* Article type: paper
* Date text written: 8th May 2019
* Number of words in main text: 5006; number of figures: 3

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Balancing Railway Network Availability and Engineering Access

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**Abstract**

As traffic on Britain’s railways has grown, the system is approaching capacity and moving towards 24/7 operations. This increases wear and tear, and reduces access for maintenance, renewal and enhancement. Increasing costs of renewals and enhancements are also questioned, amid funding scarcity. Alongside predictive and preventive maintenance, improved planning and implementation of renewals and enhancements are needed, balancing network availability for train operations with cost-effective construction activities. Typically, extended track possessions maximise construction efficiency, but also reduce network availability for operations, whereas short possessions maintain network availability, but are least efficient for construction purposes. The effects of infrastructure activities on network availability have typically been monitored and assessed retrospectively, rather than being planned proactively to maximise network availability or to optimise the trade-offs between network availability and engineering efficiency. This paper reviews the current situation, and identifies opportunities to enhance planning processes and the balance between network availability and engineering efficiency.

**Keywords** **chosen from ICE Publishing list**

Railway systems; Maintenance & inspection; Planning & scheduling

**Introduction**

As Britain’s railways are more intensively used, so the need for infrastructure maintenance, renewals and enhancements increases, while access to the network to undertake these essential works is increasingly constrained by rising traffic levels and user expectations of 24/7 travel and transport. This results in unavoidable trade-offs between network accessibility (for civil and other engineering activities) and availability (for operations). Further compromises are required and made between the efficiency with which engineering activities can be carried out and the extent to which network availability is restricted. Routine maintenance activities can often be performed efficiently during short periods of access. Renewals and enhancement works, on the other hand, are typically undertaken most effectively in the form of long possessions or line blockades, rather than in a series of short possessions, each including the time required to take and hand back possession of the infrastructure, while the opposite applies to providing network availability for operational purposes. As well as moving towards a condition-based maintenance regime and improving the efficiency with which individual infrastructure projects and activities are undertaken, it is therefore important, as noted by Li and Roberti (2017), to improve the trade-offs between network accessibility and availability, increasing, and ideally maximising, the overall benefit:cost ratio of civil engineering activities and the associated possessions and restrictions of network availability.

Following this introduction, the background and context are briefly described, including traffic growth and associated pressures on access to the network for maintenance purposes. The current process for maintenance planning, access and compensation is then reviewed, and potential alternative approaches are considered. Proposals for improvement are then presented, including ongoing and further work. Finally, some conclusions are drawn, followed by acknowledgements and a list of references.

**2. Background**

As passenger and freight traffic volumes have grown on Britain’s railways in recent decades, so the need to maintain, renew and enhance the railway network has increased, while the impacts of these activities on passenger and freight train operators and their users have also become more apparent. These conflicting trends and their impacts are most pronounced and apparent in cases of over-running engineering works which receive extensive media coverage (for example, at London King’s Cross and Finsbury Park and between London Paddington and Reading in December 2014 (BBC, 2014; Guardian, 2014).

More typically, railway users may experience train cancellations or diversions at weekends and on weekday evenings, often with trains being replaced by buses, and resulting in extended journey times, reduced passenger comfort and enforced interchange. Train operators are compensated for such planned disruptions through the Schedule 4 Compensation System (S4CS; Network Rail, 2018a), as set out in Schedule 4 of their track access contracts with Network Rail, the owner, operator and maintainer of Britain’s railway infrastructure (the objectives and elements of S4CS are described in more detail below).

***2.1 Comparison with other transport modes***

Over-running major engineering works such as those mentioned above receive arguably disproportionate media coverage, while the more routine trade-offs between engineering access and user availability are similar to those encountered by other transport modes and forms of infrastructure. This is perhaps most obvious in the case of the use of ‘lane rental’ to encourage efficient practices in highway maintenance and renewal, and highway excavation and reinstatement by utility companies and their contractors. Guidance for English local highway authorities on lane rental schemes was issued recently by the Department for Transport (DfT, 2018), aiming to

* *reduce the length of time that sites are unoccupied, hence reducing total works durations*
* *improve planning, coordination and working methods to maximise efficiency*
* *carry out more works outside of peak periods*
* *optimise the number of operatives on site to enable works to be completed as quickly as possible*

The twin objectives of increasing work efficiency and reducing user impact are very similar to those in the railway context. While the highway system typically enjoys higher levels of network redundancy and potential alternative routes than the railway, it has much less control over the traffic using it, and is subject to disruption from a wide range of street works by different utilities as well as from roadworks necessary to maintain and improve the highway itself.

