thought to the implementation of Level 3 systems. Suppliers and European railways both predict Level 3 could be in main line operation in 10 to 15 years’ time however to achieve this planning must start now.

This study has created interest and feedback from a wide range of suppliers, railway operators, train operators, the driver community, system designers and many others. The response and interest has generally been very positive and despite the current feeling that we should focus on achieving ERTMS Level 2 operation, the indication is that there is enthusiasm for overcoming the challenges to deliver the potential rewards offered by ERTMS Level 3. The market for ERTMS is not contained within Europe with 50% of planned implementations now being outside the EC and with the present world economic climate set to continue for some time, the delivery of low cost signalling solutions is a potential reward which should be explored.
7 Recommendations

7.1 Route Map

A high level route map has been developed (see Appendix F), following broadly the format developed for TSAG for implementation of the themes of the Rail Technical Strategy. The scope of the route map includes all of the principal train movement control system elements needed to deliver the industry’s aspirations as expressed to the study team. These are centred on ERTMS Level 3 but also cover other aspects which can be deployed earlier than Level 3 to deliver some of the potential benefits. The focus is inevitably on the main line route type but with some recognition of low cost, low capacity railway initiatives.

The route map activities are described area by area and incorporate specific recommendations as detailed in section 7.2.

More detail on the core activities related to ETCS Level 3 has been developed at the request of the ERTMS National Sponsor and is included at Appendix H.

7.2 Specific Recommendations

7.2.1 ETCS Level 3 Core

The ETCS Level 3 core activities work forward from this study and commence with a RAMS analysis of the “simple” and “median” architectures to derive a single functional architecture including the telecoms aspect. This will lead directly into development of a deliverable operational concept for the UK, incorporating a decision on whether to go forward with a “virtual” block concept as recommended in this report. It is suggested that this is an important piece of work for the UK to do before engaging fully in a European Level 3 project, as otherwise the UK will not know what it wants and needs out of such a project. The analysis would also be a valuable contribution to European project knowledge.

In background, work to assemble a team of European railways with a common interest in Level 3 will have been brought to a conclusion and a Level 3 Project Group set up. Its first task will be to agree the Level 3 operational concept at European level, including the requirements specification for train integrity which will be fed to the Train Integrity activity (see below) and taking account of work carried out at national level including the UK’s input.

A successful feasibility activity for the Train Integrity sub-project will allow the Level 3 Pilot to start; carried through by the Level 3 Project Group. The Level 3 Pilot could in principle happen anywhere in Europe, but the most promising areas for co-operation on Level 3 appear, currently, to be Scandinavia, where work is already the most advanced and where the operational and safety background is quite similar to the UK. A key contributor to the pilot will be the Driver Support initiative (see below).

Completion of the operational concept in the UK within the next 12-18 months appears feasible given appropriate levels of priority, with a further two years for agreement at European level, and a pilot project starting around 2014 to 2015.

The following recommendations emanate from the ETCS Level 3 Core element of the route map. The position in the overall route map is illustrated in the diagram in Appendix F (Area 1.0).
### Table 12. Recommendations – ETCS Level 3 Core

<table>
<thead>
<tr>
<th>No.</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ETCS Level 3 Core</td>
</tr>
</tbody>
</table>

#### 1.1 RAMS

**RAM**

ETCS Level 3 represents a major shift in railway system architecture compared with MAS. This system change should be fully analysed from a reliability and availability perspective, using the proposed system architectures and expected component reliabilities to predict the impact on overall railway performance.

Specific RAM analysis proposed

- High level delay minute apportionment
- Delay minute apportionment to be updated to include ERTMS Level 3.
- RAM model development

Communications system dependability analysis

- Models to be developed for Crossrail, West Coast and Thameslink could incorporate Level 3 architecture.

**System Safety**

The ETCS Level 2 Safety Risk Model should be re-examined with respect to Signalling System Failures to ascertain the likely impact of changes introduced by Level 3, in particular transferring the position tracking system from lineside infrastructure to trainborne equipment.

Specific activities should include:

- Detailed re-examination of the ETCS Fault Tree and development to support ETCS Level 3 operation.

Review of ETCS Level 2 safety requirements to identify new or changed safety requirements.

#### 1.2 Operational concept/rules and control principles

It is vital that the operational concept for Level 3 is developed very early in the process, driven by business and safety needs in balance and maintained through simulation, pilot and rollout phases and covering both normal and degraded modes of operation.

A successful Level 3 system application to a mixed traffic main line railway will need to be very clearly thought through in terms of the operational rule-set and control principles that will be used, focusing on the compromises between visionary change (in order to deliver the promised benefits) and current railway rules and principles (in order to achieve a gradual transition).
### Recommendation 1.3 Agree Level 3 Common Architecture

Once the UK has developed its ideas for an Operational Concept for Level 3, including the output from the RAMS study, it should consider participating with other interested railway undertakings and infrastructure managers in developing a Level 3 Common Architecture. This will greatly assist in ensuring the success of a pilot and in delivering the prospective cost savings from Level 3.

### Recommendation 1.4 ERTMS Level 3 Pilot

The Level 3 concept needs to be piloted at European level on a representative route section which can be taken out of service for an extended period.

### 7.2.2 Train Integrity

The train integrity activity should be seen as an integral part of the Level 3 core activity, since the requirements will be derived alongside the Level 3 Operational Concept and the developments validated as part of the Level 3 Pilot. Initial trials of a system for locomotive hauled trains could be carried out anywhere that such trains operate, and is not dependent on ERTMS being installed at any level. The train integrity trialling should be carried out at European level as a preliminary to the Level 3 Pilot, as it will affect the Level 3 Operational Concept.

The following recommendations emanate from the train integrity element of the route map. The position in the overall route map is illustrated in the diagram in Appendix F (Area 2.0).

<table>
<thead>
<tr>
<th>No.</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Develop train integrity specification for new passenger trains</td>
</tr>
</tbody>
</table>

All new passenger trains to be fitted with ERTMS Level 2 should also be fitted with a train integrity function enabling them to run eventually on ERTMS Level 3. The hardware specification for this can be written immediately.

| 2.2 | Develop Train Integrity Functional Specification |

Train integrity for multiple Unit passenger rolling stock should be considered as part of the low cost train fitment initiative described below, as this can be achieved by conventional means (train wired solutions).

For freight and other loco hauled trains, the first stage is to establish the solution architecture and to decide which aspects of the overall functionality will be covered by onboard equipment. The requirements specification for the onboard equipment can then be written.

| 2.3 | Train Integrity Feasibility Demonstration |

Once the functional specification for a freight train integrity system has been developed, a feasibility demonstration at breadboard/prototype level can be carried out.

---

**Table 13. Recommendations – Train Integrity**

<table>
<thead>
<tr>
<th></th>
<th>Train Integrity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Develop train integrity specification for new passenger trains</td>
</tr>
</tbody>
</table>

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| 2.3 | Train Integrity Feasibility Demonstration |

Once the functional specification for a freight train integrity system has been developed, a feasibility demonstration at breadboard/prototype level can be carried out.
2.4 Train Integrity Trial

A full-scale trial of a freight train integrity system can be carried out independently of ERTMS development. This should preferably be carried out at European level because it will validate some aspects of the Level 3 Functional Specification.

7.2.3 Low Cost Onboard

This initiative is a mitigator of risk for both Level 2 and Level 3 (see section 5.3.6). There are two parallel paths for the workstream initially. First, the minimum requirements for interoperability on domestic rolling stock need to be determined. It is suggested that this should be no more than the ability to operate without restriction on a Level 2 fitted route with no line-side signals. In parallel, a study should be carried out to determine what the key drivers for ERTMS onboard cost are, for both retrofit and fit from new. Inputs to this should come from a “Lessons from Cambrian” initiative as well as from European projects. Once these first steps have been completed, a feasibility study for low cost ETCS-compatible onboard can be carried out, leading to a pilot project, ideally at European level.

The following recommendations emanate from the low cost onboard element of the route map. The position in the overall route map is illustrated in the diagram in Appendix F (Area 3.0).

