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Title: **Benefits from the Remote Monitoring of Railway Assets**

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Abstract

Railway infrastructure already has some ‘smart’ characteristics, in that it ‘knows’ where trains are located, and can sometimes detect track and other equipment faults. There is considerable scope to increase these capabilities.

There is also significant and urgent need for such improvements: railways have limited operational flexibility, and face increasing passenger and freight traffic demand on existing infrastructure. The reliable provision of additional capacity requires improved system ‘self-knowledge’ for traffic control and management purposes, as well as for system reliability and safety. The use of smart infrastructure for fault prediction and the guidance of preventive maintenance helps to maintain operational capacity. This approach also helps to reduce track access requirements for traditional maintenance and renewals activities, thus increasing network availability and total capacity.

Climate change presents the railway industry with significant challenges, notably in terms of flooding and earthworks failures resulting from increased rainfall intensity. Smart infrastructure includes the prediction and monitoring of such events to maintain safety and enable the timely implementation of operational contingency plans.

This paper draws upon a range of sources to identify the needs for and potential benefits of increased deployment of smart infrastructure and other assets on railways in Britain and elsewhere.

Keywords chosen from ICE Publishing list
Railway systems; Sustainability; Infrastructure planning

1. Introduction

The safe, reliable and efficient operation of a railway system is heavily dependent upon the integrity of the system infrastructure, which depends in turn upon asset management policy and practice. On Britain's heavy rail system, responsibility for infrastructure management and operation lies with its owner and operator, Network Rail, which was responsible for over eight million minutes of delay to passenger train services in 2015/16. Of these delay minutes, approximately 12% were due to track failures, and 29% to non-track asset failures, including signalling and power supply problems. Annual delay minutes in these two categories have remained quite constant in recent years.

Monitoring asset conditions over approximately 16,000 route km of railway, many of which are heavily-trafficked and/or difficult to reach, is a considerable logistical and operational challenge, and conventional manual or automated (by Measurement Train, for example) monitoring can only be undertaken intermittently, with the consequence that infrastructure components may fail without warning between inspections, with implications for safety and operational performance. The impacts of such failures are exacerbated by increasing levels of traffic on the network, and the twin aims of improving performance and facilitating further modal shift of traffic to the railways, largely on environmental grounds, can only be successfully achieved by improving infrastructure reliability. The risks of such failures are increased by the likely impacts upon the infrastructure of the extreme weather conditions associated with the predicted effects of climate change, while increased levels of traffic reduce the opportunities for access to the infrastructure for conventional means of infrastructure inspection and monitoring.

Given this combination of the need for improved reliability and performance, increased performance risks, and reduced opportunity for conventional inspection and monitoring, there is a clear need for, and significant potential benefits to be obtained from, the increased use of remote monitoring techniques to provide smarter railway infrastructure.

Following this introduction, concepts and definitions of smart infrastructure and remote monitoring are first reviewed. The needs for both are then considered, in the context of increasing network availability, improving performance and responding to climate change. The opportunities and potential and realised benefits are then assessed. Finally, some conclusions are drawn.

2. Infrastructure 'smartness' and remote monitoring

As a relatively new concept, there are various definitions and 'understandings' of smart infrastructure. The Royal Academy of Engineering (RAEng, 2012) describes a smart system as using a "feedback loop of data, which provides evidence for informed decision-making." The RAEng identifies different levels of smart systems, from those that provide feedback to enable the design of improved future versions, to those that

> *collect data, process them and present information to help a human operator to take decisions*

or

> *use collected data to take action without human intervention.*

The first of these two levels of intervention is likely to apply to infrastructure condition monitoring and maintenance, and to initial developments of improved traffic management systems, while the second level is likely to be adopted subsequently for traffic management purposes as systems improve, and perhaps eventually for some elements of infrastructure maintenance, as needs for human intervention are reduced. Both levels of intervention are illustrated in Figure 1. The RAEng acknowledges that railway systems already include elements of smartness, including the use of automatic sensors and automatic route setting, but notes that there is considerable scope for improvement.

<Figure 1 about here>

The work of the Cambridge Centre for Smart Infrastructure and Construction (CSIC) focusses particularly on smart infrastructure in the context of cities, but CSIC (2015a) envisages a situation where

> *self-aware infrastructure assets direct their own maintenance, leading to condition-based maintenance, reduced down time and greater operational efficiency of the infrastructure overall.*

In an essay commissioned by the Government Office for Science, CSIC (2015b) advocates the use of “sensing and data analysis to enable smarter, proactive asset management decision-making.” Such an approach enables the quantification and definition of remaining infrastructure design life, reducing the risk of failure and increasing system resilience. The document notes the importance of infrastructure robustness, resilience and adaptability to changing patterns, including changes resulting from the effects of natural disasters and climate change.

As indicated above, existing railway infrastructure ‘knows’ and provides information on train locations, but typically only to a relatively coarse level of resolution: the signalling system indicates which signal block(s) a train is occupying, but, since the spacings between signals are typically hundreds of metres or more, the location precision is quite low, and insufficient for optimal ‘fine-tuning’ of train movements and trajectories through network bottlenecks. The track circuits typically used to detect the presence of trains and indicate their location may also provide indication of broken rails when the circuit is broken as a consequence. The signalling system also detects whether points are set and locked in their normal or reverse positions, and the absence of such detection again indicates an infrastructure fault (although the fault could lie in the detection process, rather than the underlying infrastructure). However, such faults are only detected when they occur, typically without prior warning, and are likely to result in operational disruption and the need for rapid intervention and emergency repairs. For these reasons, Network Rail is moving towards a risk-based approach to maintenance, and has started to improve its remote condition monitoring capabilities as part of its development of intelligent (i.e. smart) infrastructure (Network Rail, 2013).

