Our Members
Research, development and innovation have a significant role to play in enabling the railways to play their part in 21st century mobility. The academic science base has much to offer towards finding solutions to meet the country’s needs in a way that can deliver long term value-for-money. At the same time, the rail industry is finding new ways to get more all-round value out of this research spend by collaborating with universities and other academic research organisations.

There is a wealth of knowledge, ideas and creativity at universities. Tapping into the huge potential of the UK’s world class academic research will bring benefit to the railways, to universities, to the customers of the railways – passenger and freight – and to the UK economy as a whole.

Rail Research UK Association (RRUKA) has been set up to do just that – make the most of what we’ve got, stimulate further thinking, broaden the reach of rail research and bring a focus to the creating of new solutions and new thinking. It brings together those who can use and fund railway research with those who do it.

RRUKA is a partnership between the British rail industry and UK universities. It was established in 2010 to build on the success of Rail Research UK which had been funded by the Engineering and Physical Sciences Research Council (EPSRC). RRUKA’s core activities are funded by RSSB and Network Rail on behalf of the industry.

The Association builds on the resurgence in university-based railway research, and seeks to enhance already strong collaborative relationships between academia and the railway industry.

Its aims are to:

- Support and facilitate railway research in academia
- Develop a common understanding of research needs to support the rail industry and its future development
- Identify opportunities for research, development and application in railway science and engineering
- Provide technical, operational and organisational solutions to the rail industry.

Since its formation, RRUKA has firmly established itself in the research landscape and has initiated many activities which are central to the link between the industry and the academic community.

RRUKA member universities1 and a wide cross-section of industry representatives have enthusiastically embraced the opportunity to foster relationships with each other, building a greater mutual understanding of the benefits research can offer and the issues industry faces.

The Academic Response to the RTS is a product of RRUKA’s mission. It provides a strong example of the dynamic engagement between industry and academia and of RRUKA’s commitment to becoming a significant contributor to the delivery of the rail industry’s longer term strategy and plans.

1 RRUKA has 43 members (as of September 2014).
Throughout Europe and the rest of the world, railways are recognised as essential national infrastructure. Both politicians and the public view them as increasingly important in fulfilling economic, environmental and social needs. At the same time, governments are seeking to ensure rail infrastructure and services develop in a variety of ways to meet national requirements for high quality cost effective transportation. The onus is on the rail industry and its stakeholders to set out appropriate business visions which make full use of current technical knowledge and future capabilities to deliver these aspirations.

The challenges across Europe have a common theme. The ‘four Cs’ – increasing capacity, reducing carbon, lowering costs and improving customer satisfaction as described in the Rail Technical Strategy 2012 and reflected in the Academic Response document capture them very effectively. Today’s technology step-changes need to bring together fundamental science domains and advanced and emerging technologies. The vision and technology planning for Great Britain’s railways have high commonality with the broader Europe ambitions, as set out in the European Rail Research Advisory Council, namely in ERRAC Rail Route 2050 vision document.

Railway is now a knowledge-intensive and internationally competitive sector and is striving to create an eco-system for innovation involving excellent research institutions, vibrant companies devoting time and energy to R&D and demonstration activities and finally pulling the required financial support to effectively carry out such an ambitious program. Complementary to the collaborative research program in: Horizon 2020 SHIFT²RAIL will be the first European rail joint technology initiative to seek focused research and innovation (R&I) and market driven solutions by accelerating the integration of new and advanced technologies into innovative rail product solutions.

There is a coherent set of tools and partnership mechanisms, which, with the involvement of the right stakeholders, allow us to respond to the mobility challenges we all are facing at the European level.

Universities have an important part to play, both in the early development of new concepts and in collaborative research with industry. It is excellent to see that UK universities already have a well-prepared view of the contribution they can make to the industry’s priorities, both within Great Britain and more widely within Europe (and, in all probability, the rest of the world). Clearly, the Academic Response to the Rail Technical Strategy 2012 will be important to UK universities as an authoritative means for prioritising university-based research; it will also provide an excellent framework for similar prioritisation in the wider domain.

I commend the initiative of Rail Research UK Association in producing this document, and look forward to seeing how it develops into the future as the technology and research priorities evolve.

Professor Manuel Seabra Pereira
Instituto Superior Técnico, University of Lisbon, Portugal and Vice-Chairman of ERRAC
On behalf of the Technical Strategy Leadership Group, I am delighted to welcome and endorse this Academic Response to the Rail Technical Strategy. Academia provides the railway with key partners in developing and taking forward delivery of the Strategy, and the academic contribution at each stage of that journey is vital. It has proved especially fruitful through the involvement of the RRUKA, both in the Strategy development process and more generally in supporting and facilitating rail research over the last three years.

The Academic Response demonstrates the common understanding of rail industry research needs that has been facilitated by the dissemination of the Strategy. The insights gained from the response will be particularly useful in planning further actions and initiatives to take the Strategy forward, and the identification of where the capabilities and strengths of our academic partners can best be deployed. Through the shared purpose established in the Strategy, and the delivery structures now in place, Britain’s academic talent can be brought fully to bear on railway development.

We look forward to continuing close co-operation with the academic community as we strive to turn the Strategy into real and valuable outputs for the benefit of the rail industry and its passenger and freight customers.

Jerry England
Group Asset Management Director, Network Rail and Chair, Technical Strategy Leadership Group

"Academia provides the railway with key partners in developing and taking forward delivery of the Strategy"
The publication of the Rail Technical Strategy 2012 by the Technical strategy Leadership Group (TSLG) on behalf of the GB railway industry has provided a unique opportunity for railway researchers.

This document, presents the Academic Response to the RTS 2012 (the ‘ARRTS’). It provides an academic perspective and proposes key areas where research is needed to provide support for the various industry challenges. We believe that this will be useful, not only to industry in highlighting what research has been carried out so far and how it might be used, but also to researchers who can use the ARRTS to help demonstrate that their work is meeting an industry need and in supporting their bids for future research funding.

The ARRTS is intended to encourage academics as well as colleagues engaged in research in industry to direct their efforts to make the breakthroughs in technology that we need in order to deliver the vision set out in the RTS 2012. Without this we cannot meet the demanding requirements that the government, on behalf of the country, are making of us.

UK and EU research bodies are already funding significant levels of research activity. New funds being administered by FutureRailway and in the CP5 settlement will further enhance this capacity. In order to make the best use of these and future opportunities it is essential that research activities are coordinated and focused.

RRUKA aims to act as a bridge between universities and the railway industry and in support of this aim we have coordinated this Academic Response to the RTS 2012. We organised workshops to map out the current research activities and to identify gaps in the research provision. The document is not meant to be static and we intend to continuously update the ARRTS to include the latest developments in university-based research activity and also in the changing needs of the industry.

On behalf of the RRUKA team that produced the ARRTS, I hope that you will find this document informative and useful in planning your research activities so that they fit the needs of the industry as it moves forward.

We would like to thank RSSB and Network Rail for providing support and funding for this and all other RRUKA activities, and all of those who contributed to the development of this document.

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Institute of Railway Research, University of Huddersfield and
Academic Co-chair of RRUKA (served from 2010 - 2014)
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1.1 The Rail Technical Strategy 2012

[1.1.1] The Rail Technical Strategy 2012 (RTS 2012) was produced by the Technical Strategy Leadership Group (TSLG) on behalf of the British rail industry, building on the first edition published by the Department for Transport in 2007. It sets out a 30-year vision of how the railway will develop as a whole system to address critical long-term challenges the industry faces, known as the 4Cs: increasing Capacity; reducing Carbon; lowering Costs and improving Customer satisfaction.

[1.1.2] The role of technologies and technical approaches in achieving these objectives is explored in the RTS 2012 through six themes: Control Command and Communication, Energy, Infrastructure, Rolling Stock, Information, and Customer Experience. It offers the prospect of a radical transformation of the technical landscape of the railway, not as an end in itself, but to provide unparallelled service quality and value to passengers and the nation.

[1.1.3] While many of the challenges this entails can be met by the industry itself, the RTS 2012 recognises that closer working relationships will need to be formed both internally and with external partners. Key objectives of the RTS 2012 include assisting the industry’s strategic planning processes, informing policy makers and funders about the potential benefits of new approaches, techniques and technologies, and providing suppliers with guidance on the future technical direction of the industry. There is also a clear and explicit requirement for longer-term research and collaboration with the academic community, which will play an essential part in the delivery of the RTS vision.

1.2 Aims, Scope and Impact of the Academic Response to the RTS 2012

[1.2.1] The Academic Response to the RTS 2012 identifies the initial framework, enablers and priorities for research to support the delivery of the rail industry’s long-term vision. In doing so it highlights clearly the role academic expertise can play in realising a growing railway which is intrinsically safe and efficient with higher standards of operational and commercial performance.

[1.2.2] The specific objectives of the Academic Response are to identify:

• future research directions consistent with the implementation of the RTS 2012
• critical gaps in the current UK research capability, in particular those that are appropriate for university-based research.

[1.2.3] The Academic Response provides an authoritative confirmation of industry priorities, their national importance and potential impact, which can be referred to when universities apply for funding. In this way, it will assist universities in maximising the number of applications which are successful, and contribute significant additional capability and resource to delivering the RTS 2012.

[1.2.4] The intention is that the Academic Response will be a live document, updated by RRUKA at regular intervals. It will reflect research progress and respond to changing needs as the RTS 2012 is developed and implemented.

1.3 Supporting industry in developing sustainable solutions to meet the RTS vision

[1.3.1] Some of the technical requirements to achieve the RTS 2012 vision have already been established by the industry and are reasonably well developed. However, there are a number of areas where sustainable solutions to future issues need to be identified and developed.

[1.3.2] The Academic Response demonstrates how research can help provide effective contributions to the industry’s greatest challenges through building on current capabilities, knowledge and collaborations, and through blue sky thinking. It focuses on the type of research (Technology Readiness Levels 1-5) appropriate for universities to undertake, and for which they can
potentially receive funding from Research Councils, the EU, and other bodies.

1.4 Dynamic engagement between industry and academia

[1.4.1] Delivery of the RTS will depend on a dynamic interplay between academia and industry, which dictates a need for strong and enduring partnerships. A number of successful avenues for cooperation and joint working are already in place, but it will be necessary to continue to enhance existing practices.

[1.4.2] In particular, it will be important for the rail industry to engage with and steer university-based research programmes to ensure an appropriate focus. There is also a need to assist research by improving access to specific knowledge and data held within the industry. Partnerships with industry should look beyond the life of research projects in order to identify effective ways to exploit research outcomes and define a viable implementation route for new technology.

[1.4.3] There is further potential to make more effective use of facilities within the academic sector and industry for mutual benefit. Universities have physical laboratories to test (for example) onboard comfort, station designs and vehicle accessibility, and virtual laboratories to test new applications of information technology. The industry’s test track facilities could be made more accessible for progressing research outputs to a higher Technology Readiness Level (TRL).
The Academic Response to the RTS 2012 has been prepared by the Rail Research UK Association (RRUKA) on behalf of UK universities with rail-related research expertise.

As part of the preparation of the Academic Response, RRUKA hosted two workshops. At the first workshop, industry experts provided briefings on the six RTS themes to encourage the academic community to identify how it can help deliver solutions to the technical challenges presented. The second workshop was attended by over 100 academics from 27 institutions (a full list of contributing institutions is in Appendix A). The overall aim was to seek answers from a broad spectrum of researchers to the following questions:

- How can existing and developing research support industry’s aims?
- Where do opportunities for new research ideas and technologies lie?