Table 14. Recommendations – Low Cost Onboard

<table>
<thead>
<tr>
<th>No.</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Low Cost Onboard</td>
</tr>
<tr>
<td>3.1</td>
<td>Establish minimum TSI compliance policy</td>
</tr>
<tr>
<td></td>
<td>A flexible approach to TSI compliance for domestic rolling stock should be adopted in order to support reduction in ETCS train fitment cost. The primary requirement should be the ability to operate safely and efficiently on a route fitted with ERTMS Level 2 or 3 with no line-side signals. Industry would need to define the high level requirements and DfT would need to agree to the necessary policy change. The CoCoSig TSI contains provisions which allow for innovation which could be cited if necessary.</td>
</tr>
<tr>
<td>3.2</td>
<td>Establish cost targets for retrofit</td>
</tr>
<tr>
<td></td>
<td>Experience with the Cambrian project should be combined with information made available from Switzerland, Sweden and elsewhere in Europe where significant numbers of older trains have been fitted with ERTMS to inform a review of the key cost drivers for retrofitting existing rolling stock. Estimates of possible savings can then be made, linked to assumptions on technological and other changes, consistent with the minimum requirements for interoperability established in 1B. A maximum cost can then be established, consistent with affordability requirements for national rollout.</td>
</tr>
<tr>
<td>3.3</td>
<td>Feasibility demonstration</td>
</tr>
<tr>
<td></td>
<td>Following up from 1B.3, a more detailed feasibility assessment can be carried out, engineered for a small set of typical vehicles, to demonstrate feasibility of the low cost solution before committing to a full scale pilot.</td>
</tr>
</tbody>
</table>
3.4 Establish Funding & Fitment Implications

The rollout of a low cost onboard solution needs to be supported by a coherent funding and access charges strategy for ERTMS, agreed between DfT, ORR and Network Rail.

3.5 Low cost onboard pilot

The pilot implementation for low cost onboard would ideally be carried out at European level. However, in view of the criticality of the issue, should this not be achievable the UK may have to decide to go ahead alone.

7.2.4 National ERTMS Rollout

National ERTMS rollout is included in the route map for completeness. Rollout of Level 2 will proceed on GWML and Thameslink in parallel, taking on board the maximum learning from Cambrian as this is completed. The next critical change will be the switch to rollout without lineside signals, which will depend on either a major reduction in the cost of fitting the onboard equipment being achieved or DfT adopting a more directive strategy for rolling stock planning (see above). Level 2 without lineside signals will then continue to be rolled out until sometime in early CP6 (i.e. around 2020), which is the earliest that Level 3 is likely to be available for wide scale rollout.

The following recommendation emanates from the National ERTMS rollout element of the route map. The position in the overall route map is illustrated in the diagram in Appendix F (Area 4.0).

Table 15. Recommendations – National ERTMS Roll Out

<table>
<thead>
<tr>
<th>No.</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>National ERTMS Roll Out</td>
</tr>
<tr>
<td>4.1</td>
<td>Learning from Cambrian</td>
</tr>
</tbody>
</table>

It would be very helpful to the Level 3 (and Level 2) initiatives if DfT could sponsor and industry stakeholders could execute a "learning from Cambrian" review, focused on operational and technical issues.

7.2.5 Future Operational Communications

GSM-R rollout is assumed to continue until completion of the main line network in around 2015. A key decision to be taken as soon as possible is whether or not to implement GPRS over the GSM-R network. The costs of implementing GPRS over GSM-R should be modest, but by the time the GSM-R rollout is complete, the technology will be obsolescent and the industry may wish to wait until GSM-R is replaced by LTE, inherently a packet switched system. LTE is not compatible with GSM mobiles and therefore its rollout in the railway environment is not likely to happen until the late 2020s. Waiting for LTE will affect both the train capacity per cell available to ERTMS Level 2 and Level 3, and the ability of the network to support Closed Loop Train Control (see below).

The following recommendation emanates from the future operational communications element of the route map. The position in the overall route map is illustrated in the diagram in Appendix F (Area 5.0).
Table 16. Recommendations – Future Operational Communications

<table>
<thead>
<tr>
<th>No.</th>
<th>Recommendation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Future operational Communications</td>
<td></td>
</tr>
<tr>
<td>5.1</td>
<td>Level 3 Communications Requirements</td>
<td></td>
</tr>
</tbody>
</table>

Further consideration needs to be given to the system architecture from an operational risk perspective. The effect of a wide area communications failure with a Level 3 system on any intensively used railway should be analysed. Consideration should be given to overlapping GSM-R cells, duplicating the FTN network (this should already be in place using the ring configuration) and duplicating elements such as the MSC. Future railway communications strategy should consider the use of diverse systems to achieve a better effect.

Level 3 does not depend on packet switching, but packet switching will be needed to support Level 2 before Level 3 is ready.

“Holistic” view needs to explore diversification of Telecom system functions and plan for GSM technology obsolescence so that best advantage is made of emerging technology. (May require government intervention).

7.2.6 Closed Loop Train Control

The industry’s aspirations for energy efficiency improvement and better response to perturbations require the loop to be closed between the driver and the infrastructure based regulation function, part of traffic management. This is not part of ERTMS and there is a strong argument for rolling it out independently of ERTMS, as this will allow it to be applied across the network much earlier. The first step is to agree the concept of this system, which is actually extremely simple and is capable of being extracted from RSSB research, and then to agree the track to train communications channel which will be used and the protocols for communicating train location from train to track and regulation information from track to train. Network Rail will then be free to develop the closed loop control capability as part of Traffic Management (see below) and the Train Operators will be able to fit trains with train location and driver advisory subsystems in the knowledge that the investment will pay back as soon as the regulation capability is available in a particular area. The critical path to delivery of benefits is likely to be the availability of a packet switched communications channel (see above).

The following recommendations emanate from this element of the route map. The position in the overall route map is illustrated in the diagram in Appendix F (Area 6.0).
Table 17. Recommendations – Closed Loop Train Control

<table>
<thead>
<tr>
<th>No.</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Closed Loop Train Control</td>
</tr>
</tbody>
</table>
| 6.1 | Closed Loop Control Concept & Cross-Industry Business Case  
Building on driver advisory speed work already carried out by RSSB, a control concept and high level architecture for closed loop train control should be established along with a cross-industry business case. This will include the establishment of the minimum update rates for train location and driver information and the precision requirements for train location. |
| 6.2 | Establish Closed Loop Comms requirements  
The closed loop train control concept requires continuous, dependable two way data communications between train and track. Currently the only carrier likely to be universally available is GSM-R, but this does not have packet switched data capability which is likely to be needed for this kind of application. Establishing the requirements for closed loop train control should lead directly into a decision as to whether to implement GPRS over the GSM-R carrier, or whether to wait for a future wireless communications system to be deployed. |
| 6.3 | Regulation (Driver Advisory) Interface and Protocol  
Realisation of the industry’s aspirations for traffic management, energy efficiency and better passenger information requires an industry agreed protocol for transmission of regulation information (short term updates to the timetabled movement) from track to train. |
| 6.4 | Train Location Interface and Protocol  
Realisation of the industry’s aspirations for traffic management, energy efficiency and better passenger information requires a protocol for transmission of train location information (short term updates to the timetabled movement) from train to track. |

7.2.7 Traffic Management

Network Rail is already proceeding with traffic management system development as part of its network management initiative. The development of a base capability is likely to focus first on establishing an interface from control centres to all signalling control areas, including those currently using mechanical interlocking, so that operational cost savings can be achieved and an infrastructure based technology similar to Automatic Route Setting (ARS) deployed more widely. The development of closed loop control capability (see above) is on the agenda but may need to be given priority so that the industry can be confident in its investment in the trainborne and communication aspects of this initiative. The rollout plan for Network Rail’s initiative is not yet clear, but it is assumed that significant areas of the network could be covered in 10 years.

The following recommendations emanate from the Traffic Management element of the route map. The position in the overall route map is illustrated in the diagram in Appendix F (Area 7.0).
Table 18. Recommendations – Traffic Management

<table>
<thead>
<tr>
<th>No.</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Traffic Management</td>
</tr>
<tr>
<td>7.1</td>
<td>Develop Closed Loop Control Capability</td>
</tr>
<tr>
<td></td>
<td>As part of the Network Rail traffic management initiative, the capability for traffic management based on closed loop train control should be developed and implemented.</td>
</tr>
</tbody>
</table>

### 7.2.8 Driver Support

Industry’s aspirations for increased driver flexibility and reduction in dependence on route knowledge will not be fully delivered by ETCS, which mitigates the risk of collision or of derailment due to overspeed arising from driver error, but does not support the driver in station stopping or position reporting during emergency or partial failure conditions or help efficient driving. It is suggested that a separate initiative to provide driver support based on commercial off the shelf satellite navigation could be highly cost effective. Such a system could be virtually self supporting and capable of deployment very rapidly, independent of any other initiative. The availability of an independent driver support system could actually assist industry acceptance of the Level 3 moving block concept, and avoid the need for maintaining extensive wayside markers and signs. Rollout over the next 5 years seems entirely feasible.

It is clear that technology will rapidly change the future role of the driver. There is a significant aspiration within the industry to introduce more automation, going as far as main line “Supervised ATO”. Key to any such initiative is a focused initiative to establish a clear view of the future role of the driver within the main line railway. The technology, in comparison, is of secondary importance.