In the cases of ports and airports, sufficient berth, runway or terminal capacity may be available to enable part-closures for maintenance and upgrade works. Otherwise, port calls and flights may have to be diverted to alternative ports and airports, or cancelled, requiring considerable advance planning and potential disruption and inconvenience to users.

***2.2 Traffic trends***

Annual passenger train km in Britain (excluding Heathrow Express (HEx)) and S4CS payments from Network Rail to train operators between 2011-12 and 2016-17 are shown in Figure 1, derived from Table 12.13 of the Office of Rail and Road’s (ORR’s) 2017-18 Quarter 4 Statistical Release on Passenger Rail Usage (ORR, 2018a) and Network Rail data on historic Schedule 4 payments (Network Rail, 2018b). It can be seen that the Schedule 4 payments are (i) large, running to hundreds of millions of pounds per annum, and (ii) appear to reflect variations in passenger train km, indicating that, all things being equal, compensation payments, and the planned disruptions that trigger them, are likely to increase further if and when traffic levels resume the growth trend seen prior to 2016-17. The reduction in passenger train km has been followed by the first reduction in franchised passenger journeys since 2009-10, as shown in Table 12.6 of ORR’s (2018a) 2017-18 Q4 statistics and summarised in Figure 2 (note: the data for 2017-18 Quarter 4 are provisional). ORR notes that some of the declines in passenger train km and passenger journeys, notably on Govia Thameslink Railway and the South Western Railway, are due to industrial action, staffing problems and planned cancellations of services, and also engineering works, notably major, disruptive works at London Waterloo station.

<Figure 1 about here>

<Figure 2 about here>

Annual freight train km in Britain over the same period, with the addition of data for 2017-18 and disaggregated by freight operating company (FOC), are shown in Figure 3, based on Table 13.25 of ORR’s 2017-18 Quarter 4 Statistical Release on Freight Rail Usage (ORR, 2018b). It can be seen that, following a period of sustained post-privatisation growth, traffic has declined in recent years. This is due largely to the loss of coal traffic resulting from the decline in coal-fired electricity generation (Network Rail, 2017), which is reflected in the reduced train km operated by DB Cargo UK and, particularly, Freightliner Heavy Haul, which dominated coal haulage by rail in Britain. Direct Rail Services has also seen a smaller decline, possibly due to the decommissioning of Britain’s older nuclear power stations, but Freightliner (intermodal container traffic) and GB Railfreight volumes have both increased in recent years. While freight has a small (at less than 10% of passenger train km) and declining share of total railway traffic, container traffic volumes are disproportionately significant in the context of planned disruptions, in that these services are relatively time-critical and use some of the busiest, most capacity-constrained routes in the country (e.g. South West Main Line, Great Western Main Line, Great Eastern Main Line, North London Line and West Coast Main Line). These routes require significant maintenance and renewal (M&R) activities, and the trains also tend to operate at night and weekends, when most engineering possessions take place, emphasising the need for engineering efficiency and effective access planning.

<Figure 3 about here>

***2.3 M&R costs***

The costs of maintaining and renewing Britain’s railway infrastructure (and of asset management generally) seem high by international standards, as noted in the Rail Value for Money Study, or ‘McNulty Report’, commissioned jointly by DfT and ORR (2011). The report highlights the trade-offs between possession duration and engineering efficiency (and costs), and also the potential benefits of moving towards a risk- or condition-based approach to maintenance, instead of the more traditional calendar- or interval-based approach. The potential benefits of condition-based maintenance and the use of remote condition monitoring (RCM) and ‘intelligent infrastructure’ generally were also illustrated by Armstrong and Preston (2017). However, while improved technology and engineering efficiency have valuable roles to play in the reduction of M&R costs, the wider relationship and trade-offs between network accessibility for M&R works and network availability for operations also need to be considered. This should reduce and, ideally, minimise the overall costs of maintaining, renewing and upgrading the railway network, as indicated by the conclusions of the EU INNOTRACK project (EIM, EFRTC and CER, 2011),

*significant savings in [M&R costs] may be achieved not just through the implementation of innovative solutions in technology but also by improving the logistics, planning and execution of track maintenance and renewal works.*

