Robust automated servicing of passenger trains- fluids

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ABSTRACT

To meet increased capacity demands of passengers in the rail industry, a robotic and autonomous system that services the fluids on passenger rail vehicles was proposed. A hierarchical task analysis of fluid servicing processes was conducted and human and system errors were highlighted. This information, along with opinions of technical managers and staff were inputted into a quality function deployment matrix to make a design specification; from this specification two concepts were proposed. Both concepts are viable but modification to rail vehicles is required. A proof of concept will next be developed to begin a path to a commercial product.

1 INTRODUCTION

1.1 Project Context

Total passenger rail miles grew by 106% between 1994 and 2013, achieved with a total national passenger rail fleet increase of 11%. The projected increase in rail traffic over the next 30 years from a fleet size of 12,775 to and upper limit of over 25,000 presents an obvious and considerable challenge for the current infrastructure to perform the basic and regular fluid servicing tasks (1).

Currently passenger train fluids are manually serviced by two or more operators; this manual approach is restricted to the speed of the operators and is open to human error. As passenger fleet is expected to double over the next 30 years it has been proposed to develop a robotic and autonomous system (RAS) to perform key fluid servicing tasks, which are well-suited to a RAS due to their structured nature. The various 'fluids' that require regular servicing on passenger rail vehicles are considered to be fresh water (grey water), coolant, screen wash, diesel/ fuel, effluent (CET) and wheel sand. The areas by which these fluids enter or leave the train vehicle will be referred to as 'ports' and these ports will interface with 'nozzles'. Fluid servicing tasks include ensuring the fluids are topped up to appropriate levels as well as monitoring levels of the fluids (example: engine oil). This project is investigating the technological feasibility of a RAS to perform the key individual fluid servicing tasks, taking a human-centred approach and only the servicing of passenger train vehicles will be addressed; freight and other rolling stock will not be considered in this study.

Human centred automation is rapidly becoming a key aspect of the RAS industry; this design practice takes into account the human factors to ensure the automation designers allocate to the humans the tasks best suited to the human, and the tasks that best suited for automating are allocated to the RAS (2). This should in turn achieve the best combination of human and automatic control to manage complex systems.

To conduct such a study there will be a certain approach taken; for this a set of steps will be undertaken in this project. Firstly the main problem must be identified along with any smaller issues that are present in the current system. To help assess and map the current processes a hierarchical task analysis (HTA) will be conducted; this analysis will also highlight system and human errors. The information gained from the HTA along with other information from various customers or 'users' will provide suitable input to the design specification; the users discussed are depot and technical managers as they are viewed as the customers when considering implementing a RAS in depots. A quality function deployment (QFD) matrix will be used to convert the user opinions into design requirements which make up the majority of the specification. Once a clearly defined design specification is established, solution concepts can then be put forward and reviewed, thus the overall feasibility of the solution is assessed.

2 METHODOLOGY

2.1 HTA Methods

A set of basic steps will be what is at the core the HTA and will allow for the display and interpretation of gathered information and these are:

i. Define purpose of analysis
ii. Define the boundaries of the system description
iii. Try to access a variety of sources of information about the system to be analysed
iv. Describe system goals and sub goals and link goals to sub goals and describe conditions under which sub goals are triggered
v. Stop re-describing the sub-goals when you judge the analysis if fit for purpose (3)

Figure 1 shows the procedure for breaking down the sub-goal hierarchy which will be used in step iv. For this report the HTA will generate three main results which can then be interpreted:

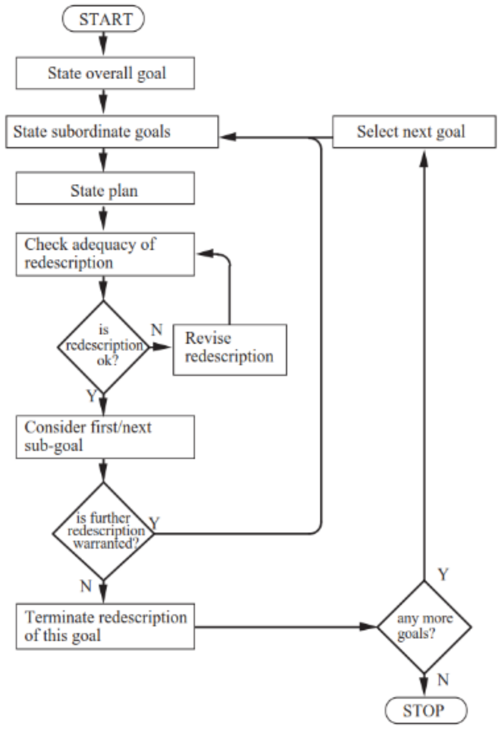

Figure 1: Procedure for breaking down the sub-goal hierarchy (3)