The following recommendations emanate from the Driver Support element of the route map. The position in the overall route map is illustrated in the diagram in Appendix F (Area 8.0).
Table 19. Recommendations – Driver Support

<table>
<thead>
<tr>
<th>No.</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Driver Support</td>
</tr>
<tr>
<td></td>
<td><strong>8.1</strong> Develop Driver Support Concept (Current Environment)**</td>
</tr>
<tr>
<td></td>
<td>Dependence on route knowledge could be reduced by providing a low cost supplementary train location system based on commercial GPS satellite navigation, which can give a reasonably accurate location at all times, and could readily be configured to show key lineside features. The first step towards such a system would be to investigate, develop and cost the concept, to be used in the current train control environment entirely with COTS technology.</td>
</tr>
<tr>
<td></td>
<td><strong>8.2</strong> Driver Support Pilot</td>
</tr>
<tr>
<td></td>
<td>Once the concept has been developed, a pilot implementation could be very easily tried, in partnership with a supportive train operator.</td>
</tr>
<tr>
<td></td>
<td><strong>8.3</strong> Future Role of the Driver (Level 3 Environment)**</td>
</tr>
<tr>
<td></td>
<td>The combination of ETCS supervision with supplementary train location and driver advisory systems will change the role of the driver and makes feasible a form of Supervised ATO. Such an initiative must start with a human factors-based consideration of the “Future Role of the Driver”.</td>
</tr>
</tbody>
</table>
**Acknowledgements**

The work described in this report was carried out in the Infrastructure Division of the Transport Research Laboratory in Partnership with Parsons. The authors are grateful to Network Rail for providing the Lea Valley data and the ERTMS Strategy Group for participation in the workshop. The authors would also like to thank Mike Grimsey, who carried out the technical review and auditing of this report.

**References**

ERA - ERTMS/ETCS – Baseline 3 System Requirements Specification Subset -026 Issue 3.0.0 - Date: 23/12/08.

Railway Group Guidance Note. GE/GN 8605 ETCS System Description Issue 1 – Date September 2009.

ERTMS Operational Concept UK Application of ERTMS RSSB-ERTMS-OC Draft I for Issue 1 27/08/09.

## Appendix A  Risk Log

<table>
<thead>
<tr>
<th>No</th>
<th>Title</th>
<th>Explanation</th>
<th>Impact</th>
<th>Mitigation</th>
<th>Natural owner</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Design</td>
<td>Performance</td>
<td>Oper-ability</td>
</tr>
<tr>
<td>1.0</td>
<td><strong>Business Focus</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Business Requirements Clarity</td>
<td>Lack of up front clarity on business requirements and constraints causes development project to be incorrectly focused or irrelevant</td>
<td>Yes</td>
<td>High</td>
<td>Med</td>
</tr>
<tr>
<td>1.2</td>
<td>Pilot project focus</td>
<td>Development project/pilot inadequately linked to operational concept needed for national rollout</td>
<td>Yes</td>
<td>Yes</td>
<td>High</td>
</tr>
<tr>
<td>1.3</td>
<td>Control systems panacea</td>
<td>Desire to solve all industry control system issues at one stroke causes delay and loss of potential medium term benefits</td>
<td>Yes</td>
<td>Yes</td>
<td>Med</td>
</tr>
<tr>
<td>1.4</td>
<td>System cost incentive</td>
<td>Project stalls because of lack of system cost incentive. (Level 3 costs benefits fall primarily to Network Rail, whereas costs to operators increase)</td>
<td></td>
<td>High</td>
<td>Very High</td>
</tr>
</tbody>
</table>

## 2.0  Industry Structure & Process


<table>
<thead>
<tr>
<th>No</th>
<th>Title</th>
<th>Explanation</th>
<th>Impact</th>
<th>Mitigation</th>
<th>Natural owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4</td>
<td>System performance risk aversion</td>
<td>Inability of any industry party to take system performance risk drives complexity and cost into the system.</td>
<td>Yes</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>2.2</td>
<td>Transfer of Responsibility</td>
<td>Operators resist the transfer of responsibility from infrastructure to train unless given excess financial compensation.</td>
<td></td>
<td>High</td>
<td>Med</td>
</tr>
<tr>
<td>2.3</td>
<td>Moving block</td>
<td>Poor industry perception of moving block systems causes industry to obstruct or obtain changes to Level 3</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2.1</td>
<td>Train retrofit cost</td>
<td>High cost of train retrofit may block rollout or drive complex and expensive overlay solutions to allow mixed use. (This is a major issue for Level 2 as well as Level 3)</td>
<td>Yes</td>
<td></td>
<td>Very High Very High</td>
</tr>
<tr>
<td>3.0</td>
<td><strong>Communications System</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>Comms system dependence</td>
<td>Current GSM-R system implementation inadequate for Level 3</td>
<td>Yes</td>
<td>Yes</td>
<td>Very High High</td>
</tr>
<tr>
<td>No</td>
<td>Title</td>
<td>Explanation</td>
<td>Impact</td>
<td>Mitigation</td>
<td></td>
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<td>------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td>--------</td>
<td>----------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>3.2</td>
<td>Dependency on advanced telecoms</td>
<td>Industry may fail to adopt an advanced data carrier in time for L3</td>
<td>Yes</td>
<td>High Industry regulators should consider how change to advanced telecoms should be incentivised and funded</td>
<td></td>
</tr>
<tr>
<td>3.3</td>
<td>Dependence on packet switching</td>
<td>Dependence on move to packet switching – may contain hidden pitfalls</td>
<td>Yes</td>
<td>Med Low Likely to be solved for L2 before L3 is rolled out</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td><strong>Operations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>Driveability of moving block</td>
<td>Driver role in moving block system may be more difficult and require more route knowledge, thus increasing overall costs</td>
<td>Yes</td>
<td>Yes Med Med Carry out intensive human factors investigation of driver role and confirm cost benefits of moving block system before committing to a solution. Consider development of backup driver information system (TomTom(R)) for rail.</td>
<td></td>
</tr>
<tr>
<td>4.3</td>
<td>Signaller interface</td>
<td>Changed route setting, locking and train display principles may impact on signaller workload and cause confusion</td>
<td>Yes</td>
<td>Yes Yes Med Can be mitigated by configuring the system as “virtual block”. Consider human factors and benefits implications carefully before committing to operational principles of system.</td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>Driver support</td>
<td>Information available to driver inadequate for degraded operation</td>
<td>Yes</td>
<td>Yes Yes Med Can be mitigated by retaining trackside location markers and/or making the system “virtual block” — but impact on system benefits needs to be assessed. Also consider low cost backup location system.</td>
<td></td>
</tr>
</tbody>
</table>

**5.0 System Development**
<table>
<thead>
<tr>
<th>No</th>
<th>Title</th>
<th>Explanation</th>
<th>Impact</th>
<th>Mitigation</th>
<th>Natural owner</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Design</td>
<td>Performance</td>
<td>Operability</td>
</tr>
<tr>
<td>5.1</td>
<td>Train integrity</td>
<td>Freight operators (in particular) resist transfer of train integrity function from Network Rail.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5.2</td>
<td>ETCS changes underestimated</td>
<td>Changes from Level 2 underestimated; Major changes to ETCS kernel to support resilient L3 function set</td>
<td>Yes</td>
<td></td>
<td>Med</td>
</tr>
<tr>
<td>5.3</td>
<td>Multi-supplier environment</td>
<td>Maintaining a multi-supplier environment during development phase makes project costly and hard to control</td>
<td>High</td>
<td>Med</td>
<td></td>
</tr>
<tr>
<td>5.4</td>
<td>Procurement strategy</td>
<td>Infrastructure procurement strategy drives a sub-optimal system architecture</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5.5</td>
<td>Train tracking</td>
<td>Split of train tracking functionality between RBC and interlocking may increase pressure on safety process and make development more difficult.</td>
<td>Yes</td>
<td></td>
<td>Med</td>
</tr>
<tr>
<td>5.6</td>
<td>Onboard equipment dependence</td>
<td>“Standard” ETCS onboard inadequate to support Level 3 train location function</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>Title</td>
<td>Explanation</td>
<td>Impact</td>
<td>Mitigation</td>
<td>Natural owner</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Design</td>
<td>Performance</td>
<td>Oper-ability</td>
</tr>
<tr>
<td>5.7</td>
<td>Standards process impact</td>
<td>Creeping change in requirements through application of standards process</td>
<td>Yes</td>
<td>Yes</td>
<td>High</td>
</tr>
<tr>
<td>4.4</td>
<td>Operating rules constraint</td>
<td>Wish to avoid change to operating rules may drive requirements creep and failure to meet business objectives</td>
<td>Yes</td>
<td>Yes</td>
<td>High</td>
</tr>
<tr>
<td>6.0</td>
<td>Safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.1</td>
<td>Track based train detection independence</td>
<td>Reduced dependence on track circuits or axle counters for train location function (benefit)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix B  Summary notes from liaison meetings with stakeholders

B.1 ERTMS Level 3: Responses to Questions by European Railways

A short set of questions was emailed to the ERTMS Users Group representatives of Prorail, RFF, SBB, RFI, Deutsche Bahn, ADIF and Banverket. This is a summary of answers received. They reflect the individuals understanding of the position in their company and their views on the subject.