3. Needs for improvement

3.1 Increasing capacity and network availability

As shown by Office of Rail and Road (ORR, 2017) data summarised in Figures 2 and 3, passenger and freight traffic have grown significantly on Britain's railways in recent decades (the recent fall in freight tonne km is due largely to the decline of coal traffic, potentially releasing train 'paths' for use by passenger and other freight traffic (Financial Times, 2017)). As parts of the railway system are used more intensively as a result, maximising the reliable capacity of the current network has become increasingly important.

<Figures 2 and 3 about here>

This is exemplified by the north-south, cross-London Thameslink route, on which it is intended to operate up to 24 trains per hour (tph) in each direction through the central core of the system between London Blackfriars and St Pancras stations (Thameslink Programme, 2014), providing Metro-like frequencies on a heavy railway. While the European Train Control System (ETCS) Level 2 and Automatic Train Operation (ATO) are being deployed (Network Rail, 2016a) to achieve this, adherence to the planned timetable will still depend on the punctual funnelling into the core in both directions of trains from the different origins and routes shown schematically in Figure 4 (this is a considerable simplification of the situation, since the lines shown also connect with the wider railway network and are shared with other traffic). The challenges involved are confirmed by the possibility of postponement of full 24 tph operation on the grounds of concerns about "presentation of services in the correct order north and south of the core" (Modern Railways, 2017).

<Figure 4 about here>

Similar service frequencies are planned for Crossrail, Thameslink's east-west counterpart, (Crossrail, 2014), which will thus face similar challenges, while train frequencies of up to 18 tph are planned for High-Speed 2 (HS2, 2013).

On the existing, conventional network, Network Rail (2015a) notes that the density of operation (i.e. train frequency) of existing morning peak traffic on the Up (London-bound) Fast line on the South West Main Line (SWML) between Surbiton and London Waterloo, at up to 25 tph in the 'peak of the peak', is already the highest in Britain, but that demand growth of up to 40% is anticipated by 2043. This combination of demand and constrained capacity means that "even the smallest delay can quickly be transferred to other services", presenting significant challenges in terms of maintaining punctuality and avoiding reactionary (i.e. knock-on) delays across the system.

The Rail Safety and Standards Board (RSSB, 2014) commissioned the development by Arup, with support from the University of Southampton and other contributors and stakeholders, of an Operational Philosophy for Britain's railways, setting out a long-term operational vision for the industry. The requirements identified for the delivery of this vision include the dynamic control of trains to minimise delays, whereby

> *the operating system will know precisely the location, performance characteristics and schedule of each train. Using this information, it will be able to dynamically and safely control the speed and operation of each train in order to avoid conflicting paths and minimise any delays.*

Such an approach is intended to maximise capacity while also ensuring punctual and resilient operations. Its successful delivery requires both smart infrastructure and smart vehicles, as intended for the Thameslink central core, Crossrail and HS2. Pending the wider implementation of similar technology across the network, the industry needs to use any existing tools at its disposal to ensure the timely arrival of services at busy "condensation zones" (Caimi et al., 2009), or 'zones of concentration', like the Thameslink core, by adjusting train trajectories as necessary in less intensely-trafficked "compensation zones" on their approaches.

Even away from the busiest parts of the network, there are increasing tendencies towards use of the railway 24 hours a day, seven days a week, as indicated by the Network Rail (2007) 'Seven Day Railway' programme. This near-continuous demand reflects desires for increasingly flexible passenger travel and for access to the network at night and weekends for freight traffic, to take advantage of relatively low levels of passenger traffic at those times, and to avoid the capacity issues and operational challenges arising from the simultaneous sharing of routes by relatively slow freight traffic with higher-speed passenger trains.

RSSB's 2014 Operational Philosophy links the need for efficient, 24/7 operations with the need for operational resilience (improving the system's ability to deal with and absorb failures, as well as reducing their frequency and severity), which in turn depends upon the availability and use of intelligent information on system assets, including infrastructure, vehicles and staff.

These approaches and features will be increasingly important, since, as smart infrastructure (and vehicles) are used to obtain more capacity from the railway system and use it more intensively, so the potential impacts of even relatively short-term infrastructure failures are magnified, as are the benefits of anticipating and preventing such failures.

3.2 Improving performance (train punctuality and reliability)

Improved network availability aside, infrastructure faults are already a significant source of operational disruption, and prevent reliable and predictable operations. Data from Network Rail (2016c) and the Office of Rail and Road (ORR, 2016) indicate that, in the year 2015/16, Network Rail was responsible for approximately 60% of delays (of three minutes or more) to passenger train operating companies (TOCs); of the remainder, approximately 31% were self-inflicted (so-called TOC-on-self delays), and 9% were caused by other operators (TOC-on-TOC).

The data are summarised in Figure 5 and show that Network Rail was thus responsible for almost 8.2m minutes of delay to passenger train operators in 2015/16, of which approximately 960,000 were due to track assets (plain line, switches and crossings) and almost 2.4m were due to non-track assets (including signalling and power supply equipment). Delays due to non-track assets have remained quite constant over the past eight years, while track-related delays have increased slightly, but by less than the total delays due to Network Rail.

Track and non-track assets were thus the source of approximately 41% of the total delays attributable to Network Rail. These could be reduced by the use of smart infrastructure and preventive maintenance, in parallel with work to improve infrastructure longevity and performance, such as that being done as part of the Track 21 and Track to the Future research programmes, undertaken by a consortium of universities led by the University of Southampton, in collaboration with Network Rail, High Speed 2 and other industry stakeholders (Ortega et al., 2016). Such preventive maintenance, undertaken outside busy times of operation, greatly reduces the risk of failures and the associated costs of disruption, while also allowing the work to be undertaken under more controlled, cost-effective conditions.