- Hierarchal Task Tree comprising of goals and sub goals (also known as tasks and sub tasks)
- Errors table with Systematic Human Error Reduction and Prevention Approach (SHERPA) error modes
- Risk impact factors

There are a number of reasons HTA will be beneficial to the project. Firstly it is able to qualitatively assess the current processes and develop a set of errors. These errors can then be organised into system and human error; the latter could be shown to be removed if a RAS is used.

2.2. Quality Function Deployment Methods

QFD is an industry used design approach that consists of four main phases which are product planning, product design, process planning and process control (4) (5). This study will look into QFD Phase 1: Product planning which translates the 'voice of the user' into design requirements. This phase of QFD has six main steps which it uses to develop the QFD matrix. In the context of this report the users are the people who will benefit from a RAS.

Step 1.	User Identification
Step 2.	Gather User Requirements (URs)
Step 3.	Prioritise URs
Step 4.	Generate Design Requirements (DRs)
Step 5.	Estimate strength of relationships between URs and DRs
Step 6.	Identify correlations between DRs

Figure 2: Six steps of QFD: Phase 1 (6)

2.3 Concept Design Methods

Using the information gathered in the HTA along with the design specification developed using QFD; a series of RAS concepts will be developed. By adhering to the design requirements, the concepts aim to not only complete the fluid servicing tasks but also do so in a way that addresses the needs of the users. The concepts aim to display the ability to complete the fluid servicing tasks with the assistance of a single human operator.

More than one concept will be procured as part of the feasibility study as this will allow for a comparative study of the concepts. To demonstrate the feasibility of the concepts, available current technology will be investigated and displayed; this will give weighting to the concepts and help establish which useable technologies are available for use.

3 RESULTS AND DISCUSSION

3.1 HTA Results Overview

After observing at a number of depots, a core set of process trees were developed for the fluid servicing tasks. These process were found to be common across depots with little to no variation between them; these were also used on the majority of most of the more modern fleets.

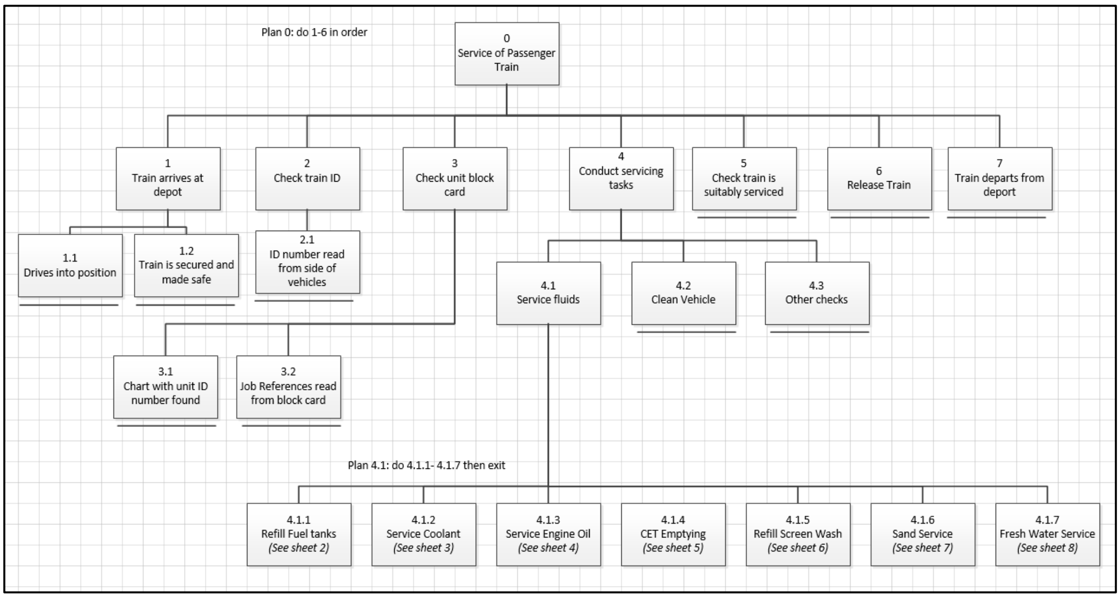

Figure 3: Main fluid servicing process from unit arriving and unit leaving the depot

