RIA Electrification Cost Challenge

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Railway Industry Association

The voice of the UK rail supply community

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Executive Summary

In 2018, the Railway Industry Association (RIA) launched a new initiative to see how the costs of rail electrification schemes could be reduced. This initiative has become known as the Electrification Cost Challenge. It brings together a number of Tier 1 and Tier 2 contractors, consultants and suppliers of electrification infrastructure together with other stakeholders to investigate why costs are high and what can be done to reduce them.

Early output from this process presented to the UK Parliamentary Transport Select Committee Inquiry into 'Rail infrastructure Investment' led to Government publicly committing to working with RIA to produce a report on cost-effective electrification by September 2019[A]. This report is intended as an input to that process.

The purpose of this report is to:

- Assist industry[B] and Government decision making on rail electrification.
- Restore Government confidence in the rail industry to deliver electrification schemes at an affordable cost on time and to budget, for the benefit of passengers and freight users.
- Identify good practice in delivering electrification schemes and effect a significant change across the whole industry in the way that electrification projects are planned and delivered, from initial business case to energisation.
- Call for a rolling programme of electrification to enable the industry to deliver schemes at significantly lower cost, retain learning and skills, and incentivise investment.

Government perception of rail electrification schemes has arisen largely from the experience of delivering the Great Western Electrification Programme (GWEP), the first major electrification programme since 1992, on which the programme and budget significantly overran. GWEP was, in fact, only about 50% of the total electrification programme launched in 2009 and much was delivered successfully. However, the almost three-fold increase in the estimated cost of electrifying the mainline between London and Swansea, from the scheme being announced in 2009 up to the Hendy Review in November 2015, resulted in the Government's decision, in July 2017, to cancel electrification of the main line between Cardiff and Swansea and on the Midland Main Line.

It was apparent that there was little Government support for further electrification; an approach that seemed unlikely to change without clear evidence of its affordability and deliverability, hence the need for the RIA Electrification Cost Challenge and this report.

This report will:

- Set out the benefits of electrification for passengers and customers, and how it supports the Government's Decarbonisation Challenge;
- Summarise UK electrification strategy since 2007;
- Discuss the Great Western Electrification Project (GWEP) and the reasons that it failed;
- Highlight the lessons that have been learnt; and
- Highlight evidence that electrification can be, and is being, delivered for between 33%-50% of the costs of some recent projects using examples from around the UK and internationally.

A. The Transport Select Committee recommendation and the Government's response can be found at – https://publications.parliament.uk/pa/cm201719/cmselect/cmtrans/1557/155702.htm

B. In this report the term 'industry' includes Network Rail and its suppliers

The respective sections in this report on each of the elements needed to deliver an electrification scheme sets out:

- The background;
- The Great Western experience;
- Conclusions and lessons learnt – these serve as a best practice guide to future electrification schemes;
- Where we are now; and
- Recommendations for future projects aimed at reducing the cost of electrification based on the lessons learnt from previous schemes.

The main recommendations identified in the report, include:

Cost

1. To establish a 10 year rolling programme of electrification to progressively lower the long-term operating costs of the railway towards European norms and to support investment in people, process and plant.
2. To endorse electrification as the first choice in a hierarchy of options for decarbonising the rail network.
3. To ensure future projects adopt a realistic programme and risk apportionment.
4. To use the Rail Method of Measurement to allow comparison between projects on a consistent basis.

Standards

5. Future projects should use proven systems that comply with the relevant standards.
6. Avoid developing and obtaining approval for new systems as part of a project.
7. Review the Network Rail (NR) standards suite and risk allocation to support output specification.
8. Implement a 'standards freeze' for the duration of a project.

Foundations

9. Have an appropriate level of design maturity before commencing foundation installation.

Masts

10. Future procurement should allow for alternative designs that deliver outcome requirements, including life cycle reliability and maintainability against the benchmark of NR Master Series.

Overhead Line Equipment (OLE)

11. To maximise value for money, the procurement process should allow for proven compliant proprietary designs to deliver outcome requirements, including life cycle reliability and maintainability against the benchmark of NR Master Series, rather than mandating the use of NR Master Series in major electrification schemes.

Power Supply

12. At the optioneering stage, future projects should ensure that all options for traction power supplies are considered, including distribution and traction power storage options.

Clearances to Bridges and Structures

13. Wherever possible, future projects should secure all necessary consents, such as via a Transport Works Order, and undertake route clearance in advance of OLE works, even if this means extending the programme.
14. Sufficient detailed design should be undertaken at GRIP 3 (Option Selection)

Plant

15. The recommendation to establish a 'rolling programme' of electrification would both reduce the competition for scarce plant by allowing forward planning and create the incentive to, over time, invest in more productive plant, process and skills to further optimise delivery.

A full list of the report recommendations is included as **Appendix 1**. A summary of the best practice identified in the delivery of electrification schemes is included as **Appendix 2**.

Contents

1. Introduction

In 2009 the UK Government announced a major programme[1] to electrify significant parts of the UK's mainline rail network, starting with the Great Western route from London to Swansea and the line between Liverpool and Manchester. This was the first major electrification[2] programme since the 1980s and suppliers were encouraged to invest very rapidly in the necessary skills and equipment to support the programme.

The Great Western Electrification Programme (GWEP) was announced in 2009, and was set to cost £1bn to electrify the route to Swansea by December 2017. By the time of the Hendy Review in November 2015 the estimated cost had risen to £2.8bn for electrification to Cardiff by December 2018. In July 2017 the Government announced the cancellation of electrification between Cardiff and Swansea and on the Midland Main Line, north of Kettering. It opted instead for diesel 'Bi-mode' trains.

So what went wrong?

The GWEP programme was over-ambitious in trying to introduce internationally novel technology – Overhead Line Equipment (OLE) and Plant – on a live project resulting in the design and development of the equipment being incomplete before construction started. Additionally, there was a non-negotiable date for the introduction of new electric trains over which industry had no control, announced before the infrastructure project had been fully scoped and costed, and which added a further major level of risk to timely and cost-efficient delivery. All this against the background of an industry that had not undertaken an electrification project the scale of GWEP for 20 years and so skills and experience needed to be rebuilt.

To further compound the challenge, an unprecedented number of other new electrification projects were commenced at the same time, all requiring and competing for similar resources. Although, as will be discussed later, most electrification projects were delivered successfully, GWEP, which was the largest and a number of other projects ran into difficulty, and the programme and therefore budget significantly overran.

The Government progressively lost confidence in the rail industry to deliver and by July 2017 – when it had cancelled electrification of a number of lines, including the line between Cardiff and Swansea – it was clear that there was little support for further electrification. This would continue unless industry was able to change Government perception of its ability to deliver electrification on time and to budget hence the need for the Railway Industry Association (RIA) Electrification Cost Challenge and this report.

What should electrification cost?

RIA's position on electrification is clear. Whilst we understand the Governments decision in July 2017, given emerging costs on GWEP, **electric traction remains the optimal technical solution for an intensively used railway**; and, as confirmed by the recent Decarbonisation Taskforce Interim Report[3], **is the first consideration in**

1 http://www.railwaysarchive.co.uk/docsummary.php?docID=2162
2 This video provides a useful introduction to electrification benefits and delivery: Electrifying the railway – Network Rail
3 https://www.rssb.co.uk/Library/improving-industry-performance/Rail-Industry-Decarbonisation-Task-Force-Initial-Report-to-the-Rail-Minis-

any move to decarbonise the railway by 2040.

The costs of operating electric trains are also significantly lower than those of diesel trains; and electric trains can provide greater journey time, customer ambience and environmental benefits (See Section 3.0). The issue is that **the cost and delivery risks of conventional (or continuous) electrification are perceived to be too high.**

This perception has come about largely due to collective rail industry failure to successfully deliver GWEP and the failure to flag up the reasons for this sufficiently early.

This report will:

- Discuss the reasons that GWEP and several other projects failed;
- Highlight the lessons which have been learnt; and
- Demonstrate electrification can be, and is being, delivered for between 33%-50% of the costs of some recent projects using examples from around the UK and internationally. Summarising Section 6.0:
  - Today, a well delivered 'simpler' electrification project should **cost £750k to £1m/stk**[4] (for the OLE, Power and associated costs)
  - More complex projects **should not normally exceed £1.5m/stk** which compares to three recent projects which experienced delivery difficulties and cost between £2m and £2.5m/stk

As described later in the report (Sections 7 to 15), completed electrification projects have resulted in a huge amount of learning and innovation which gives RIA and its members the confidence that future electrification projects can be delivered affordably. Furthermore, in the near future, the industry – both client and supplier – **can reduce costs still further if there are shared project objectives, a realistic plan and a consistent, visible, pipeline of work.**

What should happen now?

RIA believes that, given the ambition to decarbonise the railway, there is a great opportunity to reduce the long-term costs of the network by combining the best of new and proven technology.

What's more, the Government has publicly committed to working with RIA to produce a report on cost-effective electrification by September 2019[5]. On 28 June 2018, the UK Parliamentary Transport Select Committee made the following recommendation, as part of its Inquiry into 'Rail infrastructure Investment':

> *Electrification should be delivered through a long-term rolling programme, in which the Department, Network Rail and the wider industry learn the lessons of earlier schemes and strive to reduce the costs.* ***The Department and Network Rail should engage with the Railway Industry Association's Electrification Cost Challenge initiative, and together produce a report on cost effective electrification within 12***

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4 Single track kilometre – the measure of electrification. Electrifying 1 km of two track railway is 2 stk.

5 The Transport Select Committee recommendation and the Government's response can be found at – https://publications.parliament.uk/pa/cm201719/cmselect/cmtrans/1557/155702.htm

> ***months**. (Paragraph 45)*

On 19 September 2018, the Government responded:

> *We will continue to engage with the industry and RIA on initiatives that could reduce the cost of enhancing the railway and improve the outcomes for its users. We will work with RIA to produce a report as recommended and will revert to the Committee on the most appropriate timetable to deliver a meaningful report.*

However continuous electrification will not be the answer everywhere. In simple terms, RIA believes that the future rail passenger[6] network can be considered in three categories:

1. The core electrified network, where traffic is most intense and there is therefore a business case to electrify;

2. The parts of the network for which, due to lower traffic levels and/or long distances, there is unlikely to be a business case for continuous electrification and where consequently new technology low-carbon self-powered trains and the relevant refuelling/ recharging infrastructure will need to be developed[7]; and

3. The parts of the network between so-called Category 1 and 2, which can be served, in the medium term, by bi-mode trains which draw power from the OLE in electrified areas but are self-powered 'off the wires' currently by diesel[8] but increasingly for lighter duty cycles by other zero carbon technologies.

A forthcoming second Decarbonisation Taskforce Report will examine the economics and route map for an approach of this sort.

RIA believes that this presents the opportunity to progressively lower the long-term operating costs of the railway through a rolling programme of electrification which progressively expands the 'frontier' of Category 1 parts of the network, supports route improvements for customer benefit and gradually reduces the proportion of category 3 routes. As demonstrated (Section 6.5) such a rolling programme in Germany, by retaining learning and skills and incentivising investment, is able to deliver at significantly lower cost than the best costs currently achieved in the UK

RIA recommend **a rolling programme sufficient to keep two to three delivery teams consistently in action** each delivering 75-100 single track kilometres (stk) per annum, for at least 10 years, across the UK which would maintain a core capability in design and delivery and support a culture of continuous improvement. This would be expected to further reduce the current costs towards European norms. However, it is important to recognise that delivering at these costs will also require adoption of the good practice identified in this report and a significant change across the whole industry in the way that electrification projects are planned and delivered from initial business case to energisation.

6 For freight trains, there is not currently a viable alternative to diesel for operating 'off the wires' and therefore further electrification of core routes and cleaner diesel options are important to reduce the carbon impact of freight operations.
7 Although, as the decarbonisation report notes, "there is no silver bullet to replace diesel for traction"
8 The major challenge with any bi-mode rolling stock is delivering the same performance as an electric train with an on-board power source the mass of which must also be moved. For example, a typical diesel bi-mode has 60% more power available in electric mode compared to diesel mode.

2. Background to the RIA Electrification Cost Challenge

It was apparent to RIA by late 2017 that because of major cost and programme overruns on GWEP, the reputation of railway electrification had suffered to the extent that there was a risk there would be no more electrification projects in England or Wales. Already major electrification schemes such as Midland Main Line were being cut back with bi-mode and other new forms of traction being cited as an alternative solution. Whilst bi-modes have a role in providing through services beyond 'the end of the wires', they are more expensive to buy and operate than an electric train and it is RIAs view that electrification and electric trains are the most efficient way to run an intensively used railway provided the necessary electrification infrastructure can be delivered affordably. This had clearly not been the case with some recent projects including GWEP, but RIA was aware of other projects in the UK and internationally that were being successfully delivered at unit rates at or below the original estimate for GWEP. This suggested that **projects like GWEP should not be the benchmark for electrification costs**.

It was clear to RIA that the perception of high cost and delays on some early projects, notably GWEP, were in danger of destroying confidence in future electrification which can deliver significant benefits for passengers, freight users and the environment. In 2018, RIA therefore established the Electrification Cost Challenge to ensure that objective and independent evidence was available, and that electrification remained one of the options to be considered when upgrading the UK railway system and its trains as demonstrated by a range of more successful projects.

During 2018 RIA presented their emerging evidence to the Transport Select Committee who recommended in June that:

> *Electrification should be delivered through a long-term rolling programme, in which the Department, Network Rail and the wider industry learn the lessons of earlier schemes and strive to reduce the costs. **The Department and Network Rail should engage with the Railway Industry Association's Electrification Cost Challenge initiative**, and together produce a report on cost effective electrification within 12 months. (Paragraph 45)*

The Government responded in November[9] saying:

> *Government partially accepts this recommendation. In making decisions about whether an enhancement should progress through the pipeline we will consider whether it provides the best outcomes for passengers using the seven Principles for Investment set out in the RNEP (p.7). This means that Government will remain agnostic on how the outcome can best be achieved. The RNEP makes clear that all rail enhancements must be led by the needs that they are fulfilling rather than the methods by which they propose to fulfil them.*

9 The Transport Select Committee recommendation and the Government's response: https://publications.parliament.uk/pa/cm201719/cmselect/cmtrans/1557/155702.htm

> *We do not, therefore, expect proposals for new enhancements to begin with a pre-defined solution or input, such as electrification, but rather to set out the case for making an intervention to support a desired outcome. The RNEP sets out a rolling programme of investment in rail enhancements, including relevant and value for money electrification schemes. This approach only commits to take a project forward to the next stage when we have an appropriate understanding of how much it will cost, how long it will take, and the benefits it will deliver. This will avoid the problems of the past, where funding was committed before schemes were fully developed.*
>
> *We will continue to engage with the industry and RIA on initiatives that could reduce the cost of enhancing the railway and improve the outcomes for its users.* ***We will work with RIA to produce a report as recommended*** *and will revert to the Committee on the most appropriate timetable to deliver a meaningful report.*

This document is intended as an input to the dialogue with Network Rail which has already started and DfT to produce the report recommended above with the objective of ensuring that electrification remains the best option for future railway upgrades where it has a sound business case. Clearly demonstrating that electrification can be confidently delivered at an acceptable cost helps increase the number of routes which will have a good business case through reducing long term railway rolling stock operating costs.

