An Intelligent Framework and Prototype for Autonomous Maintenance Planning in the Rail Industry

C. J. Turner[1], A. Tiwari[1], A. Starr[1], I. Durazo-Cardenas[1] and K. Blacktop[2]
[1]Manufacturing and Materials Department, Cranfield University, Bedford, U.K.
[2]Network Rail, Milton Keynes, U.K.

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Abstract: This paper details the development of the AUTONOM project, a project that aims to provide an enterprise system tailored to the planning needs of the rail industry. AUTONOM extends research in novel sensing, scheduling, and decision-making strategies customised for the automated planning of maintenance activities within the rail industry. This paper sets out a framework and software prototype and details the current progress of the project. In the continuation of the AUTONOM project it is anticipated that the combination of techniques brought together in this work will be capable of addressing a wider range of problem types, offered by Network rail and organisations in different industries.

1 INTRODUCTION

Recent developments in both Computational Intelligence and web based information systems have made possible a new era of interconnected decision support platforms capable of autonomous operation. The AUTONOM project provides such an enterprise system tailored to the planning needs of the rail industry. AUTONOM aims to extend research in novel sensing, scheduling, and decision-making strategies customised for the automated planning of maintenance activities within the rail industry. The case study for this work is UK rail infrastructure provider Network Rail (Network Rail is the organisation that is responsible for maintaining and developing the UK rail infrastructure including signalling, bridges, tunnels, level crossings, viaducts and 17 key stations within the country). Maintenance of widely-dispersed assets is expensive because it involves widespread inspection, checking and measurement. The integration of sensor-based information in geographically dispersed and less structured environments poses challenges in technology and cost justification. Academic challenges include improvement of embedded sensing, reliable estimation of monitoring parameters, a unified approach to the mathematics and data structures, and a rigorous approach to cost estimation and benefit analysis. The industrial drivers include standardisation, automation, connectivity, and reduction of unit cost (Starr et al. 2013). The overall aim is to enable improved integration between architectural levels in data-rich environments in automated, intelligent maintenance, responding to business pull and demonstrating value. A prototype is currently being developed by the authors that will deliver this vision as a web enabled platform capable of delivering automated decision capability to managers involved in rail maintenance planning activities.

2 RELEVANT RESEARCH

On embarking on such a project it was necessary to investigate current approaches to planning and cases of autonomous operation in the rail industry. In addition to literature a think tank group was convened to examine areas of railway operation that would benefit from automation. The think tank group was made up of senior representatives of Network Rail and other corporate partners of the wider AUTONOM project. The four areas shown in Figure 1 were highlighted by this group as having potential for automation and are considered as priority areas by Network Rail and the authors.

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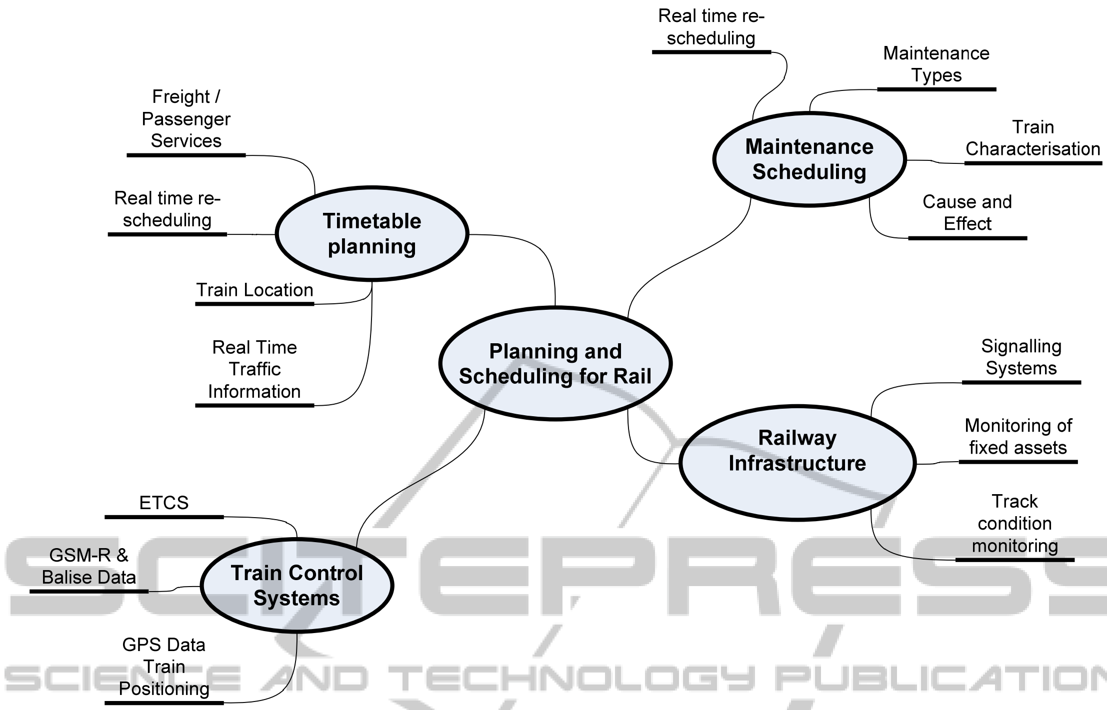