The workshops have played a significant part in informing the Academic Response, including its proposals for an underpinning research strategy. This strategy will support the RTS 2012 agenda and ensure university research is aligned with the industry’s long-term vision.

### 2.1 Structure

The structure of the Academic Response follows that of the RTS 2012 by addressing its six key technical themes:

- Control, Command and Communication
- Energy
- Infrastructure
- Rolling Stock
- Information
- Customer Experience.

Each theme is analysed in a separate chapter starting with an assessment of the knowledge already held by the railway industry and developments in other sectors which could potentially be transferred. In addition, typical ‘key landmark projects’ are highlighted to show the type of research that has been carried out from which results are available. The exercise has illustrated the base for further research, or in some cases the base from which implementation of existing research can begin.

Building on this available knowledge, the Academic Response then sets out the research priorities for each theme and the impact they can make in delivering the industry’s long-term vision. Finally, assessments have been made of some of the ways the industry can support universities as they seek to deliver against the various research requirements.

The analysis undertaken forms an initial research strategy for each theme. Each research subject area identified is categorised by TRL and as either Collaborative, Strategic or Blue Sky according to the following definitions:

- **Collaborative**: Partnership with industry to meet medium-term RTS requirements
- **Strategic**: New academic input required to enable industry’s longer-term plans
- **Blue Sky**: New idea that needs formative academic research

The next step will be to identify and develop specific project proposals for each subject area in co-operation with the industry and apply for funding.

 Chapters 3-8 cover the research strategy theme by theme under the following sub-headings:

- **Current rail industry knowledge and capability** - Existing understanding of the theme
- **Relevant knowledge from other sectors** - Capability that can potentially be transferred
• **Research requirements and impact** - *Recommendations on research subject areas and summary of what could be achieved*

• **Industry input requirements** - *How the rail industry can assist universities in stimulating research and maximising its quality*

[2.1.7] Each chapter includes a summary table that lists the key research areas identified and indicates their potential impact on achieving the RTS vision.

[2.1.8] Although the chapter sub-headings are consistent throughout the Academic Response, the considerable differences between current knowledge and research requirements in each theme means presentation approaches and the extent of the content vary.

### 2.2 RTS Themes

#### [2.2.1] Control Command and Communication

The Control Command and Communication theme is concerned with establishing optimal control of the operation of the whole railway network. It seeks to deliver a flexible transport system that capitalises on progressive developments in Driver Advisory Systems, signalling technology and automation to increase capacity and enable significant improvements in operational performance.

#### [2.2.2] Energy

Reducing energy use to the lowest possible levels in line with emerging technical developments will cement and enhance the railway’s reputation as the lowest carbon form of travel and cut costs. Continually seeking to lower the carbon intensity of traction fuel and reduce consumption form the cornerstone of this theme. Advances in control systems, and in rolling stock and infrastructure design and maintenance, will assist in minimising energy usage and emissions.

#### [2.2.3] Infrastructure

The infrastructure theme sets out a framework for the renewal of assets with new low-cost, high-resilience materials, and for future-proofing infrastructure to take account of foreseeable requirements. Intelligent maintenance will be based on absolute knowledge of asset condition through automated monitoring techniques. Impacts will include minimal disruption for passengers from infrastructure failures, lower costs and catering more effectively for demand.

#### [2.2.4] Rolling Stock

Rolling stock design, maintenance and selection of materials will be integrated into a whole system approach, which reduces track wear, suspension and body fatigue, improves asset condition monitoring and reduces train failures. It will also minimise environmental impact including noise, vibration and waste disposal. Interior layouts will reflect changing demand, and be optimised for different markets.

#### [2.2.5] Information

A coordinated approach towards system architectures and information management will improve efficiency, mitigate costs and identify opportunities for better use of the vast amounts of data held. A new generation of IT tools will allow the exploitation of rail information to enable improved operational performance and personalised customer services, and support new revenue streams.
[2.2.6] Customer Experience

The quality and value of rail transport will ensure both passenger and freight customers view it as their preferred choice. New information and ticketing products mean journeys will be simple, seamless and integrated with the entire transport system. Continuous improvement in reliability will be delivered through new asset management and control technologies. Customer service and facilities will be flexible, tailored to individual need and fully complement passengers’ lifestyle and journey purpose.

2.3 Cross-cutting issues

[2.3.1] Although the RTS is strongly focused on its six technical themes (as reflected in this document), it also acknowledges the importance of two distinct types of cross-cutting requirements – common foundations and common design concepts. Taking account of these requirements forms an integral part of the Academic Response. The way they are accommodated in university research is summarised below.

2.3.2 Common foundations

[2.3.2.1] Whole-system approach: Although research is traditionally carried out in highly specialised teams, it is important that the outputs are applied in ways that cross boundaries between different systems and provide benefits that supplement the primary focus of the research project wherever possible. There is strong potential to enhance the value of all research through whole system considerations. RRUKA will work with industry to provide mechanisms which engender a whole system approach for all rail-related research activity.

[2.3.2.2] Innovation: University research is naturally innovative, but UK researchers have not traditionally been as successful as some of our competitors in converting advances made in their work into effective products and processes. RRUKA will work with FutureRailway, the Railway Industry Association and other funders and industry bodies to ensure any barriers to innovation are removed and that the most innovative research is stimulated and funded.

[2.3.2.3] People: Potentially the greatest challenge facing the rail industry is to ensure its next generation of employees possesses the appropriate skills. Universities have a clear role to play in meeting this need, especially in highly skilled areas where the ability to adapt to change and to adopt new techniques and tools is vital.

[2.3.2.4] RRUKA has been working closely with the National Skills Academy for Railway Engineering (NSARE), professional institutes and other bodies to encourage universities to consider improved ways in which the most able young people can be made aware of the exciting and challenging careers railway can offer. Next Generation Rail conference has been established as an annual forum targeted at early-career researchers, undergraduates and young professionals working in industry to promote the exchange of knowledge and ideas, stimulates collaboration, innovation and professional development for the next generation of rail leaders and educators. The Routes into Rail group, which acts as a delivery sub-group to the NSARE Industry Promotion Steering Group, has also been established to oversee the development and delivery of a number of projects aimed at attracting graduates to the rail industry, including the production of a promotional video, a joint university presentation programme (JUPP) and the development of a career portal.
2.3.3 Common design concepts

[2.3.3.1] Common design concepts are technical issues applicable across RTS themes. In many cases they relate to particular research skills that are already available. The table below lists the seven common design concepts in the RTS: as the name implies, they apply to some extent to all the themes, but the table includes an indication of where research specialisms in each design concept may be particularly relevant to the technical and research agenda for each theme. This will assist researchers possessing the requisite common design skills to understand the railway-specific linkages.

<table>
<thead>
<tr>
<th>Common Design Concept</th>
<th>Command Control Comms</th>
<th>Energy</th>
<th>Infrastructure</th>
<th>Rolling Stock</th>
<th>Information</th>
<th>Customer Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole-system reliability</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
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<td>✓</td>
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<td>✓</td>
</tr>
<tr>
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<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>Flexibility</td>
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<td>✓</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
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<td>✓</td>
<td>✓</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

✓ ✓ design concept has high relevance to technical theme
✓ design concept has moderate relevance

Fig. 1: Diagram representing the structure of the Rail Technical Strategy 2012.
Control Command and Communication
3 Control, Command and Communication

[3.0.1] Control, command and communication (CCC) systems that optimise train movements are a key strategic technological capability for the delivery of the RTS 2012’s vision. New technologies are starting to challenge existing principles, providing a basis for future developments which can lead to radical change in how CCC is carried out.

[3.0.2] Recent progress in developing UK CCC systems includes progressive rollout of GSM-R, commissioning of the first European Rail Traffic Management System (ERTMS) project, initiation of Network Rail’s control centre consolidation strategy, pilot projects for Driver Advisory Systems (DAS) and planned use of Automatic Train Operation (ATO) on Thameslink. The RTS envisages building rationally on these projects towards CCC systems which offer network-wide traffic management capabilities for intelligent, predictive and adaptive control of train movements optimised to deliver a variety of objectives critical to the 4Cs.

3.1 Current rail industry knowledge and capability

[3.1.1] Advanced traffic management technology is being widely developed worldwide with various aspirations, particularly in relation to the functionality provided by advanced CCC systems such as ERTMS.

[3.1.2] The UK industry is developing the major Future Traffic Regulation Optimisation (FuTRO) programme, aimed at identifying new and emerging technologies to support future rail operations, based on improved real time, or near real time, management of train operations. Its scope ranges from DAS through to ATO. It will link to Network Rail’s Traffic Management Project, which includes modernising legacy signalling to enable consolidation into modern Rail Operating Centres. These initiatives will focus on adopting proven technology used by railway administrations around the world and can be applied using a modular approach so that new capabilities can be embraced as the technology evolves.

[3.1.3] The EU-funded Optimal Networks for Train Integration Management across Europe (ONTIME) project includes the following activities:

• Optimisation of the static timetable to minimise the allowances needed for realistic management of the network
• Implementation of an optimised timetable and recovery from perturbations
• Processes and information flow for DAS
• Partnerships with suppliers to prove optimisation algorithms.

[3.1.4] The UK university sector has completed five projects on increasing capacity at nodes funded through a strategic partnership between the rail industry and EPSRC. These projects had a specific mandate to think long-term and beyond current industry practice. The projects are:

• Overcoming Capacity Constraints - A Simulation Integrated with Optimisation for Nodes (OCCASION)
• Overcoming the Railway Capacity Challenges Without Undermining Rail Network Safety (SafeCap)
• Dynamic Responsive Signal Control for Railway Junctions
• Challenging Established Rules for Train Control Through a Fault Tolerance Approach
• Redundantly Engineered Points (REPOINT) for Enhanced Reliability and Capacity of Railway Track Switching.
[3.1.5] These projects were largely concerned with potential future concepts, and therefore can provide a starting point to feed into the academic research strategy.

[3.1.6] FuTRO (Future Traffic Regulation Optimisation) is now an established programme of research and innovation concerned with how the regulation of trains on the railway must change, adapt and improve. Two challenges have been launched under the FuTRO banner, one about data and one about mapping which will fund a number of feasibility studies and demonstration projects.

[3.1.7] In addition, RSSB has funded a significant programme of command control and signalling research activity for the past decade. Its command control and signalling guide T932 provides a thorough overview of completed research.

3.2 Relevant knowledge from other sectors

[3.2.1] The British rail industry has strong relationships with other European railway organisations, and its strategy is well-developed. Available knowledge indicates that UK aspirations and capabilities reflect worldwide best practice.

[3.2.2] Therefore, the most significant opportunities to enhance current knowledge relate to transfer from other sectors. Traffic management and optimisation concepts being developed for the automotive and aviation industries are particularly relevant, although it is important that railway-specific constraints are considered in any transfer process.

[3.2.3] Accurate information on the location of trains is critical to future command and control systems. Although the British rail industry is engaged in a development project in this area, knowledge from other industry sectors also offers considerable opportunity. Automotive systems generally rely mainly on GNSS (commonly known as ‘SatNav’ systems). However, aerospace and defence are highly advanced in developing ‘data fusion’ technologies which bring together information from a variety of sensors (GNSS, inertial, etc.) and integrate it in an optimal manner with geographical mapping data.

[3.2.4] The automotive sector has undertaken significant work on ‘platooning’ technologies over several decades, investigating electronic convoy control to enhance highway capacity. Notable examples include the California PATH programme in the 1990s and a more recent demonstration by Volvo as part of the EU-funded Safe Road Trains for the Environment (SARTRE) project.

