Applications of Robotics and Autonomous Systems to Rolling Stock Maintenance
The Rail Safety and Standards Board (RSSB), via the Rail Research UK Association (RRUKA), is to invest up to £250,000 in academic-led feasibility studies to respond to the challenge of applying robotic or autonomous system technology to rail vehicle maintenance, in order to assist humans with monotonous and labour intensive tasks.

Proposals funded through this call should develop novel ideas and innovative solutions that can help the rail industry reduce time, cost and improve quality of rolling stock maintenance. Once completed, the successful feasibility studies may be considered for further funding for trials and demonstrations.

Submissions are welcome from non-rail experts who may have experience in other fields, which could be transferred or applied to the rail industry.

This competition opens on 16 November 2015. The deadline to submit proposals is at 17:00 on 22 January 2016.

This document contains some background information about the challenge and serves as guidance for the submission of proposals.
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1 Problem statement

Well maintained rolling stock is a vital part of running any railway. Trains are composed of many complex mechanical, electrical, pneumatic and hydraulic parts that need to be inspected and maintained at regular intervals, to ensure the safe and efficient operation of traction and rolling stock on the railway.

Robotic systems provide an accurate and flexible way of handling inspection processes in repetitive environments where the defects may be very few and far between but critical to safety in their nature. In hazardous, high voltage and hard-to-access environments, robotic systems could potentially minimise the risks humans are exposed to. The high accuracy and path repeatability of robotic systems enable them to repeat tasks that humans find dull and monotonous.

The transportation sector is one of the first sectors to take advantage of robotic systems for manufacturing; however, only a small fraction of the potential benefits that robotics could bring to the railway industry is being taken advantage of. It is anticipated that robotics may have a huge impact on many other areas outside manufacturing, which could drastically change the industry.

According to the McNulty Rail Value for Money Study, the maintenance and financing of rolling stock is estimated at approximately £1.8 billion per year, accounting for 15% of total rail industry costs. Approximately 40% of this is spent on maintenance activities. A significant proportion of these costs are related to labour-intensive maintenance processes, both preventive and corrective, which is estimated to be approximately £360 million per annum. This figure is likely to increase, given the total number of passenger vehicles is predicted to increase.

There are a number of key challenges currently being faced by operators and maintainers:

- The rolling stock maintenance and inspection procedures are largely dependent on humans and although no one intends for errors to happen, psychology informs us that by nature humans are prone to error and it is inevitable that mistakes will be made from time to time.
- Train maintenance is particularly vulnerable to error because the work is often complex, involving the frequent removal and replacement of a variety of components. Certain tasks also require high levels of vigilance and skill to detect faults that can be infrequent and difficult to spot.
- Train maintenance is also commonly performed in difficult working conditions and often under time pressure.
- Depots are reaching full capacity, therefore thought must be given as to how to accommodate and where to carry out maintenance for larger fleets in the future.

Would the application of robotics and autonomous system (RAS) technology help the rail industry reduce maintenance time and cost and improve the reliability of rolling stock inspections?

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1 Technology watch on robotics and autonomous systems, RSSB & TRL, March 2015
2 Rail Value for money study - Rolling stock whole life costs, Arup, March 2011
3 How big is RISAS? RISAS Board Paper, January 2011
4 Long Term Passenger Rolling Stock Strategy for the Rail Industry, February 2013
5 Human Factors of Train Maintenance, Paper presented at World Congress on Railway Research (WCRR) 2008, Seoul, Korea
The growing adaptability of robotic technology is already paving the way for automated technology to transform the manufacturing industry. In the UK, the resurgence of railway transportation, coupled with the fact that RAS were identified as one of the eight great technologies that supports the UK Industrial Strategy, means this is the right time for the rail industry to invest in robotic technology. The use of RAS in transportation over the next 20 years is estimated to have economic benefits in the order of £1tn.

