

Developing system models to help Great Britain's railways embrace innovative technologies with confidence

Bouch, Christopher; Roberts, Clive

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Developing system models to help Great Britain's railways embrace innovative technologies with confidence

Christopher J Bouch

(Civil Engineering,) University of Birmingham, United Kingdom

Clive Roberts

(Electronic Engineering and Computer Science,), University of Birmingham, United Kingdom

Abstract

Railways are under pressure to become more efficient and cut their costs; innovation has a part to play in achieving these goals. The railway is, however, a complex and closely-coupled system, making it difficult in the early stages of development, to be clear what the system-wide impact of innovation will be. The research covered in this paper stems from the idea that computer-based models of existing systems can help overcome this problem, by providing a baseline framework against which the impact of innovation can be identified. The paper describes development of a repeatable modelling methodology, which elicits objective system data from Railway Group Standards and integrates it using CORE[®], a powerful system modelling tool, to create system models. The ability of such models to help identify impacts is verified, using as an example the introduction of RailBAM (a new technology that acoustically monitors the health of rolling stock axle bearings) into the existing hot axle bearing detection system.

Keywords: Model-based systems engineering, innovation, railway group standards, CORE[®]

Introduction

The railway needs to innovate if it is to become more efficient and cut costs. In its recent White paper (EC, 2011), the European Commission set out its vision for a sustainable and competitive transport system, and identified innovation as being an essential part of the delivery strategy. The Department for Transport's Railway Command Paper (DfT, 2012) stressed the importance of taking advantage of technical innovation, if the railway is to continue to improve its cost effectiveness and performance, and reduce its environmental impact.

The rail system's complex and closely-coupled nature can, however, act as a disincentive to innovation, because it makes it difficult to see at an early stage in the development process, what the impact of innovation will be on the system as a whole. The railway's complexity is manifest in the wide range of infrastructure (track, structures, signals), and train characteristics (high speed passenger, slow freight, frequent stop commuter) present in the system. Close-coupling is revealed in the need for all the sub-systems to interact properly, in order to deliver the timetabled service: for example, localised failure of a switch can result in train delays over a wide area, as well as disruption to train diagrams, train crew rosters and planned maintenance activities.

Model-based systems engineering (MBSE) can help overcome this problem by creating baseline models of the existing system, against which the impact of innovation can be identified. MBSE is defined as the ‘formalised application of modelling to support (system development)’ (INCOSE, 2007); it joins modelling with systems engineering techniques, to create an integrated view of the engineering problem and the proposed solution (Long and Scott, 2011). Model building requires: clear definition of the system boundary; elicitation of system data, ideally from an objective source, and; integration of that data to create the model. A common data integration approach involves linking system entities such as requirements, functions and components (together with their attributes) using relationships. An outline of a schema for such an entity-attribute-relationship database (attributes omitted) is shown in Figure 1.

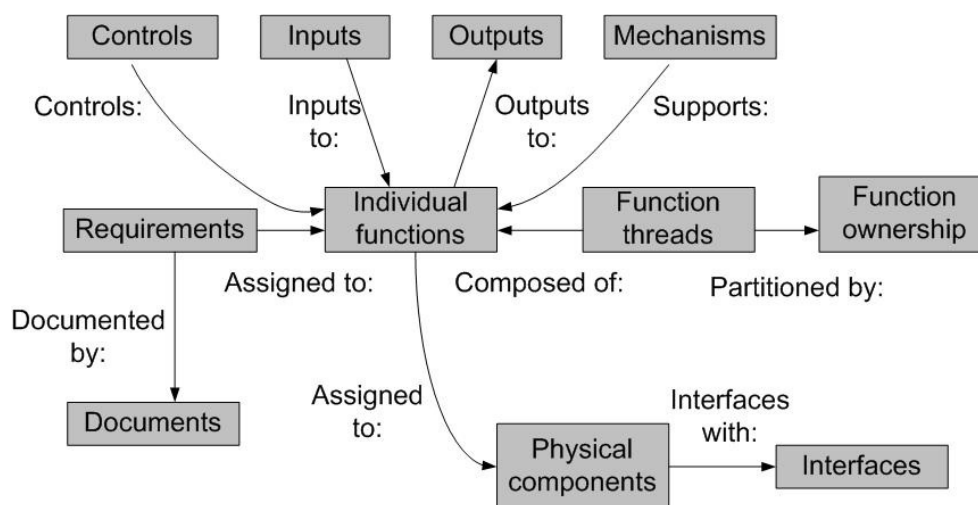


Figure 1: Indicative Diagram of an Entity-Attribute-Relationship Database Schema (Attributes not shown)