<Figure 5 about here>

As already noted above, the effects of disruptions can spread rapidly and widely across a busy network (Network Rail, 2016b), and such pro-active, preventive measures are particularly valuable in the case of through-running initiatives like Crossrail and Thameslink, where the effects of disruptive events on one part of the network can ‘infect’ operations on another part.

3.3 The Effects of Climate Change

The risks of asset failures, and thus the associated effects on network availability and system performance, are likely to be exacerbated by the increasingly extreme weather conditions associated with the emerging and predicted effects of climate change, which poses particular risks of increased temperatures, high winds, flooding and the effects of extreme rainfall (and drought) on earthworks. RSSB’s Executive Report (2016a) on Tomorrow’s Railway and Climate Change Adaptation (TRaCCA) found

> *unequivocal evidence that Britain’s railway will, as our natural environment and socio-economic systems, be affected by changes in weather conditions caused by climate change.*

Among the implications listed in the report for the railway are higher average temperatures, sea levels and rainfall, increasingly “frequent and severe adverse weather events”, including not only floods and heatwaves (and thus the risk of track buckling), but also heavy snowfall. These will all pose additional risks to railway infrastructure and vehicles, operations and maintenance, and to users and staff. The recommended responses to these increased risks include improved weather reporting and asset condition monitoring.

Prior to the issue of this TRaCCA report, and as a consequence of the severe weather experienced in the winter of 2013/14, the UK Department for Transport (DfT, 2014) undertook a review of the resilience of the national transport network to extreme weather. The review noted that the effects of extreme weather on the railways are compounded by the age of much of the network’s earthworks and their relatively poorly-engineered (by current standards) construction. More generally, the review identified three elements of resilience to extreme weather:

- *It is about increasing the physical resilience of transport systems to extreme weather, so when extreme weather is experienced, people and goods can continue to move.*
- *It would be both very difficult and prohibitively expensive to ensure total physical resilience, so secondly it is equally about ensuring processes and procedures to restore services and routes to normal as quickly as possible after extreme weather events have abated.*
- *Thirdly, as part of this, it is essential to ensure clear and effective communications to passengers and transport users so that the impact of disruption on people and businesses is minimised.*

The second of these elements reflects the acknowledgement in the RSSB’s (2014a) Operational Philosophy that the risk of failures cannot realistically be wholly eliminated, but that the system should be better able to absorb and work around failures that do occur, thus maintaining services, even if at a degraded level, in all but the most severe weather conditions. The monitoring of long- and short-term weather and asset conditions will be necessary to facilitate and develop such resilience.

4 Opportunities for Improvement

Drawing upon the findings presented above, the opportunities and potential benefits provided by smarter infrastructure and improved remote monitoring are now considered.

4.1 Increasing capacity and network availability

For the purposes of routine daily operations, improved control and traffic management systems such as those anticipated in the Operational Philosophy for Britain’s railways (RSSB, 2014a) will provide the system knowledge and control required to maximise reliable capacity. These systems are exemplified by the European Train Control System (ETCS), Level 2 of which is being deployed on Thameslink and Crossrail, and the associated European Rail Traffic Management System (ERTMS). It is claimed (UNIFE, 2014) that such systems can deliver capacity increases of up to 40%, although the same source acknowledges that Swiss experience indicates that increases of 25% are possible on mixed traffic lines, and just 15% on lines on which traffic has already been optimised. These lower values are consistent with findings in Britain (Barter, 2010; Rail Engineer, 2015). Prior to the full introduction of such systems, and/or in situations where such investments cannot be economically justified, there is scope to exploit and develop existing technologies to deliver improvements.

Recent initiatives in this area include the successful testing (RSSB, 2015) of a Connected Driver Advisory System (C-DAS) to slot eastbound longer-distance, high-speed trains approaching Airport Junction on the Great Western Main Line between the actual (as opposed to timetabled) paths of shorter-distance train services from Heathrow Airport to London Paddington. Standalone Driver Advisory Systems (DASs) were originally introduced to enable energy-efficient driving and reduce fuel consumption, but linking them to the network control system can thus deliver wider performance benefits. This type of approach could be used as an interim measure to ensure that trains approaching the Thameslink and Crossrail central sections from conventional routes arrive within sufficiently precise ‘time windows’ to enable ETCS Level 2 and ATO to successfully and consistently deliver the specified high-frequency timetables through the central cores.

These operational and capacity enhancements can only be delivered, however, if the infrastructure and rolling stock are sufficiently reliable and are available as and when needed: even in an inherently flexible and resilient system, the intensity of service planned for Thameslink, Crossrail and HS2 leaves negligible margins for error and inconsistency. Hence the Operational Philosophy’s requirement for the availability of enhanced data and information to provide improved understanding of failure risks and prediction of failures, enabling the preventive repair or replacement of the assets in question. This depends upon improved asset management by means of remote condition monitoring and diagnostics, self-assessing (and, ideally, as also envisaged by CSIC, ‘self-healing’) assets, the installation of assets away from running lines where this is feasible, and automated inspection (using equipment mounted on passenger and freight trains where possible) and, eventually, robotic maintenance. Britain’s Cross-Industry Remote Condition Monitoring Strategy Group (XIRCMSG) envisages a ‘four-quadrant’ approach to Remote Condition Monitoring (RCM) as part of an Intelligent Infrastructure Strategy, employing both infrastructure and rolling stock for monitoring purposes, as shown in Table 1 (RSSB, 2011).