The Rail Technical Strategy (RTS) 2012 set out a vision for the railway where repetitive and arduous tasks are automated. This vision portrays a future that is likely to be technologically complex, but more automated and managed by fewer, highly skilled people. Automation is one of the common design concepts in the RTS, and maintenance is highlighted as one of the key areas where increased levels of automation could benefit industry. Automating a wider range of maintenance operations will lower the risk to maintenance personnel and improve asset management and maintenance scheduling.

According to the Long Term Passenger Rolling Stock Strategy the number of vehicles (currently approx. 12,500) could almost double over the next 30 years. This growth, coupled with committed national electrification plans, leads to a forecast rise in electric vehicles to over 90% of the national fleet total in the same time period. It is expected that a minimum of 13,000 new electric vehicles will be required by 2042. Requirements for diesel trains in the same period will be smaller by comparison (the demand is estimated at 400 to 800 vehicles).

![Composition of Fleets 2014](image1)
![Composition of Fleets 2042](image2)

*Figure 1 Change in National Passenger Fleet Size and Composition (Medium Scenario)*

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7 Rail Technical Strategy 2012, 4.24
8 Long Term Passenger Rolling Stock Strategy, February 2013
Robotics and autonomous systems do not work in isolation; there are a number of nontechnical aspects which are a prerequisite for further development and implementation. Given the fact that rail is a highly regulated industry, consideration must be given to not only safety benefits but also regulatory challenges, changes to standards, development of testing facilities, demonstrators and skill development.

**Key Drivers**
- Need to deliver greater capacity
- Need to meet environmental and energy usage targets
- Need to reduce accidents

**Key Enablers**
- Definition of cross industry regulation and safety validation
- User trust and acceptance
- Legal framework for autonomy and insurance

**Key Impacts**
- Improve safety
- Improved infrastructure utilisation
- Reduced travel times

*Figure 2 Transport and Cities, UK Landscape for Robotics and Autonomous Systems 2015*
3 Introduction to train maintenance

The rail industry, train operation and maintenance in particular, is very complicated, with a number of different stakeholders involved, different maintenance structures, contracts and agreements in place across the UK.

**Department for Transport (DfT)**
The DfT is the franchising authority for the rail network, responsible for designing and procuring rail franchise services.

**Rolling Stock Operating Companies (ROSCOs)**
ROSCOs own the trains. It is their responsibility to help develop services by phasing out old and aged rolling stock to make way for modern, more convenient and safer trains. In some cases ROSCOs are responsible for some aspects of train maintenance.

**Train Operating Companies (TOCs)**
TOCs are responsible for the day to day running of the train service. In many cases TOCs carry out maintenance themselves. In other instances maintenance is contracted out, either completely or partially.

**Contracted maintainers**
Suppliers can be contracted to carry out train maintenance.

**Manufacturers**
Some train manufacturers have contracts in place for some or all aspects of train maintenance.

*Figure 3: Train maintenance stakeholders*
There are a number of different contract types which determine who maintains what and the intervals at which maintenance should take place.

Train maintenance is currently procured through a number of different mechanisms.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry leases</td>
<td>The TOC is responsible for carrying out both the day-to-day light maintenance and the less frequent heavy maintenance overhauls. TOCs can either carry out the work in-house or contract with a range of different types of maintenance supplier</td>
</tr>
<tr>
<td>Wet leases</td>
<td>The ROSCO is responsible for providing all of the maintenance, contracting it out to suppliers. In some cases they actually contract the service delivery back to the TOC</td>
</tr>
<tr>
<td>Soggy leases</td>
<td>These are part-way between dry and wet leases with the TOC responsible for light maintenance and the ROSCO responsible for heavy maintenance.</td>
</tr>
<tr>
<td>TSAs</td>
<td>It has become increasingly common for the maintenance of new-build rolling stock to be carried out by the rolling stock manufacturer (OEM) through a Train Service Agreement (TSA). These contracts often cover a long time period (normally longer than the duration of an individual franchise) and include development of new depot facilities.</td>
</tr>
</tbody>
</table>