**3. Network access planning and compensation**

***3.1 The current approach***

##### As explained by Network Rail (2018a), the aim of the Schedule 4 regime is to compensate train operators for long-term revenue loss resulting from users being deterred from using the railway as a result of planned possession-related disruptions, and for other costs incurred (rail replacement buses, for example) – it is not related to user compensation from train operators. The compensation is calculated and paid automatically at the end of every four-week operating ‘period’, in accordance with formulae set out in operators’ track access contracts, although bespoke payments may be made to cover additional costs arising from unusually disruptive possessions. The loss of revenue, and thus the payments and the values used in the formulae, vary with the type of operator (inter-city, commuter, regional) and the length of notice provided by Network Rail (the more notice provided, the more warning and opportunity that operators and users have to plan around the disruption, reducing its impact). As summarised by Armstrong et al. (2015), the three main factors included in the calculations are:

* The effects of possessions on fare revenue, based upon the cancellations of scheduled stops at stations (and weighted by the busyness of those stations) and extended journey times
* Additional costs arising from the running of replacement buses
* Costs or savings (typically the latter when services are fully or partially cancelled) due to changes in train mileage

Access requirements for engineering purposes are reviewed, and planned possessions for a given year are set out in Network Rail’s annual Engineering Access Statement (EAS; Network Rail, 2018c). This takes the form of a register of possessions for each of eleven Routes and sub-Routes (as reported by Railway Gazette (2019), Network Rail’s Routes structure is subject to change as a result of internal reorganisation), together with a possession strategy and a list of standard possession opportunities for each Route (some of which are further sub-divided). The EAS also includes guidelines for granting possessions, an access impact matrix, a glossary, and, in the Introduction, an explanation of the overall possession planning process.

The preparation of the EAS begins over a year prior to the start of its period of validity, initially through informal discussions between Network Rail and the train operators. The process becomes more formalised as the EAS is developed, and takes account of Bank Holidays and significant sporting and other events across the network when deciding upon track closures. Train operators’ bids for train ‘paths’ in their timetable proposals must comply with the contents of the EAS and thus reflect planned closures. The overall aim of the EAS development process is to achieve

*the optimal balance between access to the network for train operations and access for maintenance, renewal and enhancement work.*

The sequence and timescales of the possession planning and EAS preparation processes are set out and summarised in a report by Europe Economics (2017), reviewing Network Rail’s network availability (for operations) metrics and outputs. The report found that the engineering and possession planning process “appears to be fit for purpose”, avoiding unnecessarily disruptive possessions and, via consultation with train operators, taking account of passenger and freight user needs. This is broadly consistent with the objectives of the formal measures of network availability that the report notes were put in place in the railway’s five-year Control Period 4 (CP4: 2009-2014), in response to concerns about excessive taking of possessions and associated disruption to train services during the previous five years of CP3. This was also part of the move towards encouraging the provision of a ‘7-Day Railway’ service, operating throughout the week, including weekends.

Network Rail’s network availability metrics are summarised on its website (Network Rail, 2018d) focussing primarily on the Possession Disruption Indices for Passengers and Freight (PDI-P and PDI-F, respectively). These and the other network availability metrics are described, explained and presented in Network Rail’s Periodic (i.e. every four weeks) Possession Indicator Reports (see, for example, Network Rail, 2018e). Nine Key Performance Indicators (KPIs) are reported in addition to the PDIs:

1. *CPPP [Confirmed Period Possession Plan] and EAS Disputes*
2. *Weekend Working Timetable Compliance*
3. *Rail Replacement Bus Hours*
4. *Number of Planned Disruption Mitigation Interventions*
5. *Possession Notification Discount Factor*
6. *Late Changes to Possessions*
7. *Delay Minutes Due to Possession Overrun per 100 Train Kilometre*
8. *Cancellation Minutes Due to Possession Overrun per 100 Train Kilometre*
9. *Unplanned Temporary Speed Restrictions (TSR)*

The first three are aimed at monitoring the extent to which passengers are kept on trains, i.e. the use of replacement bus services is avoided, the second three are aimed at monitoring the mitigation of disruption to train services, and the last three are aimed at monitoring additional, unplanned disruption arising from possessions themselves.

