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An autonomous system for maintenance scheduling data-rich complex infrastructure: Fusing the railways' condition, planning and cost☆

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ABSTRACT

National railways are typically large and complex systems. Their network infrastructure usually includes extended track sections, bridges, stations and other supporting assets. In recent years, railways have also become a data-rich environment.

Railway infrastructure assets have a very long life, but inherently degrade. Interventions are necessary but they can cause lateness, damage and hazards. Every day, thousands of discrete maintenance jobs are scheduled according to time and urgency. Service disruption has a direct economic impact. Planning for maintenance can be complex, expensive and uncertain.

Autonomous scheduling of maintenance jobs is essential. The design strategy of a novel integrated system for automatic job scheduling is presented; from concept formulation to the examination of the data to information transitional level interface, and at the decision making level. The underlying architecture configures high-level fusion of technical and business drivers; scheduling optimized intervention plans that factor-in cost impact and added value.

A proof of concept demonstrator was developed to validate the system principle and to test algorithm functionality. It employs a dashboard for visualization of the system response and to present key information. Real track incident and inspection datasets were analyzed to raise degradation alarms that initiate the automatic scheduling of maintenance tasks. Optimum scheduling was realized through data analytics and job sequencing heuristic and genetic algorithms, taking into account specific cost & value inputs from comprehensive task cost modelling. Formal face validation was conducted with railway infrastructure specialists and stakeholders. The demonstrator structure was found fit for purpose with logical component relationships, offering further scope for research and commercial exploitation.

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1. Introduction

1.1. The British railway maintenance system

Railway systems are key enablers of economic prosperity. The British railway is considered the fastest growing and safest in Europe (Network Rail-1, 2013). It has been estimated that over 1.6 billion annual passenger and 282,000 freight journeys took place during 2014–2015 (Anon., 2015; Nair, 2015). The British network infrastructure comprises over 20,000 miles of track, 30,000 bridges, 2500 stations, some of which are almost 200 years old, and a multitude of geographically dispersed signaling, electrification and crossing systems. It is the very large number of assets, the long distance interactions and complex interdependencies, as well as its day to day management that clearly make the British railway compliant with the widely accepted classification of a complex transportation system (Magee and de Weck, 2004).

Railway network infrastructure has a very long life, but inherently degrades. Interventions are necessary but they are costly, and can cause lateness, damage and hazards. For example, over 40, 000 infrastructure incidents causing delays were reported in the British railway in 2011–2012; with the top contributors being signaling malfunction, rail crossings, broken rails and detection failures (Network Rail-2, 2013). Effective asset management is crucial to maintain the network reliability and ultimately the users' safety. Network Rail PLC manages and maintains the British railway infrastructure. As many as 17,000 people are engaged in the maintenance activities (Sheeran et al., 2015).

The British railway operates a complex maintenance system by virtue of its own nature; one where multiple failure modes can occur in large numbers, from a range of geographically dispersed assets. Network Rail's comprehensive asset management program is supported by state-of- the- art track inspection trains which are run periodically across the country. These specialist "New measurement trains" (NMT) are equipped with a range of sensors including scanning lasers, high-resolution cameras, ultrasonic systems and linear variable differential transformer probes (LVDT), amongst others. Inspection periodicity varies in accordance with the track speed and importance. During inspection, a number of railway track profile parameters are evaluated against their corresponding thresholds; which are based on Network Rail's standard NR/L2/TRK/001/mod11 (Network Rail-3, 2015). When any of the thresholds is exceeded, a maintenance corrective action notice is issued. Standard prescribed intervention timescales are specified depending on fault severity, and these broadly range from track closure to 28 days to enact repair. Additional measures might include, for example, speed restrictions.

The gradual adoption of remote condition monitoring systems (Network Rail, 2014) for an increasing number of the assets means that more data than ever is being acquired. At present large amounts of data are captured, analyzed and fed into several of the internal systems and databases transferred from the inspection trains to the data centers. Data Collection Services analyze and process the data, performing quality control, post processing and conversion to standardized formats. To support decision making, a linear asset decision support system (LADS) has been recently introduced (ORR, 2014). LADS overlays several geo-tagged information streams, over a graphical representation of the railway. This enables visual identification of the network's "hot spots". However, reasoned supervisory decision making input (e.g. diagnosis and prediction of failure), as well as scheduling of the required tasks for incipient faults, is still required.

1.2. Towards more complex, data-rich automatic railway maintenance systems

Train services are expected to substantially increase over the next 30 years (TSLG, 2012). As a result, railway systems are undergoing a profound modernization. As railway systems progress, the complexity in scheduling maintenance jobs efficiently will increase; and inevitably, a more refined and autonomous decision making capability will be demanded. Fig. 1 illustrates transitional concepts and high-level system characteristics of the UK railway, from a conventional complex system to a complex maintenance system and to a complex data-rich automatic maintenance system. This illustration was constructed from elements in the literature and communications with the stakeholders. The elements in the definition of a complex system (Magee and de Weck, 2004) applied to railway infrastructure primarily refer to the network's complex operation and size, the number of assets and personnel, the long distance interactions and interdependencies. Underneath its operation, a complex stakeholder hierarchy exists, including public funders and regulatory bodies, rolling stock companies (train owners), train operating companies, service providers and the general public (ORR, 2016).

Despite some recent technological developments, railways still rely on resource intensive and less economical time-based preventive maintenance practice to ensure the network availability. A further level of complexity applies when its assets deteriorate and unplanned interventions become necessary. Preventive interventions are carefully planned by qualified personnel to minimize train service disruption. Network disruptions are cost penalized at tabulated rates. Unplanned corrective actions generate a "domino" effect that affects many of the closely related network interactions (Wang, 2008). Their economic and public image impact costs are critical. Clearly railways are becoming a data-rich environment with a substantial number of data streams and operating data-bases. In addition to track inspection data-sets, delay incidents, flooding, CCTV, cost, timetables and users social media data are generated daily (Durazo-Cardenas et al., 2016; Rahman et al., 2015). It is clear that a new structured automated approach is necessary to more efficiently transform current and new generated data to maintenance decisions, to more comprehensively support safer and continuous operation of the network.