RIA recognises that there are some parts of the network which are unlikely to ever have a business case for continuous electrification and therefore originally intended that this report would also consider the 'off the wires' options to provide continuous journeys such as bi-mode trains and discontinuous (short gaps or earthed sections) and discrete (long gaps) electrification facilitated by energy storage. In the event this was overtaken by the work of the Decarbonisation Taskforce, of which RIA was a member.

The Taskforce published their Interim Report[10] on 31 Jan 2019 finding that "*where it is cost-effective to do so, electrification is the benchmark for the most carbon efficient way to power trains. It will remain so as the carbon impact of grid electricity continues to fall, and traction comparisons have to be made in this light.*" **Consequently, electrification is the first choice in a hierarchy of options for decarbonising the network**.

This Electrification Cost Challenge report will feed into the second stage of the Taskforce work which includes economic appraisal and a route map.

In the preparation of this report during 2018 RIA has consulted with its members and stakeholders, notably, but not exclusively, those listed in Appendix 3, to understand what lessons can be learnt from the recent experience of electrification, both good and bad, and to establish what electrification should cost. RIA would like to take this opportunity to thank all those who provided support and evidence for this project however the Conclusions drawn and Recommendations are RIA's responsibility.

10 https://www.rssb.co.uk/Library/improving-industry-performance/Rail-Industry-Decarbonisation-Task-Force-Initial-Report-to-the-Rail-Minister-January%202019.pdf?web=1

3. The Benefits of Electrification

Around 40% of the UK rail network is electrified - much less than comparable European countries which are typically 60% or more electrified. Railway electrification has been shown to benefit passengers and the wider travelling public as it is:

- **Better for the environment** with carbon emissions 60% lower than those from diesel trains today and 80% less[11] with the estimated 2040 grid mix. They also produce no air pollutants at the point of use;
- **Quieter,** reducing noise pollution for those living and working near the tracks and reduces noise and vibration for passengers;
- **Costs less in the long term** when compared to the whole-life costs of diesel services[12];
- **Improves journey times** due to superior braking and acceleration;
- **Is lighter,** meaning less wear to the track and therefore less maintenance; and
- **Reduces passenger delays,** as electric trains are more reliable than diesel trains.

The Decarbonisation Taskforce Report also makes clear[13] that, whilst new technology has a significant role to play, **only electric and diesel traction can deliver the full range of requirements including high speed, long distance passenger and freight haulage**. Therefore, as the railway moves towards de-carbonisation and conventional diesel traction becomes increasingly unacceptable then further electrification should be considered wherever there is a good business case to do so.

In simple terms a business case compares the monetised value of the benefits cited above with the costs. A problem in the UK rail industry is that the benefits are largely realised by the public and train operators and the costs are experienced by the Infrastructure Manager, usually Network Rail. Presently Government has the role of 'squaring this circle' and making the assessment as to whether the high upfront capital costs of electrification will be rewarded by longer term benefits. In this respect the business case for any electrification scheme must compete with other priorities for railway or wider government investment.

The opportunities presented by new traction technology will not make these 'whole-system' business cases any easier as issues such as duty cycles and refuelling/ re-charging infrastructure will also need to be considered. Electrification is a well understood technology but needs to demonstrate that it is affordable, and that it is the most effective way to run an intensively used railway provided the cost is acceptable. Hence this report.

11 Fig.1 RSSB Research project T1145 'Options for traction energy decarbonisation in rail'. Note that, if implemented, advanced diesel hybrids could be 40% more carbon efficient that current diesels.

12 Electric trains are over 35% cheaper to operate than diesels according to the 2009 DfT Rail Electrification Paper. They require less maintenance and have considerably lower energy costs since electricity is a significantly cheaper fuel than diesel. They are lighter and so do less damage to the track. Although there are additional costs involved in maintaining electrification infrastructure, these are significantly outweighed by the train operating cost savings.

13 Decarbonisation Taskforce Interim Report Para 59

Fleet mix is also an important factor. In the original GWEP scheme approximately two-thirds of the fleet were pure electric and the remaining third was diesel bi-mode which could operate as electric trains when ‘under the wires’ but still provide through services to destinations ‘off the wires’. This was a compromise that realised the maximum possible benefits from electrification whilst accepting some benefit reduction due to the additional vehicle and track maintenance costs of the bi-mode. When the fleet, due to construction delays, became 100% bi-mode the benefits were further reduced.

4. UK electrification strategy since 2007

Since 2007 rail policy in England and Wales on electrification has changed several times as summarised in Figure 1 and in a Parliamentary Briefing Paper from 27 July 2017[14]. In Scotland the policy since 2009 has been consistent, in favour of a rolling programme of electrification[15] which the analysis in (See Section 6.0) suggests has delivered valuable benefits. Figure 1 also includes a timeline relating specifically to Great Western.

Figure 1 – The Recent history of railway electrification in England and Wales

Date	Announcement/ Document	GWEP Progress
2007	• RSSB T633 Research Report estimates electrification costs at £500 to 650k per stk • July - DfT White Paper delays electrification pending clarification on future energy sources and until cab signalling completed • 23 Oct - Network Rail and Association of Train Operating Companies write to DfT – electrification should not be delayed as benefits will be realised sooner and electrification has multiple sources of low carbon supply • 9 Sept - DfT respond - a rolling programme will contribute to reducing costs	• No GW electrification – new IEP trains to be diesel
2009	• July – DfT Rail Electrification Paper[16] announces a £1.1Bn electrification programme including Liverpool to Manchester and the Great Western Main Line to Swansea • Oct – Scottish government “Strategic Transport Projects Review”[17] proposes a rolling programme of electrification of the bulk of the network to reduce journey times and emissions • Major electrification programme announced in England and Wales	• GWML to cost c£1bn - c£1m per stk • GWR fleet to be Electric and B-Mode IEP

14 https://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN05907#fullreport
15 In the context of the Rail Enhancements and Capital Investment Strategy (the “pipeline” approach) and the funding available to Scotland. Referenced for example in Para 3.7 of the 2017 Transport Scotland HLOS https://www.transport.gov.scot/media/39496/high-level-output-specification-hlos-for-control-period-6-final.pdf
16 https://webarchive.nationalarchives.gov.uk/20090805225151/http://www.dft.gov.uk/pgr/rail/pi/rail-electrification.pdf
17 https://www.transport.gov.scot/publication/strategic-transport-projects-review-final-report/

Date	Announcement/ Document	GWEP Progress
2011		• Oct - NR commits to buying 'factory train' (Section 13)
2012	• Electrification Route Utilisation Study considers the possibility of discontinuous (short gaps) and discrete (long gaps) electrification, facilitated by energy storage	• Apr - Development starts on 'Series 1' OLE system (Section 10) • July - Order placed for GWR fleet to be Electric and Bi-Mode with delivery by Feb 2018 • July – Electrification of London to Swansea included in High Level Output Statement (HLOS)
2013	• Jan – NR commits to electrification in Strategic Business Plan	• GWML to Cardiff to cost £1.1bn, c £1.1m per stk
2014		• GWML to Cardiff to cost £1.7bn, c £1.7m per stk • Jan – Construction Starts • July – Factory Train Completed
2015	• Midland Main Line (MML) "paused"	• May – 'Series 1' catalogue completed • Nov – Hendy replan delays GWEP completion to Cardiff by one year, to Dec 2018
2016		• Critical National Audit Office (NAO) Report - GWML to Cardiff to cost c£2.8bn, c£2.8m per stk, GWR fleet to be 100% bi-mode
2017		• July - Cancellation of Cardiff-Swansea and MML, facilitated by the availability of diesel bi-mode trains • Dec – original planned date of electric services to Swansea (DfT 2009) • Dec – electric services to Cardiff (NR 2012 plan)
2018	• Second NAO[18] report identifies that the cancellation was due to affordability, not because new technology was available • RIA present evidence to UK Parliamentary Transport Select Committee (TSC)	• Dec –planned date of electric services to Cardiff after 2015 Hendy Replan
2018	• Jo Johnson challenge to "remove diesel only trains from the Network by 2040" • Government responds positively to the TSC recommendation to work with RIA on cost effective electrification	

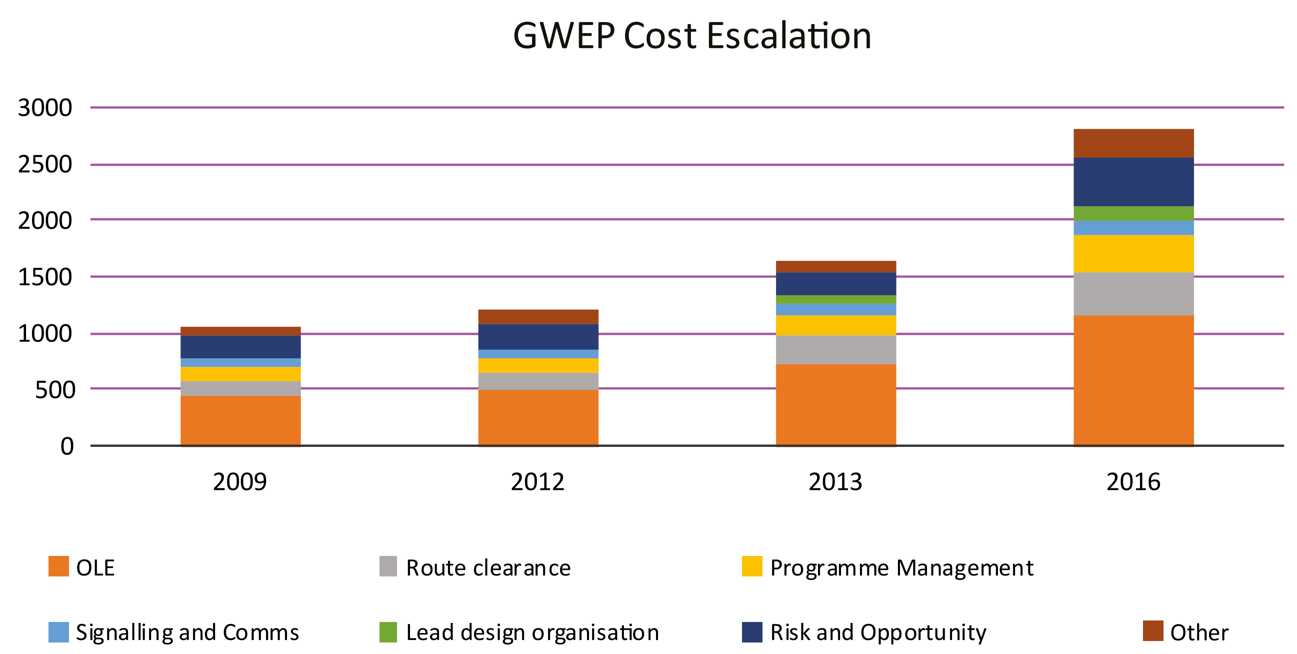
18 https://www.nao.org.uk/report/investigation-into-the-department-for-transports-decision-to-cancel-three-rail-electrification-projects/

5. Electrifying the Great Western

Electrification is costly by its nature as it requires not just masts and wires but also new power supplies and other enabling works including reconstructing or adapting bridges and other structures to accommodate the wires. It is clearly more challenging and costlier to electrify a busy four track high speed main line railway like Great Western than it is to work on a lower speed two track railway. Also, due to the growing use of the network the opportunities to close the railway for engineering works have reduced significantly both in number and duration. This increases the cost and length of time required for the work, but it does help ensure the line stays open for passenger and freight use.

However as illustrated by Figure 2 the estimated cost of GWEP increased from £1bn in 2009 to £2.8bn in 2016.

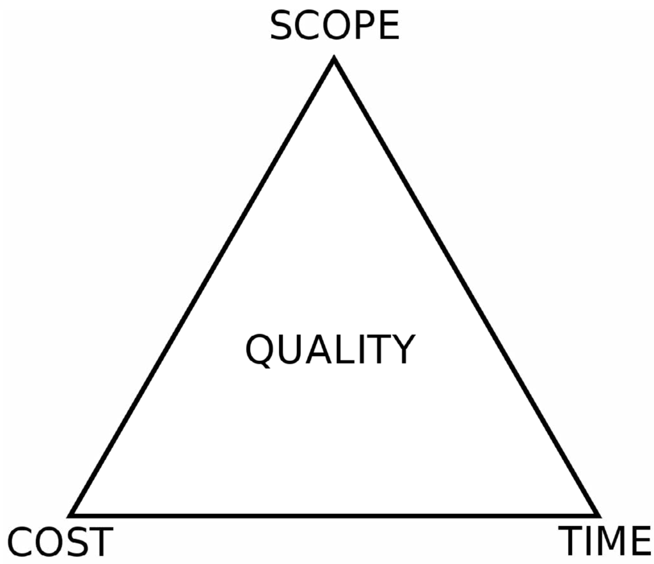
Fig. 2 – GWEP Cost Escalation from 2009 to 2016



(RIA analysis of 2016 NAO Report)

There are a number of reasons for this cost escalation which are discussed in detail for each component of an electrification scheme in Sections 7 to 15. It is significant that the greatest increase was after 2013 when delivery commenced and the largest increases were in risk and OLE reflecting the productivity and rework issues described below. In summary the major cause of the issues on Great Western can be explained by the classic project management time-cost-scope-quality schematic in Figure 3.

Figure 3 – time-cost-scope-quality



Once the end date was fixed by the delivery dates of the trains, and given the scope was initially poorly understood then to maintain quality the only remaining variable was cost which would inevitably rise. The causes of this escalation include:

- **Unrealistic Programme:** The completion date for the programme was set by the delivery date for the new trains – ie before Network Rail were able to fully scope and programme the works or engage suppliers to support them. The National Audit Office (NAO) report found:

  > *The 2012 schedule for the infrastructure programme was unrealistic. Network Rail has had to carry out a complex set of infrastructure works, on a working railway that passes through heritage areas and areas of outstanding natural beauty. When the Department [for Transport] entered into a contract to buy the Intercity Express trains, creating fixed deadlines for electrification, Network Rail had only just identified that it would need to develop a new type of electrification. The electrification timetable was not based on a bottom-up understanding of what the works would involve (paragraphs 2.6 and 2.7).*

- **Immature Estimates:** GWEP was included in the 2009 electrification strategy on the basis of a very early estimate of scope and cost and without the benefit of any recent cost data, as the last significant electrification scheme (East Coast) finished in 1992 and there was very little survey information from the Great Western route. The 2009 and later 2012 estimates were therefore understated. However, costs should still not have escalated three-fold as they did.

- **Novel Technology:** Network Rail correctly recognised that productivity in the limited track access periods available was key to minimising the programme length. They therefore set out to create a 'high output' system comprising a new fleet of specialist 'factory' trains (the High Output Plant System - HOPS) and a new Overhead Line System which was designed; to complement the 'factory train', to; maximise productivity, meet customer requirements for multiple pantograph operation at up to 140mph[19] and be compliant to an

19 High Speed twin pantograph operation is not unique in Europe. What is unusual is the variation in contact wire height when electrifying an existing UK main line with its much smaller structure gauge.

updated Technical Standard for Interoperability (TSI) which was not finalised until November 2014. All of these were world firsts and therefore represented a high risk to the programme (see Sections 10 & 13).