Systems engineering (SE) techniques are used to support the model building process. They first started to emerge in the 1920s, with work to improve the movement of fundamental scientific discoveries into innovative new products (Kelly, 1950). Further developments in the 1950s played a big part in helping engineers cope with the design complexity of projects such as the U.S.A.’s inter-continental ballistic missile defence system, and the Apollo space projects (Gibson et al, 2007). Essentially, SE is about ‘...creating effective solutions to problems, and managing the technical complexity of the (associated) developments’ (Stevens et al, 1998).

SE is commonly visualised as a top-down process, associated with the design of new systems, during the course of which the system boundary is defined and the system data required for model building is generated. The process starts with a statement of client or user need, which is developed into a set of capability requirements stating what the system should be able to do. These are worked up into a set of system requirements, describing what the system must do to achieve the required capabilities, but not how it will do it. The ‘how’ comes in the development of the system architecture, or framework, in which functions are derived from the system requirements and assigned to the resources (people, components) that will carry

them out. Finally, detailed design and manufacture of components is done, the components are assembled to create the system, and tests are made to check the emergent properties meet the original requirements.

Modelling of existing systems cannot, however, start with the same ‘clean sheet of paper’ assumed for new systems; a different SE approach, called ‘middle-out’, is employed.

Middle-out SE is the term given to the process of introducing new sub-systems into existing systems, while taking account of legacy components and interfaces. It begins by modelling the as-built state of the system, to give engineers a better idea of development constraints and opportunities, and is followed by top-down methods for detailed design (Long and Scott, 2011). Research has identified only a limited number of papers on the topic, and while they describe specific instances of the middle-out approach, none demonstrates a repeatable and objective methodology (Dam, 2007; Logan and Harvey, 2010); the research described in this paper addresses that shortcoming.

The research is presented in four sections that underpin methodology development. The first defines the boundary of the system-of-interest using Railway Group Standards (RGS) as the objective data source. The second uses top-down system engineering techniques to identify the types of data required for model building, and then elicits the data for the model from the RGSs identified in section 1. The third uses a commercially available system modelling tool (CORE[®], produced by Vitech Corporation in the USA) to integrate the data from RGSs to create system models that can help identify the impact of innovation (Vitech, 2012). And finally, the fourth verifies that models generated using the methodology can be used to establish the impact of an innovative system change. This and the work of the other three sections are illustrated using the example of the introduction of RailBAM technology (Track IQ, 2012) into the hot axle box detection (HABD) system.

The paper concludes with a summary of the research findings and areas requiring further research.

Section 1: defining the system/system interfaces

This section of the paper describes the use of Railway Group Standards (RGS) to define the interfaces and boundary of the system-of-interest.

RGSs facilitate the management and operation of the railway by ‘...defining requirements for assets or processes which involve co-operation between two or more duty holders, and assigning responsibility for compliance with these requirements’ (RSSB, 2008). As such, the RGSs relate to one another in a way that reflects the complex and closely-coupled nature of the railway. The diagram in Figure 2, based on information from the Railway Safety and Standards Board website (RSSB), shows the organisational structure involved in the development and maintenance of RGSs.

The stakeholders to the RGS process, such as passenger and freight train operators, are shown at the top of the diagram. RSSB coordinates the activities of the various standards committees, shown in the centre of the diagram. The Infrastructure Standards Committee is

used as an example to show the interfaces between standards committees, system interface committees and the European Railway Agency (ERA), which has responsibility for Technical Specifications for Interoperability (TSI). RGSs can be divided into two groups: Notified