From Figure 3 the main process to servicing the vehicle's fluids is shown. This doesn't display detail for each fluid service as the tree would become complex; the details to each specific fluid servicing tasks are shown in their own process trees. There are official processes in place for the servicing tasks but in reality these aren't always strictly followed. In Figure 3, block 2.1 it says 'ID read from side of vehicle/ recognise vehicle'; the most common method of this check is for a staff member to know what vehicle it is and therefore know what ports to service and where the ports will be located. Vehicle number is always read to input into fuel pump and to correlate to maintenance documents.

The HTA extends further than this version of the tree; the cleaning has several sub processes as does other checks, however due to this project only focussing on the fluid servicing aspect of the maintenance they have not been included. For this project the HTA highlighted fluid servicing processes to a higher level of detail.

3.2. Design Specification and QFD

Most of the staff interviewed held senior roles in the various MWs and therefore have relevant opinions for this project. Key areas were determined from discussion with MW staff, managers and the design team; scores were assigned to the key areas and then split between URs based on information and opinions of the MW managers. Then using the percentage of the fleet sizes the values were modified further to give a proportional representation of opinions. A set of DRs were generated by the design team in response to the URs. These DRs aim to give direction to the design but not overly constrain it. The DR and UR have relationships and synergies with each other.

These DRs were refined and iterated across several design team meetings. This project takes a human-centred approach - improving the quality of work and ensuring staff are matched with tasks better suited to humans – which could deliver improved results. Reducing the man hours taken to service fluids will allow for increase of capacity but not reduce overall staff numbers.

The QFD matrix generated with the information gave a final weighting to each design parameter. To better understand these values figure # shows a graphical representation shown the QFD scores for each DR.