Table 1: Rolling stock and value for money, An ATOC discussion paper, December 2011

The activities generally referred to as train maintenance fall under 3 broad categories; maintenance, inspection and servicing:

**Definition**
- Maintenance: Routine and ad-hoc repairs. This includes both regular light repairs and the less frequent heavy maintenance and overhauls.
- Inspection: Routine fault finding and condition monitoring and checks. Certain aspects are mandated by standard, others by manufactures.
- Servicing: Activities related to the day to day upkeep and running of the service.

**Activities**
- Maintenance: • Routine maintenance • Overhauls • Life extension work • Repairing broken assets e.g. windows, seat covers
- Inspection: • Non-destructive testing of wheel and axels • Checking consumables (e.g. brake pads, pantographs) • Visual inspections
- Servicing: • Cleaning (e.g. floors, toilets, cabs etc.) • Restocking consumables (e.g. sand, fuel) • Disposing of waste

**Challenges**
- There are a number of challenges related to maintenance activities, such as: working at height, asset security, human factor issues (repeatability, attention to detail, access), access under trains to inspect connections and condition, time consuming and labour intensive activities

Figure 4: Train maintenance, inspection and servicing
3.1. Maintenance specifications

Railway standards define what must be done in order to achieve technical compatibility on the GB mainline network. Railway Group Standards (RGS) and Technical Standards for Interoperability (TSIs) set out technical requirements applicable to vehicles or the infrastructure, or processes applicable to transport operators.

There are number of standards related to rolling stock maintenance that specify the areas and components that need to be inspected and maintained on a routine basis. The detail of what maintenance needs to be carried out is stock specific and detailed maintenance plans are provided for each fleet.

Manufacturers provide initial guidance governing rolling stock maintenance to the train operators and/or maintainers as part of a specific vehicle maintenance plan, which describes maintenance activities and examination frequencies for that vehicle. Adjustments and variations to these plans take place over time through a change control process.

Brakes: Train brakes are vital components, both in terms of safety and performance.

**Key Challenges:** Access under trains to inspect integrity, condition, dimensions and functionality.

Doors: Fast, efficient, reliable door operation is vital in order provide a good service.

**Key Challenges:** Inspecting and maintaining locking arrangements, interlocks, door sensitive edges, positioning and controls.

Axles and wheelset maintenance: Wheels and axles are key components that can be vulnerable to fracture and wear.

**Key Challenges:** Human factors issues (repeatability, attention to detail, access). Time consuming as well as labour intensive.

Shoe gear (if present): Collector shoes are used on some lines to draw power from conductor rails.

**Key Challenges:** Access under trains to inspect connections and condition.

Pantographs (if present): Pantographs collect power from overhead lines.

**Key Challenges:** Working at height; inspection and maintenance related to integrity, security, dimensions, condition and cleaning.

Cleaning (interior and exterior): Maintenance of train exteriors and passenger facing features, like train toilets which are an important part of improving the customer experience.

**Key Challenges:** Cleaning and emptying, both at depots and in service.

Underframe & bogies: Looking for missing, loose, worn or broken parts.

**Key Challenges:** Difficult view in stooped position, poorly lit, a lot of items to look at.

Figure 4: Maintenance areas
4 Definitions of robotics and autonomous systems

Robotics: The term “Robotics” is used to define a branch of engineering that focuses on the design, construction and operation of robotic systems (robots). A robot is a machine that is specifically designed to perform a particular task (or a range of tasks). Robots can be fully autonomous, semi-autonomous or controlled by human operators. A fully autonomous robot will make all of its decisions and actions without direct human intervention. A semi-autonomous robot will have some degree of autonomy (e.g. some tasks, like balancing or object tracking, will be fully automated, while others will be controlled by a human operator) while non-autonomous robots are directly controlled by an operator (e.g. remote controlled CCTV camera that can be rotated 360°).