Figure 1: Planning and scheduling activities relevant to the rail industry.

2.1 Maintenance in the Rail Industry

As mentioned by Dadashi et al. (2011) there has been a move from reactive to diagnostic and prognostic modes of railway maintenance; where fault diagnosis and prediction are key. As part of this movement work has been conducted into the area of fault states and the interdependencies between the states in Schöbel and Maly (2012). This paper makes clear the need for active monitoring of rail vehicles so logical connections between fault states can be made. In the work of Dadashi et al. (2012) data from assets deployed in the field can increasingly be made available to mobile devices. Bye (2013) details the use of mobile devices and the design of application interfaces with case studies drawn from Network Rail. The subject of risk centred maintenance is investigated by Selvik and Aven (2011). These authors make the point that Reliability Centred Maintenance (RCM) for preventative maintenance practice is well understood in industry though it does present limitations when used to quantify risk and uncertainty in projects. The importance of organisational design in railway maintenance operations is highlighted by Jiang et al. (2012) Maintenance operations may be performed by a collection of co-operating organisations, having a model of how such organisations operate together is in the opinion of Jiang et al. (2012) essential.

2.2 Planning in the Rail Industry

Timetable planning is an active area of research for the rail industry. The work of Yang et al. (2010) investigates the development of incomplete cyclic timetables for trains. Real time re-scheduling of trains is the subject of Wegele et al. (2010), where genetic algorithms are used to perform a heuristic re-ordering of trains when delays are encountered in the rail network. The mark-up language RailML is also mentioned in this work. RailML is an XML based metadata language that defines a set of common rail specific terminology as meta-descriptions (RailML is detailed in Nash et al. (2004)). The timetabling problem is framed by Ho et al. (2012), as one of multi objective-optimisation in that a feasible solution must be identified within a limited time constraint that satisfies a number of objectives. Scheduling of trains in terms of energy efficiency goals is another active area of interest and one such approach is described in the work of Hu et al. (2013). This approach utilises a combination of a standard multi-objective optimisation algorithm and a fuzzy multi-objective optimisation approach to find train allocations and movements that balance fuel efficiency with passenger travel time. In Peng et al. (2013) the optimal routing and scheduling of periodic inspections in a rail network are explored in the context of long term planning. A heuristic algorithm is put forward as part of this research that utilises a local search method allowing for the scheduling problem to be divided into sub sets, as in similar work by Peng et al. (2012). Improved results are found over existing manual techniques although this approach is only able to add new tasks at the end of the schedule rather than within the schedule.

2.3 Sensor Fusion

One of the major developments in train control systems in recent years has been the European Rail Traffic Management System (ERTMS). The ERTMS system is composed of two main entities, the European Train Control System (ETCS) and Global System for Mobile Communications-Railway (GSM-R) (Abed, 2010). ETCS is comprised of two main components, the Automatic Train Protection System (ATP) (automated emergency braking at red signals) and signalling system (in cab signalling). GSM-R is an international standard for mobile voice and data communication transmission in a railway environment and primarily used for train to control centre communication. The different levels of ERTMS are detailed in Abed (2010). Beyond the area of train control systems, such as ETCS, much research has been carried out in the area of signalling and its analysis for safety related purposes. The work of Filip et al. (2010) examines the use of Global Navigation Satellite Systems (GNNS) in relation to railway safety applications. In this study the authors examine the applicability of existing GNSS technologies and their modes for use in the railway industry, highlighting their current limitations. As Filip et al. (2008) mentions satellite technology will have a significant impact on the railways in that the trackside sensor equipment (such as Balaises and hot box sensors) will be superseded by asset located sensors that determine the actual real time position of moving assets (Rail vehicles) via satellite. In terms of railway signalling, research has been conducted involving areas such as satellite technology (Filip et al., 2008, 2010) though there has also been an investigation into the use of Internet Protocol for the control of signals reducing the need for the installation of traditional copper wiring (Endo, et al., 2008).