- **Poor productivity and rework:** These world first risks not only materialised but were compounded by what proved to be an unnecessarily conservative design approach for the piled foundations, resulting in very poor productivity and many repeated visits to individual work sites. RIA believes that these issues were a major factor in the escalation in the estimates between 2013 and 2016. The NAO report found:

  The cost increases arose, in part, because assumptions in Network Rail's 2014 cost estimate were unrealistic. Network Rail was too optimistic about the productivity of new technology. It underestimated how many bridges it would need to rebuild or modify. It also underestimated the time and therefore costs needed to obtain planning permission and other consents for some works, for example those which could affect protected species or listed buildings. It needed more than 1,800 separate consents for such works (paragraphs 3.6 and 3.7).

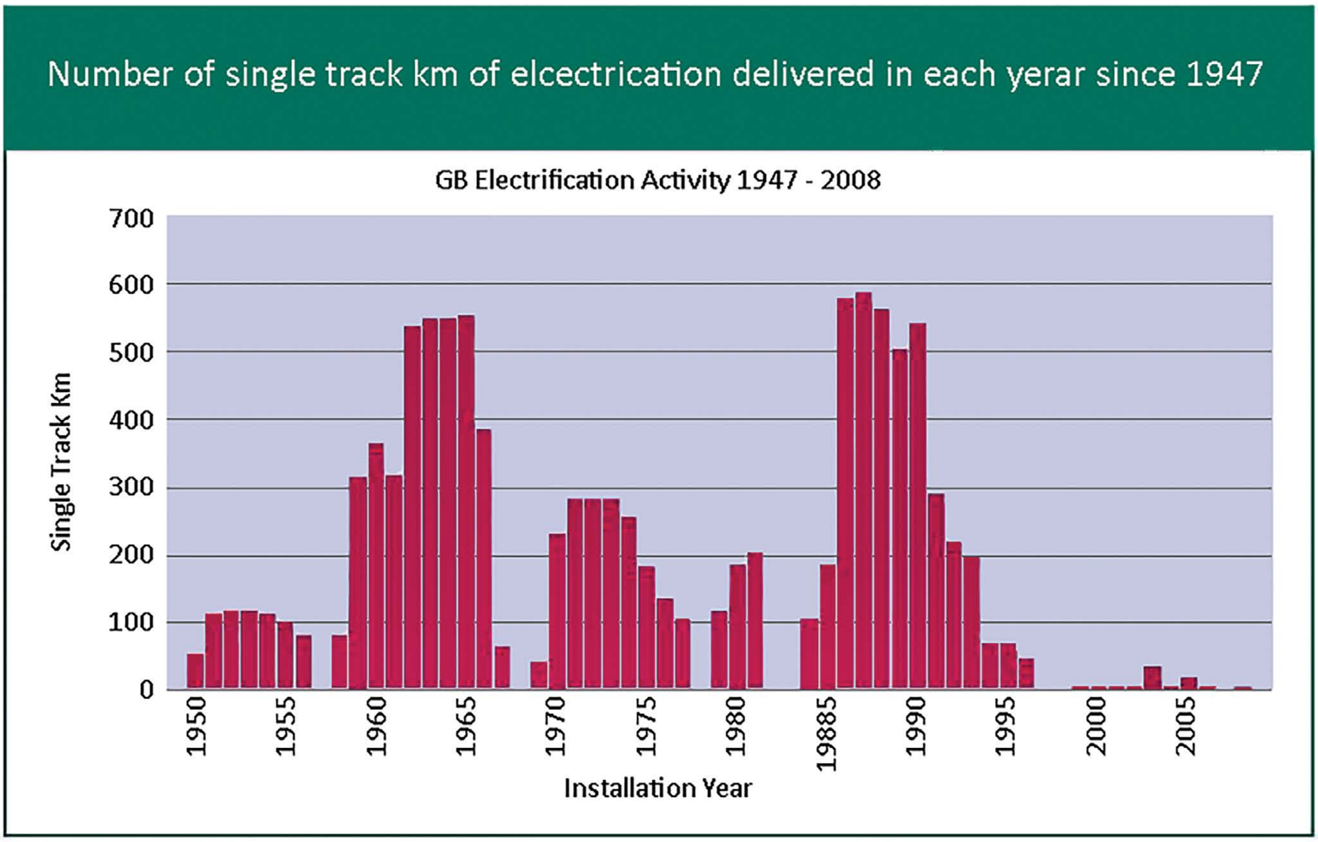
  Failings in Network Rail's approach to planning and delivering the infrastructure programme further increased costs. Network Rail did not work out a 'critical path' – the minimum feasible schedule for the work, including dependencies between key stages – before starting to deliver electrification. It failed to manage the technical challenges and risks of using new technology, specifically a new design for the electrification equipment and a new 'factory train' for installing the equipment and its supporting steel structures. Network Rail did not conduct sufficiently detailed surveys of the locations for the structures, which meant that some design work had to be repeated (paragraphs 3.7, 3.8 and 3.11).

- **Sub-optimal Technical Solution:** Due to the unrealistic programme, and perhaps a focus on delivery rather than cost, many opportunities to optimise the technical solutions were not taken. The most notable example was the adoption of normal clearances rather than undertaking a risk assessment and implementing measures (see Section 12.0), to justify a reduction and perhaps avoid a multi-million pound bridge reconstruction. This was perhaps exacerbated by an, at the time, ongoing debate between the Office of Rail and Road (ORR) and NR relating to means of compliance with the Electricity at Work Regulations (See Section 7.0). Risk assessment has not yet been routinely embraced by designers although there have been some good examples, such as at Paddington where with client support risk assessment has been successfully used.

- **Strategic Technical Leadership:** Related to the previous point there are many examples in this report where the absence of clear thinking authoritative technical leadership at the time led to unnecessary cost and delay. There continues to be inconsistent awareness and application of the technical options and risk assessment approaches available. For the future it will be important to ensure this leadership is put in place with some form of Technical Authority.

- **Feast and Famine:** With only 150 km miles of new electrification work since 1993, in 2009 the supply chain was expected to start delivering over 2000 km of electrification. As Fig 4 shows, although there had been previous gaps, this 20 year gap (by the time work started) was the longest on record. Inevitably it was going to take to reacquire the necessary capabilities to deliver the schemes, incurring costs which were expected to be recovered over a long-term programme of work. The rapid ramp up and then stalling of electrification projects has only helped increase uncertainty in the sector, also escalating costs. If electrification is not restarted then the investment and hard-won experience of recent projects will soon be lost.

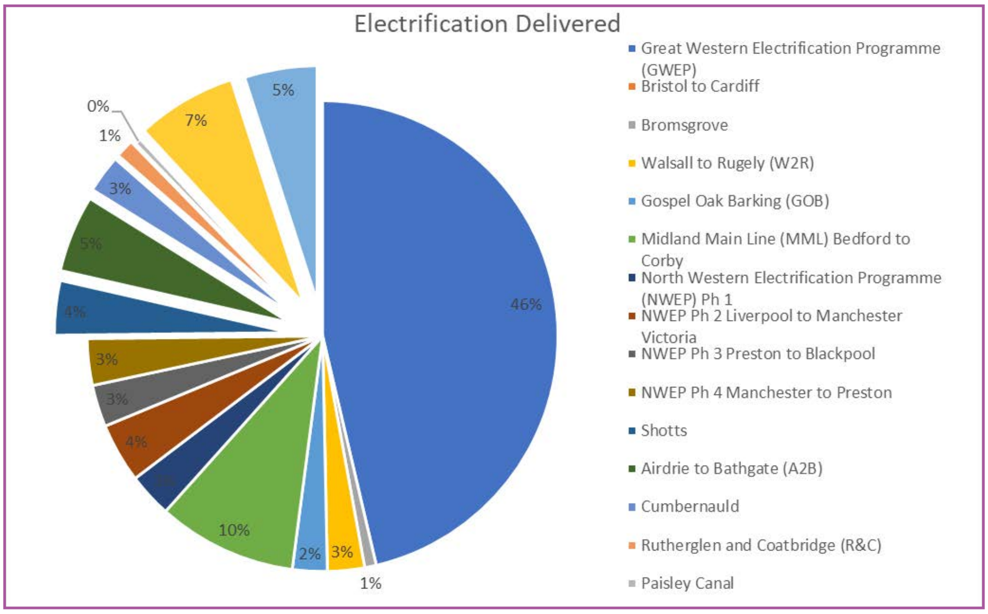
Fig 4 GB Electrification Activity 1947 – 2008



(Source DfT Rail Electrification 2009)

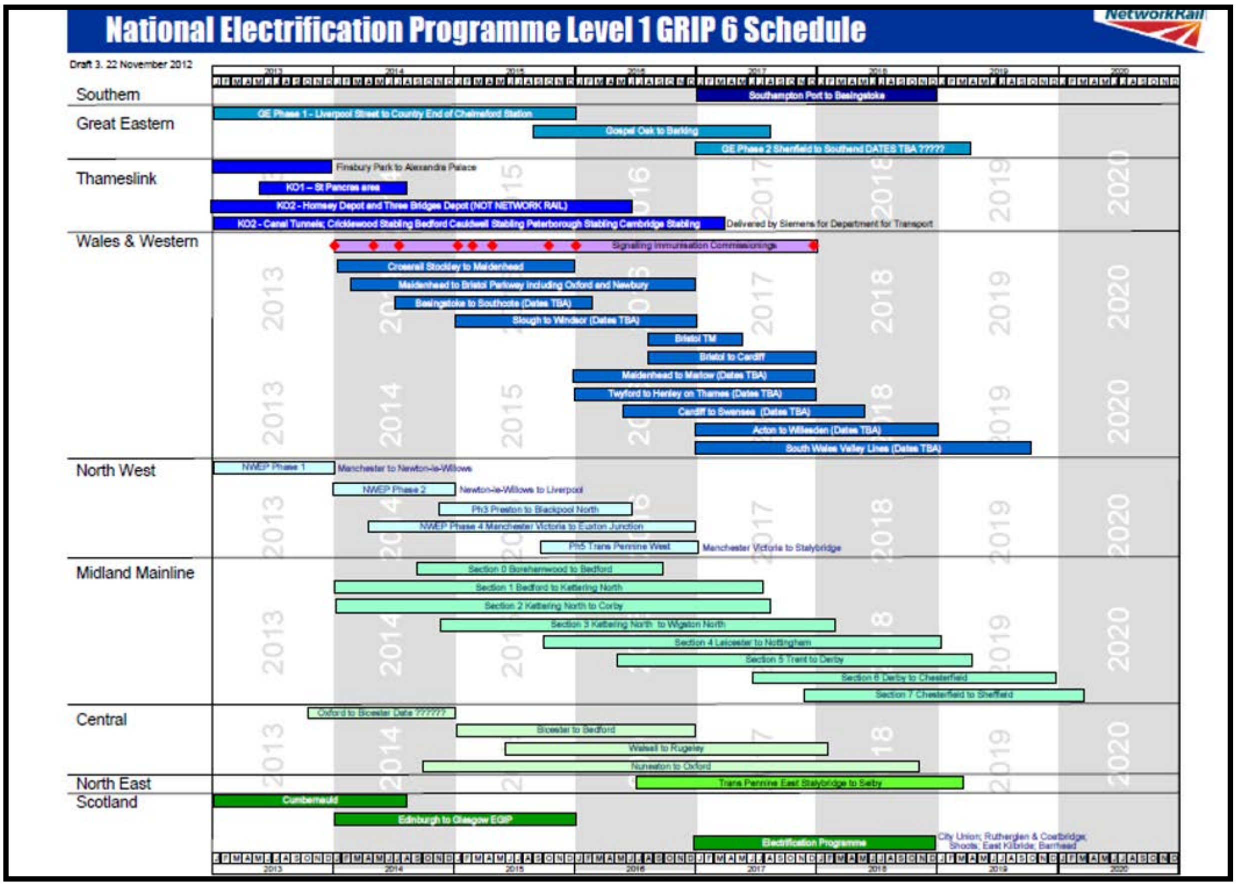
- **Competition for Resources:** GWEP was not the only active electrification project competing for scarce delivery resources (Fig 5). Although GWEP was by far the largest project (See Figure 5) representing c50% of the total programme, others in various stages of development or delivery in this period were:
  - **In England:** North West Electrification, Walsall to Rugley, Bromsgrove, Midland Main Line, Gospel Oak to Barking, West Anglia and Great Eastern upgrades and Thameslink and Crossrail programmes.
  - **In Scotland:** Airdrie to Bathgate (A2B), Paisley Canal, Cumbernauld, Rutherglen and Coatbridge (R&C), Edinburgh Glasgow Improvement Programme (EGIP), Shotts, Stirling Dunblane Alloa (SDA) – together representing about 25% of the total programme.

Figure 5 – National Electrification Programme Delivered Volumes



(RIA Analysis – 'exploded' segments are projects in Scotland)

Figure 6 - The National Electrification Programme in 2012



(Source: National Electrification Programme 2012)

Although there was a Network Rail 'National Electrification Programme' body it had no authority over the individual projects which were all competing for the same scarce resource. At one point, due to the lack of UK based resource, design work was being carried out in 8 countries around the world in an attempt to meet programme deadlines. In this situation of 'overheating', and with the signs of significant delivery issues, and with hindsight, it is clear that the industry should have instigated a pause until these issues were resolved. In the event it took the intervention of the then Transport Secretary, Patrick McLaughlin, to pause a number of projects in 2015. This was a collective industry failure of accountability.

- **Contracting Strategy:** The NAO identified that it was not until 2015 that the DfT and NR started to manage all the projects on the Great Western route in a joined-up way, to ensure alignment of objectives. A similar situation of misaligned objectives applied to the suppliers delivering electrification. Before coming to market NR had already made crucial 'make or buy' decisions to use the project to develop their own novel High Output Plant and OLE system which immediately reduced the scope of the supply chain to offer their expertise and international best practice. In effect, this meant that the client rather than the supplier was making the choices which would drive productivity which is an unusual approach. The NAO report found:

  > *Network Rail did not recognise that making best use of the new technology required significant changes in its management systems and culture, including its relationships with suppliers and contractors. To operate efficiently and be as productive as expected, the factory train needed to be treated as part of a broader construction system from the beginning. This meant Network Rail had to align the capabilities of the factory train, the equipment installed and the way the factory train was used, with its management of other contractors (such as those producing site designs) and of the component supply chain. For example, delays in completing designs prevent Network Rail from using the factory train effectively, since the cost of filling in gaps in a sequence of masts is high. An integrated 'design and build' contract might have helped, since this would have eliminated the interface between the contractor carrying out the design and the contractor responsible for construction.*

  As described by the NAO, NR chose to use a 'hub and spoke' model, which meant that they were responsible for programme management and procured suppliers to deliver individual packages of work. This meant that suppliers were focussed on their individual objectives and deliverables rather than the overall objectives of the programme, and it left NR with responsibility for managing all the interfaces and the overall programme risk. A more genuinely collaborative approach with shared incentives and as few interfaces as possible would have delivered better results and was discussed on GWEP early in 2016 but not adopted. Projects such as the Staffordshire Alliance and Ordsall Chord have demonstrated the benefits of this approach.

- **Input and not output specification:** Input specification is where the client details what they want to be built rather than the output performance they require. In the case of the electrification programme, the detailed specification and the client choice of (unproven) plant and OLE equipment limited the ability of suppliers to offer readily available and proven solutions or, where appropriate, to innovate. This approach could be facilitated by a Network Rail Technical Authority who would be responsible for considering the whole system issues and providing objective advice to both bidders and client. The use of output specifications has proven its potential in Denmark (See Section 6.5) and, in the UK, the PSU2 Alliance on East Coast is expecting to reduce power supply upgrade costs by 60% compared to the original estimate by adopting an output specification approach (See Section 11).