Autonomy: While robots are usually viewed as physical machines performing some form of physical action, autonomous systems cover a much wider spectrum, which is not defined by physical structures. Autonomous systems are defined as self-monitoring adaptive intelligent systems that have control over their own actions and internal state, and that can operate independently from direct human intervention. This may include robotics or autonomous vehicles, where data acquired by a sensing or monitoring capability is utilised as part of the overall autonomous decision-making process.

Some examples of autonomous systems include autonomous space exploration vehicles, intelligent transport systems, automated control for nuclear power plants, autonomous aerial vehicles, automated trading systems used for high-frequency trading, etc.

A fully autonomous system has the following characteristics: it is able to learn from experience, interact and cooperate with other autonomous systems, is flexible in handling the uncertainty associated with its environment and has the means to take rational decisions, leading to a specific goal. Autonomous systems differ from automated systems, which also can function without human operators but are unable to adapt or make “decisions”.

In general, systems can be grouped into six types based on their level of autonomy and control:

<table>
<thead>
<tr>
<th>Level</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Human operated</td>
<td>All activity within the system is the direct result of human-initiated control inputs. The system has no autonomous control of its environment, although it may have information-only responses to sensed data.</td>
</tr>
<tr>
<td>2</td>
<td>Human assisted</td>
<td>The system can perform activity in parallel with human input, acting to augment the ability of the human to perform the desired activity, but has no ability to act without accompanying human input. An example is automobile automatic transmission and anti-skid brakes.</td>
</tr>
<tr>
<td>3</td>
<td>Human delegated</td>
<td>The system can perform limited control activity on a delegated basis. This level encompasses automatic flight controls, engine controls, and other low-level automation that must be activated or deactivated by a human input and act in mutual exclusion with human operation.</td>
</tr>
<tr>
<td>4</td>
<td>Human supervised</td>
<td>The system can perform a wide variety of activities given top-level permissions or direction by a human. The system provides sufficient insight into its internal operations and behaviours that it can be understood by its human supervisor and appropriately redirected. The system does not have the capability to self-initiate behaviours that are not within the scope of its current directed tasks.</td>
</tr>
<tr>
<td>5</td>
<td>Mixed initiative</td>
<td>Both the human and the system can initiate behaviours based on sensed data. The system can coordinate its behaviour with the human’s behaviours both explicitly and implicitly. The human can understand the behaviours of the system in the same way that he understands his own behaviours. A variety of means are provided to regulate the authority of the system with respect to human operators.</td>
</tr>
<tr>
<td>6</td>
<td>Fully autonomous</td>
<td>The system requires no human intervention to perform any of its designed activities across all planned ranges of environmental conditions.</td>
</tr>
</tbody>
</table>

Table 2 - Levels of Autonomy (from US Navy Office of Naval Research and used by SEAS DTC)
There is no clear distinction between the different types of autonomous systems. The level of autonomy can be correlated with a proportional lessening of the degree of human intervention or interaction.

The development of artificial intelligence (AI) is closely linked with system autonomy, as the goal is to create such intelligent machines that perceive their environment and take actions that maximise their chances of success. In other words, artificial intelligence can be viewed as the “brain unit” of a fully autonomous system.

Autonomous systems have a wide variety of possible applications in fields such as robotics, software engineering, machine automation, network optimisation, image recognition, etc.

Figure 5: Venn diagram showing the relationship between robotics and autonomous systems (from TRL/RSSB knowledge search)
The objective of this call is to establish a number of cross-disciplinary consortia to conduct research into novel applications of robotic and autonomous system technology for train maintenance, inspection and servicing to:

- reduce operating costs;
- improve the speed and efficiency of maintenance practices;
- reduce risk to maintenance personnel.