2.4 Autonomous Systems

Autonomous systems may range from semi-automated to totally autonomous (without human intervention) operation. Semi-automated operation includes ETCS in-cab signalling and automated train braking systems. Fully automated operation examples include the automated operation of trains. Autonomous systems can contain complex control logic often incorporating computational intelligence techniques such as fuzzy logic, genetic algorithms and autonomous agents. Agents are said to embody two principles: an ability to act autonomously and the capability to interact with other agents (Wooldridge, 2008). Multi-agent systems are then, by definition, interacting collections of agents (Wooldridge, 2008). The subject of autonomous real-time planning has been investigated by Cresswell et al. (2013) in their work on the LOCM (Learning Object-Centred Models) system. Automated planning has also been investigated by Fernandez et al. (2013) who propose an architecture for the automation of data mining tasks. Again the PDDL (Planning Domain Definition) language features heavily in this approach. These papers, while not currently applied to rail uses, do hold some potential for further investigation with regards to autonomous rail research. There are only limited investigations into fully autonomous systems usually concentrating on the automatic operation of metro/light rail systems as in Dominguez et al. 2010) and Wackrow and Slamen (2013). Of interest in the enablement of autonomous operation is the use of ontology. An example of the use of ontologies in the management of rail systems is provided by Briola et al. (2013) who present a semantic architecture for the centralised control of railway traffic. One of the main advantages of this system is the ability for a user to make natural language queries on the data being collected. Two key objectives of this approach are to reduce the overall cost of managing the rail system through autonomous or semi-autonomous operation and the ability to make real time changes to train movements and their scheduling when encountering problems that may lead to service disruption such as faulty trains and damage within the infrastructure (Briola et al., 2013).

Opportunities exist to review maintenance planning and scheduling, among other activities, with a view to autonomous or semi-autonomous operation.

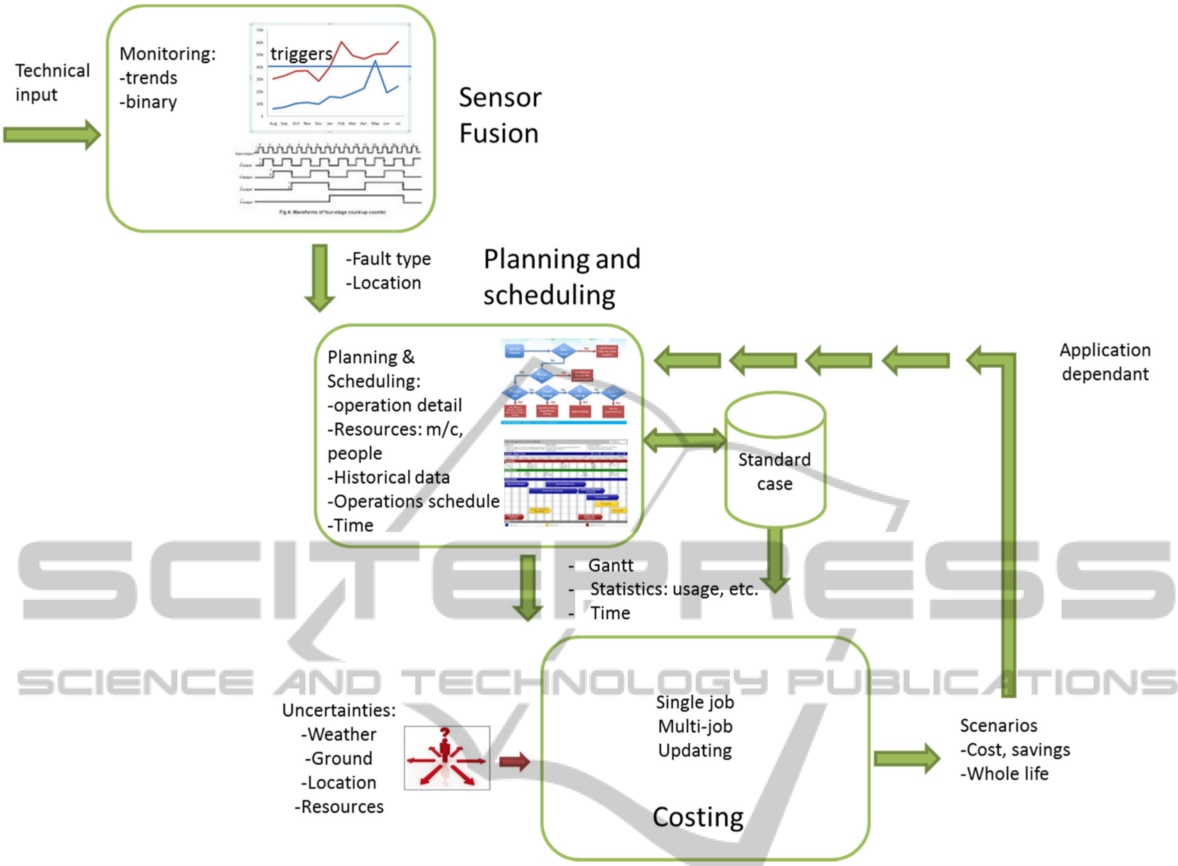

Figure 2: AUTONOM Framework Illustration.