The PDIs comprise the ‘headline’ regulatory metrics of network availability, and are supported by the KPIs. At the time of writing, PDI-P reporting could not be updated “due to issues with the Network Availability Reporting System [NARS]” (Network Rail, 2018d). This is consistent with observations made by Europe Economics (2017) in their review, in which they found that the PDI measure “was unavailable for a period in 2015.” They also found that some of the weightings used in the PDI calculations were out of date, that the calculations include a known error, and that “PDI-P does not fully capture passenger preferences [and] PDI-F does not accurately measure disruption.” More generally, the metrics were found to be complex and opaque, poorly understood and thus not widely used, and are ‘lag variables’ calculated and presented in arrears. Moreover, they cannot provide information at a route level, despite the facts that possession planning tends to take place at that level, and a process of devolution of network management responsibilities to the routes is underway, increasing the need for route-level information.

For all these reasons, the PDIs tend not to inform or guide the possession planning process with a view to increasing network availability for users. Europe Economics found that

*Network Rail … does not take into account the PDI or the range of other possession indicators in its decision-making, and there is little understanding of how changes to the number / timing of possessions taken would impact on the PDI metric calculated.*

This is consistent with the findings of reviews of the network availability metrics undertaken for ORR and Network Rail in CP4 by the Part A independent Reporter, in which the PDI calculation process was found to be complex and unclear (Arup, 2010a), and it was questioned “whether the data is in fact being captured to drive improvement” (Arup, 2010b). In fairness to Network Rail, the various network availability metrics were not originally developed with a view to optimising possession planning, but, as noted by Armstrong et al. (2015), it did seem that an opportunity in this area was being missed. Europe Economics also found indications that the possession planning system relies heavily on staff experience rather than planning tools, and that possession planning on individual routes tends to be undertaken in isolation, without considering or coordinating with planned work elsewhere on the network. This means that optimal possession delivery is not always achieved, and “may lead to the overall volume of possessions being higher than it needs to be”, whereas

*reducing the number of possessions should be driven by the Schedule 4* *[S4] incentive, whereby planners are incentivised to optimise the use of possessions (e.g. by using them for more than one type of work where this is efficient) in order to reduce the number of possessions and resulting S4 payments.*

***3.2 Alternative approaches***

Partly in response to the issues described above, Britain’s Rail Delivery Group (RDG) investigated possible reforms to asset management and engineering access planning, and set out its findings (RDG, 2014). These included plans for (i) better cross industry access planning, with potential savings in Control Period 5 (CP5: 2014-2019) of £150m - £350m and (ii) improved productivity and ‘time on tools’ during possessions, with projected savings of £60m - £140m. The first of these was implemented as the Industry Access Programme (IAP), consisting of two phases, the first of which comprised nine steps, summarised by Armstrong et al. (2015) as follows:

1. *Review access requirements for the work that needs to be done in CP5 across all work programmes.*

*2. Collect data to compare whole-industry cost of current access strategy with alternative access options.*

*3. Assess trade-offs between delivery and operations for different access options, making use of decision support tools.*

*4. Review options to obtain cross-industry agreement on preferred access option.*

*5. Develop an agreed statement of the risks and benefits of the preferred access option.*

*6. Formalise and publish the agreed access option.*

*7. Manage change by assessing its impact on the access plan through its development.*

*8. Deliver the work and the associated amended timetable.*

*9. Review the access taken and the achieved vs. projected benefits, and capture any lessons to be learned for future reference.*

As RDG (2014) observed, this approach encourages and facilitates liaison and cooperation between Network Rail, train operators and contractors

*to agree the best access option which balances the costs for maintenance, renewals and enhancement work with revenue and customer impact.*

The approach was piloted on the South East route in 2013, and Phase 2 of the IAP aimed to develop a “new cross industry access and timetable planning process”, with the objectives of reducing the costs of M&R and enhancements planning and execution, and Schedule 4 compensation, and reducing disruption to railway users.

Both phases of the IAP thus seek to address the problems identified above, by improving engineering efficiency and reducing network access requirements and the associated disruption. However, according to Europe Economics (2017), Phase 1, and the approaches developed to identify least cost possessions for freight operators, have so far been restricted to the South East route and “there are no immediate plans to roll it out across other routes.” As part of Phase 2 of the IAP, a set of Access Framework Principles (AFPs) was developed, initially for the Wales route, the aim of which is, according to Europe Economics,

*to facilitate better long-term planning of access through a set of pre-consulted access patterns and guidelines, with associated governance.*

The access patterns and guidelines reflect train operator input and include:

* *Operator-specified access limitations*
* *Preferred time and hours*
* *Times of year to be avoided*
* *Diversionary route information*
* *Other key possessions (on other routes) that must be taken into account*

The AFPs provide additional criteria for consideration when planning engineering access, and inform possession planning negotiations between Network Rail and the operators; they have been applied in Wales and “developed for all routes but are not mandatory.” It is also understood that further work is required at the national, multi-route level, particularly in respect of diversionary routes and longer-term track ‘blockades’ for major works (Europe Economics, 2017).