Table 1: Four Quadrants of Remote Condition Monitoring

		Asset Types	
		Infrastructure	**Trains**
Monitoring Type	**Infrastructure**	**Infrastructure monitoring infrastructure** e.g. Points Condition Monitoring	**Infrastructure monitoring trains** e.g. Wheel Impact Load Detection, Acoustic Axle Bearing Monitoring (AABM)
	Trains	**Trains monitoring infrastructure** e.g. Unattended Geometry Measurement Systems	**Trains monitoring trains** e.g. Train Management Systems

4.2 Improving performance (train punctuality and reliability)

While the characteristics outlined in the preceding section are essential for the successful operation of the high-frequency services described above (and for enhanced capacity on conventional routes such as the SWML between Woking, Surbiton and London Waterloo), they have much wider potential benefits, facilitating the seven-day railway and reducing maintenance costs, and improving the punctuality and reliability of train services across the network.

In 2007, Network Rail, in collaboration with the Railway Industry Association and the then London Underground infrastructure companies, Metronet Rail and Tube Lines, produced a Good Practice Guide for the development of intelligent infrastructure (Network Rail et al., 2007). The broad objectives set out in the guide include:

- A more affordable railway, resulting from improved productivity
- Maintenance efficiencies arising from improved asset management
- Improved operational performance, providing increased capacity and reduced levels and costs of disruption, and thus better meeting customer requirements

Specific anticipated benefits include:

- The elimination (or reduction) of manual inspection
- ‘Fix before failure’
- Reduced maintenance volume (i.e. targeted, risk-based, rather than interval-based maintenance)
- Self-repair/self-adjustment of assets
- Automated detection of asset deterioration
- Just-in-time replacement of assets
- Lower spare parts inventories
- Quicker failure rectification

- Repairs and maintenance undertaken without, or with minimal, intrusion on scheduled services
- Assets that are easier to renew or repair
- Reduced support and equipment costs
- Assets which require less specialist, highly-qualified (and expensive) maintenance staff
- Identification of root causes of asset failures, accelerating repair of single failures and preventing their repetition on those and similar assets
- Reduced working of anti-social hours [and thus potentially reduced costs]

It can be seen that these objectives and anticipated benefits are consistent with and reflected in the requirements of RSSB's Operational Philosophy for Britain's railways, and that they enable more efficient and effective (and safer) maintenance and renewal of the network, while reducing the potential for system failures and delays to train services and users.

Improvements to asset management require improved asset information and analysis. The volumes and disparate sources of data involved mean that these are significant challenges in themselves, necessitating the introduction of Network Rail's ORBIS (Offering Rail Better Information Services) programme (Network Rail, 2013), and the use of asset management optimisation approaches such as those described by Rama and Andrews (2016). The deployment of RCM and risk analysis as part of Network Rail's Intelligent Infrastructure programme is providing improved asset information and enabling the shift from frequency-based towards risk-based, reliability-centred maintenance, providing improved cost-effectiveness and system reliability (Network Rail, 2013).

Network Rail's published Annual Returns for the first two years of Control Period 5 (CP5: 2014-19) include sections on Intelligent Infrastructure implementation and the benefits derived from it. Prior to CP5, the Annual Returns do not contain specific data, reflecting the fact that Intelligent Infrastructure implementation was then in its early stages. However, Network Rail Consulting (2015) quotes pre-CP5 statistics of 12,000 RCM-enabled assets providing annual savings of 153,000 delay minutes, equivalent to approximately £4.66m in reduced compensation payments (as specified in Schedule 8 of Train Operators' track access contracts with Network Rail). Plans were then in place to add 23,000 assets to the system, with annual benefits expected to rise to £14m from 2014 onwards.

In its 2014-15 Annual Return, Network Rail (2015b) stated that 35,000 assets had been included in the Intelligent Infrastructure system, matching the plans quoted above, but that 543,250 delay minutes had been avoided (it is not stated explicitly, but the values used are presumably based on delays incurred as a result of previous or similar incidents that did occur). This represented a Schedule 8 cost avoidance of £24.4m using CP4 average Schedule 8 delay minute values, considerably greater than had previously been predicted, and included 372 successful interventions and incident avoidances in the period prior to the end of the year, a trend that was being maintained in early 2015-16. By the end of 2015-16, the number of RCM-fitted assets had increased to over 40,000, reducing delays for those assets by 35%, and saving 571,000 delay minutes, an additional saving of 27,250 minutes (Network Rail, 2016c). These results are summarised in Table 2.

Table 2: Remote Condition Monitoring Deployment and Benefits

Year	RCM-Fitted Assets	Delay Minutes Saved	Minutes Saved per Fitted Asset
Pre-CP5	12,000	153,000	12.75
2014-15	35,000	543,250	15.52
2015-16	40,000	571,000	14.28

Both Annual Returns indicate an emphasis on fitting track circuits and other signalling components with RCM, consistent with the reduction in delays due to non-track assets shown in Figure 5. It can be seen that the savings per installation increased from CP4 to 2014-15, and then decreased slightly to 2015-16, possibly as a result of the most critical/delay-generating assets having been equipped first.

4.3 Adapting to Climate Change

The potential benefits of smart infrastructure and remote monitoring, as described above, will be equally applicable to maximising the residual availability of railway networks affected by the results of climate change (e.g. flooding, high winds) and to predicting and preventing the failure of system components similarly affected. They also have an additional, wider and longer-term role, in monitoring network conditions and changes over time, in response to a changing climate, and thus enabling the system and network to adapt gradually, rather than experiencing repeated and potentially catastrophic failures.