[3.2.5] The wide use of distributed traction in which many/all vehicles have powered bogies means that, in principle, electronically-coupled trains are feasible. While railways would have some substantially different requirements in this respect, knowledge transfer can provide valuable input.

[3.2.6] A notable divergence in the rail sector is the move towards greater centralisation with a relatively small number of Rail Operating Centres interacting with ‘dumb’ trains. By contrast, both the automotive and aerospace industries are pursuing autonomous ‘smart vehicle’ technologies. Although high levels of autonomy do not necessarily fit with a timetabled operation, nevertheless some autonomous vehicle approaches incorporate important knowledge that the rail industry can draw on.

3.3 Research requirements and impact

[3.3.1] Capacity definitions and metrics: Current methods of calculating infrastructure capacity (e.g. the UIC method and the Capacity Utilisation Index) do not yet provide a practical measure for assessing more complex networks with a number of nodes. Therefore a consistent, scientifically formulated measure is needed to clearly identify capacity enhancement opportunities, and to strengthen the capability to assess and prioritise organisational, operational and technological
options. Relevant academic disciplines in this subject area include operational research and transport planning.

[3.3.2] **Whole system modelling:** A standard, validated, open source simulation tool, sufficiently versatile to represent a variety of network configurations, would significantly enhance university-based research by providing a consistent framework within which train control and management strategies can be tested and compared. It would be used either purely as a simulator with the control integrated; or as an emulator so that connections can be made to other software platforms. Potentially, it could also be used as a ‘hardware-in-the-loop’ testing environment. Relevant academic disciplines in this subject area include computer science and systems simulation.

[3.3.3] **Optimisation:** Current optimisation techniques and those under development have variable capability to address optimisation issues. There is a need to determine which approaches are suitable in terms of problem formation and practical in terms of processing power and time. The need to incorporate a stochastic capability is particularly important so as to allow for uncertainties (inaccuracies and time/distance updates) in position and speed of trains as part of the optimisation process. Research should not only include off-line optimisation for planning and timetabling of normal operation, but also real time techniques for optimised response to disruption. Relevant academic disciplines in this subject area include mathematics, computer science and systems science.

[3.3.4] **Methods for train location:** Increasingly accurate train location systems (better than 1 metre) that dynamically combine inputs from all available sensors are required to facilitate a range of advanced approaches for controlling trains. They must be able to provide data integrity consistent with the requirements of current signalling systems (SIL 4) while providing continuity of accurate information. System reliability and availability requirements must also be assured. Relevant academic disciplines in this subject area include systems science, data fusion and sensor systems.

[3.3.5] **Levels of autonomy:** This subject relates to possibilities for evolution (potentially revolution) of the CCC hierarchy with more autonomy attributed to vehicles and less dependence on centralised network control centres. Opportunities for improved recovery from disruption is a particular area where research would be beneficial. Relevant academic disciplines in this subject area include intelligent control, autonomy and computer science.

[3.3.6] **Platooning trains:** This research would draw on experience in the automotive industry and incorporate a variety of opportunities. The fundamental premise is that vehicles (or subsets of vehicles) in a train formation would be coupled electronically, rather than mechanically, through control of the traction equipment. The prospective benefits are centred around enhanced operational flexibility. Relevant academic disciplines in this subject area include control and vehicle dynamics.

[3.3.7] **Vision for future generations of train control:** Academic research can speculatively consider possibilities for fundamental changes to current practice, incorporating some or all of the study opportunities identified above (e.g. autonomy, platooning, enhanced train location), and analyse the corresponding benefits in terms of the 4Cs.

[3.3.8] **Human aspects of the transition from DAS to ATO:** Progressive moves towards greater automation of the driving function will require the role of the driver (in particular) to be understood in greater depth. For example, safety aspects of the system will need to be managed differently as the role changes. Relevant academic disciplines in this subject area include human factors and automation.
[3.3.9] **Vehicle-infrastructure communications technology:** This subject will need continuous research. As control and information requirements progressively increase, new communications technologies will need to be incorporated to accommodate enhanced bandwidth, integrity and diversity of data transmission. Possibilities include leaky feeders, phased arrays, use of Network Rail telecomms masts and LiFi. Relevant academic disciplines in this subject area include electronic engineering and communication systems.

[3.3.10] **Video sensing:** Enhanced capability to collect and process video data provides opportunities for detecting a variety of external influences on train operation. Currently, these systems are fitted on some trains to monitor track. However, they could also be used to detect obstacles and vandals and other issues. In addition, processed video data could be used to assist with train location. Relevant academic disciplines in this subject area include video processing and computer science.

[3.3.11] The table below lists the research requirements identified in relation to this theme, categorises them, and sets out the potential contribution to the vision in the RTS 2012.

<table>
<thead>
<tr>
<th>Research subject</th>
<th>Type*</th>
<th>TRL</th>
<th>Contribution to the RTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Capacity definitions and metrics</td>
<td>C</td>
<td>4</td>
<td>Fundamental requirement</td>
</tr>
<tr>
<td>2 Whole system modelling, simulation and emulation</td>
<td>S</td>
<td>3</td>
<td>Fundamental requirement</td>
</tr>
<tr>
<td>3 Optimisation</td>
<td>S</td>
<td>3-4</td>
<td>Reliable and resilient CCC systems</td>
</tr>
<tr>
<td>4 Methods for train location</td>
<td>C</td>
<td>3-5</td>
<td>Reliable and resilient CCC systems; widespread use of ATO</td>
</tr>
<tr>
<td>5 Levels of autonomy</td>
<td>B</td>
<td>1</td>
<td>Beyond the current RTS horizon</td>
</tr>
<tr>
<td>6 Platooning trains</td>
<td>B</td>
<td>2</td>
<td>Consistent with the long-term RTS vision</td>
</tr>
<tr>
<td>7 Vision for next generation train control</td>
<td>B</td>
<td>1</td>
<td>Reliable and resilient CCC systems; widespread use of ATO</td>
</tr>
<tr>
<td>8 Human aspects of the transition from DAS to ATO</td>
<td>S</td>
<td>4-5</td>
<td>Reliable and resilient CCC systems; widespread use of ATO</td>
</tr>
<tr>
<td>9 Vehicle-infrastructure communications technology</td>
<td>S</td>
<td>3-4</td>
<td>Reliable and resilient CCC systems; high-speed, high-bandwidth communications networks</td>
</tr>
<tr>
<td>10 Video sensing of environment</td>
<td>S</td>
<td>3</td>
<td>Various contributions to system reliability</td>
</tr>
</tbody>
</table>

* Concept type: -

Collaborative: Partnership with industry to meet medium-term RTS requirements

Strategic: New academic input required to enable industry’s longer-term plans

Blue Sky: New idea that needs formative academic research
3.4 Industry input requirements

[3.4.1] Assessing the value of research on enhanced capacity and operational effectiveness is highly complex. At present, universities often do not have the information or capability to demonstrate significant and clear added value. An industry-developed tool that would assist in evaluating benefits – akin to the Vehicle Track Interaction Strategic Model (VTISM) for determining the benefits of improved running gear – would be beneficial.
[4.0.1] Energy efficiency has become an increasingly significant issue to the rail industry for financial and reputational reasons. The RTS 2012 recognises that its importance will continue to grow and has identified cutting the sector’s carbon intensity and energy use as a major target for the future success of the industry. It envisages that the railway will expand in an energy efficient way through use of lower carbon (predominantly electric) traction and materials.

[4.0.2] The energy used by the railway in its full life cycle, including operation, construction, maintenance and renewals, is the major contributor to the carbon that is emitted by the railway directly or indirectly. Many associated activities have a system-wide impact on energy use and so a whole system view is required to realise the benefits of energy-related research.

[4.0.3] Developments in control, light-weighting, power electronics drives, energy storage devices and novel power sources are all being driven by challenges which exist across application areas. Fundamental research at low TRLs can therefore be rapidly adopted within the railway industry through effective partnerships between the industry and academia.

4.1 Current rail industry knowledge and capability

[4.1.1] Railway energy research is a broad subject which can be broadly split into two key aspects.

[4.1.2] The first aspect is fundamental research at the component level (TRL 1-3). This type of research can have impact across sectors. Examples of recent research include projects such as the EPSRC-funded Sustainable Power Generation and Supply (SUPERGEN) programme which forms part of the EPSRC’s energy theme of activities. This programme includes projects such as Hub for Energy Networks (HUBNET) which address challenges in power systems, and has relevance to railway power systems and knowledge and technology transfer.

[4.1.3] The second aspect is specific research on the current needs of the railway sector (TRL 3-6) and addressed through RSSB’s energy research topic. Energy projects in RSSB’s research portfolio are categorised under the following headings:

Area 1: Identification and deployment of electrification safety systems to manage the associated safety risks (4 projects)
Area 2: Optimising electrification systems to provide a cost effective railway (15 projects)
Area 3: Sustainable use of energy to maintain rail’s competitive advantage (9 projects).

[4.1.4] Research at lower TRLs is also included in RSSB’s portfolio.

[4.1.5] In line with the growing importance of energy efficiency to the railway sector, the industry and universities have examined new techniques to use energy more effectively. This programme incorporates improved operation of existing equipment and rolling stock, and the procurement of new equipment with improved energy utilisation.

[4.1.6] Notable recent projects which have been implemented include: the introduction of regenerative braking on both AC and DC routes, optimisation of traction system control for both diesel and electric trains, management of hotel and auxiliary loads, and the introduction of DAS.

[4.1.7] Fundamental component level research, together with system optimisation, was addressed in the EU-funded RAILENERGY project. The EU-funded MERLIN project is a new collaborative research initiative that aims to advance the fundamental research developed in RAILENERGY to the next TRL.

[4.1.8] Research into novel propulsion systems includes investigation of hydrogen as a fuel for railway vehicles, the use of bio-diesel, and energy storage devices for hybrid vehicles (both electric and diesel hybrid).
4.2 Relevant knowledge from other sectors

[4.2.1] Research expertise and knowledge in other sectors covers a wide area and could potentially have significant impact and application in the rail industry. Sectors where there is potential for knowledge transfer and cross-fertilisation of ideas include the automotive and aerospace industries’ development of advanced combustion systems, lightweight materials, aerodynamics, and control systems.

[4.2.2] The energy theme managed by the EPSRC is developing fundamental science and engineering related to basic energy research. Several of its sub-themes can have a direct impact on the railways. Particularly relevant research areas within EPSRC’s energy theme include research into:

- Bio-energy
- Energy efficiency (end use energy demand)
- Energy networks
- Energy storage
- Fuel cell technology
- Hydrogen and alternative energy vectors
- Materials engineering - metals and alloys
- Materials for energy applications
- Solar technology
- Transportation operations and management
- Whole energy systems.

4.3 Research requirements and impact

[4.3.1] The main research requirements relate to the cross-cutting, inter-related areas of vehicles, infrastructure and system optimisation. Taken together, research in these areas has the potential to make a significant impact on the railway’s energy usage.

[4.3.2] Vehicles: In recent years, rolling stock mass has increased on a per passenger basis. This has been driven by more exacting performance and comfort requirements placed on new rolling stock. A key topic for investigation is use of lightweight materials for rolling stock applications, which will have an associated benefit in terms of traction energy savings. Other research areas include developments in traction machines, combustion engines, hybrids with onboard energy storage, and novel fuels. The control of train movement through advanced CCC applications can also be used to optimise for reduced energy consumption. In addition, there is a need to build on developments in the energy efficiency of subsystems and other non-traction components.