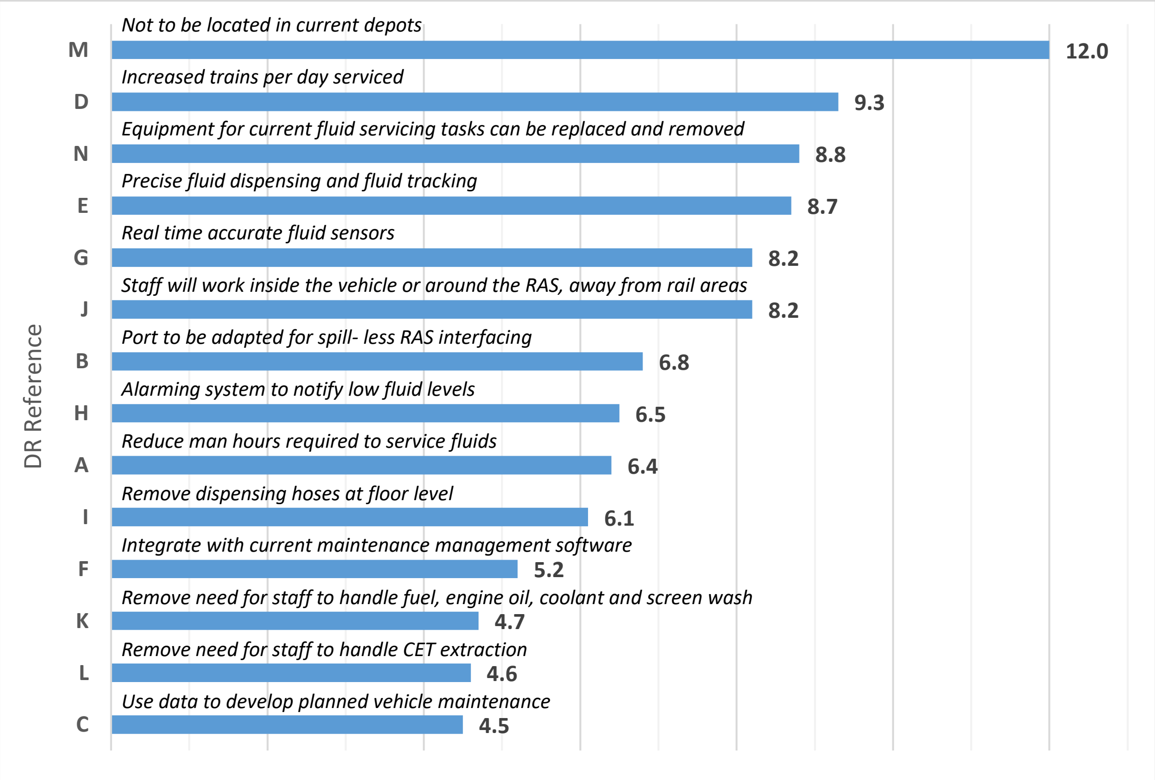

Figure 4: Graphical representation of highest QFD scores for each DR

The only strong negative correlation identified is between DR: D and DR: M. It is because having a separate area in which a RAS services the fluids could mean having to move and stop the vehicle twice.

Overall the QFD has proved useful and helped identify major DRs; the DRs with the highest QFD score and therefore the highest priority are:

- DR: **M**- *Not to be located in current maintenance workshops*
- DR: **D**- *Increased trains per day serviced*
- DR: **N**- *Equipment for current fluid servicing tasks can be replaced and removed*
- DR: **E**- *Precise fluid dispensing and fluid tracking*

These four DRs will therefore be the main overall focus of the RAS design. While DR: D and DR: M have a strong negative correlation it has been stated previously that this can be overcome using an adapted maintenance schedule. This schedule will be designed to suit the RAS and will allow the fluid servicing to be completed efficiently alongside other maintenance activities; for example any internal checks can be carried out when the RAS is in operation.

3.3 RAS Concepts

When considering RAS concepts the first area to consider is what type of automation could be utilised. A number of robotic systems were considered but two robot types prevailed to become concepts. Both concepts aim to address the top design requirements discussed in section 3.2. The concepts are design to be installed trackside near current maintenance workshops but not within them. The speed of the system will dictate the ability to service more vehicles per day; by using modern robotic systems alongside accurate dispensing pumps, a RAS can be fast and precise when servicing the fluids. By installing a RAS, most of the previous equipment in the maintenance workshop should be removed apart from some equipment for emergency manual servicing purposes.

3.3.1. Cartesian Concept

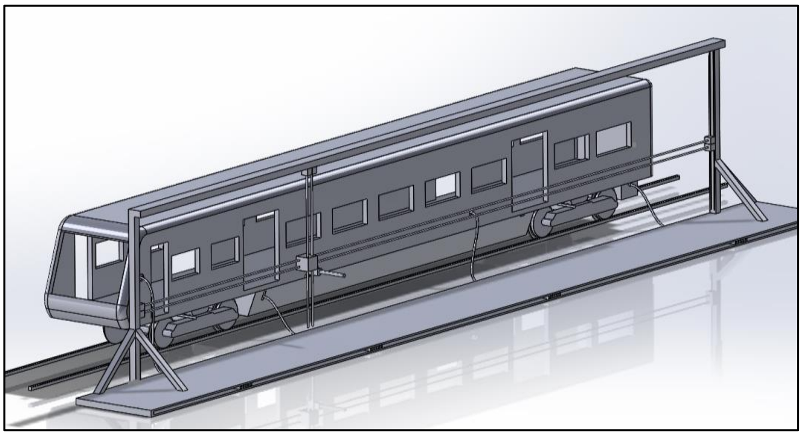

Figure 5: Cartesian Robotic system Concept

The Cartesian concept shown in Figure 5 uses an XY locator system with a linear actuator in which the motion is carried out. The RAS will first utilise RFID tags on vehicles to know what vehicle model it is which will detail the location of the fluid ports along with the size of the fluid reservoirs; both concepts will use the tags to identify the vehicle. It will then pick up a hose from a set of sliders which are designed to stop hoses dragging on the floor and and locate the port for the fluid. The hose is then inserted into an adapted port that locks the hose into place and allows the fluid to be dispensed with no spills.

For this design to be feasible appropriate port adaptations must be made as the current system is designed for human usage which means more complex port interfacing mechanisms are able to be utilised. Due to the simple box shape operating envelope a more compact system could be developed to fit on a wider range of trackside locations.