The Europe Economics report goes on to consider alternatives to the PDI measures, focussing upon network availability. The alternatives include route-based PDIs, possession disruption based on Schedule 4 data (PDI-P already uses Schedule 4 as an input), comparisons between planned and actual timetables (already the basis of the Schedule 4 calculations, to determine cancelled stops and extended journey times and distances) and possession efficiency (with a view to ensuring that possession time is used effectively). However, as noted above, efficient possessions tend to be longer ones, where a smaller proportion of the overall time is required for setting up at the start and restoring the railway to normal use at the end. Ideally, and as also advocated by Li et al. (2013a), an improved metric should consider both possession efficiency and network availability by including both the engineering costs and the Schedule 4 costs (as a measure of, or at least a proxy for, the operational disruption caused). This should be done for individual pieces of M&R or enhancement work and also overall, for individual routes and, ultimately, for the network as a whole (another aspect for consideration is the risk of ‘premature renewal’ of assets that are not yet life-expired, and this should also be included in the assessment process). ORR (2018c) also produced a list of possible Network Availability metrics, including timetable changes and a ‘Quality Possession Metric’, but also including ‘early warning indicators’, and the number of days on which travel between key Origin-Destination pairs is impossible, as an incentive to ensure that diversionary routes are used wherever possible.

As the Europe Economics report acknowledges, possession planning is a complex optimisation process. However, the current approach to possession planning is unlikely to produce an optimal outcome, given that its effects on network availability are not explicitly considered, as noted above, and based as it is upon a process of negotiation and compromise between Network Rail and the individual operators, and conducted on a route-by-route basis, without generally taking account of the network as a whole.

Considerable work has been undertaken elsewhere on the application of optimisation techniques to M&R work generally, and to maintenance scheduling and possession planning in particular, dating back at least to the 1960s (e.g. Wagner et al., 1964). This work ranges from comprehensive, strategic M&R approaches based upon the maintenance of a given standard of track geometry, as investigated by Andrade and Texeira (2016), for example, to the efficient scheduling of track possessions, Initial work in this area tended to focus upon minimising the duration of track possessions (e.g. Budai and Dekker, 2004) or minimising delays to trains (Higgins et al., 1999). In the former category, Budai-Balke (2009) presents a comprehensive overview of mainly European approaches to the scheduling of preventive railway maintenance activities, including the IMPROVERAIL project, and a range of algorithmic approaches are presented to the solution of the Preventive Maintenance Scheduling Problem (PMSP). In a definition of the PMSP in an earlier paper, Budai et al. (2006) list among the inputs known execution/maintenance (i.e. construction) and possession (roughly equivalent to Schedule 4) costs, and a list of activities that can be combined in a single possession, and seek to minimise the overall possession and maintenance costs, as advocated above. The combination/clustering of maintenance tasks is also considered by Peng and Ouyang (2014): while their work is geared primarily towards the need of North American freight railroads and the organisation of work crews, it may also have some relevance to the operating context in Britain. Li and Roberti (2017) extend and combine some of these elements in the railway track possession scheduling problem (RTPSP), taking account of the variability of overall construction costs with possession duration, while also noting the difficulty of obtaining accurate prior valuations of these costs.

Li (2017) takes a broad view of the scheduling of railway maintenance, and presents two decision support systems (DSSs). The first of these has five phases, comprising data collection, technical optimisation to identify the minimal maintenance requirements, economic optimisation to minimise the costs associated with the minimum maintenance requirements, constrained optimisation to reflect operational conditions and enable the adjustment of input parameters, and evaluation. The second DSS considers life-cycle costs in the planning and evaluation of possession strategies, and both were found to have considerable potential for reducing total infrastructure costs while maintaining infrastructure quality. As described in the following section, these techniques (and others, as appropriate) will be further assessed in relation to the detailed characteristics and requirements of the possession planning regime in Britain, to identify the most appropriate means of reducing the construction and delay costs associated with track possessions, including the incorporation of Schedule 4 criteria. The authors’ immediate, short-term aim is to use combinations (and variations, to reflect unique local characteristics) of the approaches described above to reduce the overall construction and compensation costs associated with the M&R and enhancements works already planned, while the longer term objective is to develop an improved, strategic approach to condition-based maintenance planning, as set out by Li et al. (2013b), for example.