At a strategic level, in future the government could, rather than specifying electrification as the solution, have specified the whole system outputs in terms of journey times, frequency, reliability, emissions, whole-life cost etc, which would have allowed the industry to optimise the solution to deliver these outputs.

- **Strategic Programme Management:** Electrification is rarely justifiable on its own and should usually be considered as part of a route-wide upgrade to respond to growth in demand. The optimum time to consider electrification is when the existing fleet is becoming due for replacement. Both these criteria were satisfied on Great Western but, as discussed in the NAO report on Modernising the Great Western, all the contributory projects were not initially managed as a single Programme which contributed to the delivery problems. Worse, as discussed above, there were multiple electrification projects competing for scarce resource and no effective National Programme management. This can be contrasted with the East Coast Main Line (ECML) Electrification, which was the single focus of the electrification resources and where the project included all aspects of the route upgrade including train procurement. All involved were clear about who the Project Director was and what the objectives were, to get electric trains to Edinburgh by May 1991[20]. The NAO report also noted that:

> *The Department [for Transport]'s approach to managing such interdependencies has varied between different rail investment programmes. For the Thameslink rail programme, infrastructure improvements also needed to be coordinated with the introduction of new trains and with changes to the franchise. In that case, the Department agreed governance arrangements from the outset which were intended to help it and other interested organisations to manage the dependencies between infrastructure, trains and franchising.6 However, in the case of the Great Western Route Modernisation industry programme, there was no integrated governance until early 2015.*

6. What should electrification cost?

6.1 A word about Unit Costs

The recognised unit cost for electrification is cost per single track kilometre (stk). Like any unit cost, the cost element is an average of the basket of costs that relate to a particular project. It is a useful means of comparing projects but it should be recognised that every project is different, and for example, not all electrification schemes need power supplies or signalling immunisation and the volume of route clearance works can vary significantly from practically nothing to 30% or 40% on

20 East Coast Main Line Electrification Project Completion Certificate http://www.railwaysarchive.co.uk/docsummary.php?docID=853 Some lessons learnt (Page 33) have had to be relearnt eg 'target dates must be realistic and underpinned with resources', 'the importance of obtaining consents was not fully appreciated at the outset'.

some recent projects which, if included, can make useful comparison difficult. Single track kilometre measures each railway line and therefore every kilometre of double track railway is 2 stk.

Therefore, whilst they are useful for comparison purposes, **unit costs should be used with caution**. **They are not an estimating tool.** Ultimately what is most relevant are the project specific estimate, then bid, then actual costs.

For unit costs to be useful the data must be collected consistently on a like for like basis and Network Rail have developed the Rail Method of Measurement Vol 1 (RMM1) which was released to the industry in July 2018 to help ensure this consistency. RMM1 collects costs against the categories shown in Figure 7. It is strongly recommended that RMM should be adopted for all future projects so that, the industry will, in future, be better able to answer what electrification *should cost, will cost, did cost* and (perhaps most importantly in each instance) explain *why*.

Figure 7 RMM1 Electrification Cost Collection

PROJECT DELIVERY & SERVICE INTRODUCTION • CAPEX/OPEX staff • Delivery Partner Fee • CAPEX Vehicles • Sponsor Costs • Maintenance • Rapid Response • TOC interface Costs • Industry Systems Integrator • HQ Engineering • Communications Team	**ROUTE CLEARANCE WORKS** • Structures • Parapets • Canopies • Track Lowers • RRAPS • Scrap removal from worksites • Vegetation clearance from worksites • Other items	**OTHER COSTS** • Access and Schedule 4 • Lands and consents • Surveys • PICOPS • NOBO DEBO • RUS Development • Project Insurance • Strategic Spares
LEAD DESIGN ORGANISATION • Design • Design Innovations	**SIGNALS & TELECOMMUNICA-TIONS** • S&T • SCADA	**POWER & DISTRIBUTION** • Power & Distribution • National Grid
OLE WORKS • Direct Works (material, plant and labour) • Indirect • High Output Plant		

(Courtesy of Network Rail)

6.2 UK Electrification Cost Analysis

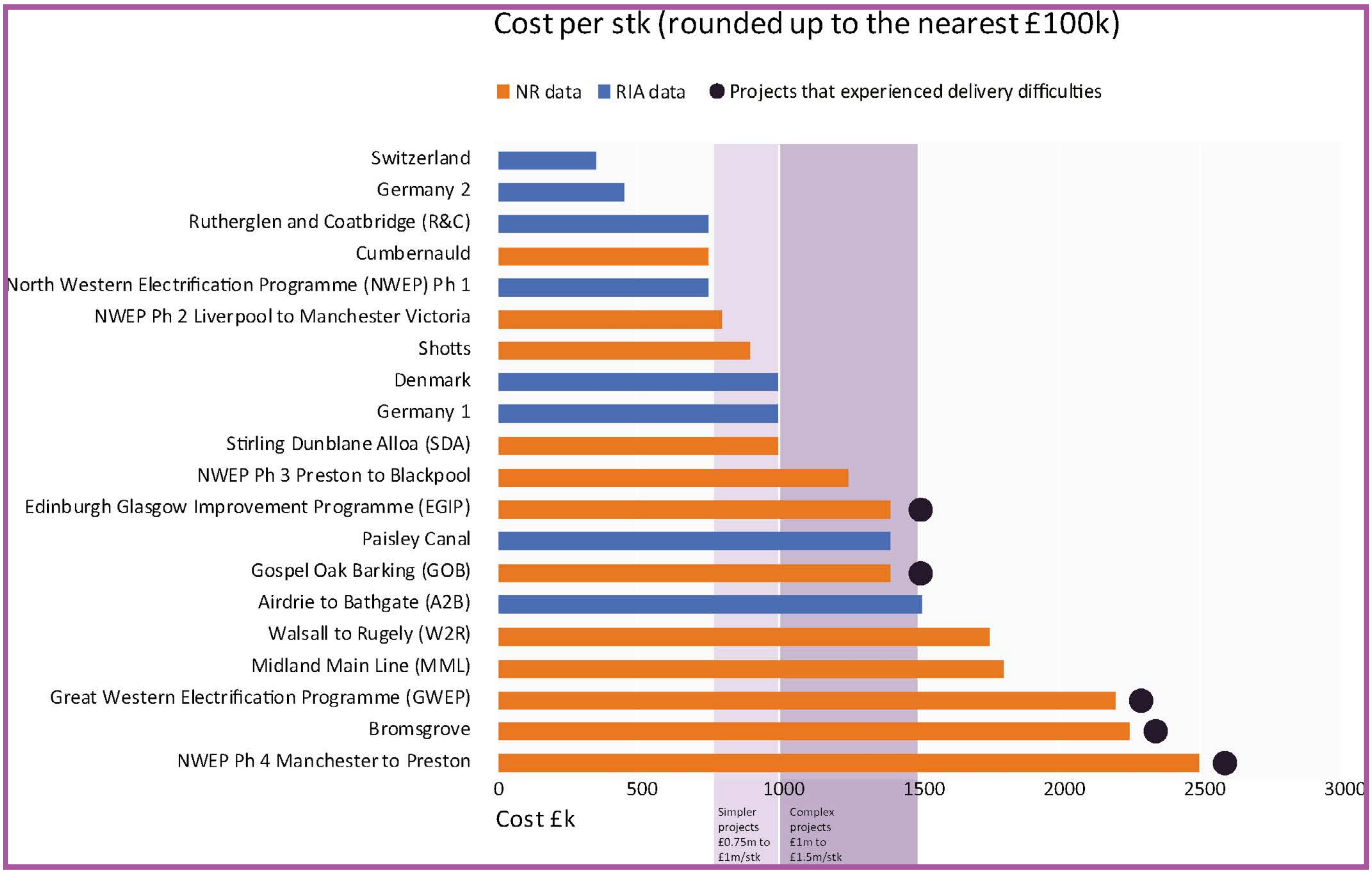
In undertaking the Electrification Cost Challenge RIA has gathered actual cost data on recent electrification projects from a) Network Rail who have shared their own analysis and b) publicly available and commercially sensitive industry sources. The latter include four International projects (See Section 6.3). Non-electrification costs such as wider route improvement and rolling stock are not included.

As described in Section 6.1, there is significant variation between projects in certain cost categories, notably route clearance, meaning that comparing the total project cost does little to inform us about the efficient cost of electrification as these variations distort the comparison. We have therefore not included these more variable cost elements (the shaded elements in Figure 7) in the following analysis and compared those 'core electrification' items which are less variable namely the Overhead Line (OLE), Power and Distribution and the relevant proportion of design and project delivery costs.

That does not mean we are ignoring route clearance as a major cost driver of electrification schemes. In Section 12 of the report we identify a range of new techniques to minimise the need to reconstruct bridges in situations where increased gauge is not a requirement for other reasons such as larger freight wagons. These techniques have not been widely used and so there appears to be a significant opportunity to reduce the cost of clearance works which, as described above, has been 30 to 40% of the cost of some electrification schemes.

The Network Rail data is collected in the RMM1 categories but there is less consistency in the second data set which has necessitated some adjustment and indexing to make it comparable and the result rounded up to the nearest £100k/stk. However, as can be seen in Figure 6, there is a good correlation between these two main sources. We are grateful to Network Rail for their collaboration in this cost analysis and we have discussed our conclusions with them. It is therefore our view that the conclusions drawn are robust and well evidenced.

Figure 8 - Unit Costs of recent UK and International Electrification Project



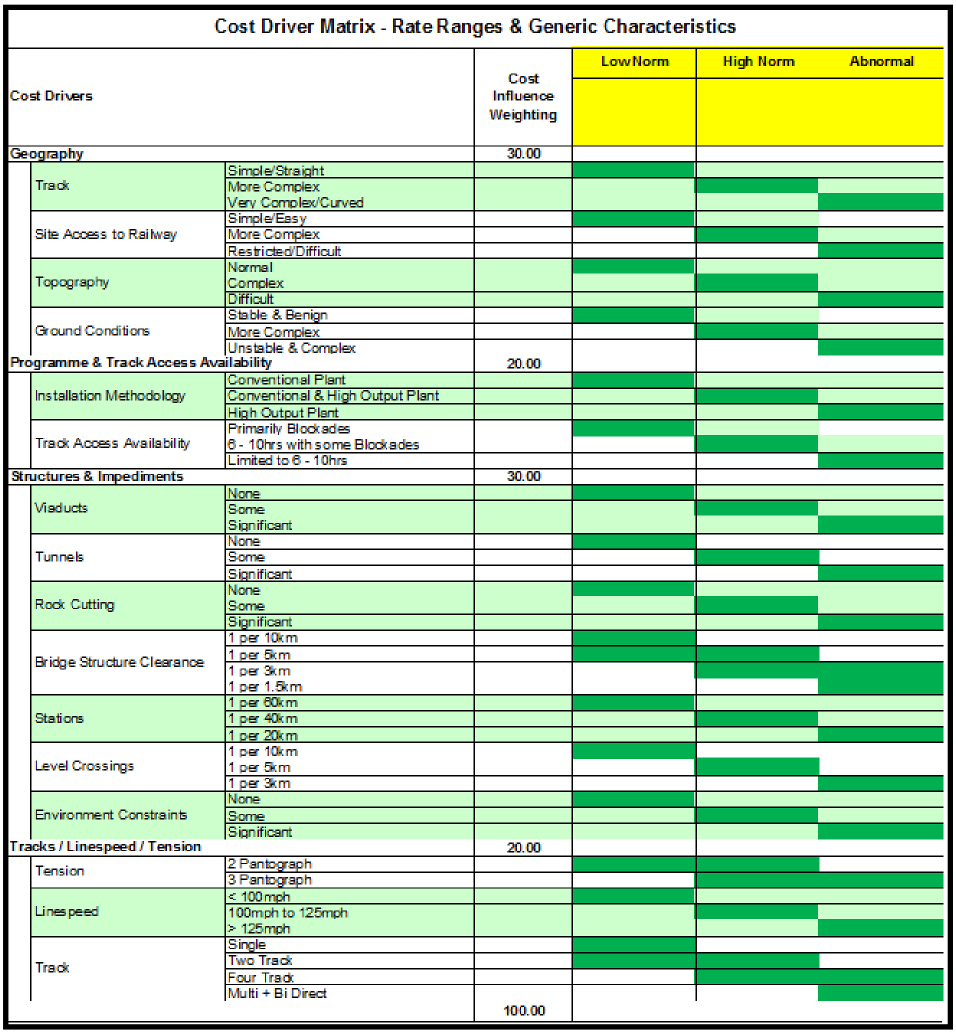
(RIA Analysis - for large graph, see Appendix 4)

There is still a significant range in these actual project costs and there seems to be two major drivers for this variation. The first is the engineering and other cost driving characteristics of the scheme and the second is the degree to which the project experienced delivery difficulty.

6.2.1 Engineering and other cost driving characteristics

Network Rail have done some interesting work on this and identified three generic types of scheme; 'Low-Normal', 'High-Normal' and 'Abnormal'. These categorisations reflect assessments against a blend of factors from geography & topography, programme & access availability, through to structures & impediments, line speed and track layout, as shown in Figure 9.

Figure 9. Cost Driver Matrix



(Courtesy of Network Rail)

Based on this matrix Network Rail characterise the 12 projects they provided data for as follows:

'low normal'	'high normal'	'abnormal'
• NWEP Ph 3 Preston to Blackpool • Shotts • NWEP Ph 2 Liverpool to Manchester Victoria • Cumbernauld	• Bromsgrove • Midland Main Line (MML) • Walsall to Rugely (W2R) • Gospel Oak Barking (GOB) • Edinburgh Glasgow Improvement Programme (EGIP) • Stirling Dunblane Alloa (SDA)	• NWEP Ph 4 Manchester to Preston • Great Western Electrification Programme (GWEP)

Although this was done retrospectively the intent was to develop a methodology which would help future projects better understand the characteristics which drive cost.

6.2.2 Delivery Performance

Whilst the characterisation of projects is clearly a helpful approach, the 'basket' of projects in the analysis includes some projects which most observers would say experienced delivery problems for a variety of reasons, many of which are discussed elsewhere in this report. These projects are identified in Figure 8 and underlined in the table above.

So, whilst the cost driver characterisation would suggest these projects could be expected to be in the higher ranges of cost, the question is what should they have cost if they had been delivered more successfully? In simple terms they were going to be more costly projects, but they should not have been so costly.

6.2.3 RIA conclusions on UK projects

Examining the data (See Figure 8) for these 20 actual projects, almost half of the projects delivered[21] in a range of £750k to £1m/stk. Two of the OLE only international projects (See Section 6.3) were even lower cost.

A further 5 projects, including Gospel Oak to Barking and EGIP which experienced delivery difficulties, delivered in a range of £1m to £1.5m/stk. Of the remaining projects Walsall to Rugely and MML were c. £1.8m/stk and NWEP 4, Bromsgrove and GWEP were all in the £2m to £2.5m/stk range.

From this RIA concludes that a well delivered 'simpler' electrification project should deliver for £750k to £1m/stk and a more complex project for between £1m and £1.5m/stk. It is RIAs view that we should not expect projects to cost more than that at the outset unless there are exceptional reasons which should be challenged until they are clearly understood.