3.3.2. Articulator Concept

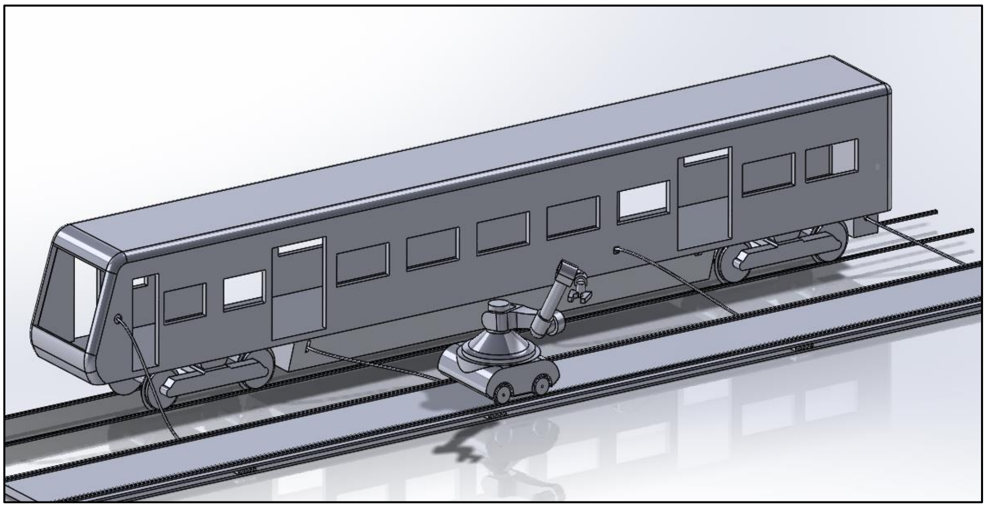

Figure 6: Articulator Robotic system Concept

The second concept to be developed is the articulator concept which utilises a six axis robotic arm platform to attach the hoses to the vehicle. Once the vehicle has been identified using the RFID tags, the robot arm will move the ports location on a motorised moving platform, it will then pick up the hoses from the sliders and attach them to the vehicle to dispense the fluid.

This concept allows for more complex port interfacing mechanisms due to the ability to carry out complex movements with a six axis robot arm; however this model has a more complex operating envelope compared the simple box shape operating envelope in the Cartesian concept.

4 CONCLUSIONS

4.1 HTA Conclusions

4.1.1 Aim 1: Evaluate current passenger rail vehicles fluid servicing processes and identify what tasks could be automated to increase effectiveness of the services

Most fluid servicing processes could be automated by implementing a RAS. The HTA proved to be a useful tool which showed that most of the human errors observed can be removed; even one simple solution like utilising RFID tags would remove a large number of errors. The fluid servicing processes were similar between depots with differences coming from the different types of ports; by adapting the fuel, coolant, fresh water, sand, CET and screen wash ports could allow a RAS to service the fluids. Due to the variation in engine oil port location it could be quite challenging to reach in most cases; this fluid would likely only be monitored by a RAS not actually serviced. Overall a RAS would likely remove a large number of human errors which could be replaced with a relatively small amount of RAS errors.

4.1.2 Aim 2: Investigate fluid port locations and evaluate the variation in port locations between vehicles

To record the locations of the fluid ports a range of vehicles were observed and images of the ports were taken. The port locations were not precisely measured but categorised into three areas in which a RAS would have to reach to service them; these were underframe, above solebar and the ends. For some ports there was no variation in location however some ports were different on certain fleets. Screen wash had the largest variation in port location. It was also found that some vehicles had the ports omitted due to their design, namely, CET and fresh water were omitted on some of the older vehicle classes.

4.1.3 Aim 3: Observe the depot environments in which the fluid ports are serviced and discuss where a RAS could be implemented

A range of depots were visited and it was found that depot sizes vary based on what maintenance is carried out at the depots. There are smaller depots that service the fluids as well as carrying out other maintenance tasks. These generally had less space for a RAS to be implemented however a small 'add on' shed could house a RAS. Larger depots which carry out more extensive maintenance on top of the basic maintenance tasks had space next to vehicles in the main sheds, however adding a RAS in these spaces might hinder the other maintenance tasks. Main sheds of large maintenance depots have large amounts of space between vehicles however this is likely due to the space needed for higher level maintenance checks; there are smaller refuelling/ refilling sheds located on large maintenance depot sites that might house a RAS.