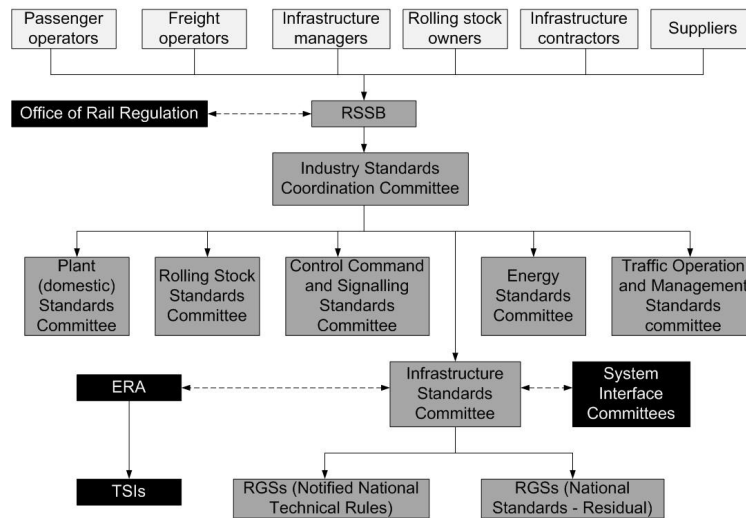


Figure 2: Organisational Structure for Development and Maintenance of RGSs

National Technical Rules (NTRs), which ensure a safe interface between TSI and RGSs, and; National Standards Residual (NSRs), which deal with how the railway is run and the procedure for making changes (RSSB, 2012).

In general the RGSs are published with a similar format; and in most cases they contain references linking a given standard to other relevant RGSs. This supports the system /system interface definition process, which is shown diagrammatically in Figure 3. It begins with a search of the RGSs database, using a term(s) closely describing the system-of-interest, to identify the key standard(s); for simplicity, Figure 3 assumes one key standard has been found, numbered 1. The key standard’s references are identified (2, 3 and 4 in the diagram). The references for those standards are then in-turn identified (2, 5, 6 and 7); this is termed the ‘first iteration’ of the boundary/interface definition process. Not all of the standards emerging from the

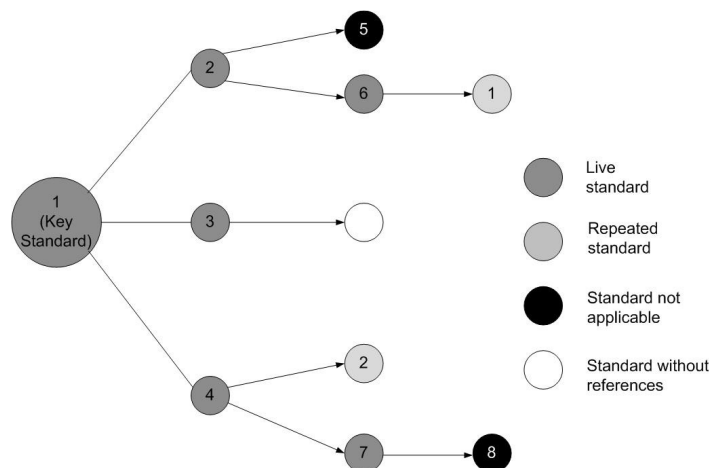


Figure 3: Diagrammatic Representation of the System Boundary Definition Process

boundary definition process result in further iterations: for example, standard 2 in the first iteration is a repeat of an earlier standard; engineering judgement is used to conclude that standard 5 is not relevant to the system-of-interest, and; standard 3 does not have any references. In each of those cases the relevant arm of the diagram can be terminated. Further iterations of the process are made until all of the branches are terminated, at which point all standards on the diagram, except those not relevant to the system-of-interest, are deemed to be the ones defining the system/system interfaces.

In the case of the hot axle box detection system, one key standard was identified: GE/RT8014 Hot Axle Bearing Detection (RSSB, 2001). The system/system interfaces definition process went through seven iterations to identify a total of thirty-two relevant standards. These have been summarised into the nine sub-system interface groups show in Figure 4.