[4.3.3] Infrastructure: Energy efficient infrastructure is essential for whole system optimisation. Important topics include research into high voltage systems, reliable and reconfigurable transmission systems, condition monitoring, and power electronics. The use of wayside energy storage can improve network capability and reduce energy consumption by increasing the receptivity of the line.

[4.3.4] System optimisation: A whole system optimisation approach is necessary to enable the costs and benefits from energy saving technologies to be accounted for properly. Currently, there is no universal framework for system optimisation from an energy use perspective. There is considerable expertise in other sectors that have taken a whole system approach, which can be translated to railway applications.

[4.3.5] There is relevant expertise in these three research areas across the university sector,
particularly with regard to system and component modelling, high voltage systems, power electronics and drives, and testing facilities.

[4.3.6] The table below lists the research requirements identified in relation to this theme, categorises them, and sets out the potential contribution to the vision in the RTS 2012.

<table>
<thead>
<tr>
<th>Research subject</th>
<th>Type*</th>
<th>TRL</th>
<th>Contribution to the RTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Vehicles: Light weighting</td>
<td>C</td>
<td>1-5</td>
<td>More energy efficient rolling stock</td>
</tr>
<tr>
<td>2  Vehicles: Aerodynamics</td>
<td>S</td>
<td>1-5</td>
<td>Lower resistance to motion and quieter vehicles</td>
</tr>
<tr>
<td>3  Vehicles: Drives</td>
<td>C</td>
<td>1-5</td>
<td>Improved traction performance</td>
</tr>
<tr>
<td>4  Vehicles: Hybrids</td>
<td>S</td>
<td>1-3</td>
<td>Energy savings and improved performance</td>
</tr>
<tr>
<td>5  Vehicles: Novel prime movers</td>
<td>B</td>
<td>1-3</td>
<td>Long-term sustainability</td>
</tr>
<tr>
<td>6  Vehicles: Fuels</td>
<td>C</td>
<td>1-3</td>
<td>Long-term sustainability</td>
</tr>
<tr>
<td>7  Vehicles: Control</td>
<td>C</td>
<td>3-5</td>
<td>Reduced energy consumption and performance</td>
</tr>
<tr>
<td>8  Infrastructure: Electrification system components</td>
<td>S</td>
<td>3-5</td>
<td>Improved electrification systems</td>
</tr>
<tr>
<td>9  Infrastructure: Electrification reliability and resilience</td>
<td>C</td>
<td>2-4</td>
<td>Improved network performance</td>
</tr>
<tr>
<td>10 Infrastructure: Asset management</td>
<td>C</td>
<td>2-5</td>
<td>Improved asset performance</td>
</tr>
<tr>
<td>11 Infrastructure: Power Electronic Devices</td>
<td>S</td>
<td>2-5</td>
<td>Improved asset performance</td>
</tr>
<tr>
<td>12 System optimisation: Cost, Carbon and Performance</td>
<td>C</td>
<td>2-5</td>
<td>Overall energy reduction</td>
</tr>
</tbody>
</table>

* Concept type:-
  - Collaborative: Partnership with industry to meet medium-term RTS requirements
  - Strategic: New academic input required to enable industry’s longer-term plans
  - Blue Sky: New idea that needs formative academic research

[4.3.7] Each research subject is linked through interdependencies within the overall energy theme and with the other themes described in this document.

4.4 Industry input requirements

[4.4.1] Improvement in energy efficiency is often an additional benefit from research projects conducted to deliver different objectives. In order to help secure the investment case for these projects, data is required to enable a whole system evaluation of the impact of the energy saving aspect. The same applies to projects where the primary aim is to reduce energy use and carbon emissions.

[4.4.2] Data could be made available by building an open-source model of the flow of energy through the industry to allow projects to be clearly assessed in terms of the impact on energy use and other industry issues. This would optimise the research effort deployed.
[5.0.1] The RTS envisages a substantial re-engineering of railway infrastructure into a high-reliability, high-capacity system with reduced maintenance requirements. The vision for infrastructure includes extensive use of remote condition monitoring, trainborne inspection and technology to better understand substructure in order to provide complete knowledge of asset condition and optimise planning. Development of automated maintenance techniques, standardised asset designs and use of long-life materials – such as premium steels and low carbon plastics and composites – in renewals programmes would further reduce infrastructure and maintenance requirements and cut costs.

[5.0.2] In addition to increasing network availability, whole system benefits would be derived from technology which enables infrastructure to interact effectively with rolling stock through mutual monitoring, and through optimisation of the wheel/rail interface (e.g. train suspension characteristics included in track designs). Stations would be adapted so that their design enables increased passenger flow to be catered for in safety and comfort. Further whole system benefits would include use of materials and designs which reduce noise and vibrations.

5.1 Current rail industry knowledge and capability

[5.1.0] To gain a clear insight into how existing and future research can contribute to delivering the RTS vision, the Academic Response has separated this theme into the following areas:

- Track
- Stations
- Freight depots and handling
- Overhead line/power supply
- Tunnels, bridges and other structures.

5.1.1 Track, including track specific inspection technology

[5.1.1.1] Research focused on track encompasses a wide spectrum of projects. It ranges from projects close to industrial application (especially at EU level) through to lower levels of TRL research, for example into the effect of different rail metallurgies on the mechanisms of rail failure.

[5.1.1.2] Areas of particular strength include understanding how railway track behaviour is governed by ground stiffness and how this behaviour can be optimised. Research to understand how rail wear and fatigue is affected by rail metallurgy has advanced considerably for conventional rail steels. However, as yet there has been little research into the behaviour of newer premium grade steels being installed by Network Rail beyond macro scale tests on wear resistance.

[5.1.1.3] Broadly, there are two scales of understanding of track behaviour:

- Micro-level models and experiments on how materials behave
- Macro-level models suitable for application to many miles of track.

Linking these areas to facilitate industrial application of micro-level materials understanding (and better specification of new materials requirements) remains an under-researched area. Key recent projects include the ongoing EPSRC-funded multi-university Track21 project, and the EU-funded Innovative Track Systems (INNOTRACK) project.

[5.1.1.4] Condition monitoring and inspection technologies have been developed through a large body of work. A major issue is that practical application requires either a person on the track or vehicle(s) running below normal passenger train speeds. Opportunities exist for research into technology which can be operated without human intervention on the track, and at much higher speeds, thereby unlocking additional network capacity and reducing safety risk through automating
potentially hazardous tasks. Recent research includes the EU-funded Predictive Maintenance Employing Non-intrusive Inspection and Data Analysis (PM ‘n’ IDEA) project which aimed to contribute to the realisation of a 24/7 railway by minimising disruption from activities such as inspection. The EPSRC-funded Novel Sensing Networks for Intelligent Monitoring (Newton) project focused on development of a wireless sensor network for structural health monitoring, including feature extraction and data fusion, with application to railways and the nuclear industry.

[5.1.1.5] Design work has been undertaken on novel track forms to avoid failures of, for example, switches and crossings. However, there are challenges in testing them on the operational network. Future research would be supported by facilities to test novel track components in a realistic environment to build confidence before transfer onto the network. Work in this area includes the EUfunded New Concepts for Turnouts in Urban Rail Transit Infrastructures (TURNOUTS) project and the RSSB/EPSRC-funded Redundantly Engineered POINTs (REPOINT) for Enhanced Reliability and Capacity of Railway Track Switching project.

[5.1.1.6] The vehicle/track interaction topic in RSSB’s research portfolio categorises projects under the following headings:

Area 1: System modelling to identify the optimum parameters for the vehicle track interface (15 projects)
Area 2: Research into the operating environment experienced by axles to enhance wheelset design and maintenance practices (17 projects)
Area 3: Research to better understand the nature of adhesion problems to improve management of low adhesion (16 projects)
Area 4: Research into the optimal management of rolling contact fatigue and vertical track damage to reduce whole life costs (15 projects).

[5.1.1.7] The infrastructure topic in RSSB’s research portfolio covers the five subject areas identified by the Academic Response, with some overlaps between them. Projects are categorised under the following headings, some of which relate to infrastructure more generally rather than solely to ‘track’, but all are included here for ease of reference:

Area 1: Making better use of available gauge capability to increase the capacity of the network (13 projects)
Area 2: Utilising available capability of structures to increase the capacity of the network (5 projects)
Area 3: Improving the understanding of the risks associated with the vehicle to station interface to improve management of the safety and capability of the network (4 projects)
Area 4: Improving the understanding of the relationship between vehicle behaviour with track and structures to ensure cost effective and safe operation of the railway (5 projects)
Area 5: Understanding the environmental effects on the utilisation of infrastructure, particularly with regard to the adaptation required in response to climate change (7 projects)
Area 6: Gaining a more accurate understanding of the rates and modes of deterioration to determine remaining service life of structures and earthworks (4 projects)
Area 7: Understanding how aerodynamics influence the interaction between vehicles and infrastructure to ensure cost effective and safe operation of the railway (12 projects)
Area 8: Research to improve the understanding of track structure and componentry (3 projects)

5.1.2 Stations

[5.1.2.1] Stations form part of the wider built environment and feature in a large number of generic projects examining issues including urban design, interchange between transport modes and urban
gateways. In addition, there has been some specific research on stations in a railway context. At the highest level, research to improve stations has the capacity to influence mode choice, and hence cross-cutting issues including overall energy use and safety in the rail industry and wider transport sector. The following station-specific research and practice can be built on in future projects.

[5.1.2.2] Network Rail's recent Guide to Station Planning and Design provides an overview of a wide range of issues which remain areas of active research. They include planning spatial capacity to match flows of people, designing safety and security into station buildings, and identifying ways in which accessibility can be improved within existing buildings.

[5.1.2.3] EU-funded research includes the Advanced Virtual Agents for Testing the Accessibility of Rail Stations (AVATARS) project which developed simulation tools to model general circulation as well as passenger evacuation. There is also considerable active research using agent based approaches to crowd modelling in stations and other crowded venues (e.g. sports and concert arenas). Research on emergency situations includes the ongoing EU-funded SECURESTATION project on improving passenger station and terminal design for safety, security and resilience to terrorist attack.

[5.1.2.4] Twelve projects within the infrastructure and operational categories in the RSSB portfolio have stations in their titles. Infrastructure, projects include research into gauging issues between the track and the platform. Operational projects include, research into glazing materials suitable for use at height in stations and other public buildings, and security issues at stations. In a number of respects, operational and infrastructure issues are interdependent in the station environment.

5.1.3 Freight depots and handling

[5.1.3.1] Freight rail operations typically have slim financial margins, and have struggled to exploit the potential for new services or new cargo handling systems and facilities. In part, this is due to the global nature of freight markets, which means a UK, or even EU, change in cargo systems from standard ISO freight containers is not tenable.

[5.1.3.2] Many freight-related projects have a logistics focus, for example the ongoing EU-funded SPECTRUM project aims to determine how to integrate low density, high value, time sensitive freight services with existing passenger services. There are few freight-specific infrastructure developments, although the EU-funded SUSTRAIL project is working to combine improvements in both freight vehicles and track components to enhance reliability and the performance of the rail freight system as a whole.

5.1.4 Overhead line/power supply

[5.1.4.1] Research on overhead line and the power supply focuses particularly on reliability and understanding the link between design and management of conductors and insulators.