As indicated above, the TRaCCA project (RSSB, 2016a) has found that by the second half of this century in Britain,

> *temperatures will be higher, summers will be hotter and drier, and precipitation will increase. Extreme weather events, such as heat waves, drought, heavy rain and snowfall, and storm surges will be more frequent and more severe.*

Smart infrastructure can be used to monitor some of these effects (e.g. rail temperatures and surface water levels) in real time, and to enable infrastructure managers and train operators to take the appropriate short-term action, while longer-term measurements of the same effects can be used to review and, as necessary, update standards with respect to the appropriate tensioning of continuously welded rails (DfT, 2014) and the provision of drainage, for example. More generally, TRaCCA (RSSB, 2016b) advocates the long-term monitoring and integration of weather and performance (i.e. weather-related failures) data, to improve the understanding of the relationships between the two, and update them as necessary.

Of the potential risks, flooding and earthworks failures are perhaps the most challenging, since they cannot typically be rectified quickly, and, particularly in the case of earthworks failures, they can occur with little warning. As noted by DfT (2014), 'single points of failure' are a particularly severe problem in this regard, since they can cause severance of the network for significant periods of time. Recent examples include the flooding of Cowley Bridge Junction, north of Exeter, and the collapse of the sea walls at Dawlish and between Folkestone and Dover. DfT recommends that these and other elements of a national 'critical network' should be identified and maintained and, as necessary, enhanced to provide increased resilience.

The unpredictable nature of earthworks failures, their potential consequences and the need for improved monitoring were illustrated by the derailment of a southbound train by a landslide following very heavy rain on the West Coast Main Line near Watford on 16 September 2016 (CIHT, 2016). As reported by the Rail Accident Investigation Branch (RAIB, 2016), a northbound service collided with the derailed train, but the collision was fortunately relatively minor, partly due to the issue of an emergency stop warning to all trains following the derailment, with the result that the speed of the northbound service had been reduced from 129km/h to 51km/h by the time the collision occurred. In its 2016 Annual Return, Network Rail (2016c) recorded 163 reportable earthworks failures for 2015/16, including “a number of significant failures” following the second wettest winter on record. It also shows the five-year moving annual average (MAA) national numbers of earthworks failures between 2011/12 and 2015/16 inclusive, the rising trend in which can be seen in Figure 6. DfT (2014) recommended a range of earthworks condition monitoring, slope stabilisation and classification, and vegetation management initiatives to address these problems, as well as several recommendations relating to the monitoring and management of flood risk.

<Figure 6 about here>

The TRaCCA project (RSSB, 2016a), estimates that, based on analysis undertaken by Network Rail in 2013, the average annual cost of weather-related delay and cancellations to train services (excluding repair costs) is £40-50m. The estimated annual costs of track buckling are £4.8m, and are predicted to double by 2020, double again by 2050, and be ten times greater by 2080. Flooding in 2013 is reported to have cost Network Rail approximately £12m in compensation costs and another £15m for repairs, while 12 (now 13) derailments were recorded since 2005 as a result of heavy rainfall causing earthworks failures. The undertaking of targeted pre-emptive enhancement works would avoid (much of) the compensation payments, and would enable the work to be undertaken in a better planned, controlled, co-ordinated and cost-effective manner. As the TRaCCA project (RSSB, 2016b) notes, such an approach has the added benefit of reducing the exposure of railway maintenance staff to the risk and hazards associated with extreme weather and its effects.

DfT (2014) advocates enhanced monitoring of forecast weather conditions when extreme conditions are expected, and the preparation and implementation of contingency plans to provide “the best practicable service which they can realistically deliver”, managing users’ expectations while also providing them with certainty as to the level of service they can expect. Consistent with this, and with elements of RSSB’s 2014 Operational Philosophy for Britain’s railways, the TRaCCA project (RSSB, 2016a, 2016b) advocates the use of a ‘Journey Availability’ performance metric in place of/in addition to the existing performance measures. The use of such a measure would incentivise the monitoring, maintenance and operation of the system with a view to encouraging the continued operation of services, even if via diverted routes, in the event of severe weather and associated infrastructure or vehicle failures.

5. Conclusions

Smart, or intelligent, infrastructure, using various forms of remote monitoring, provides its users and maintainers with a range of valuable information, and with enhanced system capacity, operations and reliability. These benefits are multiplied when the system is at or near capacity, with minimal operational ‘slack’ and restricted access for inspection and maintenance activities. In addition to the beneficial effects on day-to-day operations and maintenance, ongoing monitoring of systems enables the analysis of trends and the long-term effects of changes in operations, maintenance practices and weather (reflecting climate change) on system components and overall performance, the findings of which can then be fed back into the operation and management of the system to further enhance its performance and cost-effectiveness.

Analysis of Network Rail’s reported implementation of RCM and its results indicates clear performance benefits, although these benefits appear to be at least partly offset by increases in delays due to other causes, given the consistency over recent years of delay minutes arising from track and non-track assets. As RCM is extended across the network and systems, these benefits should become increasingly apparent, although they may be subject to diminishing returns as RCM is extended beyond the most critical and delay-prone elements of the system.

The efforts and costs associated with adapting the railway network to the likely effects of climate change, including long-term condition monitoring and analysis, are considerable, and the quantification of the resulting benefits is challenging. However, like the wider effects of climate change, intervening to anticipate and avoid the worst of its consequences is likely to be much more cost-effective than adopting a purely reactive approach; it also has the wider benefits of enabling the system to continue providing a reliable service, while using rail’s relatively low environmental impact to play a role in mitigating climate change.