B.1.1 Prorail:

1. Do you foresee any role for ETCS Level 3 on your network?
   
   We hope that Level 3 can reduce costs and improve the availability of the track side signalling system. Therefore, we think L3 should be implemented in principle on the whole network (so not restricted to certain types of infrastructure). However, we think that L3 in station areas will be too complicated from technical and operational point of view (e.g. odometry accuracy, "parking" of trains/wagons). This will mean that L3 will only be installed on the open track; station areas will be equipped with L2.

2. When might this be?
   
   Not earlier than 2015, perhaps somewhere 2020.

3. What would be the reasons for using Level 3 instead of Level 2?
   
   See 1), we don't expect that L3 will deliver more capacity than L2 with optimised block lengths. We are convinced that L3 should still work with "fixed blocks" instead of "moving blocks".

4. Are you aware of any studies that have been done on Level 3, either on the technical issues, operational implications or economic matters? Are any of these available?
   
   I'm not aware of available studies (except the "end of train device" study done by the Users Group). I'm convinced that the operational implications are not yet fully understood and should be studied. In my view, the main operational issue to be solved in an operational interoperable way is the situation where one or more trains get "lost" (or break) on a L3 line. We need to have an European harmonised process to find these (bits of) trains and conclude "we have found them all, they are complete and thus we can restart the service without restrictions"

5. In particular, has any work been done in the last few years on the 'end of train’ problem with freight? (I am aware of some Users Group work in the early days).
   
   No additional information

B.1.2 SBB:

1. Do you foresee any role for ETCS Level 3 on your network?
   
   Not at the moment and if two cases would be evaluated:
   
   a) Regional lines with low density traffic and low capacity needs in order to save infrastructure costs
   
   b) Main lines with high density traffic and high capacity needs in order to shorten headways as much as possible (moving block)

2. When might this be?
a) Not before 2020
b) Not before 2025

3. What would be the reasons for using Level 3 instead of Level 2?
   a) Lowering costs on infrastructure
   b) Getting the last second out for capacity reasons
   See as well 1 a) and b).

4. Are you aware of any studies that have been done on Level 3, either on the technical issues, operational implications or economic matters? Are any of these available?
   No studies done so far. Following the activities in Sweden / UIC

5. In particular, has any work been done in the last few years on the ‘end of train’ problem with freight? (I am aware of some Users Group work in the early days).
   Not at SBB. I'm aware of the Users Group activities too. Personally I think this will be a key for the success. Instead we face totally another problem down here. Most of our lines (not to say all) are mixed traffic lines and therefore we have, at the time being, the challenge of free standing freight cars. This circumstance is increasing heavily the complexity of the problem.

**B.1.3 Banverket:**

1. Do you foresee any role for ETCS Level 3 on your network?
   Yes, on Regional lines (ERTMS Regional). To replace the manual system in operation at present.

2. When might this be?
   Starting commercial operation in the end of 2010.

3. What would be the reasons for using Level 3 instead of Level 2?
   L3 lead to lower installation and LCC cost compared to L2. We need an "affordable" system. The traffic amount need [sic] to be able to carry the installation cost of a system that has the needed performance.

4. Are you aware of any studies that have been done on Level 3, either on the technical issues, operational implications or economic matters? Are any of these available?
   Banverket has 15 years experience of a L3 look-alike system (Radio block system) in commercial operation on a Regional line.

5. In particular, has any work been done in the last few years on the ‘end of train’ problem with freight?
   Yes, In the UIC-project ERTMS Regional lead by Mr Poul Frösig.
   From ERTMS Users Group web page:
   The Västerdal Line (Repbäcken-Malung)
   - In service October 2010
   - 134 km
   - Freight and passenger traffic
   - ERTMS Level 3 (ERTMS Regional)
   - STM Ebicab 700 needed for interconnections
- Contract awarded to Bombardier for trackside 5-6 low-density lines ERTMS Level 3 (ERTMS Regional) in 2010-2015. The Hargshamn Line (Örbyhus-Hargshamn) is one of them.

**B.1.4 ADIF:**

In principle the target system in ADIF is Level 2. The main cost saving from Level 3 comparing with Level 2 will be removing the track circuits, but this will create big problems in degraded situations, if one train loose connection with RBC this will stop the operations since we don't know where the train is. So we can't consider the situation without track circuits. We are very conservative, since we won't remove signals in Level 2. As far as I now [sic] we haven't done any formal study on this.

The main benefit in our situation will be the increased capacity of the moving block, but we are not reaching that situation yet. We are still expecting to learn from the Level 2 in service (We still don't have a date)

Regarding the end of train I know that in the Grail project some options were considered, as placing one GPS receiver at each end of the train and monitor the distance.

**B.1.5 RFI:**

Do not foresee in medium term any application of ETCS Level 3 in their network

**B.1.6 Deutsche Bahn:**

Deutsche Bahn has placed an order with the University of Technology Darmstadt, chair of railway engineering to “study possibilities of trainside integrity test”.

Their contact Jorg Brill reports:

'As one of the first steps, I started a search in the database of German Patent Agency, which connects to lots of patents in Europe and worldwide. I found a lot of patents about trainside integrity test. Some of them are really interesting, other are funnier.

In the next step I will develop some criterions to select the most promising ideas and then starting a defeasibility study. We are planning to develop a test in reality in 2011/12.

The problem of train-integrity is in Germany particularly interesting for freight-trains as well as in GB, because the most passenger trains have got some electric connection.’

The implications are that Deutsche Bahn has a long term interest in the potential of Level 3

**B.1.7 Banedanmark:**

Banedanmark have considered Regional ERTMS for secondary lines in Denmark as part of the development of their national roll out of ERTMS. They have not considered Level 3 for main lines as their project is active and issuing tenders this year for roll out completion by 2021. The conclusions about Regional ERTMS are awaited but indications are that they see a simple application of Level 2 being the most likely solution. This is for supply
reasons, risk control, likely real cost savings and the prevalence and possible growth of freight traffic.

**B.1.8 RFF:**

RFF is expected to join the Regional ERTMS project and plans to develop two pilot lines to test this application on its conventional network. These pilot lines will also be used to test the use of Galileo rail applications. (Source: European Report)

**B.1.9 Regional ERTMS:**

For around a decade, the UIC has been running a study to devise an implementation specification for ERTMS use on secondary routes. This is envisaged as a Level 3 type of solution. The work assumes a standard onboard ERTMS fitment with train integrity monitoring, as foreseen by the Class 1 specifications. The UIC project therefore has focused on the infrastructure specification. It is interlinked with the Banverket project and intends to use the specifications developed as part of that, although there are signs of further change and adaptation. Participation at meetings (about 3 per annum) is from Germany, France, Slovenia, Italy, Sweden and Norway. The project has latterly started to take an interest in train integrity monitoring and resurrected an FRS from 1999/2000 prepared by the ERTMS Users Group, but never completed. Details of the UIC project can be found through the UIC website at: [http://www.uic.org/spip.php?rubrique871](http://www.uic.org/spip.php?rubrique871) or via http://ertms.uic.asso.fr/
Appendix C  PRIME – Parsons Railway Integrated Modelling Environment

C.1 Pedigree
Parsons have utilized their Capacity Planning tool (PRIME) on a number of railway projects including:

- Evaluation of the costs and benefits of Unattended Train Operation for the Copenhagen suburban rail system (S Bane);
- A study of the maximum capacity that could be obtained for future operations on the YUS Line in Toronto.
- A subset of the capability was built into CPetcs for Department for Transport looking at the ability of Level 3 ETCS to support high density commuter services such as Thameslink upgrade and Crossrail.
- Capacity optimisation for the Copenhagen Metro City Ring project.
- Developing a business case for unattended operation on the Stockholm commuter lines.

C.2 PRIME Features
The advantages offered by PRIME include:

- Providing a flexible modelling environment which is easily adaptable to different study objectives as well as different railway characteristics.
- Giving a full profile of signalling headways at each point on the line. This not only identifies the main bottlenecks but also shows potential secondary pinch points that could limit capacity if the primary bottlenecks are eased.
- Simulating target service patterns to evaluate the actual headways can be achieved.
- Simulating different patterns of service perturbations to determine realistic operational headway targets.
- Evaluating the impact of rolling stock traction systems.
- Evaluating the impact of train design on passenger capacity and dwell time efficiency.
- Exploring different service patterns and timetables.
- Exploring operational strategies such as unattended operation and automatic reversing.