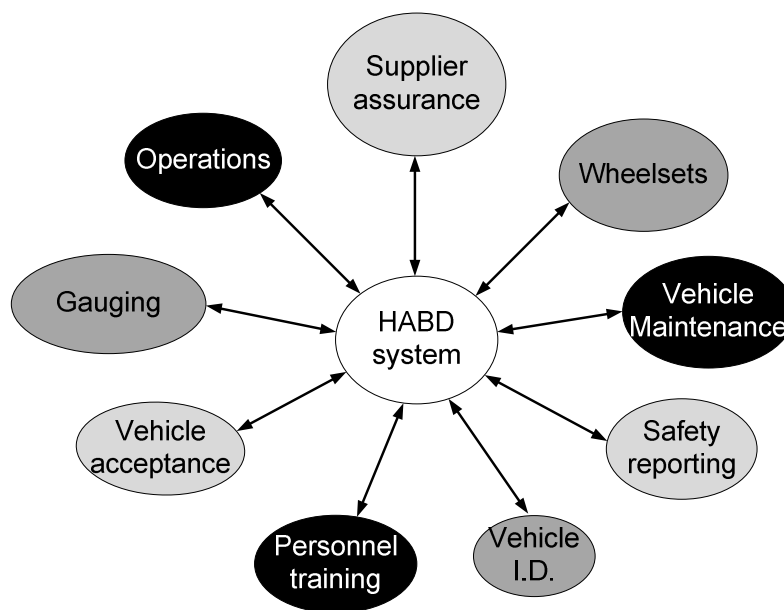


Figure 4: HABD System Interfaces

Section 2: eliciting the modelling data

This section of the paper uses top-down system engineering techniques to identify the types of data required for system modelling and describes elicitation of the data from RGSs.

The introduction summarised the top-down systems design process; based on that, the data types involved in the creation of new systems and required for system modelling are:

- User requirements (user needs);
- Capability requirements;
- System requirements;
- System architecture;
- Functions, and;
- Resources (including components and people).

The first three types of data are requirements: user, capability and system (Hull et al, 2011). Requirements define what stakeholders want from a new system, and what the system must do in order to satisfy that need. User requirements (often called user needs or mission requirements) are the highest level; they do not result from a rigorous analysis and often contain woolly expressions of need mixed with descriptive material: for example, ‘a new tool is required to help cut the number of hot axle box detection system false alarms’. Capability (or originating) requirements provide more detail; they are statements about what the system should do (but not how it should do it) and ‘...define the constraints and performance parameters within which the system is to be designed’ (Buede, 2000). They are characteristically written in the form ‘The system shall be capable of...’. System requirements are the most detailed type of requirement; they describe what the system must do in order to deliver the capabilities to satisfy user needs. They are characteristically written in the form ‘the system shall...’. The three types of requirement form a hierarchy with the top level user requirements being decomposed to form first capability requirements, and then detailed system requirements.

HABD system key standard GE/RT8014 was analysed for examples of the three types of requirement data described above. No instances of user or capability requirements were found; this was not unexpected bearing in mind that those types of requirement relate to the development of new systems, whereas the standard is describing the existing system. Consistent with this thinking, numerous examples of system requirements, describing what the system has to do, were found.

Moving on to system architectures, there are three principal types in system design: the physical architecture, which defines the system’s physical resources (components, people) that will perform the system’s functions; the functional architecture, which defines the system’s functions (verb-based descriptions of what the system must), and; the operational architecture, which maps functions to resources (Buede, 2000). For the physical architecture, RGSs GE/RT8014 Issue 1 and GE/RT8000/TW5 (RSSB, 2008) were analysed to determine whether they contained the necessary data. Many examples of resources were found; however, they were distributed through the document as required by the narrative, rather than presented in a tabulated form. Therefore, identifying the data and organising it hierarchically required a degree of skill on the part of the modeller. The sample results in Figure 5 show four high-level resource groups, with each group decomposed to lower levels of detail, including the component level.

For the functional architecture, analysis showed that some standards were better than others in presenting function data: for example, RGS GE/RT8250 Issue 2 ‘Reporting High Risk Defects’ (RSSB, 2007) uses functional flow block diagrams to identify some of the functions and the relationships between them. However, many of the RGSs do not and in those cases it was necessary to elicit the functions by reading through the standard, looking for characteristic ‘the system shall...’-type sentences. Guided by the standard, functions then had to be ordered hierarchically, and linked sequentially, to create descriptions of the