4.2. QFD Conclusions

4.2.1 Aim 1: Develop a set of design requirements for the RAS that accurately address the user's needs

QFD is a useful tool which can be used to help guide design processes. In this project a QFD matrix was utilised to identify DRs that address the needs of the users; in this case the users are MW managers. Having a RAS '*not located in current maintenance workshops*' was the highest rated DR due to its effects on health and safety. It has a strong negative correlation with another highly rated DR *'Increased trains per day serviced'* and this conflict will have to be compromised when developing a design.

4.2.2 Aim 2: Develop a set of design requirements for each of the ports

Additional DRs seek to address port-specific requirements and add a level of detail too deep for the QFD of the overall RAS concept. The additional DRs for the ports are few but they help guide work on the design of new ports and nozzles to ensure industry standards are complied with. Most of the new DRs are based on health and safety; even if the RAS were to predominantly service the fluids, operators will still be working with the RAS and will therefore need protecting where necessary. Also three of the fluids (fuel, engine oil and screen wash) cannot be close to ignition sources means that use of electrical equipment must be carefully considered against hydraulic and pneumatic alternatives.

4.3. RAS Concepts conclusions

The concepts provided in this paper are potential starting points for anyone looking to develop such a system. Both concepts have their advantages and disadvantages and both are worth considering when developing a commercially viable product. The Cartesian concept looks to be a more bespoke solution however it would require extensive port modification on the vehicles.

Additional issues arise when looking to implement a RAS for the purpose of fluid servicing tasks. Initially only a very small number of workshops will have a RAS to service fluids meaning there must remain the ability fluids to be serviced using current manual methods until a fluid servicing RAS is rolled out network wide. When considering the power driving the system, hydraulic and pneumatic systems will require additional fluid reservoirs which must be contained on site.

5 FUTURE WORK

5.1 Broader Feasibility Study

5.1.1 HTA

A number of avenues could be further explored. Due to the time available and project scope there was not enough time to visit many depots; a comprehensive study that looks at up to date platform 5 publications and Rolling Stock Library (RSL) be carried out to establish vehicle types, fleet size, depot allocation, depot type, locations. From this base data (if required) maintenance plans, block cards, local instructions, GA drawings, diagrams for the vehicles could be obtained and analysed as well as depot and fuel point lay out and asset inventories. This would be an extensive and more in depth audit that if it were its own project could provide improved breadth to the analysis. Further work into workplace ergonomics could be carried out; the long term effects of current working conditions (reaching ports, day to day work) could be done and with that improve the depth at which a RAS could improve current working conditions.

5.1.2. QFD

A much greater in-depth survey could be conducted across the industry to gather opinions on which user requirements take priority. Using a wider pool of industry figures could identify further user requirements to add to the QFD, improve industry representation and improve the quality of user scores. Most of the information was primarily received from Chiltern Railways; therefore, being a large industry, there are small variations to this report which apply to different MWs; this includes the type of vehicles (700VDC, 25kV etc.), different processes and different fluids used. Different fluids could have different COSHH assessments and could therefore need different port specifications. Further extensive MW visiting could be carried out to make the design specification more representative, which is not within the scope of this project.

5.2. Phase 2: Proof of Concept and Beyond

This study aims to be a starting point for a product to be developed and used in industry and as such there will require a proof of concept. The next phase in the RASPT-F project will be to develop a proof of concept device. By using the information gathered in this report, the RAS developed would aim to service the fluids on a range of different types of passenger rail vehicles to ensure there is capability of an industry used system. The proof of concept will be developed with industry and tested in a laboratory environment. This environment will aim to simulate various port locations for each of the fluids; these locations will be according to the varying models of rail vehicle. It will also aim to simulate varying weather conditions that the ports and the RAS will be exposed to.

If proof of concept proves to be a success then a prototype system will be developed further and will looks to be fitted into a maintenance depot to begin assessing the effectiveness of the RAS in a practical setting. This phase will be extensive as the RAS will have to meet the current fluid servicing demands as a minimum; it would also have to ensure it complies will all rail industry regulations. This phase will likely be one of the final stages of research as the RAS will be close to becoming a commercially viable product that will be nearing production with the intent to roll out across the UK rail network.

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