**4. Proposals for improvement**

As noted previously by Armstrong et al. (2015), the Industry Access Programme (IAP) seemed to be “a significant improvement upon previous practice” in possession planning, using a practical, empirical approach typical of the railway industry in Britain, and it is unfortunate that it does not appear to have been more widely and fully adopted. It is understood from discussions with Network Rail that their Transformation and Efficiency Team (TET) is continuing to work in this area, and that they are receptive to further input and contributions.

Based upon the preceding review of the current situation and research and practice elsewhere, it is clear that the application of formal, Operational Research-based scheduling and optimisation techniques to the possession planning process has the potential to deliver significant improvements, saving time and/or money, and improving engineering efficiency and/or network availability.

The availability of the necessary data is a key requirement, if these potential benefits are to be achieved. This data includes the lists of planned possession activities included in Network Rail’s work banks, and a railway network representation indicating route sections within which multiple pieces of work could potentially be undertaken in a single possession (where this is not precluded by access requirements for engineering trains), and corresponding diversionary routes, if any. This information should be readily available or relatively easy to compile, but it is likely to be more challenging to produce the different estimates of programme duration and (as also observed by Li and Roberti, 2017) costs required to evaluate alternative approaches to engineering interventions (i.e. series of short possessions vs. longer blockades), and the corresponding timetable changes needed to assess the alternative Schedule 4 – or equivalent – impacts. The authors have previously developed tools to calculate and forecast Schedule 4 payments, as described by Armstrong et al. (2015). The calculations are normally based upon the automated comparison of stopping patterns, journey times and distances in the normal (‘Corresponding’) and amended (‘Applicable’) timetables, but these changes can also be estimated and the results used for the purpose of forecasting. However, this approach would be quite difficult/time-consuming for the assessment of multiple alternative options, and an improved approach would be useful.

Such an approach to improving railway possession planning in Britain is proposed as follows:

* Ascertain details of the current state of possession planning in Britain
* Review, adapt and adopt possession planning and scheduling practices used in continental Europe and elsewhere for application in Britain, where this is practicable and consistent with local working practices and requirements, taking account also of the IAP and work being done by TET
* Identify the data requirements for these enhancements, and how the data may best be obtained and/or the requirements relaxed
* Develop a possession planning methodology and prototype tool, the results of which can be compared with existing methods and network availability measures, to ascertain and then reduce the extent of the gap between current and best practice

This approach, methodology and tool would help to identify improved approaches to maintaining Britain’s railways, improving network availability and reducing total engineering and possession-related costs, while also reflecting the comparative access requirements of train operators competing for residual train paths. This would be consistent with the objectives of the Operational Philosophy for Britain’s railways, developed for the Rail Safety and Standards Board (RSSB; 2014), one of whose requirements is that trains should be able to operate 24/7, with “reduced access to the network for inspection, maintenance and renewal works.” In the longer term, techniques and tools developed to minimise the impacts of planned, possession-related disruption might also be applied (in simplified/accelerated form as necessary, and/or in the form of improved contingency plans) to unplanned disruptions, reducing the impact of operational perturbations on services, and improving system resilience.

**5. Conclusions**

Passenger and freight traffic growth over recent decades, while welcome, presents Britain’s railways with significant challenges in the form of increased maintenance and renewals needs, and reduced network ‘downtime’ in which to meet these, resulting in increased engineering and possession compensation costs, while also providing less network availability for operations than is ideally required. While the existing approach to possession planning works reasonably well, it does not make proactive use of network availability metrics, and has considerable scope for improvement in terms of reducing total engineering and possession compensation costs, and improving the balance between network access and availability.

These issues can be partly addressed by means of improved infrastructure design, drawing upon the outputs of the *Track to the Future* (T2F; 2018) research project, for example, and also through increased use of RCM and predictive and condition-based maintenance, and the use of more efficient, less disruptive engineering and construction techniques. However, while improved engineering efficiency is a necessary and desirable element of reducing M&R costs, it is not in itself sufficient to fully address the issue, and improved planning of the timing, sequencing, and, where appropriate, combination of activities is essential if the total engineering and possession-related costs are to be reduced and, ideally, minimised.

As well as describing the current situation and recent developments in Britain’s railway industry, this paper presents scheduling and optimisation approaches applied elsewhere to the process of possession planning with demonstrable benefits, and sets out a proposed approach to adapting them to and incorporating them in the domestic industry, while also identifying potential gaps to be filled in terms of data availability. It thus sets out a practical, pragmatic approach to balancing network access and availability, and exploiting ‘possession synergies’, where possible, with a view to achieving the optimal trade-off between access to and availability of the railway network.