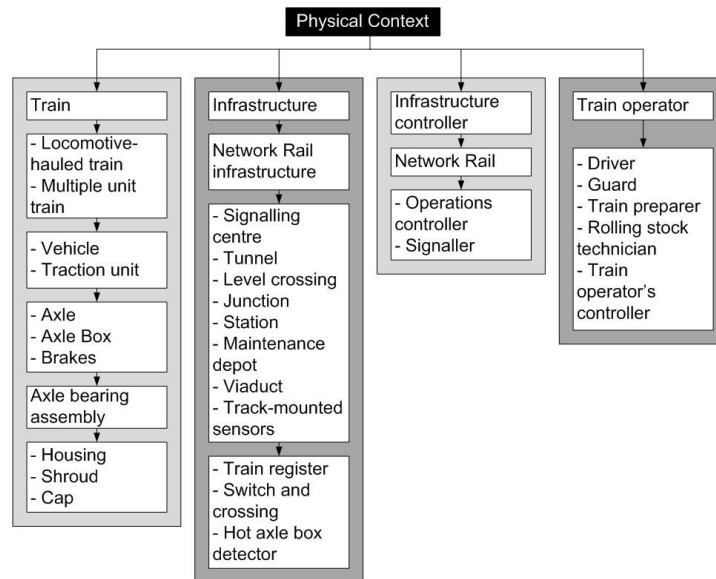


Figure 5: Indicative View of the Hot Axle Bearing Detection System Physical Architecture

processes that the system carries out. Therefore, again, a degree of skill was required on the part of the modeller to gather and organise the data effectively. An example of linked functions is shown in the diagram of Figure 6, and described in more detail below.

In the case of the operational architecture, analysis of the standards found strong evidence of functions being mapped to resources. For example, GE/RT8000 TW5 provides many examples of tasks assigned to signallers and train drivers. Figure 6 shows functions relating to the ‘inspect bearings’ task. The diagram is drawn to illustrate the operational architecture involved: the upper strand of functions starting with ‘Contact signaller’, has to be carried out by the driver; while the lower strand starting with ‘Instruct driver to inspect’, is all carried out by the signaller. The last four functions of the upper strand also involve other resources such as the train itself and the diagram could be developed further, if need be, to show this.

Section 3: integrating the data to create the system model

This section of the paper describes how Vitech Corporation’s CORE[®] system modelling tool is used to integrate the system-of-interest data elicited from RGSs to create the model.

Figure 1 shows an outline schema for an entity-attribute-relationship database, similar to the one on which CORE[®] is based. It shows how a selection of entity data classes (for example, function and requirement) can be linked using relationships; some of the most common relationships are shown as examples. The CORE[®] schema contains a predefined set of relationships, which have been developed over many years of modelling experience in a range of industries. Additional relationships can be added if the circumstances demand, but care has to be taken to ensure any changes do not disturb the logic of the schema.

The HABD system was too big to model in its entirety; therefore, modelling was restricted to the part of the system dealing with activation of the HABD and inspection of the train out on the track. Data for modelling was elicited from two standards: GE/RT8014 Hot Axle Bearing

Detection, and; GE/RT8000-TW5 Preparation and Movement of Trains: Defective or Isolated Vehicles and On-train Equipment. The data used was from entity classes: document; component; function; requirement and item (inputs and outputs). The relationships describing the various links between the entities were selected by the modeller from the menu provided by CORE[®], rather than being elicited from the RGSs. Functions were ‘partitioned’, or allocated, to the components that carry out the activity, and were also linked together to describe some of the system processes. Items (inputs and outputs) were added to the functions to show the flow of data through the processes.

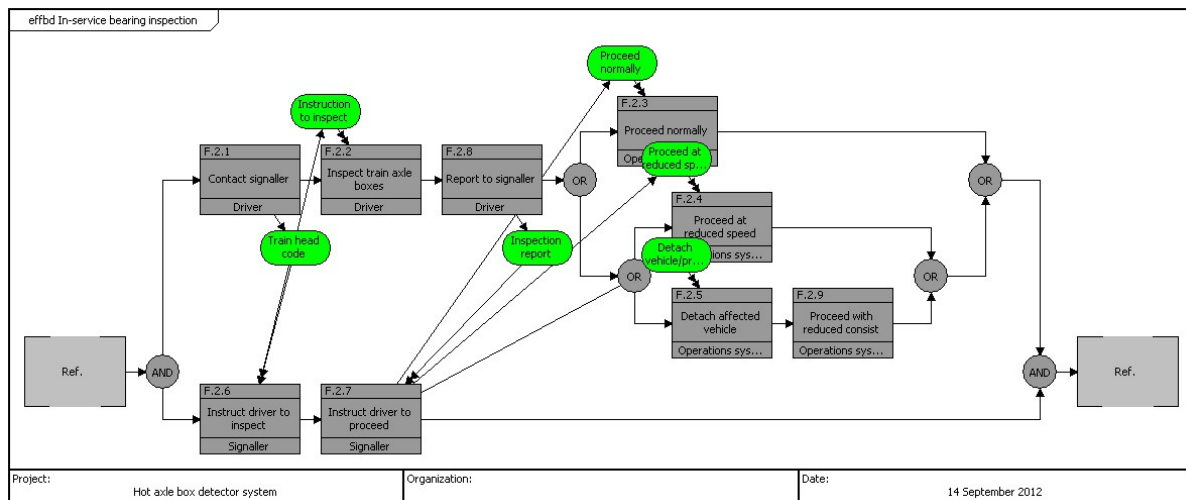


Figure 6: Diagram Showing Decomposition of the ‘Inspect Vehicle’ Function and Operational Architecture