The proposals must cover the following areas:

### Technology:
The projects should investigate applications of robotic and/or autonomous systems in the following areas:

- Semi-autonomous robotic system
- Semi-autonomous systems
- Autonomous robot
- Fully autonomous systems

We do not expect projects to focus solely on software development. Consideration must be given on how the technology will be deployed as part of a robotic/autonomous system. We encourage academics to form inter-departmental consortia.

### Rolling stock:
The focus of this call is maintenance of the next generation of railway vehicles. We are looking for maintenance solutions for electric passenger trains, for both mainline and metro systems.

Solutions for diesel trains will be considered.

This call does not cover freight vehicles.

### Maintenance:
Activities addressed should fall within the categories of:

- Maintenance - Routine and ad-hoc repairs, including both regular light repairs and the less frequent heavy maintenance and overhaul activities.
- Inspection - Routine fault finding and condition checks
- Servicing - Activities related to the day to day upkeep and running of the service

### Technology readiness:
The majority of the technology content of each project will be at TRL 1-3. We will facilitate contact with industry representatives in order to allow projects to develop their technologies to higher TRL.

### Challenge areas:
The proposals should focus primarily on innovative technological solutions. Many potential technologies are currently only in the early development stages meaning that huge investments and scientific breakthroughs might be necessary before a certain technology could be adapted to specific applications.

Considerations should also be given to the following challenge areas:

- Reliability and safety
- Policy and regulatory implications
- Ethical and moral concerns
6 Feasibility studies

Potential bidders are encouraged to think beyond traditional constraints and foster collaborations with colleagues in disciplines and backgrounds different to those they would normally collaborate with. Inter-departmental collaboration is highly recommended.

We encourage bidders to consider working in partnership with a Train Operating Company (TOC) and/or a rolling stock maintainer.

6.1 Proposal format and guidance

We are expecting good quality proposals, clearly written and formatted. Please use the proposal template provided.

Your proposal should be between 8-12 pages long and should include the following:

- Description of the proposed research including clear scope and objectives; methodology; breakdown of tasks; description of expected deliverables for each task and associated delivery dates. (4-6 pages max.)

- Workplan\(^{10}\), a Gantt chart or other graphic representation comprehensive of milestones, activities and deliverable dates. (1 page max.)

- Pathway to impact: this should be a high-level description of next steps and an explanation of all the associated potential benefits to the industry, should the proposal be successful. This section is expected to be kept live during the life of the project (1-2 pages max.)

- Justification of resources: Breakdown of costs using the template provided. Feasibility studies should be cost at 80% FEC. Overheads and bursaries are allowable costs. (1 page max.)
  - Track record: a list of all academic consortium members and industry supporters (if any), which should detail the relevant expertise that each investigator will bring to the research. (1-2 pages max.)

- Half-page lay summary which we will upload on SPARK, if your feasibility study is selected and funded. (half page)

Please note that the assessment panel may request additional clarifications or may ask for a proposal to be resubmitted if it does not meet the requested format.

6.2 Evaluation criteria

All proposals will be assessed by a panel drawn from industry and academia. Proposals will be assessed according to the following criteria:

**Quality and clarity of the proposal**

1. Relevance to the scope of the call
2. Scientific value and novelty of the proposed work (i.e. novel concepts, appropriateness of proposed methodology etc.)
3. Ability of bidding team to deliver the research
4. Evidence of adequate plans for industry engagement during the life span of the research.