[5.1.4.2] Reliability improvements can be addressed though better understanding of the causes of failure for conventional equipment, how different materials may reduce failures caused by wear and fatigue, and how electrical reliability and efficiency could be improved.

[5.1.4.3] Recent work in this area includes the EU-funded RAILENERGY project on innovative integrated energy efficiency solutions for rolling stock, infrastructure and train operation, and the EUfunded Pantograph and Catenary Interaction Total Regulatory Acceptance for the Interoperable Network (PANTOTRAIN) project.
### 5.1.5 Tunnels, bridges and other structures

[5.1.5.1] For newly built infrastructure there is great commonality with requirements of road tunnels and bridges. However, the railway has many older structures (>100 years) that require management and maintenance.

[5.1.5.2] Recent research on structures has included the EPSRC-funded Ultimate and Permissible Limit State Behaviour of Soil-filled Masonry Arch Bridges project, and the EU-funded Sustainable Bridges project on upgrading European railway bridges to meet increased demand.

[5.1.5.3] Issues relevant to both modern and older structures include understanding and avoiding structural resonance that can develop in bridges during passage of high speed trains. Rail-specific research is needed in this area since speeds far exceed road traffic.

[5.1.5.4] For tunnels, a large body of research exists on managing airflow. This issue affects energy consumption, particularly where the train almost fills the tunnel cross-section, and noise levels created by sonic booms when exiting tunnels.

[5.1.5.5] Research to support life extension of bridges, tunnels and other structures, or their replacement, using lower environmental impact alternative materials can help improve their sustainability and resilience.

### 5.2 Relevant knowledge from other sectors

[5.2.1] While rail infrastructure is distinct from most other sectors at first sight, closer examination of underlying research issues shows a number of cross-sector themes including:

- Materials modelling and development
- Human factors including aging society
- Systems modelling and life cycle costing
- Sustainability
- Resilience, including natural disasters and security
- Noise and vibration
- Inspection/condition monitoring.

[5.2.2] Knowledge and skills from other sectors therefore have potential application in the rail industry, particularly through cross-sector partnerships to examine specific technologies with potential for transfer.

### 5.3 Research requirements and impact

[5.3.1] The range of infrastructure supporting railway operation is wide, with a correspondingly wide range of potential research requirements. A significant enabler to undertaking this research and bringing new technologies to rail applications would be providing universities with greater access to existing railway data. For example, a freely accessible database of representative track forces and wheel geometries would allow new components and new materials for specific duties to be developed using optimal standard designs. This data is often only available to established parties undertaking research relevant to the rail sector.

[5.3.2] Research connected to the RTS 2012’s Infrastructure theme should also consider communications infrastructure with appropriate consideration of the strong linkage with the Control Command and Communication theme.

[5.3.3] Use of new or alternative materials to address longstanding issues at the rail/wheel and pantograph/overhead line interfaces is a promising research direction to address problems with
these areas of infrastructure.

[5.3.4] A study of techniques applied in the highways sector would further understanding of how infrastructure with similar physical proportions (i.e. long and thin) approaches asset management. Outside core rail research institutions the academic community has limited knowledge of the status of technologies used by the rail industry for monitoring, data collection and condition monitoring of structures. Greater knowledge of specific industry needs could unlock targeted research or technology transfer from other sectors.

[5.3.5] Additional areas for research include:

- Perception of noise and vibration among passengers and the railway’s neighbours
- Security/resilience of rail systems including cascade or domino effects leading to unexpected or multiple failures
- Methods of accelerated testing for long life components
- Winterisation technologies to avoid cold weather issues
- New fuel systems, for example fuel cells which could reduce reliance on both fossil fuels and overhead electric lines.

[5.3.6] The table below lists the research requirements identified in relation to this theme, categorises them, and sets out the potential contribution to the vision in the RTS 2012.

<table>
<thead>
<tr>
<th>Research subject</th>
<th>Type*</th>
<th>TRL</th>
<th>Contribution to the RTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Access to data already collected on the railway</td>
<td>C</td>
<td>3-4</td>
<td>An enabler of research projects across multiple areas</td>
</tr>
<tr>
<td>2 Asset management with possible transfer of approaches from the highways system</td>
<td>C</td>
<td>4-5</td>
<td>World class asset management; asset failures seldom occur; track availability rarely impeded</td>
</tr>
<tr>
<td>3 Use of new/different materials and component designs for track and overhead line</td>
<td>S/B</td>
<td>1-3</td>
<td>High network resilience and integrity; low carbon materials; asset failures seldom occur; increased network availability</td>
</tr>
<tr>
<td>4 Monitoring, data collection and health monitoring of structures</td>
<td>C</td>
<td>3-5</td>
<td>Intelligent maintenance based on train-borne inspection provides accurate, timely information for condition-based intervention and reduces the need for workers to be on the operating railway</td>
</tr>
<tr>
<td>5 Understanding perception of noise and vibration among passengers and neighbours of the railway</td>
<td>C</td>
<td>3-5</td>
<td>Environmental factors such as vibration and noise are included at the design stage</td>
</tr>
<tr>
<td></td>
<td>Improving security and resilience of rail systems including cascade or domino effects leading to multiple or network failures</td>
<td>C/S</td>
<td>2-4</td>
</tr>
<tr>
<td>---</td>
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</tr>
<tr>
<td>7</td>
<td>Methods of accelerated testing for long life components</td>
<td>C/S</td>
<td>2-5</td>
</tr>
<tr>
<td>8</td>
<td>Winterisation technologies to reduce cold weather problems</td>
<td>C</td>
<td>3-4</td>
</tr>
<tr>
<td>9</td>
<td>Developing new fuel systems (e.g. fuel cells) which could reduce reliance on fossil fuels and overhead electric lines</td>
<td>S/B</td>
<td>1-4</td>
</tr>
</tbody>
</table>

* Concept type:-
  Collaborative: Partnership with industry to meet medium-term RTS requirements
  Strategic: New academic input required to enable industry’s longer-term plans
  Blue Sky: New idea that needs formative academic research

### 5.4 Industry input requirements

[5.4.1] Providing access to data is critical as an enabler of innovative research, and as a prerequisite for testing the feasibility of new modelling approaches.

[5.4.2] The progression of research outputs to higher technology readiness levels often requires test track facilities as the next step in assessing whether results achieved under laboratory or modelling environment can be transferred to operational conditions. An important industry input would be to develop mechanisms for academic partners to access test tracks at viable costs and timescales.

[5.4.3] If research outputs continue to show promise in the test track environment, the next move is to apply the results on the live network. Again effective partnerships between academia and industry are required, potentially crossing different industry sectors.
Rolling Stock
[6.0.1] The RTS sets out a framework for rolling stock design to become fully integrated within the railway system and overall industry objectives. It envisages that existing and new technology can be used to produce trains that are lightweight and energy efficient without compromising performance, safety or passenger comfort. Whole system, whole life cost would be reduced continuously through the rapid introduction of technologies that improve reliability and operation, a requirement for fewer components and optimisation of the wheel/rail interface. The efficiency and effectiveness of vehicle maintenance would be improved through intelligent use of high quality data gathered from onboard and wayside monitoring. Mechatronic bogies, adaptive braking systems, integrated diagnostic systems, and remote condition monitoring are among the technologies identified to start realising the vision.

[6.0.2] Carriage layouts would make the best use of available gauge and the capabilities of new materials to provide a superior passenger environment.

[6.0.3] To date, research has been effectively applied in a number of areas: traction (power but not energy storage); suspension; wheel/rail interaction; crashworthiness; remote condition monitoring (measuring rather than data use); and human factors (e.g. relating to cab design).

6.1 Current rail industry knowledge and capability

[6.1.1] Rolling stock research has traditionally been carried out by vehicle manufacturers and their research partners. The UK has a strong track record in this area. British Rail Research made significant progress in understanding vehicle stability and developed computer simulations tools which led to the widely-used VAMPIRE vehicle dynamics package and to a number of innovations in vehicle suspension and construction. Examples include: active tilting; high speed freight suspension; low track force bogies for passenger and freight applications; low speed maglev; and welded aluminium bodies.

[6.1.2] Since rail privatisation, university research has expanded with projects funded by the Research Councils, central government and the European Commission. The number of universities carrying out significant research in areas related to rolling stock has also grown.

[6.1.3] Rolling stock projects in RSSB’s research portfolio are categorised under the following headings:

**Area 1:** Research to further improve vehicle design to reduce injury in accidents (39 projects)
**Area 2:** Modelling whole life system costs to increase cost effectiveness (8 projects)
**Area 3:** Identify drivers high vehicle mass and incentivise reductions (5 projects)
**Area 4:** Modelling to optimise seating/loading capacity and speed (none)
**Area 5:** Research to support emerging European legislation to understand risk, cost and performance implications (3 projects).

[6.1.4] RSSB research areas for vehicle/track interaction are listed in Section 5.1.1.6

[6.1.5] To gain a clear insight into how existing and future research can contribute to delivering the RTS vision, the Academic Response has translated RTS requirements into the following broad research topics:

- Rolling stock architecture
- Rolling stock performance
- System capacity.
6.1.1 Rolling stock architecture

[6.1.1.1] Development and introduction of mechatronic bogies: Considerable research has taken place including the EU-funded Mechatronic Train project. Concepts are well understood and there is potential for significant benefits in terms of reduced mass, improved energy efficiency and reduced maintenance. There has been some translation of research into prototypes and products (e.g. the Bombardier ‘Flextronic’ bogie). However, adoption has been very limited to date.

[6.1.1.2] Remote Condition Monitoring: In many industries, remote condition monitoring (RCM) is well developed, and in some areas condition monitoring techniques are well established. Research into intelligent data processing is ongoing. However, existing industrial systems are available. Compared to other sectors, adoption in the rail industry is still relatively low. Hardware improvements are required including cost reductions, miniaturisation and improvements in reliability. Research includes RSSB’s T1010 Cross interface RCM programme.

[6.1.1.3] Lightweight and crashworthy materials: Aluminium is widely used in bodies and specific welding techniques have been developed and adopted. Hollow axles are used but are not universal. There is potential to introduce lower mass bogies through optimised, fabricated steel structures. Fatigue failures are still an issue in some areas. Research includes the EU-funded EUROBOGIE project on developing the use of glass fibre reinforced plastic springs and suspensions, and the EU-funded EURAXLES projects on minimising axle failures.

[6.1.1.4] Interiors: Research has focused on areas such as fast boarding and alighting, reduced mass, durability, attractiveness and security. It includes the EU-funded SAFEINTERIORS project to reduce injuries during collisions.

[6.1.1.5] Modular systems: Designing standardised, interoperable components can potentially offer significant reductions in cost and improvements in performance. Research includes the EU-funded MODTRAIN project on improving performance and reducing cost through use of standardised components.

6.1.2 Rolling stock performance

[6.1.2.1] Wheel/rail interaction: Research has focused mainly on vehicle dynamic behaviour and improving understanding of vehicle-track interaction, the influence of track geometry on vehicle behaviour and the effects of vehicle design on track deterioration. Better understanding of the impact of unsprung mass on track settlement and of primary yaw stiffness on rolling contact fatigue has been developed and other types of deterioration have been investigated. Research and tools include the DynoTrain, VTISM (WLRM) FOOTPRINT project which aimed to relate the environmental footprint of a vehicle to infrastructure maintenance costs to inform access charging regimes.

[6.1.2.2] Human response to noise and vibration: Human response to noise and vibration has been widely studied through tests carried out using volunteers. The outputs have been incorporated into industry standards.