**Acknowledgements**

Part of this paper draws on work undertaken for the *Track 21* (EP/H044949/1) and *Track to the Future* (EP/M025276/1) projects, funded by the Engineering and Physical Sciences Research Council (EPSRC).

**References**

Andrade, A.R. and Teixeira, P.F. (2016), *Exploring Different Alert Limit Strategies in the Maintenance of Railway Track Geometry*. In: Journal of Transportation Engineering, 142(9): 04016037

Armstrong, J., Preston, J and Hood, I. (2015), *Possession Compensation and Network Availability on Britain’s Railways*. In: Proceedings of the 6th International Seminar on Railway Operations Modelling and Analysis (RailTokyo2015), Tokyo, Japan

Armstrong, J. and Preston, J. (2017), *Benefits from the Remote Monitoring of Railway Assets*. In: Proceedings of the Institution of Civil Engineers – Transport (Ahead of Print)

Arup (2010a), *Independent Reporter (Part A) Q3 Data Assurance Report: Safety Risk, Network Availability, Infrastructure Condition Report (ICR) and Network Condition Report (NCR)*. See http://orr.gov.uk/\_\_data/assets/pdf\_file/0008/2015/reporters-audit-ove-arup-feb10.pdf (Accessed 7 September 2018)

Arup (2010b), *Independent Reporter (Part A) Q2 2010-11 Data Assurance Report: Network Availability*. See http://orr.gov.uk/\_\_data/assets/pdf\_file/0014/2039/reporters-ove-arup-data-assurance-q2-2010-11.pdf (Accessed 7 September 2018)

BBC (2014), *Rail regulator to investigate rail work delay chaos*. See <https://www.bbc.co.uk/news/uk-england-london-30607689> (Accessed 4 September 2018)

Budai, G. and Dekker, R. (2004). *A dynamic approach for planning preventive railway maintenance activities*. In: Advances in Transport, 15, 323-332

Budai, G., Huisman, D. and Dekker, R. (2006). *Scheduling preventive railway maintenance activities*. In: Journal of the Operational Research Society, 57:9, 1035-1044

Budai-Balke, G. (2009), PhD Thesis: *Operations Research Models for Scheduling Railway*

*Infrastructure Maintenance*. See [http://repub.eur.nl/pub/16008/thesis\_GabriellaBudaiBalke\_TI456.pdf](https://www.dropbox.com/referrer_cleansing_redirect?hmac=o0Y%2Fs13d6%2Fk9eJLn7DAkfTHdW47unc3IC%2B%2Fn9MeNkfA%3D&url=http%3A%2F%2Frepub.eur.nl%2Fpub%2F16008%2Fthesis_GabriellaBudaiBalke_TI456.pdf) (Accessed 10

September 2018)

DfT (2018), *Lane Rental Schemes: Guidance for English Local Highway Authorities*. See <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/746070/lane-rental-bidding-guidance.pdf> (Accessed 8 May 2019)

DfT and ORR (2011), *Realising the Potential of GB Rail: Final Independent Report of the Rail Value for Money Study*. See <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/4204/realising-the-potential-of-gb-rail.pdf> (Accessed 5 September 2018)

EIM, EFRTC and CER (2011), *Report from the EIM-EFRTC-CER Working Group on Market Strategies for Track Maintenance & Renewal: Follow Up to the Conclusions of the EC INNOTRACK Project/WP5*. See <http://oldsite.riagb.org.uk/wp-content/uploads/files/MarketStrategyReport.pdf> (Accessed 5 September 2018)

Europe Economics (2017), *Availability Output Measure Review*. See http://orr.gov.uk/\_\_data/assets/pdf\_file/0015/25305/availability-output-measure-review.pdf (Accessed 1 August 2018)

Guardian (2014), *Network Rail bosses could face grilling over Christmas chaos*. See <https://www.theguardian.com/business/2014/dec/29/network-rail-christmas-chaos> (Accessed 4 September 2018)

Higgins, A., Ferreira, L. and Lake, M. (1999). *Scheduling track maintenance to minimise overall delays*. In: Proceedings of The 14th International Symposium on Transportation and Traffic Theory, Jerusalem, Israel