3 FRAMEWORK AND PROTOTYPE

In the development of the framework and prototype it was decided that the area of planning and scheduling for rail maintenance should be addressed by the AUTONOM project. As a first stage the framework shown in Figure 2 was developed, outlining the major units of research that are required to address maintenance planning activities.

3.1 AUTONOM Framework

In Figure 2 it can be seen that there are three key areas of research that comprise AUTONOM, sensor fusion, planning and scheduling and costing. Sensor fusion involves the processing and analysis of raw data provided by sensors located on assets; in the case study (detailed later in the paper) this data will be supplied by Network Rail. The data received will describe the degradation state of the tracks and faults found along the line. From this data it will be possible to look for trends and identify triggers for when track repairs become necessary and the urgency of the repair. On identifying when a repair has become urgent sensor fusion will raise an alert. The planning and scheduling area will provide a Gantt chart of all scheduled maintenance activities for certain aspects of track maintenance. It will be possible to schedule or reschedule a maintenance job depending on the urgency of the work and the resources available. An important component of scheduling is of course cost. The area of costing will also be examined by AUTONOM. It will be possible to cost a repair in the context of it being a single (one-off) job or in combination with other maintenance activities. It will also be possible to build in costing for uncertain elements such as the effect of the weather, ground conditions and resources available at the site of the repair and the time window when the repair will take place. When undertaking repairs on the rail system the time window available is often limited by the amount of possession time available to Network Rail (that is the amount of time when access to the track by rail vehicles can be denied for safe completion of maintenance activities). In some cases such as when repairs can be made by track grinding machines it may be possible to complete a maintenance activity outside of track possession time. Within the framework outlined it will be possible to pass data between areas such as the feedback loop between costing and planning and scheduling.

3.2 AUTONOM Prototype

Figure 3 shows a schematic of the prototype that is currently being developed as part of AUTONOM. In this prototype it can be seen that the three areas illustrated in the framework (shown in Figure 2) have now become components In addition a fourth component has been added, the integration component. This component will coordinate the data being passed between the other three components and act as a portal for the user interfaces presented by each component. This application will make full use of networked data (shown as 1 in Figure 3) as many live (or near live) streams are available. Where live data is not available as a stream data files will be made available on Network Rail servers (updated on a regular hourly/daily basis). As mentioned in the framework description the sensor fusion component (2 in Figure 3) will utilise a combination of data mining techniques and statistical approaches to identify when urgent track maintenance is necessary and raise an alert to the integration component (3 in Figure 3). The integration component sends the alert to the planning and scheduling component (4 in Figure 3) for the scheduling of the maintenance that is necessary for the repair required. A further loop through integration allows for the repair to be valued by the costing component (6 in Figure 3). Once a costing is available it will be possible for the planning and scheduling component to produce an optimised scheduling for the repair. As the data made available by each component will accessible to the prototype as a whole it will be possible for the planning and scheduling component to produce a range of scheduling scenarios each, perhaps, with different time and cost implications.

It would then be for the user to either select the scenario (through the interface provided by the integration component) or set rules on how scenarios should be chosen to allow for fully automated scheduling to occur. The optimisation approach will build on existing heuristics for track repairs in combination with the use of a multiple objective optimisation approach such as genetic algorithm (where a population of schedules may be developed and optimised for trade-off between cost and time). In the development of the prototype it is envisaged that the application should be web accessible. The application will be built on a Microsoft platform