C.3 PRIME Description
PRIME is a Modelling Environment rather than a modelling tool. This means that it is a toolbox of compatible modelling modules that can be configured and customised to the requirements of a specific project. As with other railway models, its heart is the evaluation of train run times considering rolling stock capabilities, passenger loads, alighting and boarding times, signalling constraints, track characteristics etc. Where it differs from other simulators is the use of two levels of model:

a) A static model looking at an individual train run to determine unimpeded speed / time profiles and effective headways (required separation in front of and behind a train).
b) A full dynamic simulation to explore interaction between simultaneous operation of multiple trains and their ability to satisfy customer demand.

C.4 Static Model

This provides the following functionality:

- **Representation track layout including:**
  - main and branch line segments
  - gradients
  - speed limits
  - grade separated and flat junctions
  - terminal and intermediate stations
  - cross-overs
  - reversing sidings

- **Modelling multiple rolling stock types defined in terms of:**
  - train consist
  - length of each vehicle
  - tare mass of each vehicle
  - passenger / freight capacity
  - motor tractive effort curves
  - braking characteristics
  - traction control response times
  - braking system response times
  - rolling resistance and drag (separately for tunnel and open sections)

- **Modelling multiple signalling types including:**
  - 2 or 3 aspect colour light systems
  - ETCS level 1 Automatic Train Protection (ATP)
  - ETCS level 2 Automatic Train Protection (ATP)
  - ETCS level 3 Automatic Train Protection (ATP)
  - Automatic Train Operation (ATO) overlays on the above APT systems
  - Metro Communications Based Train Control (CBTC)

- **Modelling of nominal station dwell times**
- **Modelling of predefined routes through the rail network**
- **Generation, for each route, of normal (unimpeded) speed and time profiles**
- **Computation, at each point on the predefined routes, of the minimum technical (signalling) headways**
- **Identification of the most restrictive headway location for each defined route (this defines the design capacity)**

Normally a margin will be applied to the design capacity to allow for expected variations in run and dwell times. The magnitude and distribution of the recovery margin can be evaluated using the dynamic modelling facility.
C.5 Dynamic Model

This provides the following functionality:

- Re-use of all relevant static model data
- Representation of target service patterns (these can be timetables or target headways by route)
- Variation of inter-station run times based on load variations, random variations or a combination of both
- Variation of station dwell times based on alighting and boarding times, random variations or a combination of both
- Modelling of various Automatic Traffic Regulation (ATR) schemes (these could actually be manual schemes applied by traffic controllers but must be systematic according to pre-defined rules)
- Modelling of defensive driving rules
- Modelling of predefined fixed delays (to evaluate recovery time)
- Generation of time distance plots for each train (waterfall diagrams)
- Generation of plots of departure time variation from timetable at each station
- Calculation of mean and standard deviation of delays at each station

C.6 Other Modules

In addition to the core simulation modules, other modules are:

- The Track Builder which converts input data, in a simple form, to a complete representation of the railway network.
- The Timetable Module which constructs a timetable from target frequencies in each railway section.
- A Passenger Flow Module that determines numbers of boarders and alighters to/from each service at each station in predetermined time periods.
- A Profile Output Module that produces charts of train speeds and technical headways over the rail network.
- A Simulation Output Module that produces time / distance (waterfall) diagrams and charts of dwell times and departure headways at each station.
Appendix D  Capacity Evaluation Report

7.2.9  Approach

Capacity benefits have been evaluated using a combination of PRIME (Parsons Railway Integrated Modelling Environment) with domain knowledge and judgement. PRIME has a wide range of functionality but only the headway evaluation capabilities have been employed so far in this study. The following steps were involved in the modelling process:

- A generic track layout was devised and its details entered into the PRIME Track Builder.
- The Track Builder module was then used to construct the track model required for simulation together with a routing table showing the potential routes through the layout.
- Rolling stock and signalling data were entered into the corresponding PRIME libraries.
- The main PRIME module was then loaded with the appropriate selections from the Track, Rolling stock and Signalling libraries.
- The “Profile” function in PRIME was then used to generate speed / distance and time / distance profiles. At the same time “Technical Headways” are computed for each point on each route through the layout.

Capacity evaluation in this study has been based on the following principles:

\[
\text{Capacity (in trains per hour – tph) } = \frac{3600}{\text{Operational Headway (in seconds)}}
\]

Operational Headway = Worst Case Technical Headway + Operating Margin.

The Operating Margin allows for minor fluctuations in run times and dwell times, conflicts at junctions etc. The value of Operating margin depends on the length and complexity of the route and is determined from experience. For this study a typical value of 30 seconds has been used throughout.

The influence of the train control system is represented within the Technical Headway. PRIME can model Technical Headways for:

- 3 or 4 aspect coloured light signalling systems
- ETCS Level 1, 2 or 3 Train Control
- Communication Based Train Control (normally used for metros).

In this study ERTMS Levels 2 and 3 have been included and compared with conventional 4 aspect signalling. The way in which PRIME calculates Technical Headway is as follows:

- A simulation is performed of a single train running through each route within the track layout.
- A pre-defined time intervals (set at 1 second for this study) the train calculates the minimum Movement Authority required to avoid Automatic Train Protection (ATP) intervention.
- The minimum train separation, between this train and a preceding train is then calculated taking into account the required Movement Authority plus the distance from the end of this authority to the closest position of head of the preceding train.
- The time required for the train to traverse this minimum separation is then calculated. This value is the Technical Headway. The calculation is illustrated in Figure 11 for ERTMS Levels 2 and 3.
The Required Movement Authority comprises:

- An allowance for odometry error (Odo).
- An advanced indication time to prepare the driver to take action (TIP).
- The driver reaction time (Td).
- An allowance for ERTMS system operation times (ETCS) this includes:
  - The time to update the driver’s display.
  - The cycle time of the onboard vital computer.
  - The period between Movement Authority update requests.
  - The time to transmit an updated Movement Authority over the GSM-R network.
  - The cycle time of the Radio Block Centre (RBC).
- The service brake build-up time (Tbs).
- The longest of:
  - Service brake application to bring the train to a stand (SBD) at the End of Authority.
  - Service brake application to prevent the application of the Emergency Brake (EBD) to bring the train to a stand at the Supervised Location.
  - Note here that there is a distinction to be applied depending on whether the preceding train is operating under Level 2 or 3 control:
    - Under Level 2 the required Movement Authority is effectively moved forward to the end of the signal block. The Supervised Location becomes the overlap of that block.
    - Under Level 3 the Supervised Location is set as the safe rear end of the preceding train. A margin is then applied in rear of the Supervised Location to define the End of Authority. For this study this margin has been set at the standard overlap distance (183m).
For both Level 2 and Level 3, if the Supervised Location falls within a junction area it is extended to the overlap following the clearance point and the route setting time is added to the headway calculation.

The Closest location of the head of the preceding is calculated taking account of:

- The length of the train.
- For ETCS Level 3 (not shown in the diagram):
  - Odometry error
  - Time to prove train integrity
  - Half the period between position reports. Note that the requirement for an MA update may come anywhere within this period but will on average be half that time. Trains always report position on passing a balise so these can be placed appropriately at critical locations.
  - The time to transmit the position report over the GSM-R network.
- For ETCS Level 2 (as shown in the diagram):
  - The length of the signal block plus its overlap.
  - The time for the Axle Counters (or track circuits) and the Interlocking (or equivalent functionality integrated in the RBC) to recognise block clearance.

7.2.10 D2. **Generic benefits of Level 3**

The generic approach to capacity evaluation recognises that any railways can described as a set of interconnected “Building Blocks”. The main types of Building Blocks are:

- Plain line sections (single or bidirectional)
- Terminal stations
- Intermediate stations
- Junctions
- Crossovers
- Sidings (including reversing sidings)

The generic benefits of ERTMS Level 3 can best be evaluated by looking at Plain Line sections and Junctions. It does also have benefits for station stops and reversing in sidings but these are more dependent on specific application scenarios and so are treated as part of the Case Studies.

The benefits of ERTMS Level 3 compared to Level 2 can be either capacity improvement or achievement of equivalent capacity at lower cost. In particular some ERTMS Level 3 architectures allow Level 2 as a degraded mode of operation. In these cases costs can be reduced at the expense of occasional degradation of service capacity.