There can be no doubt that the industry can deliver at these rates because these are actual projects. Encouragingly RIA understands that the current phase of Great Western (Bristol to Cardiff) is being delivered within these ranges, which seems to indicate that the lessons from earlier projects described elsewhere in this report

21 Overhead Line (OLE), Power and Distribution and the relevant proportion of design and project delivery costs

are now being applied in practice. This raises the prospect of further improvement by the consistent application of the good practice (See Sections 7 to 14) identified in this report supported by a rolling programme of electrification.

Scotland has had a rolling programme policy for a number of years, and it is noticeable that the Scottish projects are all within the ranges RIA suggests. Even the Edinburgh to Glasgow Improvement Scheme (EGIP) which experienced delivery issues is within the higher end of the range noting that when, in 2014, EGIP was seen to be in difficulty, action was taken and the overrun partially mitigated.

It seems fair to conclude that **through having a rolling programme of electrification Scotland is benefiting from learning and experience being passed from one project to the next**, and this is reflected in the fact that Scotland is delivering projects within the range of costs predicted in this report.

It is also clear that the availability of good track access is a key factor in the cost of electrification. Section 14 highlights a number of projects which benefited from extended 'rules of the route' and on GWEP the Badminton (Swindon to Bristol) and Newbury (Reading to Newbury) blockades in 2017 achieved high levels of productivity and there are sections on GWEP which achieved costs in the £1.5m/stk range.

6.3 International Experience

Looking at the international projects for which we have evidence, we see two OLE only projects, one in Germany and one in Switzerland, being delivered for £450k/stk and £350k/stk respectively. Both comprised new foundations, masts and overhead line, and were delivered in blockades. There are also two examples from Denmark and Germany where the cost comparable to the Section 6.2 analysis is circa £1m/stk.

In Denmark a substantial part of the network, totalling 1362 stk, is being electrified in a programme running from 2014-2026. Significantly this is being done in close collaboration with the supply chain. The specification required a TSI compliant OLE system with a single approval process but was otherwise on an output basis allowing the supplier to innovate. Given that the programme is providing continuous work for 10-years the 'all-in' cost is competitive at around £1m/stk.

Across the Swiss and German examples there are some notable features which may help explain the lower costs compared to the UK:

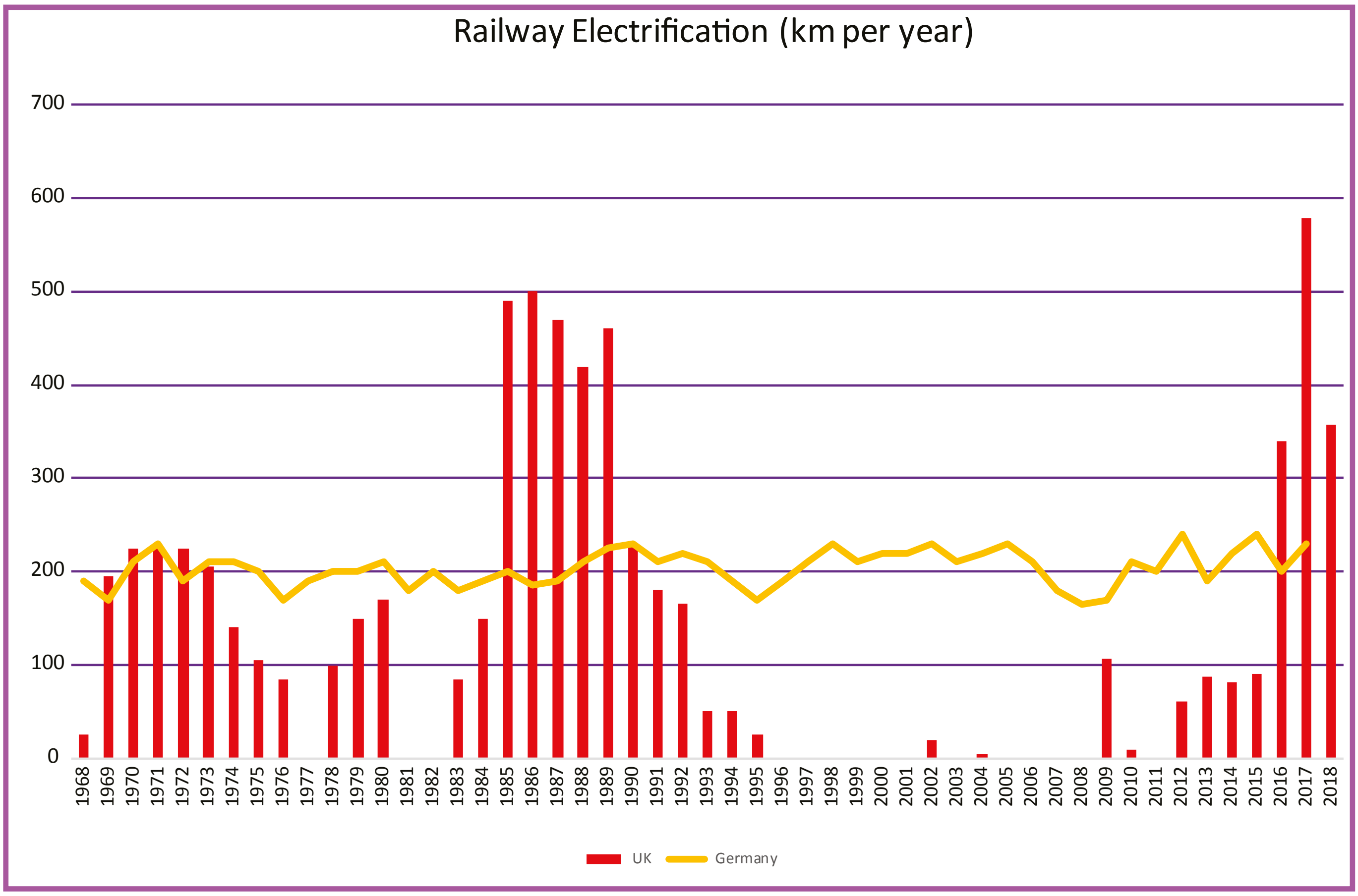
- Track access aligned to the efficient output of the installation team;
- Track access is negotiated and there is no Schedule 4[22] type cost to the project;
- Less route clearance work compared to the UK due to the more generous European structure gauge;
- A lean project management approach by the client;
- Sequencing of work – on one project a double tracking contract was let two years before electrification and the electrification detailed design was finished before the electrification tender, based on actual track data allowing a fixed price contract for electrification installation;

22 Schedule 4 compensates train operators for the impact of planned service disruption.

- The volume and continuity of work are sufficient for the installation contractors to retain skilled, full time, direct employees and make long-term investments in plant; and
- Some projects are fixed price incentivising delivery.

In Switzerland and Germany this continuity has been achieved by a rolling programme of electrification over 50-years, as illustrated by Figure 10. In particular, a steady flow of often small electrification projects in Germany has allowed the industry to retain and develop a highly skilled workforce and perfect the plant and techniques, which are allowing German electrification projects to be delivered at substantially less cost than is experienced in the UK.

Fig 10 - Railway Electrification Volume in UK and Germany in the last 50 years



(Source: Noel Dolphin, Campaign to Electrify Britain's Railway)

6.4 Conclusion on Costs

Based on the above analysis of actual projects, RIA conclude that:

- Today a well delivered 'simpler' electrification project should cost £750k to £1m/stk (for the OLE, Power and associated costs) and more complex projects should not exceed £1.5m/stk;
- Most projects are already successfully delivering at this cost level by

applying the good practice described in this report;

- There is significant scope to reduce route clearance costs by using the techniques identified in Section 12;
- In the future these costs could be secured and reduced over time towards European norms by a rolling programme of electrification; and
- RIA recommends a rolling programme sufficient to keep two to three delivery teams consistently in action, delivering 75-100stk each per annum across the UK.
- This programme should have at least a 10-year horizon to support investment in people, process and plant.

7. Standards

7.1 Background

Any engineering project needs a specification for what is to be delivered. This will usually draw on relevant international and national standards which helps ensure that recognised good practice is used. In some cases, there may be a legal requirement and there is usually a contractual requirement to comply with relevant standards.

The UK standards regime has changed since the last major electrification scheme. The ECML electrification completed in 1991 largely used British Standards for matters such as civil and electrical engineering which apply across all industries and British Rail standards which applied to the national rail network.

Since then purely British Standards for all sectors, including railways, have tended to be replaced by international standards[23] - a process in which the British Standards Institute is closely involved and influential. This is a move which has wide support, having delivered tangible benefit in economies of scale and risk reduction. It is worth noting, given the current Brexit debate, that these standards are genuinely International rather than European and will therefore not change because of Brexit. However, also since ECML was completed, the European rail industry has developed a new standards regime. At the head of this regime are Technical Standards for Interoperability (TSIs) which aim to define common interfaces to support opening the market to both cross border traffic and common technology. The more recent TSIs focus on the interface requirements and call up international standards for the detail.

The Energy (electrification) TSI[24] specifies interface matters such as the power supply parameters, the geometric position of the contact wire and the quality of current collection. The organisations developing and implementing electrification systems must demonstrate that their solution meets these interface requirements before they will be allowed to put it into use. Therefore, any OLE manufacturer will want to ensure that their OLE system is TSI ‘approved’ on earlier projects to minimise the approvals risk on the current project. This became an issue on Great Western because the system was entirely new and therefore it needed to be

23 This process was underway during the ECML electrification project the ‘lessons learnt’ for which noted “The progressive working towards European standards, as opposed to BR specifications, was generally welcomed, although statements were made to the effect that the end product was, in fact, superior when working to BR specifications.”

24 http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:JOL_2014_356_R_0003&qid=1418658301848&from=EN

approved on that project against a TSI which itself was also recently updated.

The TSIs recognise that the European rail network is not homogenous and so member states will have 'special cases' to deal with this issue. The main UK special case is the historically small structure gauge compared to Europe which means, for instance, that the contact wire height is usually much lower in the UK than the TSI would normally require. In the UK these special cases are defined in Railway Group Standards developed by RSSB in consultation with industry.

However, the greatest volume of standards, relating to electrification in the UK, are the Network Rail Company Standards which have become more prescriptive (potentially in response to the experience of recent years) and are accused of creating UK specific requirements and cost escalation. Conversely, Network Rail argue that they had to intervene, for example, to reintroduce an empirical foundation design standard.

7.2 Great Western Experience

At the time of developing Great Western the Energy TSI was being updated to combine the previous 'High-Speed' and 'Conventional' documents and the final version was approved in November 2014. This was followed by a Railway Group Standard in Dec 2014[25]. GWEP had been underway since 2009 and NR and RSSB were closely involved in the development of the TSI and so were familiar with its requirements. There was the option to request a derogation on the basis of the project being in an advanced stage as the implementation plan for the Energy TSI[26] published by DfT in February 2016 which stated:

> *The intention is to progress with the upgrade and renewal schemes to meet business and strategic needs and when doing so to comply with the in force version of the Energy TSI (using UK specific cases where appropriate), unless the project has been notified as being at an advanced stage when a revised version of the Energy TSI is published.*

The project did not request a derogation which is indicative of the view that TSI compliance was not a major challenge. However national standards were also changing. As described in Section 12 the standards for clearances changed driven by both the TSI and the Electricity at Work Regulations. Network Rail also updated their isolation policy which had a significant impact on switching and isolation requirements.

7.3 Conclusion and Lessons Learnt

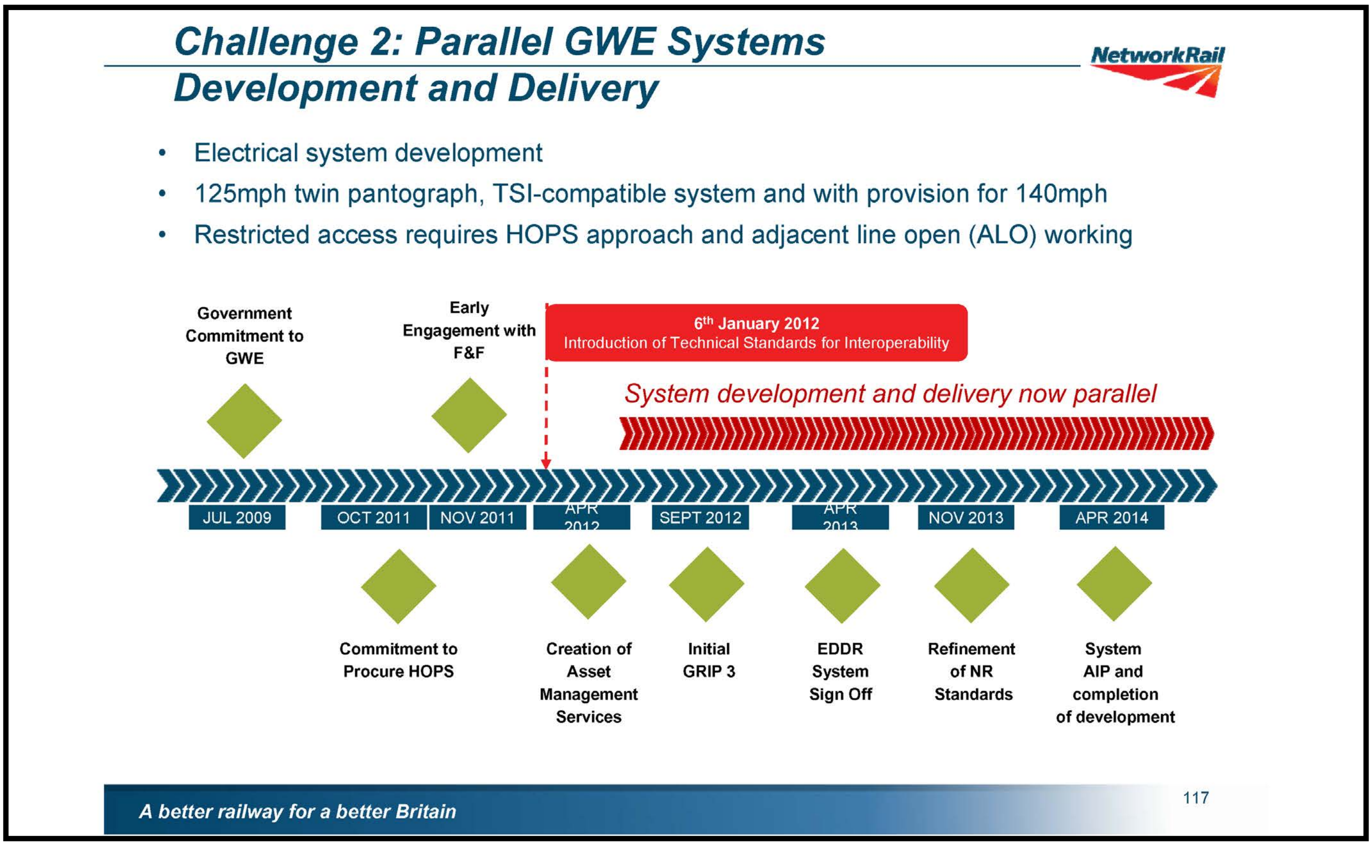
It would be wrong to state that the TSIs themselves were anything more than a contributory factor to the issues experienced on the Great Western. Although the update of the TSI is often used to explain some of the difficulties on GWEP there is no evidence that existing internationally available OLE systems had to be changed or European electrification projects changed to comply with the updated TSI.