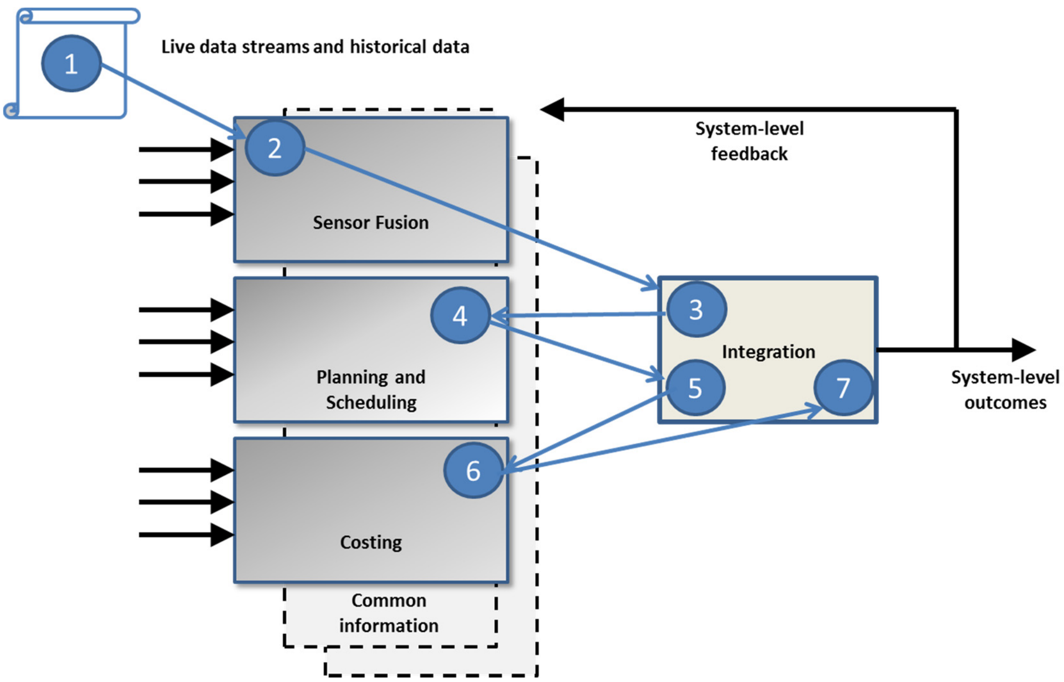

Figure 3: Schematic diagram of the AUTONOM Prototype.

utilising the C# programming language and the integration component will provide a web based interface. The use of web technologies also raises the possibility of utilising the application at trackside for scenarios when work has to be rescheduled at short notice due to unforeseen circumstances (such as a change in weather/ground conditions and overruns in time taken to complete the repair). In this case the work of Bye (2013) will be instrumental as the interfaces provided to Network Rail mobile devices could be utilised in the display of the AUTONOM prototype. In terms of data exchange it is likely that many streams (and data files) provided by Network Rail will be in a proprietary format. This will necessitate the data fusion component to provide a transformation of this data into an XML format. In this task the RailML format (Nash et al., 2004) may be informative in constructing a suitable XML representation.

4 CASE STUDY

As a practical demonstration of the approach outlined in this paper the illustrated prototype (Figure 3) is currently under development with the UK infrastructure provider Network Rail providing a case study for its practical use. In terms of the maintenance activities to be analysed by AUTONOM it is likely that there will be a concentration on track repair activities performed by rail grinding and tamping vehicles. The practice of rail grinding is used into to address defects such cracks in the rail head (the part of the rail in contact with train wheels). In practice the top layers of metal of the track head (containing the crack) are ground away to the depth of the crack. Rail grinding machines are normally deployed as rail vehicles that can perform the grinding operation while in motion along the length of track affected by rail head cracks. The practice of tamping is different from grinding in that it addresses problems in track subsidence by lifting the track and squeezing the ballast underneath to raise the height of the track. As with grinding tamping machines normally take the form of a rail vehicle that can move up and down the affected length of track. As tamping can over time damage the ballast underneath the track (crushing it into a finer grain) the practice can be combined with stone blowing where new stones can be inserted below a section of track.

Both tamping and grinding rail vehicles contain a range of sensors and are capable of producing data on the state of the track and the repairs being carried out. In addition Network Rail utilise a number of track inspection trains that they use to monitor track condition throughout the UK rail network. Such inspection trains also produce track condition data in volume.

As the AUTONOM project progresses use will be made of these data sources in order to develop, test and eventually validate the software prototype.

5 CONCLUSIONS

This paper has set out the current position and stage of development of the AUTONOM project; a project that aims to provide an enterprise system tailored to the maintenance needs of the rail industry, with an initial focus on that area of rail maintenance planning. The software prototype resulting from this project will take advantage of the recent developments in computational intelligence and the availability of networked data stores and feeds made available by the case study organisation UK rail infrastructure provider Network Rail to provide a web based enterprise solution for maintenance activities.

In the continuation of the AUTONOM project it is anticipated that the combination of techniques brought together in this work will be capable of addressing a wider range of problem types, offered by Network Rail and organisations in different industries.

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