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Figures

Figure 1: Alternative Data Feedback Loops

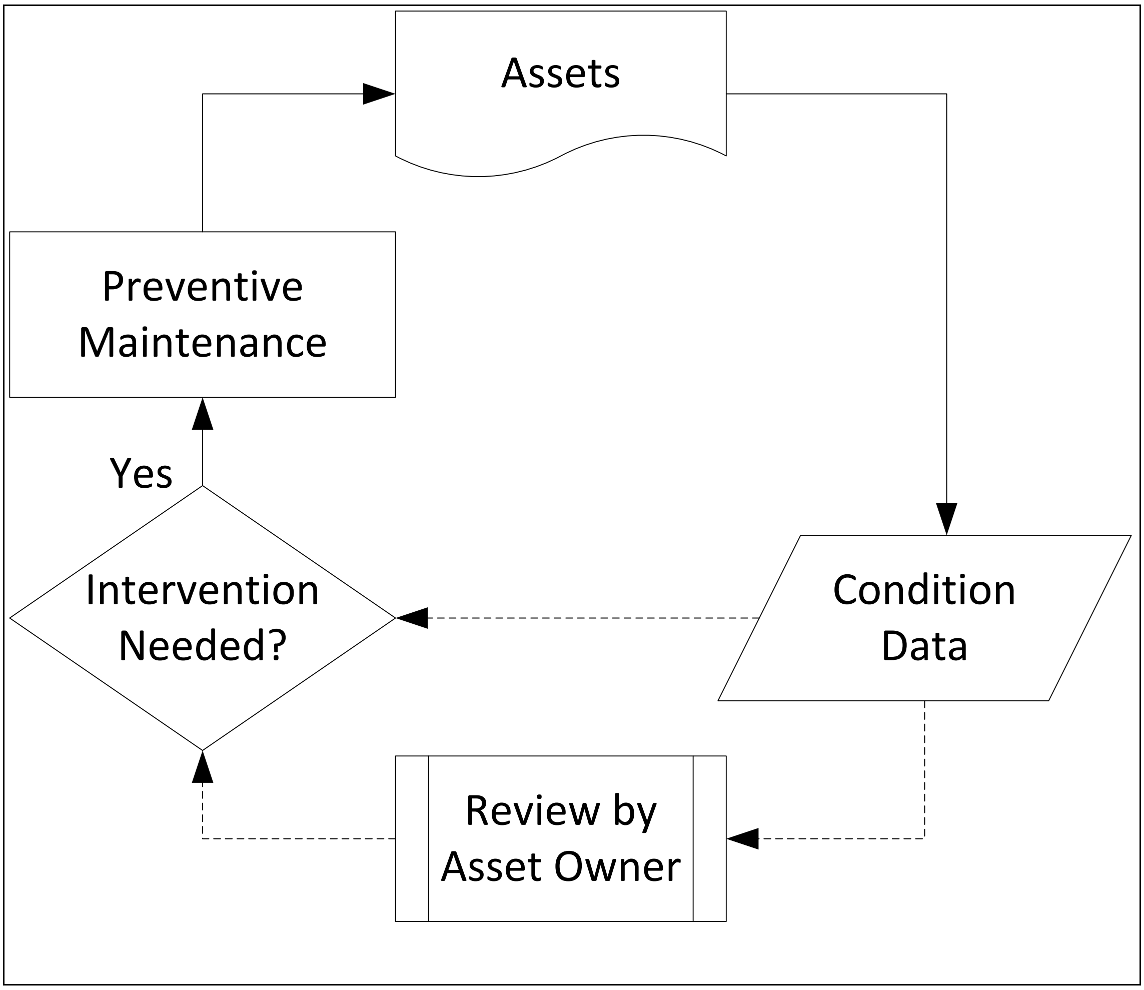

Figure 2: Rail Passenger Traffic Volumes in Britain

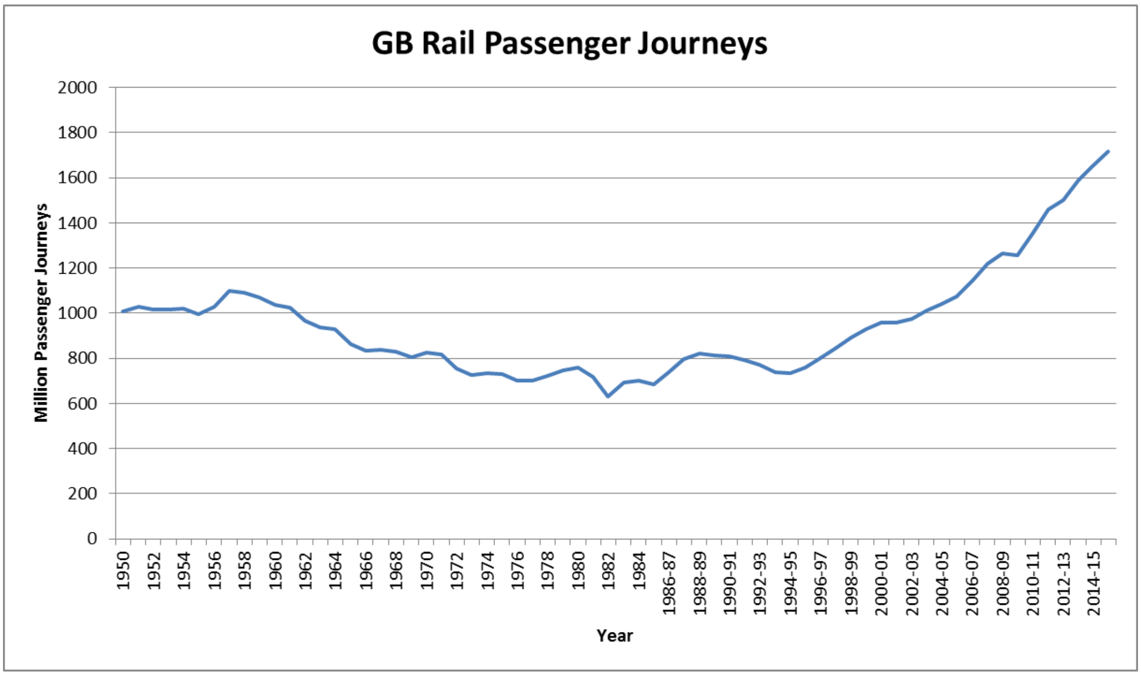