However, rather than develop an existing TSI compliant system to meet these customer requirements, NR took the decision to develop an entirely new system. As discussed later (Section 10) this would take time and overlapped with site delivery as shown in Figure 11. It is this overlap rather than TSI compliance itself

25 https://www.rssb.co.uk/rgs/standards/GLRT1210%20Iss%201.pdf
26 https://www.gov.uk/government/publications/energy-technical-specification-for-interoperability-implementation-plan

which is the more significant cause of issues on GWEP. This is not to underplay the significance of the new experience of securing ORR approval to 'bring into use' a new TSI compliant UK OLE system, a process which is still underway.

Fig. 11 The overlap of OLE System Development and GWEP Delivery



(National Electrification Programme 2016)

7.4 Where we are now

The Energy TSI is now established and there are multiple TSI compliant design ranges on the market internationally. Subject to final approval being achieved through the Bedford to Corby project the UK will soon have developed a compliant OLE Design Range and gained approvals experience. Providing the UK keeps up to date with the development of international standards it should be possible to maintain this position, using the UK or International design ranges provided the UK customer requirements do not significantly change. Maintaining this position should be the responsibility of a NR Technical Authority.

7.5 Recommendations for future projects

It is recommended that future projects use proven systems which are compliant to the relevant international and national standards and avoid developing and obtaining approval for new systems as part of a project. If this is considered necessary, sufficient time should be built into the programme to avoid an overlap with construction and ideally such development should be on smaller pilot projects. The NR Company Standards suite and associated risk allocation should be reviewed as a cross-industry exercise with a view to moving towards output specification (See Section 5.0). This exercise would balance the need to avoid unnecessary prescription whilst recognising where guidance is needed when the risk is best held by the client. If standards are changing, a 'standards freeze' or derogation should be sought rather than trying to adapt the project to the emerging standard. There is a strong argument that 'standards freeze' should be the norm with projects being completed against the standards they were tendered on.

8. Foundations

8.1 Background

The live parts of the overhead line system need to be supported and held in the correct position over the track. This requires foundations, masts and other supporting 'steelwork' (See Section 9.0). In the UK historically foundations have either been mass concrete or tubular steel piles.

8.2 Great Western Experience

In 2012 the assumption on GWEP was that the majority of foundations would be 5m long steel piles placed using the 'factory train' (See Section 13). This approach was consistent with the long established 'ORE/ OLEMI' empirical design guidance which had been used on previous UK electrification schemes. However, when detailed design was started the ORE method was not used and a 'first principles' limit state design approach was adopted as the loads resulting from, amongst other things, higher wire tensions were considered to beyond the evidence base which underpinned the empirical rules. Not only that but different designers were responsible for the OLE system, the masts and the foundations. These interfaces, combined with some unduly onerous design assumptions including design life, resulted in designs for piles up to 12 to 15m long. Another factor as illustrated in Figure 12 was the decision to place piles further from the track to avoid buried cables which meant a significant loss in the power the piling equipment could apply due to the increased operating radius. This also meant the cantilevers[27] or portals needed to be longer increasing the loading on the pile which meant it had to be longer still. Unsurprisingly the 'factory train' struggled to drive such long piles and productivity was very poor. Many piles were left protruding from the ground requiring de-design and/or repositioning. This resulted in inefficient multiple visits.

All of these issues were further compounded by the immaturity of the OLE design when piling operations commenced which meant that piles, even when installed successfully, were often found to be in the wrong place when the OLE design was completed. The NAO report found:

> *Network Rail did not carry out sufficiently detailed surveys of the route before the 'detailed design' took place. This is critical, since if ground conditions at one site are not as expected, designs for a number of nearby locations could need to be changed. This delays piling and installation of masts. In November 2015, Network Rail estimated that 78% of designs completed so far had needed to be revised.*

27 Having been a broad-gauge railway Great Western is wider than other routes. The GWEP project specified four track sections to be considered as two parallel two track railways which led to the use, in many locations, of two track cantilevers. These exert higher loads on the foundations compared to a portal which 'props' the masts.

Fig. 12. GWEP - overlong piles which could not be driven offset to avoid signalling cables.

(Modern Railways)

By 2015 it was recognised that the Great Western was not so different from previous electrification schemes and there was no justification for piles sometimes up to twice as long as previous experience for the same application[28]. Network Rail therefore undertook a review[29] of past experience with the ORE method and commissioned research and full-size tests from the University of Southampton which demonstrated that the ORE method was adequate and therefore it had simply been unnecessary to install the very long piles which had so damaged productivity on Great Western.

8.3 Conclusion and lessons learnt

The University of Southampton concluded:

The apparent overdesign of the foundations appears to have arisen largely because of an attempt to carry out an explicit serviceability limit state (SLS) calculation using over-conservative soil stiffnesses, and / or carrying out limit equilibrium ULS calculations that made no allowance for three-dimensional effects. Comparative analyses by the University of Southampton show that the limit equilibrium ULS analyses give broadly similar results and are sometimes more conservative than the proven ORE/OLEMI method, and show that for these types of structure the limit equilibrium calculation is very robust. The satisfactory performance of a large number of OLEMI-designed foundations provides evidence that a specific SLS check for this type of relatively simple structure is not required.

The comparative calculations should give designers the confidence to use the OLEMI method, or limit equilibrium analysis with the partial factors specified in EC7, without the need to attempt a

28 GWEP went beyond previous BR experience and used piles for Two Track Cantilevers (TTCs) as well as Single Track Cantilevers (STC) in which case a longer pile may be justified.
29 Network Rail's In-Service Experience of the ORE Method, 133956-IED-REP-EOH-000222

displacement-based serviceability check. This should result in shorter pile lengths that will perform adequately, helping to reduce electrification costs back towards historic levels. However, it must be noted that GWEP Series 1 design loads and use of the easier to install 610 CHS piles were outside of the experiential scope of the ORE/OLEMI method and further work should be undertaken to verify the ULS and SLS performance of CHS piles. Their design performance should be linked to in-situ CPT ground profiling methods.

It should have been self-evident that the piles were unnecessarily long and it is disappointing that well established empirical methods had to be reviewed and subjected to testing before they could be re-adopted. The packaging of design work and risk transfer may also have contributed to a conservative design approach. In the meantime (see Section 13.2) the productivity of the foundation installation was very poor with many re visits often required to a site to complete an individual foundation. This was further exacerbated by KPIs which measured the number of foundations completed without any consideration as to whether they were in a continuous run which would allow mast and wire erection to commence.

The lesson learnt is that the proven ORE/ OLEMI method (in the NR PAN 101[30] standard) remains applicable to the vast majority of locations and pile lengths would typically be no more than 3m-6m for a Single-Track Cantilever allowing an acceptable level of installation productivity with readily available plant. Another important lesson is the need for design maturity before foundation installation commences and the desirability of sequencing the programme so that there is a gap between completion of foundations and erection of masts.

The presence of buried cables at the lineside led to longer piles and productivity problems. In future projects, if cables are not already in cable troughs, serious consideration should be given to repositioning/ replacing cables in cable troughs prior to installing foundations.

Fig. 13. Pile driving with commercially available plant

(Courtesy of Van Elle Rail)

30 Now superseded by NR/L2/CIV/074 "Design and installation of overhead line foundations"

8.4 Where we are now

It is encouraging that a current project (MML) is installing 95% of its piles to the empirical ORE/ OLEMI design and is achieving productivity averaging 6 piles in 4h30min working time with readily available plant such as shown in Figure 13. In practice productivity has been as high as 19 piles per shift. The empirical method is resulting in piles of 3 to 4.5m long, much shorter than originally on GWEP. The project also used standard road rail vehicles to install 111 piles in a 54 hour weekend shift however they decided to focus on a standard repeatable process, delivering a minimum of 24 piles over four midweek shifts, as the risk of production loss from one possession failure was significantly reduced.

It is also evident that the importance of sequencing and design maturity is again being understood with projects not allowing site construction of foundations until the drivers of foundation position such as Master Feeding Diagrams (MFDs) and Sectioning Diagrams are formally approved for construction. As discussed in Section 7.0 the 'as-built' location of the foundations can feed into optimising the final OLE design.

8.5 Recommendations for future projects

The clear recommendation is to continue to use the proven ORE/ OLEMI empirical design method and plant appropriate to the task. University of Southampton identify an urgent need to further verify the performance of CHS piles to in-situ ground profiling and interpreted strength and stiffness parameters derived from CPT methods. A Possession strategy and plant which optimises efficient delivery and a sequential approach to OLE installation are key productivity drivers, and these are discussed elsewhere (Section 14) as is the need to have an appropriate level of design maturity before commencing foundation installation. Careful consideration should also be given to the effect on risk-transfer of the packaging of design work and factors such as required design life so that the designer is incentivised to offer an optimised solution.

9. Masts and other Main Steelwork

9.1 Background

In previous UK practice, masts have usually been standard galvanised rolled steel 'H' sections. Other supporting 'steelwork' includes steel portals, wire headspans[31] and single or two track cantilevers. These structures have tended to be quite simple and slender both in the UK and internationally (Figures 14, 15, 18).

9.2 Great Western Experience

As previously described (Section 8.2), different designers were responsible for the OLE system, the masts and the foundations on GWEP. The Series 1 masts and other steelwork used in the early stages of Great Western are more substantial than previous practice as illustrated in Figure 16 driven by both the onerous design assumptions and a commendable desire for standardisation, ease of installation and perceived low maintenance. They are also often taller where an Auto Transformer system is used as on many recent projects including GWEP (Figure 15)

31 No longer favoured as if they fail all lines are blocked

because the feeder (ATF) wire is positioned above the catenary to provide the electrical clearances to allow maintenance to be undertaken with only the contact wire isolated. The position of the ATF can also cause challenges with clearances at arch bridges. An area of success was the design for simplifying and standard-ising connections and thus reducing site time and improving safety with 'land and leave' booms for example but this increased cranage requirements[32]. Another engineering success was the introduction of two track cantilevers and the stand-ardisation of 4 track portals but these were not a PR success in locations such as the Goring Gap.

Progress was made during the GWEP project with, for example, 'H' section masts reducing from 240mm typical to 200mm typical cross section with consequential savings in steel and foundation cost. Unfortunately, these lighter solutions were not adopted until late in the project. In a two-track installation the final Series 1 solution is no more substantial than other solutions (See Fig 18).

Fig. 14. Traditionally UK OLE Masts have been relatively simple and slender (left Cambridge, right Peterborough)

Fig. 15. International practice is similar as illustrated here.

(Pictures courtesy of Southampton University)

32 Video showing 4 track portal installation - South Gloucestershire – Network Rail

Fig. 16. GWEP Series 1 System.

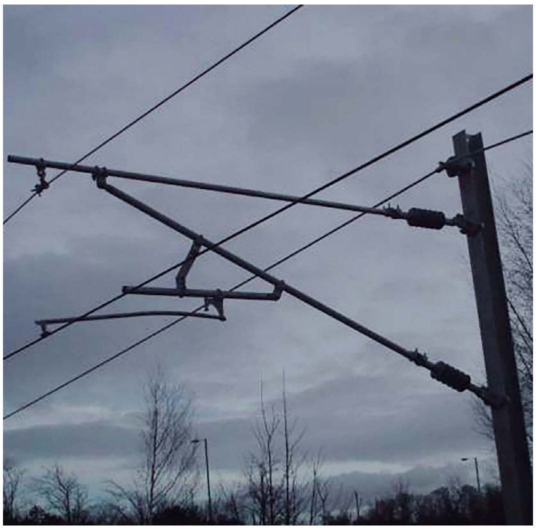
(Pictures courtesy of Garry Keenor)

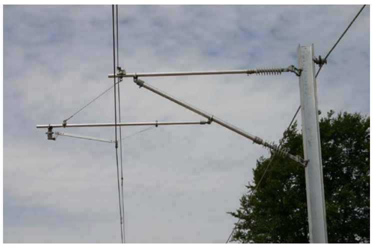
(Pictures courtesy of Furrer + Frey)

Fig. 17. Series 2 System. Cumbernauld to Springburn

(Pictures courtesy of Network Rail Scotland)

Fig 18. BR Mk 3 compared to NR Series 1 & 2 and Siemens SICAT Single Track Cantilevers





Top left: BR Mk 3 (Brian Sweeney NR Scotland)
Top middle: NR Series 1 with lightweight mast and single insulator cantilever (Network Rail)
Top right: NR Series 2 (Brian Sweeney, NR Scotland)
Bottom right: SICAT installation on Larkhall to Milngavie c2008, SICAT (Siemens)

9.3 Conclusion and lessons learnt

Much has been said about 'over design' of the Series 1 steelwork. However, on a 4-track railway, especially one which had previously been broad gauge, without using headspans the two track cantilevers or 4 track portals were going to be substantial and visually intrusive compared to a two-track railway to deal with the greater loads. The NR Master Series that has been subsequently developed has taken lessons from GWEP and has less substantial steelwork. However international structures still tend to be lighter and therefore less visually intrusive with one factor being a less onerous specification for allowable deflection.

9.4 Where we are now

The use of UK Master Series with single and two track cantilevers is tending to result in lighter masts than used on the early stages of GWEP. However, where portals or Auto Transformer Feeders are required substantial and taller steelwork is still being used. As Figure 18 shows, for two track railways the solutions are very similar. The NR Series 1 with a Single Insulator Cantilever allows a shorter mast and is arguably the simplest in both appearance and speed of construction.

There is also the opportunity to do more modelling of the OLE system to optimise the solution for a particular project. For example on Transpennine Route Upgrade (TRU) modelling has been done (but not yet adopted) to reflect the site conditions including wind loading which show the mast spacing could be increased by approximately 20% with a corresponding saving in foundations and steelwork.

9.5 Recommendations for future projects

Designers should be encouraged to adopt the simplest, lightest possible, compliant and approved design consistent with life cycle output requirements. This would require some culture change in the UK as there are a number of examples such as the 'Atkins Lite' system which have struggled to achieve adoption. This illustrates the challenge of moving to an output requirement as there is a risk and timescale associated with achieving product acceptance where this is needed. As an example of what is achieved elsewhere Figure 19 shows a very lightweight TSI compliant multi track portal structure using box section weathering steel rather than galvanised 'H' sections. Future procurement should allow for alternative designs and site specific modelling that deliver outcome requirements including life cycle reliability and maintainability against the benchmark of NR Master Series.

10. Overhead Line Equipment

10.1 Background

The core of any electrification system is the overhead line that provides the power to the train through the pantograph. Overhead line systems comprise of a 'catalogue of parts' called a 'design range' which are then used in a site-specific design. Previous British electrification schemes had used a number of different design ranges, but the de-facto standard was the long-established BR Mk 3 design which was simple, fabricated from readily available components, and available from several suppliers. However, this established system could not meet the customer requirement of multiple pantograph operation at up to 140mph or demonstrate TSI compliance without further development. The programme would also need to allow for the novel (for UK electrification) process of assessment as conforming to the TSI by a notified body (NOBO) and authorisation to be brought into service by the ORR.

10.2 Great Western Experience

Network Rail started work on what became the GWEP project in May 2009 and it was announced in July 2009. However, development did not start on the 'Series 1' design range until April 2012 once GWEP had received NR financial authority. Construction started in January 2014, but the full Series 1 design range was not available until May 2015.