ERTMS Level 2 can be applied to a railway and utilise existing track based train detection and interlocking equipment. This will give some capacity improvement. Further improvement could be obtained at the expense of decreasing the block sizes. With small enough block sizes the capacity of Level 2 may even exceed that obtained with Level 3 (as shown in the following chart). Whether there is a crossover in capacity depends critically of the difference between the time required for block occupation change recognition compared with Level 3 position report frequency and latency.
7.2.11 D3. Sensitivities and Options

ERTMS Level 3 is standardised only to the extent required for interoperability. Many parameters, particularly performance parameters, are not specified in the TSiS. The impact of some of these parameters is considered below.

PRIME simulation results for the effect of varying these parameters is presented in the "Spider" diagram in Figure 13.

![Figure 12. Trains per Hour against Block Length](image)

**Figure 12. Trains per Hour against Block Length**

![Figure 13. PRIME simulation results - effect of varying parameters](image)

**Figure 13. PRIME simulation results - effect of varying parameters**

The diagram shows the impact, in tph capacity, of changing each parameter in turn from a “Nominal” value to either Better or Worse values. “Better” and “Worse” are always in the sense of improving or worsening capacity. Each radial axis in the diagram shows the
effect of that parameter change when all other parameters are at their “Nominal” values. The parameter values used to obtain the above results are tabulated below.

### Table 20. PRIME Model Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Better</th>
<th>Nominal</th>
<th>Worse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train Integrity (seconds)</td>
<td>0</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>EOA to Supervised Location (m)</td>
<td>10</td>
<td>100</td>
<td>183</td>
</tr>
<tr>
<td>Odometry error</td>
<td>1%</td>
<td>5%</td>
<td>20%</td>
</tr>
<tr>
<td>Balise spacing (m)</td>
<td>10</td>
<td>500</td>
<td>5000</td>
</tr>
<tr>
<td>Position Report Time (seconds)</td>
<td>1</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>MA update cycle time (seconds)</td>
<td>1</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

Some comments on these parameters and their impact:

**Train Integrity**

This is the principal additional onboard functionality. Position reports to the RBC must give an indication of the safe position of the rear of the train. If integrity confirmation requires a certain time to achieve, then the reported position must be based on the train location that amount of time previously.

For passenger trains it is not considered as a significant problem and should be capable of implementation with little or no impact on performance. Thus the nominal 2 seconds allowed should be easily achieved. Efforts to reduce this 2 second time would have very modest capacity benefit (maximum 2%). Solutions for freight trains are more problematic. If such a solution involved a delay of 10 seconds the capacity penalty would be 8%.

**End of Authority**

There is an issue of determination of the allowance to be made for a distance between the Supervised Location and the End of Authority. In ERTMS this is normally the overlap distance. It should be possible to reduce the value for Level 3 so a nominal 100 m has been used. Reducing it further to 10 m (typical value used by CBTC) would improve capacity by 3% while increasing it to the standard 183 m overlap value would reduce capacity by 3%.

**Position Accuracy**

This becomes more important in Level 3 because it affects both leading and following trains. In Level 2 it only affects following trains. It is influenced by the accuracy of the onboard odometry equipment and balise spacing since trains get an absolute position reference from each balise. The maximum to be gained by improving either parameter from its nominal value is a 1% capacity improvement. 5% odometry accuracy should be easily achievable but even worsening it to 20% would only have a 2% impact on capacity. Balise spacing is a real cost factor. The analysis shows that increasing spacing to 5 km would give a 6% capacity penalty which may well be acceptable in many applications. However the effect of misreading or faulty balises should be taken into account.
**Cycle Times**

Amongst the application dependent parameters that must be defined for ERTMS, two cycle periods have a significant impact on capacity. These are the period between position reports (if no balise is passed) and the period between repeat requests for Movement Authority updates. A nominal value of 5 seconds has been used for both. There is a 10% capacity benefit or penalty by reducing the MA update request period to 1 second or increasing it to 10 seconds. The equivalent effect for the position report period is just half of these values because, when the report is required, it will on average be half way within the period. A requirement for more frequent updating would increase the load on the EVC processor and also on the communications carrier (assuming that a packet switched carrier was in use – the current circuit switched carrier has large amounts of spare capacity per circuit).

**Balise Spacing**

Variability in balise spacing has been modelled using large changes to demonstrate the impact. Reducing the balise spacing has very little effect on capacity, because the contribution of odometry error over the assumed 500m normal spacing is small compared with the length of the train.

**7.2.12 D4. Junctions**

Junctions can constrain route capacity. Specific features of a junction that impact its capacity include:

- a) The number of simultaneous movements that are possible across the junction.
- b) Priorities given to each route through the junction.
- c) The locations, on each approach line, at which routes are set and locked.
- d) Route setting time.
- e) Speed limits for different routes across the junction.
- f) Clearance points that must be passed before the route can be released.

Factors (a) and (b) have a high impact on railway capacity. They can both be modelled in PRIME. However there is no direct relationship between these factors and the choice between ERTMS Level 2 or 3 as an upgrade to conventional signalling. The other 4 factors (c to f) are all included in the following sensitivity analysis.

The analysis is based on a simple converging junction. Diverging junctions have a lesser impact on capacity. The capacity impact on more complex junctions will be similar to that on the basic case.

The location at which the route is set and locked in practice depends on a variety of timetabling issues as well as signalling. For the purpose of this analysis, it is assumed that routes are set as a train approaches the junction at the closest location that avoids the need for the train to reduce speed. No account is taken of conflicting train arrivals as this is considered as a timetable, rather than signalling issue.

The reference junction operation used in the modelling has the following characteristics:

- Level ground;
- 120 kph (75 mph) line speed;
- Minimum 4 aspect signal spacing;
- Standard 183m overlaps;
- Trains cross with points normal at line speed;
- Electrostar trains with 8 cars;
• Sensitivity is tested by varying the values of:
  o Route setting time
  o Speed limit for crossing the junction with point set reverse
  o Distance between junction entry and clearance locations.

The base case model has a plain line capacity of 41 tph for ERTMS Level 2 and 42.5 tph for Level 3. The following chart shows capacity variation with junction length (distance between the control signal in rear of the junction and the clearance point in advance of the junction).

![Sensitivity to Junction Length](image)

**Figure 14. Sensitivity of Headway to Junction Length**

Variation with speed limits with points set reverse is shown in Figure 15.

![Sensitivity to Junction Reverse Speed](image)

**Figure 15. Sensitivity of Headway to Junction Reverse Speed**
As would be expected Route setting time is a direct addition to the minimum headway time. It applies normally to the converging route, so the nominal 60 kph points reverse speed limit is applied, as shown in Figure 16.

ERTMS Level 3 moving block affords capacity increases at junction when compared with Level 2. This conclusion is valid for the “Nominal” parameter values indicated in Table 6. These should be achievable for passenger trains. For freight trains, the only parameter value that is questionable is the response time of train integrity.

Junction operation does however reduce the percentage increase in capacity offered by ERTMS Level 3 compared with Level 2. If we consider the Lea Valley application and compare stopping services from Liverpool Street or Stratford to Broxbourne with those to Hertford east we find that Level 3 gives a 24.5% improvement in the first case but only a 14.4% improvement in the second case where junction operation is involved. This reduction happens because the junction is, in effect, a fixed block in a moving block railway, with an associated built in delay (the route resetting time). The percentage improvement of Level 3 over Level 2 is therefore reduced.

*Train or Track Based Location Detection*

In the above comparisons ERTMS Level 3 always gives higher capacity than Level 2. This is because block spacing is set at 500 m, a distance appropriate to full line speed, but trains have to slow to cross the junction with points set at reverse. This effect masks the distinction between track and train based location detection at the junction. In order to address this question, a number of simulations have been performed with junction reverse speed set equal to line speed and points switch time set to zero.

ERTMS Level 2 simulations show that the presence of a junction, under these conditions, only impacts headways when the junction length exceeds the plain line block length. Technical headways for ERTMS Level 3 with train based and track based location detection are compared in Figure 17.
Figure 17. Technical headways for ERTMS Level 3 with train based and track based location detection.

In the above chart Level LP refers to Low Performance parameter settings and HP to high performance as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Level 3 LP</th>
<th>Level 3 HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position report time</td>
<td>3 seconds</td>
<td>2 seconds</td>
</tr>
<tr>
<td>Train integrity time</td>
<td>1 second</td>
<td>0 seconds</td>
</tr>
<tr>
<td>Odometry error</td>
<td>5%</td>
<td>2%</td>
</tr>
</tbody>
</table>

The conclusion is that track based location detection at junctions would give a performance benefit particularly for short junctions.