[6.1.2.3] Whole life cost modelling: Techniques have been developed which can help identify discrete costs, but effective whole system tools are still under development and better /wider use of data is needed. Empirical wear and rolling contact fatigue and wear models are still required. Research includes RSSB’s Wheelset Management Model (linked to the VTISM system modelling tool) and the EU/partner consortium-funded Wheelset Integrated Design and Effective Maintenance (WIDEM) project. Results include increased knowledge of non-destructive testing techniques and related human factors issues.
Adaptive braking: Hardware and software systems have been developed and established for conventional braking, and tools exist for designing and optimising wheel slide protection systems and for regenerative braking. Research includes the UIC’s EuropeTrain project to test an innovative low noise braking system and the European rail industry’s Innovative Modular Brake Concepts for the Integrated European High Speed Railway System (MODBRAKE) project.

6.1.3 System capacity

6.1.3.1 Gauging: Gauging is an important research area which links rolling stock and infrastructure. Current practice is summarised in the Guide to British Gauging Practice produced by the industry’s Vehicle/Structures System Interface Committee. Conventional gauging tools have been developed and are routinely used for vehicle acceptance and operation. However, the methods are not yet fully embedded in design procedures and further research into highly non-linear (e.g. freight) suspensions is required.

6.1.3.2 Freight locomotive performance: Requirements for increased speed/capacity are well understood and research is currently being carried out. In particular, research into vehicle requirements for new markets (e.g. time sensitive, high value, low density) and sustainable low environmental impact operation is ongoing. Research includes the EU-funded SUSTRAIL project on combining improvements in freight vehicles and track components to enhance reliability and the performance of the rail freight system as a whole. The ongoing EU-funded SPECTRUM project aims to determine how to integrate low-density, high-value, time-sensitive freight services with existing passenger services.

6.1.3.3 Speed: Operation at very high speed brings a unique set of research problems related to issues including aerodynamics, current collection and interaction with track. Projects in a number of these areas has been carried out by manufacturers of high speed trains. Research includes the EU-funded AeroTRAIN project.

6.2 Relevant knowledge from other sectors

6.2.1] There are a number of sectors where knowledge transfer could potentially benefit the rail industry, particularly in relation to the aerospace industry’s use of novel materials, manufacturing techniques, non-destructive testing and evaluation, and structural health monitoring. Experience from the automotive industry could inform the development and implementation of control systems. Knowledge from the material science sector could feed into the development of novel materials. Experience of adopting whole system approaches in a number of sectors is also relevant.

6.3 Research requirements and impact

6.3.1 Materials: Novel high performance (strength, durability), low cost, sustainable materials to meet future demands on rolling stock design.

6.3.2 Braking technology: Development of high performance, low noise, reliable braking systems delivering shorter stopping distances and lower impact on infrastructure and environment.

6.3.3 Interiors: Design of flexible, comfortable, accessible, adaptable, safe, low cost, sustainable interiors to meet future rolling stock requirements across different markets.

6.3.4 Maintenance: Development of efficient tools for establishing practical techniques for optimised maintenance.

6.3.5 Overcoming barriers to introduction of innovative rolling stock designs: Improved understanding of why novel solutions may not be adopted.
[6.3.6] **Reliability:** Improved understanding of reliability, cost and failure modes.

[6.3.7] **High speed freight bogies:** Development of bogies with low cost economic drivers, logistics/loading configurations.

[6.3.8] **Structural crashworthiness:** Optimise designs, materials use and all approaches to management of issues.

[6.3.9] **Demonstration of benefits:** Set up established and accepted systems and techniques for benchmarking and demonstrating performance benefits and cost reductions for non-railway-standard methods and equipment.

[6.3.10] The table below lists the research requirements identified in relation to this theme, categorises them, and sets out the potential contribution to the vision in the RTS 2012.

<table>
<thead>
<tr>
<th>Research subject</th>
<th>Type*</th>
<th>TRL</th>
<th>Contribution to the RTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Materials</td>
<td>B</td>
<td>2</td>
<td>Carriage layouts that make best use of the available gauge and the capabilities of new materials; rolling stock is mass and energy efficient and engineered for flexible use under a range of operating concepts</td>
</tr>
<tr>
<td>2 Braking technology</td>
<td>C</td>
<td>5</td>
<td>Adhesion-aware braking systems contribute to reduced headways and increased network capacity</td>
</tr>
<tr>
<td>3 Interiors</td>
<td>S</td>
<td>3</td>
<td>Comfortable and attractive train interiors; carriage layouts make the best use of available gauge and the capabilities of new materials</td>
</tr>
<tr>
<td>4 Maintenance</td>
<td>S</td>
<td>3</td>
<td>Whole life costs reduced continuously through the rapid introduction of new technologies and materials</td>
</tr>
<tr>
<td>5 Overcoming barriers to introduction of innovative rolling stock designs</td>
<td>C</td>
<td>3</td>
<td>New procedures for introducing new technologies, materials and systems</td>
</tr>
<tr>
<td>6 Improved understanding of reliability, cost, failure modes</td>
<td>S</td>
<td>3</td>
<td>Optimisation at a whole system level with rolling stock design that takes account of the interfaces with infrastructure; standardised sub-system interfaces contribute to improved cross-system efficiency</td>
</tr>
<tr>
<td>7 High speed freight bogie with low economic cost, enhanced logistics and loading configurations</td>
<td>S</td>
<td>3</td>
<td>A new generation of freight rolling stock designed to optimise the gauge</td>
</tr>
<tr>
<td>Concept type</td>
<td>6.4 Industry input requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collaborative: Partnership with industry to meet medium-term RTS requirements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strategic: New academic input required to enable industry's longer-term plans</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue Sky: New idea that needs formative academic research</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 8 Structural crashworthiness and survivability
- **B 3** Rolling stock is mass and energy efficient and engineered for flexible use under a range of operating concepts

### 9 Demonstration of benefits
- **C 5** Optimisation at a whole system level, with rolling stock design that takes account of the interfaces with infrastructure

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6.4 Industry input requirements

[6.4.1] Industry will need to implement effective methods of allocating costs and benefits across the system interfaces (e.g. track access charging) so that improvements in vehicle performance which benefit infrastructure can be effectively shared.

[6.4.2] There are significant barriers to the implementation of innovative ideas which need to be overcome. They include industry acceptance processes, risk aversion, and conservative practices.
Information
Research carried out in 2011 found that, excluding Network Rail’s own systems, the industry had over 130 information systems maintained by approximately 20 suppliers. Maintaining individual and legacy systems is expensive and inefficient. Information cannot be shared or exploited efficiently and this inhibits whole-system approaches to technology-based advances.

The RTS states that to increase efficiency, mitigate costs, enhance customer service and identify opportunities for better use of the vast collected data, the industry would benefit from a coordinated approach towards system architectures, information management and information exploitation. In addition, improved management of data to elicit information, and thus knowledge, is a key requirement to make a step change in performance in a number of areas covered by the overall RTS vision.

### 7.1 Current rail industry knowledge and capability

Currently the railway industry collects large amount of data, however, in general, this data is manually or semi-automatically processed with simple algorithms. In particular, very little use is made personal travel data (e.g. ticket sales, passenger loadings).

It is widely accepted that the provision of reusable information products within an open architecture has the potential to provide significant benefits to the British rail industry through improved, system-wide visibility of the network and the ability to migrate to service-driven IT systems in the near future.

Systems such as the New Measurement Train (NMT) and monitoring systems implemented as part of the industry’s Intelligent Infrastructure programme are improving the data available, and analysis techniques have been successful in generating information from acquired data. There is potential to widen these applications significantly.

Research including the EU-funded Intelligent Integration of Railway Systems (InteGRail) project has considered system-wide data architectures and data models based on a service-oriented architecture and ontology. A number of projects have demonstrated that a system-wide strategy for data collection, modelling, analysis and data architectures would release significant benefits.

A recent series of RSSB workshops has brought together six industry projects with information requirements, which would all benefit from a shared data model and architecture. There is potential to use such projects as demonstrators for improved data integration capabilities.

EU-funded projects have begun to extend the RailML infrastructure data exchange format to enable its use beyond signalling layout descriptions. These projects include Augmented Usage of Track by Optimisation of Maintenance, Allocation and Inspection of Railway Networks (AUTOMAIN) which has extended the schema to include descriptions of maintenance-related terms. The Optimal Networks for Train Integration Management across Europe (ON-TIME) project has extended the schema to cover interlocking.

### 7.2 Relevant knowledge from other sectors

New approaches to data collection, modelling, analysis and architecture have been developed and implemented in a number of industries, such as finance. There is significant opportunity to gain knowledge from current ‘Big Data’ and ‘Internet of Things’ research.

Industries more comparable to rail (e.g. water, power, road traffic) are at similar levels of development. However, it is notable that the oil and gas industry has developed a data modelling and architecture standard (ISO15926) which would be an appropriate basis for a railway sector.
[7.2.3] Key challenges in data collection include ensuring information is timely, trustworthy, and appropriate to task at the point of usage. Other industries that utilise mobile assets (e.g. military, logistics) share similar issues. There is potential for knowledge transfer to the railway industry if cost effective solutions can be found.

[7.2.4] It is also apparent that those industries which have embraced the concept of open data have benefited from rapid innovation and enhanced capability.

### 7.3 Research requirements and impact

[7.3.1] Research centred around business process and consumer needs will create maximum value for the industry. The ability to generate whole industry business cases is of crucial importance in leveraging research funds and delivering the fullest potential to the industry.

[7.3.2] Significant work is required to realise a railway system where all decisions are supported by appropriate information extracted from historical and real time operational data. The first step in achieving this vision is the development of a railway data model and data architecture.

[7.3.3] The data model should be able to encapsulate topological and mereological relationships, as well as retaining its underlying semantics. This is key to ensuring the model can be evolved over time and does not become obsolete.

[7.3.4] It has previously been identified in projects such as InteGRail that use of ontology meets these requirements while providing an appropriate structure for reasoning and the elicitation of tacit knowledge. The data architecture should be distributed and enable companies to project their intellectual property rights (IPR).

[7.3.5] Direction and recommendations have come from a number of collaborative projects (e.g. ONTIME, InteGRail) that point towards the use of a service-oriented architecture. However, no significant work has been carried out to develop these concepts. Once the data model and data architecture are in place it is anticipated that a large number of applications will be developed.

The key research areas identified include:

[7.3.6] **Data collection**: There is a need to establish the data and meta-data that should be collected, and how it should be collected. Relevant academic disciplines in this subject area include railway engineering and sensing.

[7.3.7] **Data architectures**: Development of open architectures for data sharing that also protects an individual company’s IPR. Relevant academic disciplines in this subject area include computer science and railway engineering.

[7.3.8] **Data analysis and data mining**: A wide range of techniques are appropriate. However, the majority of engineering systems used on the railway are well understood, and therefore model-based or heuristic approaches to information elicitation may be more appropriate than black box techniques. Relevant academic disciplines in this subject area include railway engineering, signal processing and condition monitoring.

[7.3.9] **Business models and research to understand the value of data**: This is a key enabler for progressing large-scale collaborative work. Relevant academic disciplines in this subject area include railway engineering and economics.

[7.3.10] **Data representation and visualisation for staff and customers**: Relevant academic disciplines in this subject area include human factors, signal processing and condition monitoring.
[7.3.11] Specific use cases to help support and validate the business case: Relevant academic disciplines in this subject area include railway engineering.

[7.3.12] The table below lists the research requirements identified in relation to this theme, categorises them, and sets out the potential contribution to the vision in the RTS 2012.