The decision to develop an entirely new design range is a significant factor in the difficulties experienced on Great Western. It is possible that the old BR system could have been developed to be TSI compatible or a system procured internationally. At this point the TSI was still under development, only being finalised in late 2014 and so arguably no system could immediately demonstrate compatibility. However, there is no evidence that international projects stopped work or developed new OLE designs because of the TSI update and so it seems the more significant factor is the choice to develop a UK OLE system.

This recent summary outlines the Network Rail rationale for this decision.

> *At the beginning of the Network Electrification Programme in 2009, then comprising electrification of the GWML, the MML and North*

West Electrification, significant emphasis was placed upon examining the current standard overhead line systems and identifying a system most suitable for future use. The existing Mark 3 system had served well, but the pressures of electrifying in the constrained environment of the modern railway, with significantly limited access, meant that any new system should facilitate efficient construction, and also minimise the need for maintenance interventions. A system with minimal adjustment requirements was developed, based upon existing systems in Europe, as the Series 1 system to replace Mark 3. The single insulator cantilever also produced an arrangement with the shortest mast size for any system, and overcame the additional clearance required for cantilever frames.

The intention was to tailor the design of the system to a method of high output construction, and tightly integrated with the HOPS train development. Additionally, the maintenance performance of Mark 3 was investigated, and over 80 known weaknesses were identified for removal. Balance weight anchors, which required anchor wires to cross other lines, introduce an increased rip-down risk in the event of failure, and also were subject to criticism for their contribution to the effects of the Potters Bar accident, were considered for removal, and the result was a system with tangential wiring, mechanical independence of each line both at structure level and within the wiring, the Tensorex tensioning system was introduced.

These were the primary considerations and drivers of the Series 1 system, and it was intended for all lines. Tension and line speed were not the drivers, rather given that the consideration of the GWML was indeed a higher future line speed, the option of tensions which could accommodate this was included. However, when a proper evaluation of cost is undertaken, and considering the other factors which drive overhead line cost (primarily access, utilisation, foundation construction), the line speed and tension factors are small. Series 1 would be used across the programme, with the ability to modify tension and speed, but of course retain the real design drivers of improved reliability and high output construction.

It is clear therefore, that despite the still widely held perception, TSI compatibility was far from the only reason that the existing BR Mk 3 design was not considered suitable for use on Great Western. The rationale for rejecting available TSI compliant systems is less clear as the choice by Network Rail, as a client, to lead the development of a new OLE system in preference to allowing suppliers to respond to an output specification **meant they accepted a lot of risk which would normally be the responsibility of the supplier.**

Another issue which appears to have caused significant distraction at the time was a DfT requirement for multiple pantograph operation up to 140mph which was outside both the TSI requirements and previous experience. This latter DfT requirement eventually settled on 125mph operation with two pantographs but the extensive modelling required to consider a variety of options proved something of a distraction. Perhaps the most significant change brought about by the TSIs compared to traditional British Practice was an increase in wire tension which helped multiple pantograph operation but contributed to the need for more substantial structures.

To address all these issues Network Rail decided that they needed to develop two new OLE systems, the Series 1 for up to 125mph (initially 140 mph) and the Series 2, based on the BR Mk3c, for up to 100mph (later 110mph). The Series 2 system was intended as a short-term solution to support projects such as the North West Electrification Programme for which, it was already recognised, the Series 1 would not be ready.

This work started in April 2012 resulting in a situation where the new Series 1 OLE design range was not ready when the Great Western project commenced site work in January 2014 and it continued to be developed as the programme was implemented with the full catalogue being available in May 2015. The NAO report noted as an example of unclear specifications:

> *Network Rail did not initially understand whether the Department wanted trains to run at a maximum speed of 125 or 140 miles per hour. This has implications for the strength of the steelwork supporting the electric wires. In January 2014 the Department instructed Network Rail that the maximum speed should be 125 miles per hour. By this point, design work was well underway and Network Rail expected to complete it in March 2014. In September 2014, the main design contractor was still working to a specification of 140 miles per hour.*

The decision to develop the Series 1 design was not irrational. The system was designed to be quick and easy to install, many of the components including the ‘single insulator cantilever’ which had fewer parts and simply hooked into place had been trialled on an earlier project on the Great Eastern Main Line. Series 1 was designed as an integral part of a whole ‘electrification factory’ concept to deliver, in conjunction with the ‘HOPS train’ (Section 13), high productivity in what was in practice a real working time of 2-3 hours.

The system was therefore designed to minimise on track work by maximising pre-assembly, and being quick and easy to install. The components were standardised as much as possible, but this had the consequence that some components, notably masts (Section 9.0), were oversized for their application increasing cost and weight although it has been argued that standardisation reduces fabrication cost and logistics mistakes. A consequence of this approach and a significant difference from international practice was the much greater requirement for craneage which meant that Series 1 could not be installed using Road Rail Vehicles (RRV’s) which significantly limits plant options. Internationally existing design ranges are installed from wiring trains and RRVs in equal measure.

10.3 Conclusion and Lessons Learnt

The major problem was that the development of the Series 1 system was effectively being done on a live project and it was not ready when it was needed. It was a high-risk strategy, which was recognised at the time (See Figure 11), for the client to develop a new OLE system in parallel with construction. The fact that the OLE system was, with the HOPS train, an integral part of a high output strategy was an argument used for a new system. The Series 2 system experienced fewer difficulties as it was a development of an existing system, not part of a high output concept, and could use available plant.

However other strategies could have been adopted for Series 1 in particular. It may have been lower risk to procure the development of a proprietary (pre 2014) TSI compliant systems and make the supplier responsible for the whole system including installation productivity. Whatever approach was adopted the main issue was the lack of time to develop the system which meant construction overlapped development. Therefore, the main lesson to be learnt is to not commence construction work without an available and proven compliant OLE design.

10.4 Where we are now

The Series 1 and 2 OLE systems have evolved into the 'Master Series' which creates a catalogue for future projects and allows approved proprietary components to be included in the system. For example, a number of suppliers now have lightweight cantilevers included in the range. Currently Series 1 and 2 have an Independent Safety Validation (ISV) Certificate and the Midland Main Line project is tasked with securing and ISV for the whole Master Series at which point all the major components of this UK design range for future electrification projects will be classed as 'Interoperability Constituents' which means they are recognised as conforming to the requirements of the TSI and may be 'placed on the market' throughout Europe.

10.5 Recommendation for future projects

To maximise value for money, in major electrification schemes, rather than mandating the use of NR Master Series the procurement process should allow for proven compliant proprietary designs to deliver outcome requirements including life cycle reliability and maintainability against the benchmark of NR Master Series. However, for 'infill' schemes considerations of compatibility and simplification of maintenance may be the deciding factor although in reality the UK already has a legacy of c30 different design ranges so one or two more may not be too problematic.

11. Power Supply

11.1 Background

Overhead Line Electrification, which operates at 25,000 volts 50Hz in the UK, requires a substantial and robust power supply. Where electrification is being extended it may not need a new supply point but in schemes such as GWEP, in an area which has not previously been electrified, new connections will be required which are expensive and have a long lead time.

11.2 Great Western Experience

The grid connections on GWEP were an area of relative success. The total cost was in the region of £100m and came under budget. The chosen solution was three 400kV grid supply points feeding an 'Auto-Transformer' (AT) power distribution technology. At the time this was considered to be economic reducing supply points and neutral sections, providing a high level of resilience and, with its capacity, future proofing for demand growth. Although Auto-Transformers had been successfully used on West Coast a different electrical protection philosophy on Great Western to allow maintenance to be undertaken with only the contact wire isolated reducing maintenance isolation times led to the AT feeder being placed above the contact wire leading to higher masts (Figure 13) adding to the criticisms of visual intrusion.

11.3 Conclusions and lessons learnt

Although the GWEP Power Supply was one aspect that was successfully delivered under budget, other choices were available. There is a trade-off to be made between the high costs and transmission losses from a small number of 400kV connections compared to those from a larger number of 132kV or even 33kV Distribution Network Operator (DNO) connections which are individually less expensive. Given that they are a substantial part of the cost of electrification, it is clear that power supplies need to be carefully optioneered and optimised to arrive at the most appropriate balance between cost and capability.

11.4 Where we are now

The lessons from GWEP have shown that it is possible to deliver major grid connections for a large electrification scheme in an efficient manner. However, there are differing opinions as to whether this was the most cost-efficient option. Power supply requirements can be very different depending on the scale of the project, the likelihood of further electrification on adjoining areas and the availability of grid (400kV or 275kV) or DNO (132kV or 33kV) connections. Electrical Engineers continue to develop new approaches to reducing the costs of traction power supplies.

Network Rail are adopting the IEC 61850 substation automation protocols to reduce the amount of switchgear at substations, and remove the need for full substation sites completely. They anticipate that this ‘rationalised’ approach will reduce distribution costs by 30% compared to both classic and autotransformer systems.

Another approach is the Static Frequency Converter (SFC) which addresses the limits that the electricity companies place on power quality issues (e.g. loading unbalance, load fluctuations, etc.). Although they have been used on some European railways for some time, the first application of SFC technology in the UK is part of the East Coast Power Supply Upgrade – PSU2 Alliance. The selected option for this project, which is currently nearing the end of GRIP 4, is the installation of two SFCs at Hambleton and Marshall Meadows (both 132kV connections) which is expected to reduce costs by c60% and the programme duration by a year compared to an AT system. The actual benefits achieved will need to be carefully monitored.

There is other potentially beneficial new technology for example the combination of energy storage with converter technology.

11.5 Recommendations for future projects

The choice of traction power supply solution is a key design decision which has implications for all subsequent aspects of the project and locks in costs and risks if the wrong decision is made. Future electrification schemes should ensure that all options for traction power supplies are considered, including distribution and traction power storage options.

Cost comparison should be undertaken on the basis of the basis of lowest overall electrification scheme life cycle cost. Operating and maintenance costs and the resilience of the alternatives should be included in this assessment.

12. Clearances to Bridges and Structures

12.1 Background

Most bridges on the UK rail network were not designed with electrification in mind and therefore lack the necessary electrical and mechanical clearances for the OLE to be installed without alteration. The necessary clearances must be provided for both the wires and for the current collecting pantograph on the train. It can sometimes be pantograph clearances which are the limiting factor for example, with arched bridges. These clearances are usually achieved by track lowering or, where this is not possible, jacking up suitable bridges, or complete reconstruction where there is no other viable solution. It is also often necessary to adjust lineside structures such as station awnings and to provide higher parapets and anti-climbing devices on lineside structures and bridges over the track to prevent the public coming too near to live OLE.

12.2 Great Western Experience

In evidence to the Welsh Affairs Committee[33] Network Rail acknowledged that they had "significantly underestimated" the work required and costs of modification to bridges. It is also apparent that, with regard to electrical clearances, the industry was in a transition from previous UK standards to European Standards which came into force in 2015 as explained by David Shirres of Rail Engineer[34]. For a period, this led to some confusion and onerous assumptions being adopted without a clear understanding of the economic consequences as had been recommended by RSSB.

In simple terms the new standard required a minimum clearance of 270mm unless a risk assessment is undertaken and the identified safety measures implemented. This compares with previous UK practice of 270mm for 'normal', 200mm for 'reduced' and 150mm for 'special reduced' electrical clearances which could be agreed by the accountable Network Rail engineers. The difference between these figures can lead to a bridge which would previously have been considered 'clear' to require expensive intervention. Unfortunately, it seems that on Great Western a 270mm or greater clearance[35], was usually adopted which may have been why the original Great Western estimate were significantly underestimated if they initially assumed using the previous UK reduced electrical clearances.

GLRT 1210 Issue 1 published in Dec 2014 Clause 3.1.7.3 stated: *Where it is not reasonably practicable to provide clearances in the 'normal' category, it is permissible for smaller clearances to be used where justified by a risk assessment complying with the CSM RA and the application of appropriate safety measures.*

Another factor increasing the number of bridge reconstructions is the alleged insistence of Network Rail maintainers that they did not want to accept any reduction in clearances to the underside of bridges or in track lift allowances as this would compromise long term maintainability. Taken with a 270mm electrification

33 https://publications.parliament.uk/pa/cm201719/cmselect/cmwelaf/403/40302.htm
34 https://www.railengineer.uk/2017/02/24/egip-electrification-clearance-woes/
35 GLRT 1210 notes that a 370mm 'basic' clearance gives 'basic insultation' against flashover and this seems to have been adopted as a preferred minimum clearance

clearance, a 75mm track lift allowance, could add almost 200mm[36] to the minimum clearances required. This could easily be the difference between no work being required and a multi-million pound reconstruction.

However, in electrification, achieving electrical clearances is only part of the challenge. It is also necessary to check the mechanical clearances of the passing pantograph and to allow for tolerances for the possible position of the wire under wind loading and for future track lifting. On Great Western it seems that very often all the most onerous assumptions were made without sufficient assessment of their likelihood, or the whole life impact of not providing for the future maintenance ideal, in order to avoid an expensive bridge reconstruction.

There was a further major challenge in the new GLRT 1210 standard with the requirement for a 3.5m rather than the previous 2.75m 'standing' clearance between personnel or public and a live 25kV OLE conductor or pantograph. This is not usually problematic for the more generous European loading gauge but in the UK it caused particular problems at station platforms with clearances to the live parts of the pantograph especially as, in the UK, pantograph horns are not insulated as is the practice in Europe.

The 2.75m clearance had been a UK 'special case' in the TSI and was based on the '9-foot rule' for trained railway staff that they must make sure that "you and anything you are carrying are no nearer than 2.75 metres (9 feet) from live OLE". Railway staff are trained not to raise items above their head unlike the public who may be carrying items such as umbrellas and be unaware of the risk.

The relevant 'International Standard' EN 50122 2011 specifies the European Norm of 3.5m and the ORR position was that this was the minimum necessary to comply with the Electricity at Work Regulations (EaWR) 1989. Therefore, when the UK standard committees considered whether to continue to apply the 2.75m 'special case' for 'standing surfaces' such as station platforms it was considered both non-compliant with EaWR and inappropriate to apply the '9-foot rule' to untrained members of the public. Therefore the 3.5m dimension was adopted as the minimum without risk assessment and safety precautions and the ORR provided advice on this in 2016[37].

The industry did not handle the situation of standards changing positively. RSSB were unsuccessful in organising industry workshops to explain the changes, and the expectations of some ORR inspectors was that absolute compliance was required. It took time a risk assessed approach to be proven as acceptable. It also appears that concerns about programme timescales drove the project towards adopting the 'safe' but expensive option of reconstruction rather than taking the time to explore alternatives. This would have lowered cost, but it was thought it would also delay the programme and might not be approved.

Planning permission and consents proved to be another challenge which had been underestimate on GWEP and the NAO report noted that *"with over 1800 consents to obtain NR now believes it would be better to seek route wide planning permission even if this results in a longer programme".* Although not exclusively a route clearance issue, there have been some particularly high-profile objections relating to bridgeworks. It says something about the ability of the rail industry to

36 270-150mm special reduced clearance + 75mm track lift allowance = 195mm
37 http://orr.gov.uk/__data/assets/pdf_file/0009/23004/electrical-clearances-policy-statement.pdf

forget hard won experience that the ECML lessons learnt included *"The importance of obtaining listed building and other permissions was not appreciated at the outset".*

12.3 Conclusion and Lessons Learnt

The Great Western experience with bridgeworks and electrification clearances is another example of the need for both a mature design and stable standards before construction commences. Further, it illustrates the benefit of sequencing works to not overlap. It has become the practice in Scotland, for example, to undertake all the service diversion and route clearance works as enabling works in a separate package well in advance of the electrification scheme. This would also apply to other enabling works such as signalling immunisation. It was also, as Section 12.4 illustrates, a lost opportunity for innovation to reduce costs.