7.2.13 **D5. Scenario Case Study**

When looking at an application involving mixed traffic in an area with multiple routes, we have to extend the definition of capacity from the simple “trains per hour”, used above, to “train paths per hour”. The term “Train Path” is used here to mean “the time between two successive trains commencing a defined path through a railway section, such that the movement of the second train is not impeded by the first train”. The measure of capacity then becomes “Train Paths per Hour” (TPPH). Clearly the time required for a Train Path, for a defined railway layout and signalling system, depends on a number of other factors including:

- the run time from entry to exit of the railway section;
- the characteristics of the preceding train;
- the characteristics of the following train.

The most effective use of the railway capacity is obtained when all Train Paths are identical. If the Train paths are different then an addition is required depending on the preceding type.

The application case study is based on the Lea Valley Main Line as depicted in Figure 18.
The key section for capacity is from Cheshunt junction to Broxbourne junction. The Base Train Path is taken as a non-stop intercity train moving at full speed between these junctions.

PRIME modelling of this scenario has used the following basic types of Train path:

Thru - Class 390 9 car, non-stopping train moving at full speed between the two junctions.

Commuter - Class 375 8 car train commuter train stopping at both Cheshunt and Broxbourne stations with a dwell of 45 seconds at each.

Freight - Class 90 locomotive hauling a 775 m long train.

The TPPH for combinations of these services, obtained from PRIME modelling, are shown in Table 22, Table 23 and Table 24.

<table>
<thead>
<tr>
<th>4 Aspect Signalling</th>
<th>Through TPPH</th>
<th>Commuter ETPPH</th>
<th>Freight ETPPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Following Through</td>
<td>21.9</td>
<td>7.6</td>
<td>6.5</td>
</tr>
<tr>
<td>Following Commuter</td>
<td>9.5</td>
<td>14.0</td>
<td>9.2</td>
</tr>
<tr>
<td>Following Freight</td>
<td>10.1</td>
<td>11.5</td>
<td>9.9</td>
</tr>
</tbody>
</table>
Table 23. TPH for ERTMS Level 2

<table>
<thead>
<tr>
<th>ERTMS Level 2</th>
<th>Through TPH</th>
<th>Commuter ETPPH</th>
<th>Freight ETPPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Following Through</td>
<td>31.2</td>
<td>8.4</td>
<td>7.0</td>
</tr>
<tr>
<td>Following Commuter</td>
<td>10.9</td>
<td>17.0</td>
<td>7.5</td>
</tr>
<tr>
<td>Following Freight</td>
<td>15.0</td>
<td>10.8</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Table 24. TPH for ERTMS Level 3

<table>
<thead>
<tr>
<th>ERTMS Level 3</th>
<th>Through TPH</th>
<th>Commuter ETPPH</th>
<th>Freight ETPPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Following Through</td>
<td>36.5</td>
<td>9.0</td>
<td>7.7</td>
</tr>
<tr>
<td>Following Commuter</td>
<td>11.4</td>
<td>19.8</td>
<td>8.3</td>
</tr>
<tr>
<td>Following Freight</td>
<td>16.1</td>
<td>11.9</td>
<td>10.5</td>
</tr>
</tbody>
</table>

The actual capacity, therefore, varies considerably with the service pattern. The impact of signalling can be illustrated by taking the following example:

- Take a 2 hour period.
- Allow 1 freight train path preceded and followed by commuter trains.
- Fill the remaining capacity with sequences of one through path followed by 2 commuter paths.
- Derive the total number of train paths within the two hour period.

For this example we get:

- 4 aspect signalling allows 24 train paths in the 2 hour period.
- ERTMS Level 2 signalling allows 28 train paths in the 2 hour period.
- ERTMS Level 3 signalling allows 31 train paths in the 2 hour period.

7.2.14 D6. Other Application Scenarios

The following capacity comparisons (see Table 25) are based on ERTMS Level 2 application using existing block lengths. The capacity of ERTMS Level 2 applications can be increased by reducing block lengths at the expense of increased trackside location equipment (axle counters or track circuits with associated interlocking equipment).
### Table 25. Capacity Implications for ERTMS Level 2 for Different Route Types

<table>
<thead>
<tr>
<th>Route Type</th>
<th>Capacity Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Capacity Urban</td>
<td>ERTMS Level 3, moving block, has potential for an improvement of between 10% and 20% for passenger trains depending on the application specifics. Introduction of freight train paths reduces this margin by 5% to 10% for each freight path.</td>
</tr>
<tr>
<td>Fast (200 kph), Highly Utilised Main Line</td>
<td>In this application, the capacity benefit of ERTMS Level 3, moving block, is about 20%.</td>
</tr>
<tr>
<td>Regional Main Line</td>
<td>The impact of ERTMS Level 3 will be similar to that for high capacity urban lines as outlined above.</td>
</tr>
<tr>
<td>Rural Route</td>
<td>Application of ERTMS Level 2 is likely to give sufficient capacity increase for many years. If, however, the RBC software is specified to accommodate mixed Level 2 and 3 operation, then further increases in capacity can be achieved without the need for addition or change to trackside equipment.</td>
</tr>
</tbody>
</table>

#### 7.2.15 D7. Conclusions on Capacity

The following conclusions can be drawn from the above analysis:

- With the same block lengths as 4 aspect signalling, ERTMS Level 2 signalling provides improved capacity.
- With the performance characteristics that could reasonably be expected from its subsystems and using moving block principles, ERTMS Level 3 would give further capacity improvements.
- Reducing ERTMS Level 2 block lengths could further increase capacity possibly to equal that obtainable by ERTMS Level 3 but with cost implications.
- ERTMS Level 3 performance depends critically on the ability of the RBC to accept frequent position reports and hence provide frequent movement authority updates.
- GSM-R latency is equally critical in these respects.
- Position location accuracy is more important with ERTMS Level 3 than Level 2. It is more dependent on appropriate balise location and spacing than odometry performance.
- Level 3 also gives a capacity benefit at junctions, and this benefit is increased if track based train detection is used to release the route after the tail of the train has cleared the junction.
Appendix E  Application Scenarios

Application Scenarios
Key to Diagrams

Freight Train Paths
Trains per Day

Station

Track Layout

Passenger Services & Routes

Service Frequency
Trains per Hour

Milton Keynes
Euston
Semifast

Tring
Euston
Slow

5 - 10

All Trains on Service Stop at this Station

Some Trains on Service Stop at this Station

Scenario 1a
Lea Valley Main Line
High Density
High Passenger

Liverpool St
Cheshunt
Stopping

TOTAL 14 TPH
(2 tracks)
**Scenario 1b**  
South West Main Line  
Esher – Wimbledon  
High Density  
High Passenger  

**Scenario 2a**  
West Coast Main Line  
Apsley – Tring  
High Speed  
High Passenger  
High Freight
Scenario 2b
West Coast Main Line
Preston – Lancaster

High Speed
Medium Passenger
High Freight

Glasgow
South Pendelino

Barrow
Manchester Semi Fast

Edinburgh
Manchester Fast

Barrow
Preston Slow

TOTAL 4 TPH
(2 tracks)

Scenario 3
Ely – Peterborough Line
Whittlesea - Manea

Regional Mixed Use
High Freight

Peterborough

March

Norwich
Liverpool

TOTAL 2.5 TPH
(2 tracks)
Scenario 4
Cumbrian Coast Line
Bootle – Whitehaven
Regional/Rural
Mixed Use

- Barrow
- Ravenglass
- Drigg
- Seascale
- Sellafield
- Braystones
- Nethertown
- St Bees
- Corkickle
- Carlisle
- Whitehaven

1 TPH (1-2 tracks)
Appendix F  Route Map
Appendix G  Glossary

ADIF   Administrator of Railway Infrastructures
ARS    Automatic Route Setting
ATO    Automatic Train Operation
ATP    Automatic Train Protection
CCS    Control-Command and signalling
CBTC   Communication Based Train Control
COTS   Commercial Off The Shelf
DFT    Department for Transport
DMI    Driver Machine Interface
EC     European Community
ECML   East Coast Main Line
EOA    End of Authority
ERA    European Railway Agency
ERTMS  European Rail Traffic Management System
ETCS   European Train Control System
EVC    European Vital Computer
FFCCTV Forward Facing Closed Circuit Television
FTN    Fixed Telecommunications Network
GNSS   Global Navigation Satellite System
GPRS   General Packet Radio Service
GPS    Global Positioning System
GSM-R  Global System for Mobile Communications - Railway
GWML   Great Western Main Line
LTE    Long Term Evolution
MAS    Multiple Aspect Signalling
MSC    Mobile Switching Centre
PPM    Public Performance Measure
PRIME  Parsons’ Railway Integrated Modelling Environment
PTC    Positive Train Control
RAMS   Reliability, Availability, Maintainability, Safety
RBC    Radio Block Centre
RETB   Radio Electronic Token Block
RFI    Rete Ferroviaria Italiana
RSSB   Rail Safety and Standards Board
SBB    Swiss Federal Railways (Schweizerische Bundesbahnen)
SPAD   Signal Passed at Danger
SRM    Safety Risk Model
SRS  System Requirement Specifications
TCS  Train Control System
Tph  Trains per Hour
TOM  Traffic Operation and Management
TSI  Technical Specifications for Interoperability
TPPH  Train Paths Per Hour
TRL  Transport Research Laboratory
UIC  International Union of Railways (Union Internationale des Chemins de fer)
VCC  Vehicle Control Centre
Appendix H  Level 3 – Route to Rollout