<table>
<thead>
<tr>
<th>Research subject</th>
<th>Type*</th>
<th>TRL</th>
<th>Contribution to the RTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Open architectures</td>
<td>C/S</td>
<td>3-4</td>
<td>Supports ubiquitous data concept</td>
</tr>
<tr>
<td>2 Data modelling and ontology</td>
<td>C/S</td>
<td>3-4</td>
<td>Reuse of data</td>
</tr>
<tr>
<td>3 Understanding passenger movements/feedback from customers</td>
<td>C</td>
<td>4-5</td>
<td>Supports improvements in information and customer satisfaction</td>
</tr>
<tr>
<td>4 Increased resolution positioning (GIS)</td>
<td>C</td>
<td>4-5</td>
<td>Key to a number of themes within the RTS</td>
</tr>
<tr>
<td>5 Business models for open data</td>
<td>C</td>
<td>4-5</td>
<td>Underpins developments in this area</td>
</tr>
<tr>
<td>6 Data mining and algorithms for data analysis</td>
<td>S</td>
<td>4-5</td>
<td>Key in turning data into useful information</td>
</tr>
<tr>
<td>7 Showcases for open data</td>
<td>C</td>
<td>4-5</td>
<td>Development of a showcase to highlight benefits</td>
</tr>
<tr>
<td>8 Visualisation and human factors</td>
<td>S</td>
<td>4-5</td>
<td>Ensuring solutions are usable</td>
</tr>
</tbody>
</table>

* Concept type:-
  Collaborative: Partnership with industry to meet medium-term RTS requirements
  Strategic: New academic input required to enable industry’s longer-term plans
  Blue Sky: New idea that needs formative academic research

7.4 Industry input requirements

[7.4.1] Currently, it is difficult for researchers to access data for research purposes, and it is often unclear whether data even exists. There is a need to develop a data directory and explore how real, or sample, data could be made available to researchers working in the field.

[7.4.2] It would be beneficial for industry to identify, share and support case studies that could be developed to support the RTS 2012’s strategic vision.
Customer Experience
The RTS sets out a vision of the future in which the rail system’s reliability, ease of use and value for money leads to it being perceived as the preferred means of transport for the public and freight customers.

It envisages that personalised, information systems will make use of data from intelligent traffic management technology to guide passengers throughout their entire end-to-end journey with precision and according to individual preference of how and when they want to travel. Ticketing products could develop to the extent that traditional ticket purchase is replaced by systems which automatically detect when individuals travel and bill them to account with the lowest available fare. Stations would be designed to provide the simplest possible access to and from platforms with ondemand facilities that meet market needs as they evolve. Safety and security would be a given.

In freight transport, service scheduling, real time traffic management and terminals’ management systems would be integrated with customers own systems. Consignments would be tracked throughout the journey with real-time information available for consignees. Rescheduling could be easily facilitated if required. New freight terminals would be bespoke facilities or multi-modal consolidation centres outside major cities to facilitate environmentally-friendly urban distribution.

There is a view in the academic community that there is a considerable path to travel from the current real time information position concerning, contactless ticketing systems and fares structure to achieve this vision.

8.1 Current rail industry knowledge and capability

There is a paucity of publicly available information and research related to this theme. As a result no landmark projects have been identified, although user needs and passenger comfort are included in RRUK activities.

Customer experience is not among the topics specifically covered in the RSSB research programme, however a number of designated topics (e.g. public behaviour and health) are related to it. Recent RSSB research has also covered a number of other relevant issues (e.g. the use of social media in emergencies, customer service maturity models, station design, and passenger ticketing and information systems).

Extensive data is available on customer satisfaction from the National Passenger Survey, administered by Passenger Focus. Passenger Focus also undertakes some research on the customer experience. However, this data relates solely to users and does not cover non-users, which would require surveys away from trains and train stations.

Academic evidence is emerging on human/systems interactions, which is informing developments in inclusive/universal design, user-centred design and experiential engineering. Methods and protocols for testing and design in collaboration with users are well developed. In addition, there is some knowledge of the impact of demographics (e.g. ageing population) and the spatial distribution of populations.

Some evidence on on-train activity and use of technology (including work funded by the Research Councils) is available, along with a degree of knowledge on the extent of journey planning people undertake when travelling by rail and other modes (e.g. through the usage of NRES and Transport Direct).

While there is relatively limited publicly-available information, considerable research on customer experience, generally from a commercial standpoint, has been carried out for use within
the industry. The Association of Train Operating Companies’ Passenger Demand Forecasting Handbook (version 5.1 was recently launched) details passengers’ response to factors including fares, journey times, service levels, unreliable services and crowding. There is some information on how passengers respond to ‘softer’ factors such as information and ticketing.

[8.1.7] Greater knowledge will be acquired in some areas related to this theme through the FuTRO programme. One of its aims is to deliver a personalised journey experience. In terms of meeting customers’ needs, it will address three inter-related questions:

1. How will the industry understand the needs of passengers and freight customers over the next 15-40 years? This question will examine the tools and approaches available today to understand how the population’s behaviours and needs will change over this extended period. The outputs will inform the approach to designing new railway systems and modifying existing assets as opportunity arises.

2. How will customers know what the railway offers them, both in advance and in real time? Issues to be explored extend beyond the ongoing day-to-day user experience in terms of real time information and choices. Importantly they also cover how customers will understand the service the railway offers over time – for example the quality of the service from where someone plans to live to their workplace.

3. How will system design contribute to reducing passenger stress and improving satisfaction? This question recognises that customer satisfaction is not solely about performance metrics (the service the railway provides in terms of, for example, punctuality and frequency) but also about emotional issues (how the service is delivered). It will examine how to enhance customers’ sense of wellbeing (or at least reduce stress) at any level of absolute performance.

[8.1.8] One potential means of analysing customer needs and communications identified by FuTRO could be to divide them into three epochs:

Minutes and seconds: Key questions relate to real time requirements such as where a passenger needs to travel on the day of their journey, and the real time location of their train.

Days and weeks: Key questions relate to clearly-established, longer-term needs.

Months and years: Key questions relate to perceptions of performance and overall customer expectations.

8.2 Relevant knowledge from other sectors

[8.2.1] The British rail industry’s commercial focus means the priority placed on customer experience is comparable to any of the world’s leading rail systems, although the National Passenger Survey indicates there are variations between train operating companies. International studies of customer satisfaction indicate that satisfaction levels in Britain are above the EU average.

[8.2.2] However, there is scope to transfer experience from other sectors. For example, lessons could be learnt from the design of public space (e.g. recent work in hospitals) and private space (e.g. work in the automotive sector). User-centric design is more ingrained in the aviation and automotive sectors than in rail.

[8.2.3] There is little evidence on the interplay between people’s attitudes, intentions and behaviour in the rail sector, but more evidence on the linkages and lacunae from marketing and psychology literature.
[8.2.4] Extensive Maths/Operations Research is available on path finding and journey time optimisation. This knowledge could be utilised to analyse large open data sources in real time and made accessible through mobile phone apps. Work of this type is taking place in the Research Council’s Digital Economy programme.

8.3 Research requirements and impact

[8.3.1] The railways have a wide variety of customers, sometimes with conflicting requirements. The starting point for research relating to the Customer Experience theme should be to gain a clear understanding of: who the industry’s customers are; their needs; the differences between the various passenger market segments; and the differences between the passenger and freight sectors’ requirements.

[8.3.2] The factors that make rail an attractive/unattractive mode of travel and the role of IT in influencing opinions is only partially understood. There have been some recent studies on barriers to rail use. However, greater insight depends on a well-developed appreciation of how different generations perceive travel-related interactions and their prior experience of technologies, as well as detailed understanding of the most appropriate application domains for new technologies. Improved real time information during disruption could be a key area where developments in technology could lead to improvements in the customer experience (as satisfaction levels are currently low in this respect).

[8.3.3] More information is needed on perceptions of ticketing and distribution channels and on issues of trust and technical reliability. Better understanding is required of how information, fares and ticketing, interchange, seat reservations and accessibility – both physical and virtual – impact views on the rail system’s ease of use.

[8.3.4] A key overarching question is: ‘how will rail services develop in the future?’ both in terms of rail travel as a standalone mode and as part of the wider transport system. Answering this question will require consideration of the customer in the whole supply chain. A related issue is the potential impact of any substantial change in government funding (or government’s role as a client). For example, how would a move towards a zero-subsidy railway affect customer experience?

[8.3.5] Evidence is beginning to emerge on how customers respond to different combinations of fares and ticketing systems (e.g. smartcards, e-ticketing and m-ticketing), particularly in London. However, research is required to assess the full range of options and consider the role of regulatory and commercial constraints. In particular, the value customers may place on simple, comprehensible fare structures needs to be understood, given the trend towards greater complexity.

[8.3.6] Similarly, more details are needed on the value and timeliness of information. A key challenge will be the management of a multiplicity of ticketing and information systems and distribution channels with different levels of maturity, and with differing appeal across a range of market segments.

[8.3.7] How people in different sub-groups react to changes will require further research. PDFH market segmentation is limited to ticket type/journey purpose and geography. The first and last miles in the whole journey experience are considered important, but the role of multimodal links is still not fully understood. The potential contribution of concepts such as hire bikes and taxi buses in improving access/egress requires investigation. The industry’s reliance on ticket sales data means access/egress to/from stations is poorly understood. A repeat of the 2004/5 National Rail Travel Survey could be beneficial.
[8.3.8] The role of stations as activity spaces and their interactions with surrounding land uses requires greater consideration, with particular emphasis on key hubs and interchanges. Understanding these issues will be especially critical to the success of HS2.

[8.3.9] There is greater understanding of customer experience in the passenger sector than the freight sector. Acquiring similar knowledge of areas such as demand forecasting and customer satisfaction in the freight industry could be beneficial. In addition, extending market research to consider the attitudes of non-users could give important insights and have synergies with ‘Smarter Choices’ work and Local Sustainable Transport Fund monitoring projects.

[8.3.10] New research on the relative benefits of walk-on compared to book-ahead fares and on the benefits of different classes of travel could be also be warranted; there is a view amongst some that First Class may be an anachronism.

[8.3.11] The table below lists the research requirements identified in relation to this theme, categorises them, and sets out the potential contribution to the vision in the RTS 2012.

<table>
<thead>
<tr>
<th>Research subject</th>
<th>Type*</th>
<th>TRL</th>
<th>Contribution to the RTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Cross-cultural studies of rail customer experiences in different cities and countries</td>
<td>C</td>
<td>0-3</td>
<td>(Socio-) Demographics</td>
</tr>
<tr>
<td>2 Examine the scope for systems thinking throughout the industry, along with genuine multidisciplinarity that brings together engineering, maths, social sciences, architecture etc</td>
<td>B</td>
<td>0-3</td>
<td>Integrate access, end-to-end journey, ticketing, passenger and freight customer information</td>
</tr>
<tr>
<td>3 Re-assess the seven common design concepts (reliability, resilience, security, automation, simplicity, flexibility, sustainability) through the lens of customer experience and consider others (e.g. affordability, accessibility)</td>
<td>B</td>
<td>0-3</td>
<td>Security, access, ticketing</td>
</tr>
<tr>
<td>4 Advanced modelling and simulation to determine customer preferences and the rail industry’s ability to meet these preferences</td>
<td>S</td>
<td>0-3</td>
<td>End-to-end journey, passenger and freight customer information</td>
</tr>
<tr>
<td>5</td>
<td>Development of methods for exploring multimodality, including the concept of the instrumented customer, through the use of personal GPS</td>
<td>C</td>
<td>4-7</td>
</tr>
<tr>
<td>---</td>
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<td>---</td>
</tr>
<tr>
<td>6</td>
<td>Development of navigation tools that simultaneously identify the best routes (in terms of journey time) and the best tickets, enabling customers to optimise their journeys more easily</td>
<td>C</td>
<td>4-7</td>
</tr>
<tr>
<td>7</td>
<td>Ensure rail product is fit for purpose by promoting effective testing and simulation</td>
<td>C</td>
<td>8</td>
</tr>
</tbody>
</table>

* Concept type:-
  - Collaborative: Partnership with industry to meet medium-term RTS requirements
  - Strategic: New academic input required to enable industry’s longer-term plans
  - Blue Sky: New idea that needs formative academic research

### 8.4 Industry input requirements

[8.4.1] There is a need for data collection focused on the requirements of non-rail users (but potential users in the future) to inform new customer service propositions.