Li, R. (2017), PhD Thesis: *Phase-based Planning for Railway Infrastructure Projects*. See <http://orbit.dtu.dk/files/143903449/RuiLi_PhDThesis.pdf> (Accessed 10 September 2018)

Li, R., Landex, A., Nielsen, O.A. and Madsen, S.N. (2013a), *The potential cost from passengers and how it impacts railway maintenance and renewal decisions*. In: Proceedings from the Annual Transport Conference (Trafikdage) at Aalborg University, Denmark

Li, R., Landex, A., Nielsen, O.A. and Madsen, S.N. (2013b), *Framework for Railway Phase-based Planning*. In: Proceedings from the Annual Transport Conference (Trafikdage) at Aalborg University, Denmark

Li, R. and Roberti, R. (2017), *Optimal Scheduling of Railway Track Possessions in Large-Scale Projects with Multiple Construction Works*. In: Journal of Construction Engineering and Management, 143(6): 04017007

Network Rail (2017), *Freight Network Study*. See <https://www.networkrail.co.uk/wp-content/uploads/2017/04/Freight-Network-Study-April-2017.pdf> (Accessed 5 September 2018)

Network Rail (2018a), *Payments for planned disruption on the railway*. See <https://www.networkrail.co.uk/industry-commercial-partners/information-operating-companies/payments-for-planned-disruption-on-the-railway/> (Accessed 4 September 2018)

Network Rail (2018b), *Payments for planned disruption on the railway made under schedule 4.* See <https://cdn.networkrail.co.uk/wp-content/uploads/2017/12/Payments-for-planned-disruption-on-the-railway-made-under-schedule-4-and-the-corresponding-ACS.xlsx> (Accessed 5 September 2018)

Network Rail (2018c), *Engineering Access Statement, Sunday 10th December 2017 to Saturday 08th December 2018*. See <http://archive.nr.co.uk/browse%20documents/Rules%20Of%20The%20Route/Viewable%20copy/MENU/EASMENUyearXX.pdf> (Accessed 6 September 2018)

Network Rail (2018d), *Network availability*. See https://www.networkrail.co.uk/who-we-are/how-we-work/performance/network-availability/ (Accessed 7 September 2018)

Network Rail (2018e), *Network Rail Possession Indicator Report Period 04 2018/19*. See <https://cdn.networkrail.co.uk/wp-content/uploads/2018/08/Possession-Indicator-Report-for-04-2018-19.pdf> Accessed 7 September 2018)

ORR (2018a), *Passenger Rail Usage 2017-18 Q4 Statistical Release*. See <http://orr.gov.uk/__data/assets/pdf_file/0014/28013/passenger-rail-usage-2017-18-q4.pdf> (Accessed 5 September 2018)

ORR (2018b), *Freight Rail Usage 2017-18 Q4 Statistical Release*. See <http://orr.gov.uk/__data/assets/pdf_file/0010/27919/freight-rail-usage-2017-18-quarter-4.pdf> (Accessed 5 September 2018)

ORR, (2018c), *Summary of responses to ORR’s consultation on route requirements and scorecards*. See <http://orr.gov.uk/__data/assets/pdf_file/0020/26471/summary-of-responses-to-orr-consultation-on-route-requirements-and-scorecards-january-2018.pdf> (Accessed 10 September 2018)

Peng, F,. and Ouyang, Y. (2014). *Optimal Clustering of Railroad Track Maintenance Jobs*. In: Computer-Aided Civil and Infrastructure Engineering, 29, 235-247

Railway Gazette, (2019), *Network Rail reorganisation aims to bring ‘radical change’*. See <https://www.railwaygazette.com/news/single-view/view/network-rail-reorganisation-aims-to-bring-radical-change.html> (Accessed 26 March 2019).

RDG (2014), *Running a better railway: How changes to planning rail improvement work can deliver savings and better services*. See <https://www.raildeliverygroup.com/about-us/publications.html?task=file.download&id=258> (Accessed 7 September 2018)

RSSB (2014), *Operational Philosophy for the GB Mainline Railway*. See <https://www.sparkrail.org/_layouts/15/Rssb.Spark/Attachments.ashx?Id=75NEMTS3ZVHP-8-8170> (Accessed 10 September 2018)

T2F (2018), *Welcome to Track to the Future*. See http://t2f.org.uk/ (Accessed 10 September 2018)

Wagner, H., Giglio, R. and Glaser, R. (1964), *Preventive Maintenance Scheduling by Mathematical Programming*. In: Management Science, 10(2): 316-334