Figure 3: Rail Freight Traffic Growth in Britain

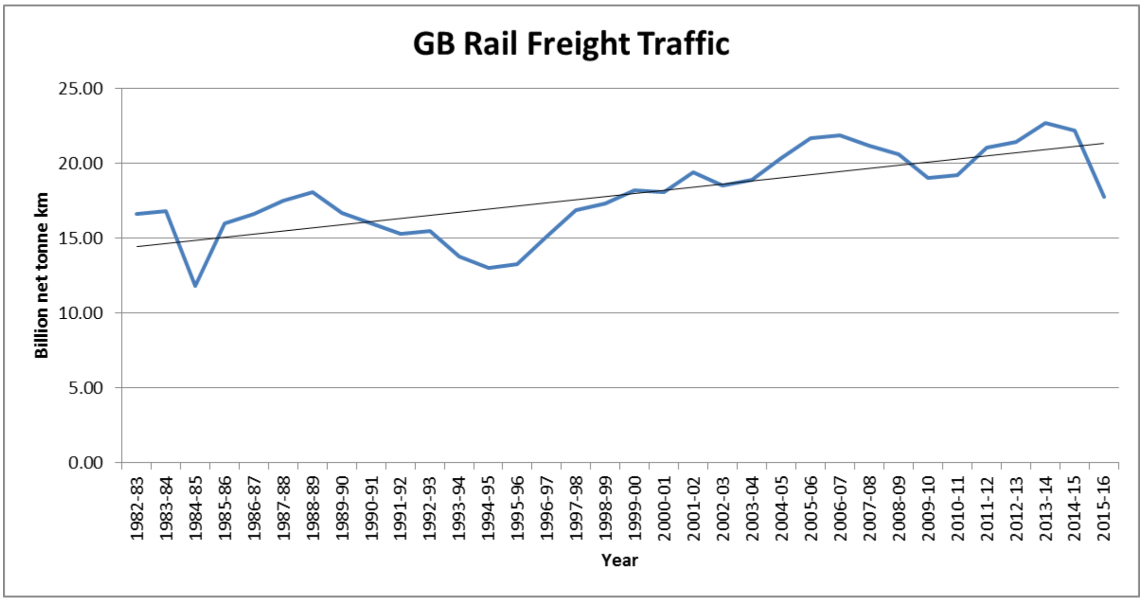

Figure 4: Thameslink Network

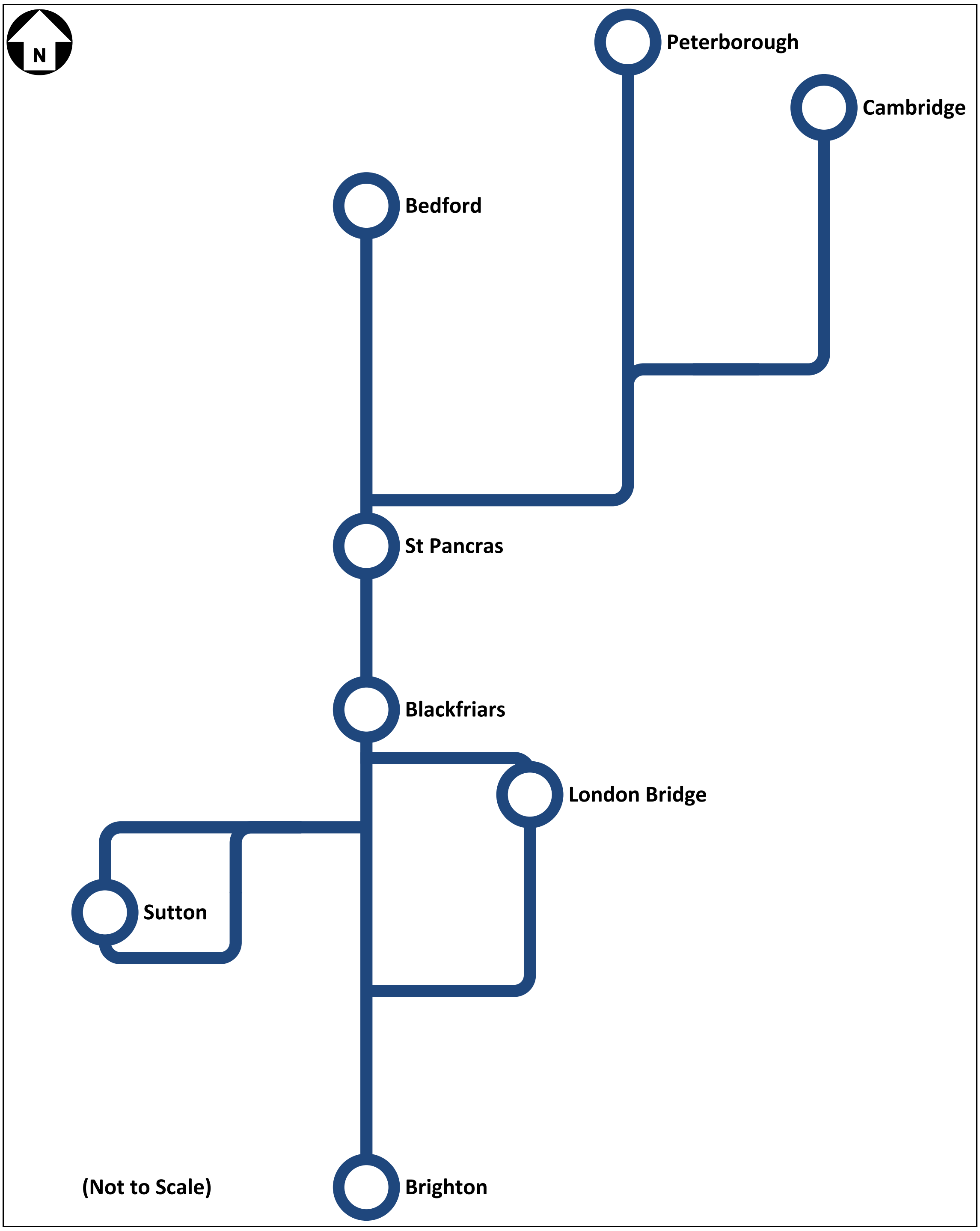

Figure 5: Network Rail Delay Minutes, 2008-2016

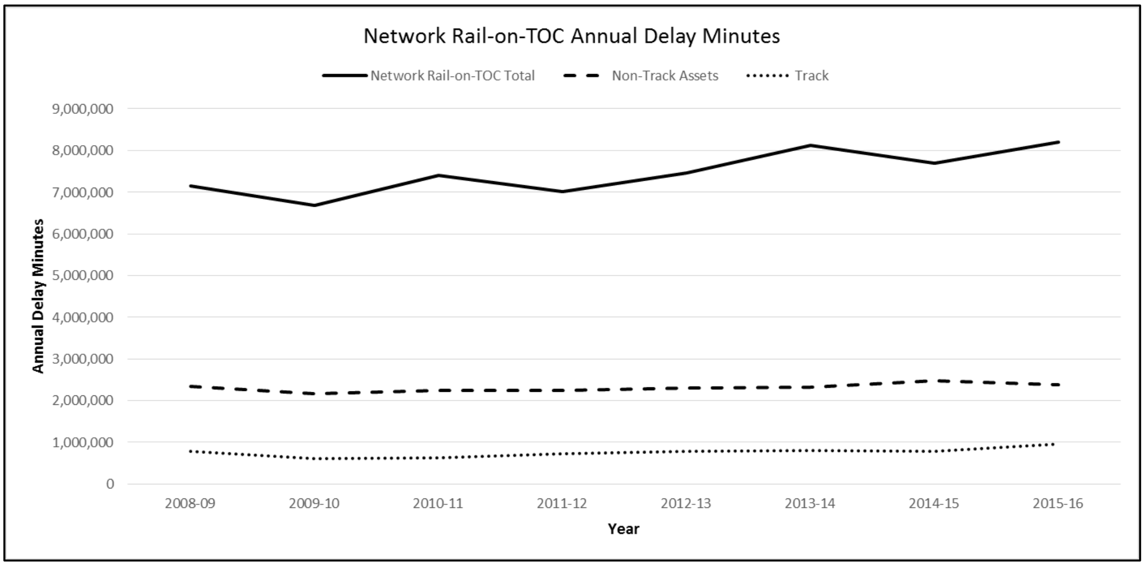