[8.4.2] Demonstration schemes of new technologies and concepts would be useful to complement laboratory-based testing.
[9.1] The aim of *The Academic Response to the RTS 2012* is to contribute significantly to research support becoming an integral part of the UK rail industry, rather than being undertaken as a separate or remote activity. To achieve this objective, it is necessary to examine how the ‘business’ and ‘academic’ sectors can work together effectively.

[9.2] Core activities of rail focused academics and rail businesses are very different. Core business activities include transporting goods and people, producing a return on investment, maintaining and developing assets and improving the operating environment. Core academic activities include generating new knowledge through research, publishing research findings, and teaching undergraduate and more specialist courses.

[9.3] Despite the differences, these activities can link in many ways to support ongoing collaboration and dialogue between industry and academia, and the exchange of data, goods, technologies and services. Examples include:

- **Consultancy and knowledge transfer partnerships (KTPs):** These activities aim to address specific industry issues using universities’ existing knowledge and skills. This knowledge includes outputs from earlier low TRL research, and expertise from other sectors which has a rail application.

- **Input to define research projects:** Input from the operational and infrastructure management sectors of the rail industry is vital in focusing research activity in universities. This applies both to shorter-term or applied research, and to long-term blue sky research to capture future opportunities and combat issues likely to arise in the future. In defining these research projects, the most important input is industry foresight beyond current business cycles, particularly in the context of helping to define research for the 30-year time frame of the RTS 2012.

- **Ongoing industry engagement in research projects after their definition:** Extended management and technical involvement is important to steer projects as industry needs evolve, and to enable the research outputs to reach those in the industry who can make use of them. Continuing involvement could include provision of industry-specific knowledge, access to key people, and contribution to project steering groups. Access to operational staff (e.g. for human factors evaluation of potential new technologies), access to data (e.g. from condition monitoring of rail infrastructure or vehicles), and access to test facilities (e.g. test tracks, or through installation of equipment onto service vehicles) also have an important role in this respect.

- **Exchange of people and developing relationships between academic and rail staff:** Mechanisms to foster closer day-to-day contacts have an important role: for example through visits and secondments of research staff to the rail industry to improve understanding of its needs, and similarly for rail industry staff to make use of university facilities and better understand what is possible in a research environment. Greatest value can be achieved if ‘champions’ are identified within the industry for individual research projects. This would considerably increase the likelihood of ideas and knowledge generated by research transferring from lower TRL development in academia to higher TRL trials and later implementation.

- **Education and training:** Universities benefit the rail industry through exposing undergraduates to the industry’s challenges, instilling enthusiasm for the industry in students, and through developing courses or full degree programmes to support rail staff development. There are also opportunities through undergraduate programmes to promote entry into the rail industry to the best new graduates, for example though rail-focused (and industry-linked) undergraduate projects, and through university careers fairs and events. Similarly, opportunities
exist to engage with PhD students and postgraduate researchers and demonstrate opportunities for them to move into appropriate sectors of the industry as they complete their projects.

[9.4] Appendix B provides further details of specific funding and collaboration routes.

[9.5] While there are many opportunities to work across the academic and business sectors, there are also barriers to be addressed and overcome. Providing universities with easier access to industry data, much of which is difficult to find, would facilitate new research opportunities. For example, if datasets from condition monitoring of rail infrastructure assets were readily available, exploratory projects could be undertaken and feasibility of new data processing ideas tested prior to applying for industry or Research Council funding to develop the concepts.

[9.6] Improved definition of research projects and more widespread application of research outputs depend on long-term partnerships such as RRUKA, and company-specific arrangements such as Network Rail’s Strategic University Partnerships. Such collaborations enable better appreciation of each sector’s needs, pace of operation, and the mechanics of how projects can be set up. They can also facilitate the development of proposals to raise funding for research, for example through Research Councils, the EU, the Transport Catapult, or as a direct business funding case.

[9.7] Equally, the route to implementation and dissemination of research findings can be enabled by these relationships. For research to translate into implementation, a business case will be required and this may be unclear when developing a project addressing the lowest TRLs. A dialogue to understand the business needs and the risks/opportunities inherent in early stage research can help to ensure there is a path to implementation.

[9.8] In this way, enhanced engagement and capitalising on its benefits will enable university research to establish itself as a genuine sector of the rail industry and play a key role in the realisation of the RTS 2012 vision.
10 Conclusions

[10.1] The Academic Response to the RTS 2012 has demonstrated strong railway research competencies within the UK in many areas. In some fields, research is already making a contribution to the prosperity of the industry and there is evidence of some strong collaboration between academic and industry groups domestically and internationally. In addition, the Academic Response has highlighted experience from other sectors where research has had significant impacts and this knowledge can be transferred for application in the rail industry.

[10.2] However, despite these encouraging findings, there are some areas of importance where research activity is not so vibrant and where the knowledge base may not be adequate to meet the rail industry’s aspirations. By identifying key research projects to support the RTS and the potential benefits they can deliver, this document will help focus the considerable UK rail research capabilities more effectively and encourage heightened engagement with industry.

[10.3] In this way, rail research can establish itself as a cornerstone in the delivery of the dynamic vision for a growing, customer-focused, high-value rail industry set out in the RTS 2012, to the benefit of universities, the rail industry and users of the network.

[10.4] Although it is not the purpose of this document to specify detailed implementation activities, it is critical that an implementation plan is agreed with wide support from industry. RRUKA will work with TSLG to establish this plan and to assist academic teams to engage with appropriate industry partners to ensure maximum research capability is accessed and that it is aligned with both the RTS and available research funding streams.

HAVE YOUR SAY!

The Academic Response to the RTS 2012 is available online. We would be very interested to receive your feedback and comments. Please visit: http://rruka.org.uk/the-arrts-document/
Appendix A

Academic Institutions represented at the ‘Academic Response to the RTS 2012’ workshop (27 February 2013, London)

City University London
Coventry University
Cranfield University
Imperial College London
Loughborough University
Newcastle University
Queen Mary University London
Swansea University
University College London
University of Birmingham
University of Bristol
University of Cambridge
University of Hertfordshire
University of Huddersfield
University of Kent
University of Leeds
University of Manchester
University of Nottingham
University of Reading
University of Salford
University of Sheffield
University of Southampton
University of Surrey
University of the West of England
University of Warwick
University of Westminster
<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Brief description</th>
<th>What is it most suitable for?</th>
<th>Typical duration</th>
<th>Typical funding requirement</th>
<th>How can RRUKA help?</th>
<th>For more information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consultancy</td>
<td>Industry has a problem or opportunity and pays a university to research it.</td>
<td>Shorter term, specific issues</td>
<td>Varied but usually less than 6 months</td>
<td>Variable: Paid by industry directly to university according to time and level of expertise needed</td>
<td>Help industry identify which universities have the capabilities they are looking for.</td>
<td><a href="http://www.ktponline.org.uk">www.ktponline.org.uk</a></td>
</tr>
<tr>
<td>Knowledge Transfer Partnership (KTP)</td>
<td>Industry company partners with university an employs a KTP Associate (recent graduate) who is responsible for transferring the knowledge that the company is seeking into the business by a strategic project.</td>
<td>Working on a strategic project or business opportunity for the company. Identifying innovative solutions. Strengthening science base in area of interest to industry.</td>
<td>Between 6 months and 36 months</td>
<td>Generally funded by a funding body such as a research council or other government funder eg TSB. Sometimes cofunded.</td>
<td>Advertise opportunities to universities. Help find suitable industry partners.</td>
<td><a href="http://www.ktponline.org.uk">www.ktponline.org.uk</a></td>
</tr>
<tr>
<td>Year in industry</td>
<td>Pre-university or undergraduate student spends a year based in the industry company, working on industry projects and learning more about the way industry works.</td>
<td>Inexpensive resource for project work. Access to the best bright students for future recruitment. Helping students understand industry better so they can develop their skills to best meet its needs.</td>
<td>One year</td>
<td>~£2000 plus VAT plus a salary for the student, to be paid for by the company</td>
<td>Help universities find industry partners who could host student. Help understand the process.</td>
<td><a href="http://www.etrust.org.uk">www.etrust.org.uk</a></td>
</tr>
<tr>
<td>Masters level final year project</td>
<td>Masters student investigates ideas or problems proposed by industry as their final year project. Supervised by the university with input from industry.</td>
<td>Ideas which a company would like investigated but which are not time critical.</td>
<td>10-12 months</td>
<td>Zero cost to industry, except any in kind contributions of their own time.</td>
<td>Advertise projects to universities. Advertise opportunity to industry.</td>
<td></td>
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<tr>
<td><strong>Undergraduate project</strong></td>
<td>Some universities have a group design project as part of the third year of their engineering degrees where students are given industrial problems to investigate. Industry could supply one or more problems for the students to explore. The students work as free (but inexperienced) consultants.</td>
<td>Non-critical ideas which a company would like investigated and for which fresh thinking could bring benefit. Due to the inexperience of the students, results will be variable.</td>
<td>Around 3 months</td>
<td>Zero cost to industry, but they will be expected to participate in a few meetings with the students and often host a visit from the students.</td>
<td>Facilitate links between universities who run such projects and industry partners who wish to become involved.</td>
<td></td>
</tr>
<tr>
<td><strong>PhD</strong></td>
<td>Industry could fund or co-fund a PhD in a subject of their choice.</td>
<td>Investigation of a broader issue with a longer time scale and open ended solution</td>
<td>3 years</td>
<td>A PhD costs roughly £65,000 for a UK student, over the 3 years. This could be wholly funded by university or cofunded with industry. For foreign students, the figure is roughly £100k, but often these are funded by the foreign student or their government with only living expenses needed.</td>
<td>Advertise opportunities to universities. Help industry understand the process.</td>
<td></td>
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<tr>
<td><strong>iCASE studentship</strong></td>
<td>Industry company is awarded PhD studentships by funding council and selects university to carry out a project to suit their needs. NB All awards are allocated directly to a limited number of companies depending on the extent of their collaboration on EPSRC research grants.</td>
<td>Specific problem or opportunity with a longer time scale and open ended solution</td>
<td>3.5 years</td>
<td>Co-funded: Funding council pays roughly £60,000 and industry company pays roughly £20,000 over duration of project</td>
<td>Advertise opportunities to universities. Help industry understand the process.</td>
<td><a href="http://www.epsrc.ac.uk/funding/students/coll/icase">www.epsrc.ac.uk/funding/students/coll/icase</a></td>
</tr>
</tbody>
</table>
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