Figure 6 shows an example of the CORE[®] model for the ‘inspect bearings on track’ process. The diagram is referred to as an ‘Enhanced Functional Flow Block Diagram’, because it shows the movement of data in addition to the functions linked sequentially to describe the processes: for example, the driver’s first task is to give the signaller the train head code, which triggers (denoted by the double arrow head) the signaller to instruct the driver to inspect the train. The diagram also shows ‘partitioning’ of functions (allocation of functions to the components that will actually carry them out): the functions in the top half of the diagram are carried out by the driver, while those in the bottom half are carried out by the signaller. Although not shown in Figure 6, CORE[®] can also model the interfaces between the HABD system and the related systems shown in Figure 4.

Section 4: methodology verification

This section of the paper demonstrates how the CORE[®] model of the HABD system can be used to identify the impact of introducing new RailBAM technology.

Current HABD equipment monitors the infra-red signature of bearings and can produce false alarms by detecting heat from brakes or other sources. False alarms are expensive, because the operating rules require the affected train to be stopped and inspected, during which time adjacent lines are closed to traffic. RailBAM on the other hand monitors bearings

acoustically and can indicate what the remaining life of a bearing is, as well as warning when the bearing has failed. This research focused on the latter capability and used the model of the existing hot axle box detection system to explore what the impact of using RailBAM to remove false alarms might be.

Figure 7 is a 'swim lane' diagram showing the principal functions involved in a hot axle box event; it is a high-level summary of the functional flow block, or process, diagram that was constructed in CORE[®]. The functions were elicited from the following documents: Railway Group Standard on hot axle bearing detection (RSSB, 2001); Railway Group Standard on preparation and movement of trains (RSSB, 2008); Arriva Trains Wales vehicle maintenance procedure for suspect hot axle box procedures (Arriva Trains Wales, 2007), and; the Delay Attributions Board's guide on delay attribution (Delay Attribution Board, 2009).

The diagram shows the functions partitioned and allocated to the five system components that carry them out: vehicle maintenance, driver, mobile operations, train control and delay attribution. The hot axle box event starts with a hot axle box detector being triggered and in response the signaller placing the appropriate signal to red. The train driver obeys the signal, brings the train to a stand and then makes an inspection of the axle boxes. If the inspection finds a serious bearing fault, the affected vehicle is detached from the train to be recovered at a later date; however, if no obvious fault is found the driver takes the train forward, though possibly at a reduced speed depending on the type of bearings involved. In cases where no fault is found, the vehicle with the suspect bearing is subjected to an inspection and test as soon as possible; if there is still no evidence of a failure the vehicle is returned to traffic.

The diagram shows the baseline process against which the impact of removing hot axle box detection false alarms (possibly through the implementation of RailBAM) can be judged. The functions shaded grey will be removed altogether; those partially shaded will remain in cases where there has been bearing failure, but will go in cases of false alarm. The diagram shows that removing false alarms will have a significant effect in reducing workload and delay costs.