**Resources and management:**

5. Clear costing and transparent breakdown of resources, which demonstrate value for money of the proposed study. Your proposal should include a clear narrative description that demonstrates:
   - All costs (and potential risks) associated with the project have been identified
   - An explanation of why you believe the costs to be reasonable
   - An explanation of how you have quantified the benefits
   - The level of commitment where funding is contributed from other sources (if any)

**Potential research impact:**

6. Evidence of early and sound thinking on next steps and possible ‘routes to market’.

Criteria will be weighted evenly and scored out of 3:

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Confident that response fully meets criterion</td>
</tr>
<tr>
<td>2</td>
<td>Minor concerns about ability to meet criterion</td>
</tr>
<tr>
<td>1</td>
<td>Significant concerns about ability to meet criterion</td>
</tr>
<tr>
<td>0</td>
<td>Does not meet the criterion</td>
</tr>
</tbody>
</table>

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\(^{10}\) It is expected that, if successful, the workplan is updated regularly by the project team and is discussed during the project update meetings.
6.3 Consortia guidance

A successful consortium is likely to consist of participants with a range of disciplinary perspectives and different rail expertise.

- **Academic input**: Please note that all academics wishing to submit a consortium bid need to be registered RRUKA members. Researchers from non-UK based universities or research institutes can take part but they need to be part of a consortium where at least one member is a UK-based institution and an institutional member of RRUKA. If you are not registered (or if your University is not an institutional member), please visit: rruka.org.uk/membership/.

- **Industry input**: Consortia should include industry experts. Industry representatives are encouraged to provide their in-kind support, however they are not eligible for funding.

- **Contractual arrangements**: Consortia must be academic-led. The funding will be given to the lead academic partner to manage.

6.4 Funding

If a proposal is accepted, each consortium must appoint a lead academic partner, who will be responsible for receiving and managing the funding accordingly. RSSB will contract directly with the lead academic partner.

The lead academic partner is required to sign and return the grant agreement within 30 days of receipt or funding may be withdrawn.

RSSB will fund as many feasibility studies as can be afforded within the available £250,000 funding. Potential bidders should note that 3 to 5 feasibility studies are expected to be funded. RSSB will pay 50% of the contribution at the start and 50% at completion, upon acceptance of the final deliverable.

A sample agreement is available on the RRUKA website for reference. Bidders are encouraged to review the grant agreement and submit any changes together with their proposal. This will enable us to accelerate the procurement process.

We expect all projects to be in contract by 1 March 2016.

6.5 Future funding opportunities

Once the successful feasibility studies have been completed, and if the projects demonstrate the required stage of development, they could be considered for trials and demonstration or for additional funding via other mechanisms. We encourage interested bidders to establish contacts with relevant TOCs and/or maintainers from the early stages of their projects.

Dissemination and networking opportunities will be made available throughout the life of the project.
7 Key dates

All the proposals should be submitted by **17:00 on 22 January 2016** via email to rruka@rssb.co.uk
Please use “Robotics Competition” in the email subject.

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feasibility studies proposals due</td>
<td>22 January 2016</td>
</tr>
<tr>
<td>Winning bids will be announced</td>
<td>Early February 2016</td>
</tr>
<tr>
<td>Feasibility studies due to start</td>
<td>March 2016</td>
</tr>
<tr>
<td>Project outcomes presentations at the RRUKA Annual Conference</td>
<td>November 2017</td>
</tr>
</tbody>
</table>

The feasibility study template is available on the RRUKA website: www.rruka.org.uk

8 How to find out more

An information day was held on 20 October 2015 at the Excel Centre, London.

A recording of the event, proceedings and background material is available on the webinar hub (see Library and Programme pages), which can be accessed via the following link: http://live.wavecast.co/ras-rolling-stock-maintenance/

For any questions, please contact: rruka@rssb.co.uk

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**Why join RRUKA?**

By joining RRUKA you will become part of a thriving community of academics who undertake research addressing issues of importance to the railways. RRUKA will help you make contact with the industry parties who could inform, support, use and fund your research.

**Who can join RRUKA?**

Membership of RRUKA is recognised at institutional level. UK universities or other institutions eligible to receive research council funding can become RRUKA members. Academics can register as individual researchers if their university is already an RRUKA institutional member.

To join, visit the RRUKA website: rruka.org.uk/membership/