The following flowchart and activity descriptions were developed at the request of the National ERTMS Sponsor to illustrate the route to rollout of the Level 3 core product, in more detail than covered in Appendix F.
The following notes summarise the key activities needed to reach the point where commercial rollout of Level 3 ETCS on the UK network can start. They accompany the flowchart “Level 3 – Route to Rollout”

<table>
<thead>
<tr>
<th>Ref</th>
<th>Activity</th>
<th>Description/Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRELIMINARY PHASE</td>
<td>Establish target route type</td>
<td>Determine the route type which will form the initial target for Level 3 rollout. This will influence the architecture to be adopted and also the choice of pilot site.</td>
</tr>
<tr>
<td></td>
<td>Acquire Level 2 reliability data</td>
<td>Acquire reliability data from operators of current Level 2 technology. The Level 3 architecture to be adopted will depend on the reliability which can be achieved by the ETCS subsystems.</td>
</tr>
<tr>
<td></td>
<td>Acquire Level 2 and Regional ERTMS cost data</td>
<td>Acquire cost data from procurers of current Level 2 technology and implementers of nearest solution to Level 3 (Regional ERTMS).</td>
</tr>
<tr>
<td></td>
<td>Execute RAMS analysis</td>
<td>Carry out a RAMS analysis using the Level 2 reliability data and the target architecture. Validates the target architecture. Next three steps are iterated until acceptable RAMS results are obtained.</td>
</tr>
<tr>
<td></td>
<td>Select Target Architecture</td>
<td>Select the system architecture within which Level 3 will operate on the target route. Validated by the RAMS analysis and underpins the operational concept.</td>
</tr>
<tr>
<td></td>
<td>Develop Operational Concept</td>
<td>Create the operational concept for the Level 3 railway. Includes decision on moving/virtual block and operational definitions of fallback and degraded modes.</td>
</tr>
<tr>
<td></td>
<td>Establish Telecoms Requirements</td>
<td>Establish the telecoms requirements for the Level 3 railway. Influences the target architecture and driven by the RAMS analysis.</td>
</tr>
<tr>
<td></td>
<td>Define Freight Train Integrity Specification</td>
<td>Define the requirements for freight train integrity for the Level 3 railway. Influences and is influenced by the Level 3 operational concept. SIL requirements may be lower if the system provides protection.</td>
</tr>
<tr>
<td></td>
<td>Define telecoms upgrade path</td>
<td>Define the upgrade path from GSM-R which is needed to deliver the telecoms requirements. May need to be iterated with the target architecture before this is finalised.</td>
</tr>
<tr>
<td></td>
<td>Freight Train Integrity Feasibility Demo</td>
<td>Demonstrate feasibility of a freight train integrity solution using a desk-based/laboratory approach. Validates the assumptions made in the Operational Concept and used in the Business Case.</td>
</tr>
<tr>
<td></td>
<td>Confirm UK Level 3 Concept</td>
<td>Level 3 concept confirmed by the business case, supported by an operational concept and target architecture.</td>
</tr>
<tr>
<td>FREIGHT TRAIN INTEGRITY TRIAL</td>
<td>Acquire freight partner</td>
<td>Acquire a freight operator partner for the train integrity trial, prepared to support non-intrusive trial operation on one or more of its trains.</td>
</tr>
<tr>
<td></td>
<td>Develop onboard equipment</td>
<td>Acquire COTS equipment and develop a freight train integrity onboard solution in conjunction with the freight operator partner.</td>
</tr>
<tr>
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<tr>
<td></td>
<td>Carry out train integrity trial</td>
<td>Carry out a real world trial on several freight train types to demonstrate practical deliverability of a solution compliant with the specification</td>
</tr>
</tbody>
</table>

**PILOT – INITIATION PHASE**

<table>
<thead>
<tr>
<th>Activity</th>
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<tbody>
<tr>
<td>Agree UK Funding &amp; Incentivisation for Pilot</td>
<td>DfT, ORR &amp; NWR agree the funding mechanism and principles of Incentivisation and risk allocation for the Pilot</td>
</tr>
<tr>
<td>Seek European Partners</td>
<td>Seek European partners for a pilot line with business requirements consistent with the UK concept for Level 3</td>
</tr>
<tr>
<td>Create Level 3 Consortium</td>
<td>Create a consortium of funders (DfT, NWR, Train Operator Group?, ETCS supplier?) with common interest in a successful Level 3 pilot. May include wider group of European bodies.</td>
</tr>
<tr>
<td>Establish Pilot Line Requirements</td>
<td>Establish the requirements for a Level 3 pilot line (infrastructure scope, train scope, service mix, interaction with other routes)</td>
</tr>
<tr>
<td>Agree Pilot procurement strategy</td>
<td>Agree the procurement strategy for the pilot (infrastructure and onboard, number of suppliers, interfaces)</td>
</tr>
<tr>
<td>Write Level 3 Operational Requirements Spec</td>
<td>Write the operational requirements specification for generic Level 3, based on the agreed concept and in preparation for the Pilot</td>
</tr>
<tr>
<td>Establish Telecoms Scope for Pilot</td>
<td>Establish the telecoms scope for the Pilot, based on the GSM-R upgrade path defined in the preliminary phase</td>
</tr>
<tr>
<td>Investigate Pilot Sites &amp; Train Fleets</td>
<td>Investigate possible pilot sites and related train fleets in UK (and potentially mainland Europe)</td>
</tr>
<tr>
<td>Consolidate Architecture &amp; Operational Concept for Pilot</td>
<td>Based on selected pilot site, agree application architecture and operational concept. Architecture will allow for interfaces between areas of procurement/partner responsibility. Validated by simulation</td>
</tr>
<tr>
<td>Validate Concept (Simulation)</td>
<td>Validate the operational concept as applied to the pilot route and train types using simulators</td>
</tr>
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**PILOT – EXECUTION PHASE**

<table>
<thead>
<tr>
<th>Activity</th>
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<tbody>
<tr>
<td>Detailed Planning for Pilot</td>
<td>Project management and planning activities for Pilot</td>
</tr>
<tr>
<td>Finalise Specifications for Pilot</td>
<td>Finalise the Level 3 Functional Specification as required for the Pilot and the onboard and trackside procurement specifications</td>
</tr>
<tr>
<td>Procure Trackside Kit &amp; Fit Track</td>
<td>Procure the trackside equipment and fit to the trackside infrastructure</td>
</tr>
<tr>
<td>Procure Onboard Kit &amp; Fit Trains</td>
<td>Procure the onboard equipment and fit to the trains</td>
</tr>
<tr>
<td>Develop Migration Strategy</td>
<td>Develop the Migration Strategy for the pilot. Detail will depend on the current system and steps to get to Level 3</td>
</tr>
<tr>
<td>Develop Test &amp; Commissioning Plan</td>
<td>Develop the Test &amp; Commissioning Plan for the pilot. Reflects the requirements of the Migration Plan</td>
</tr>
<tr>
<td>Develop &amp; Execute Training Plan</td>
<td>Develop and execute the Training Plan for the pilot. Covers drivers, signallers and maintenance staff</td>
</tr>
<tr>
<td>Develop &amp; Execute Certification Plan</td>
<td>Develop a Certification Plan for the pilot consistent with Interoperability Requirements</td>
</tr>
<tr>
<td>Execute Subsystem and System Tests</td>
<td>Carry out the sequence of testing defined in the Test &amp; Commissioning Plan and consistent with the Migration Plan. Leads to cutover of the system</td>
</tr>
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<tr>
<td></td>
<td>Operational Trial</td>
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<td></td>
<td>Validated Level 3 Concept</td>
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**COMMERCIAL PHASE**

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Agree Industry Funding &amp; Charges Principles</td>
<td>Agreement to be reached between DfT, ORR, Network Rail and Operator representatives about the funding and charging principles to be applied during Level 3 rollout</td>
</tr>
<tr>
<td>Update National ERTMS Implementation Plan</td>
<td>Update the National Plan to reflect the change from Level 2 to Level 3</td>
</tr>
<tr>
<td>Roll Out Level 3</td>
<td>Level 3 available for full exploitation across the UK network.</td>
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