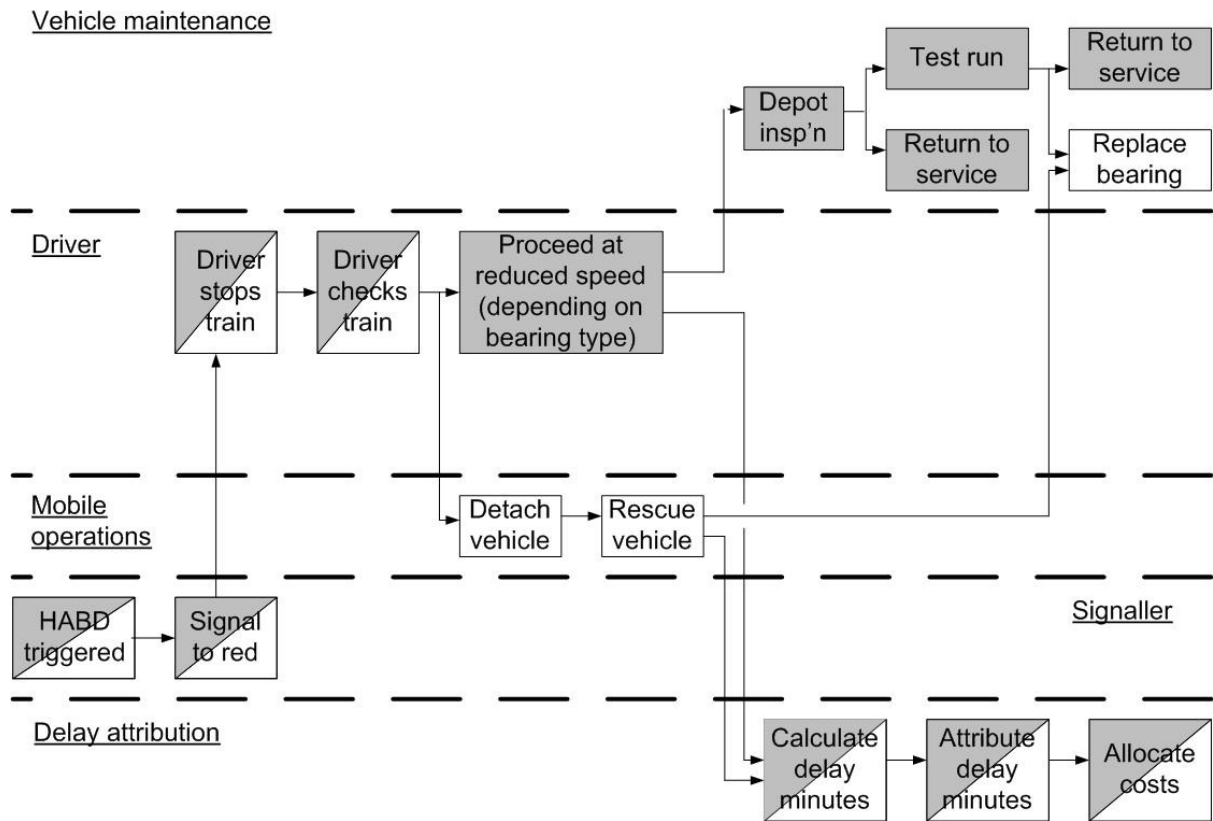


Figure 7: ‘Swim Lane’ Diagram Showing the Principal Functions of a Hot Axle Box Detection and the Functions that RailBAM Can Help Obviate (shaded)

Conclusions and further work

The research described in this paper has developed a repeatable and objective methodology for modelling existing rail systems, which can be used as a baseline for identifying the impact of innovative technologies and processes at an early stage in the development process.

The research has identified the principal types of data required to model a system: namely, the user, capability and system requirements; the system architectures; the functions, and; the components. It has made the argument that Railway Group Standards (RGSs) relate to one another in a way that reflects the closely-coupled nature of the railway, and act therefore, as high-level, objective repositories of system data. It has shown that the data types required for modelling are available in, and can be elicited from, RGSs. The case of the introduction of the new wheel bearing monitoring technology, RailBAM, has been used to demonstrate the feasibility of system/system interface definition, data elicitation and model building using the CORE[®] system modelling tool. Finally the research has demonstrated the model’s ability to help identify those parts of the existing system that will be affected by the introduction of new technologies or processes.

The work has shown that input from domain technical experts is still needed in the modelling process. Engineers with experience of the system-of-interest are required to help ‘order’ the data elicited from the RGSs, select the appropriate relationships and link functions to create processes.

Although not discussed in the main body of the paper, the research has raised a question mark over whether efforts currently underway to rationalise the RGSs, could weaken many of the links between them, reducing their ability to contribute to model building.

Further research is planned to verify the model building process against the results of recent work by the Technical Strategy Leadership Group to create a railway system functional architecture. An interesting opportunity to use the methodology to assist Network Rail in its efforts to streamline its own technical standards has been identified. And finally, it would be interesting to explore the feasibility of linking system models with cost breakdown structures, as a first step towards being able to estimate more accurately the cost impact of technology and process change.

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