Figure 6: Five-Year MAA National Earthworks Failures

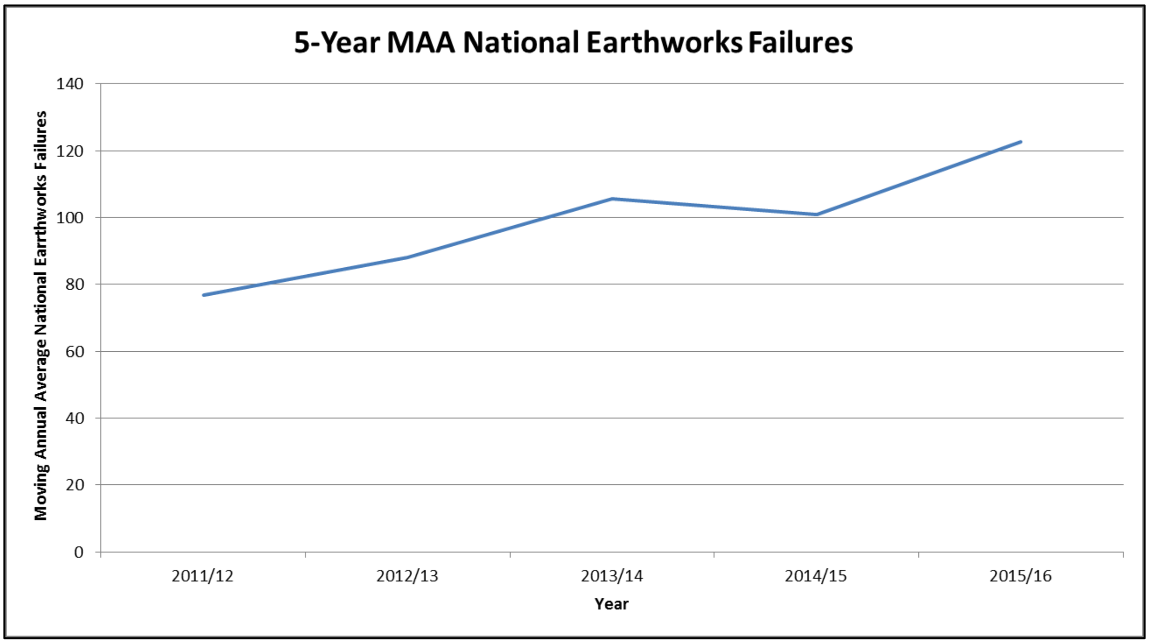

Table captions

Table 1: Four Quadrants of Remote Condition Monitoring

Table 2: Remote Condition Monitoring Deployment and Benefits