Regarding stability of standards, it should have been possible for Network Rail and its designers to work with RSSB and ORR to reach earlier mutual understanding on the implications of the changes in the standards. This would have allowed a more informed decision on compliance versus the case for requesting a standards freeze or a derogation for a project at an advanced stage. It is regrettable, and a lesson for the future, that there seems to have been insufficient alignment and collaboration between the parties such that the focus was on organisational objectives rather than the optimum way to secure the nationally important public benefit of electrification of the railway to Bristol and South Wales.

Even so, it should have been possible to undertake risk assessment, as the revised standards explicitly allowed, as part of a value engineering exercise to minimise bridge reconstruction costs. Such an exercise would have included the trade-offs between reduced capital costs and potentially increased life-cycle maintenance costs from restricted clearances or track lift allowances. However, there appears to have been a reluctance amongst designers to undertake risk assessment and such an exercise requires sufficient up-front design and optioneering time and there is often pressure on design time for long lead time items like bridge reconstruction.

Consents were a predictable requirement recognised, for example, by the 2006 to 2010 Airdrie Bathgate project which managed a similar density of consents to GWEP, albeit on a much smaller project. It seems likely that the issue on GWEP was the volume of consents and the constrained programme. This could have been addressed by securing a Transport Works Order for the whole route. Although this would have notionally delayed the programme probably by several years, in hindsight, this time could have been well utilised developing designs and proving the new plant and OLE system.

The main lessons are; to ensure there is enough time to engage all the parties and consider all the appropriate options in order to develop a mature, value for money design before site work commences and, if possible, to do the route clearance works in advance of the OLE works.

12.4 Where are we now

There is now a much better understanding in the industry of what the new standards require and how to undertake risk assessments to justify using clearances less than the 'normal standard' where these are not economic or reasonably practicable by demonstrating a different route to compliance. There is a strong case for generic risk assessments for commonly used solutions such as those detailed in the table below to support their wider and more consistent deployment. There does however still appear to be a marked reluctance to deploy these options to reduce cost.

The electrification programme also catalysed and has now proven a range of valuable innovations which will, in future, help to minimise the need for bridge reconstruction. These include:

Underbridge Arms	Building on experience from the 1970's in 2011 NR commissioned tests which demonstrated that underbridge arms which locate the OLE accurately below a bridge can allow the OLE to be 174mm from the bridge structure without flashover
Surge Arrestors	As part of their delivery alliance (See Section 6.5) The Danish Railways have successfully introduced surge arrestors – see Fig. 19 which allows the air gap clearance[38] to be reduced from 270mm to 150mm. These are now approved for use in the UK.
F&F Insulating Contact Wire Cover	This allows the air gap clearance to the contact wire to be reduced to 125mm or 70mm
GLS Insulating Coating[39]	This coating which has a 40-year life applied to the underside of bridges allows the air gap to be reduced to 100 mm or less when in combination as below. It has been successfully used on a number of UK bridges.
Combination of surge arrestor, insulated coating and contact wire cover (See Figure 20)	In tests conducted by Southampton University for Network Rail it was demonstrated that even in wet conditions the air gap could be reduced to 20mm before flashover. This effectively means the tipping point for bridge reconstruction is mechanical rather than electrical clearances.
Probabilistic Gauging[40]	A statistical simulation method to 'squeeze more' out of a structure compared to the traditional and conservative gauging methods.
Bar Conductor	Bar or beam conductors have been successfully[41] used in tunnels worldwide to achieve the necessary clearances.

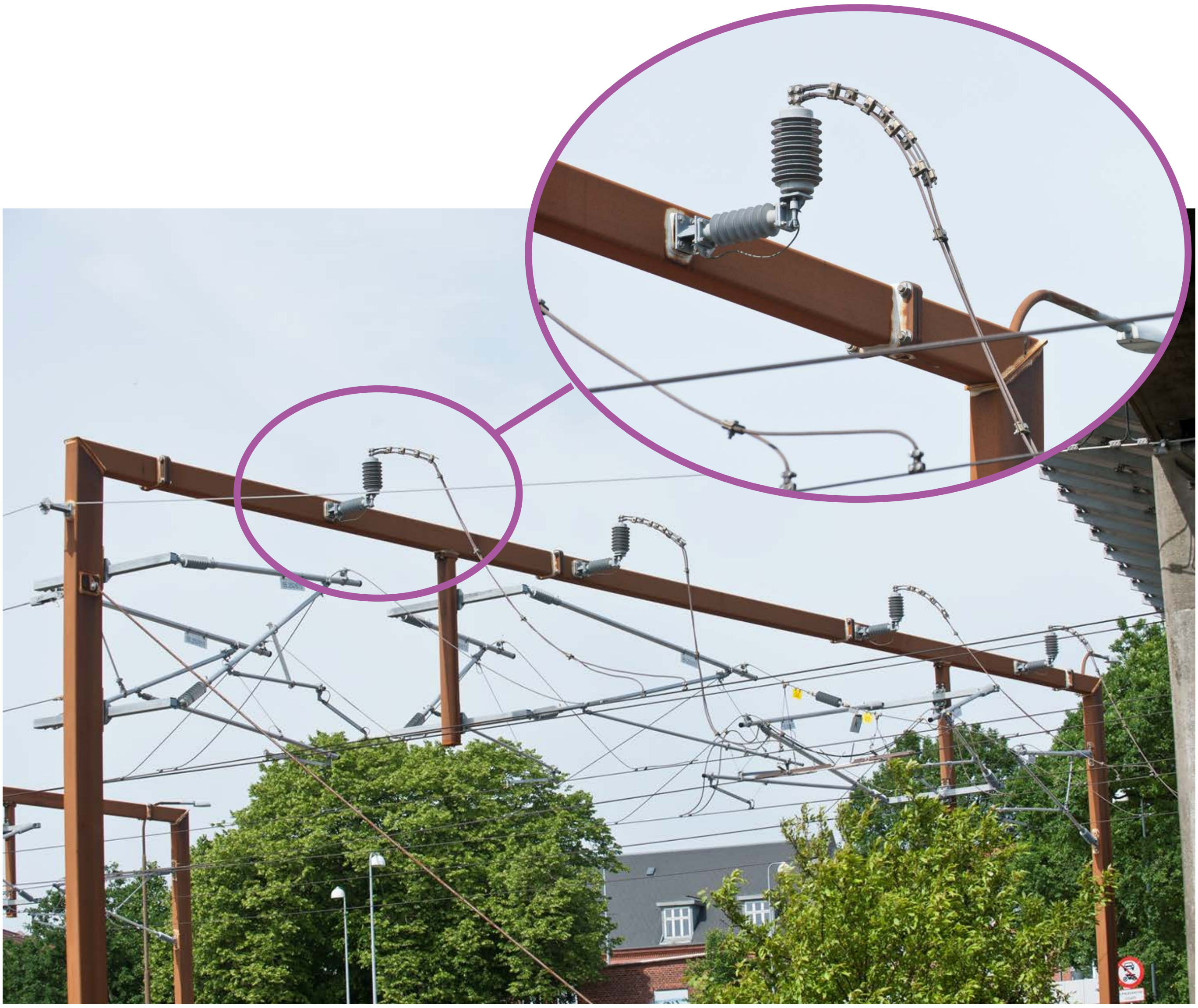
38 The surge arrestor also reduces the compliant clearances for the pantograph which is often the limiting factor for arch bridges
39 https://glscoatings.co.uk/gls100R-electrical-insulation.php
40 https://www.railengineer.uk/2013/07/12/predictive-and-probabilistic-gauging-the-shoehorn-effect/
41 There have been maintenance issues with two UK installations which need to be fully understood

Neutral Section	There are four examples in the UK where 'dead' sections of conductor wire under a bridge have been used to avoid bridge reconstruction. These sites are: 1. Paisley Canal – Scott's Road Bridge 2. Romford - Upminster – Brentwood Road Bridge 3. Romford - Upminster – Heath Park Road Bridge 4. Ayr – 'Tam's Brig' Although these are little different from a normal neutral section they require careful consideration about the resulting wire gradients which may cause reliability issues with the in-line insulators and also limit speed. Another factor is the risk of a train becoming stationary in this location as an electric only train will need to coast through the 'dead section'. For these reasons this solution is likely to be a 'last resort' when other options have been exhausted.
Discrete electrification	Discrete (long sections of unwired route) electrification changes the business case as both an onboard power supply and a local lineside power supply are required. The potential gaps would be based on the self-powered range of the train and the local 25kV supply could be costly. To date this approach has been considered where it would help a bi-mode train maintain maximum performance but it has not yet been demonstrated that there is a positive business case with the performance gain from localised electrification offsetting the initial infrastructure costs.
Discontinuous electrification (short gaps)	This can be achieved by an electric train coasting through 'long neutral sections' or having a physical gap in the wire and some form of on-train energy storage (eg bi-mode). Although attractive in principle, experience is showing that once the many factors about which locations are suitable for raising or lowering the pantograph are considered the actual gap achieved may be much smaller than expected and so the infrastructure benefit is reduced. But see also 'smart electrification' where the availability of on-board battery power can presumably reduce the frequency of raising/ lowering the pan. It will be important to consider all the infrastructure and train whole life costs and risks of discontinuous compared to continuous electrification to make an objective decision.
Smart Electrification	The recently awarded Wales and Border Franchise[42] is procuring bi-mode (25kV Electric and Battery) tram trains and tri-mode (25kV, Battery and Diesel) multiple units which will avoid bridge reconstruction and other difficult to electrify areas through smart (or discontinuous) electrification.
ElevArch[43] – Jacking up a masonry arch bridge See Figure 21	In a world first, Freyssinet have successfully demonstrated that it is feasible to safely jack up an entire masonry arch bridge to achieve electrification clearances at approximately 33% less cost and programme duration than demolishing and reconstructing the bridge. This approach which can be applied to multi-span bridges also has the benefit of retaining the visual appearance of the existing bridge and requiring less track access.

42 https://www.railwaygazette.com/news/passenger/single-view/view/wales-borders-electric-train-order-confirmed.html
43 http://freyssinet.co.uk/worlds-first-elevarch-bridge-lift/ https://youtu.be/KhumV315nFk

Insulated Pantograph Horns	Traditionally the UK has not had insulated pantograph horns as is European practice. This is now being reconsidered to reduce the risk to passengers on platforms with 'selfie sticks' or similar but also to potentially assist in route clearance.
Standard Bridge Designs	Where it is necessary to re-construct a bridge this should be done as efficiently as possible. Earlier (pre 1993) electrification schemes used standard designs which could deal with the relatively minor variances between many overbridges crossing a (say) two track railway. There is a strong case for a return to a national approach to standard bridge designs.

Fig 19. BaneDanmark surge arrestors (circled) also showing the relatively lightweight weathering steel structures roughly comparable with Series 2.



(BaneDanmark)

Case Study - Cardiff Intersection Bridge

This case study very well demonstrates that it is possible to electrify through an extremely challenging bridge without reconstruction and thus avoid significant expenditure. Cardiff Intersection Bridge is a very low and highly skewed bridge just outside Cardiff Central Station carrying a local railway over the Great Western Mail Line which itself crosses a substantial culvert. Reconstruction was costed at £40m-£50m, track lowering and culvert diversion was estimated to cost £10m-£15m and either option would cause very significant train disruption.

A collaboration between Network Rail Route (Client), Andromeda Engineering (Design), Siemens (Surge Arrestors), GLS Coatings (Insulated Coating on the underside of the bridge) and the University of Southampton (HV lab tests to prove concept) helped develop from the concept to a proven viable design solution which was implemented in 2018 for a combined design and installation cost of below £1 million. The project deservedly won a Railway Industry Innovation Award in 2018.

Fig. 20 Cardiff Intersection Bridge

NO TRACK INTERVENTION WITH THE APPLICATION OF INSULATED COATIG AND SURGE ARRESTERS

(Pictures courtesy of Siemens & Andromeda Engineering)

Using these techniques, a desktop study of bridges between Cardiff and Swansea and concluded that bridge intervention costs could be reduced by up to 70% and this model could easily be replicated across other schemes.

Fig. 21. The ElevArch demonstration – jacking up rather than demolishing and rebuilding a masonry arch bridge

Before After

(Freyssinet Ltd)

12.5 Recommendations for future projects

It is recommended that, wherever possible future projects should secure all necessary consents, perhaps via a Transport Works Order, and undertake route clearance in advance of OLE works even if this means extending the programme. The work required should be based on a developed design options which include detailed evaluation of the benefits and trade-offs of adopting innovative methods of reducing the need for bridge reconstruction and other route clearance works.

This should be based on a thorough understanding of the flexibility in the standards regime and early engagement with standards owners and ORR. To provide certainty for that project the contract should include a standards freeze. Where legal standards are changing a derogation should be sought if the project can be demonstrated to be in advance stage.

Network Rail should develop generic risk assessments[44] for solutions such as those in Section 12.4 to support site specific risk assessments. RSSB should support the industry in examining the case for adopting insulated Pantograph Horns.

Given the range of potential options to reduce the need for reconstruction of structures described in Section 12.4 it is recommended that an appropriate level of detailed design is undertaken at GRIP 3 (Option Selection) to ensure an objective assessment of the options.

44 These should be embedded as part of the CSM RA (Common Safety Method – Risk Assessment) process to increase consistency and reduce assessment time.

13. Plant

13.1 Background

Electrification requires a range of plant to support construction. Foundation have to be dug or piles installed, masts lifted into position to allow the installation of 'small parts steelwork'[45] and finally the catenary and contact wire needs to be pulled out, fixed and adjusted. This usually means specialised or specially adapted plant is needed to support safe and efficient delivery.

13.2 Great Western Experience

Electrification plant is available in the market but, on the basis that it was the start of a major programme of electrification, the Great Western programme took an ambitious approach to the perennial problem of maximising productivity in short midweek possessions. The proposal was to use a specially designed 'factory train' which was originally conceived to be able to install piles, masts and overhead line in a single shift and outperform readily available plant in terms of productivity and disruption to train services.

With the Series 1 OLE system (Section 10) the 'factory train', more properly called the High Output Plant System (HOPS)[46], was the other half of the 'high output system' intended to significantly improve productivity compared to previous electrification projects. The 'train' was in fact 23 vehicles which could be marshalled in different 'trains' or 'consists' to work in three phases of OLE construction as shown in Figure 22.

45 Masts are often 'pre-dressed' with small parts steelwork to reduce site time
46 https://www.networkrail.co.uk/running-the-railway/looking-after-the-railway/fleet-machines-vehicles/high-output/hops/

Fig. 19 The High Output Plant System (HOPS)

(Pictures courtesy of Network Rail)

The plan in 2013 was that the three separate consists would work 6 shifts a week and install foundations, steelwork and wiring in 7-hour possessions. The HOPS was designed for ALO (adjacent line open) working which meant trains could still run at full line speed on the adjacent line. This was a significant advance on previous plant and aimed to minimise disruption to the operational railway. The ORR required significant modifications to the train before ALO was approved which highlights the importance of early engagement and adequate programme time for development.

The ambition for the HOPS was to be 'right first time' and not revisit sites. Documentation from 2013, before the train had been delivered assumed the following outputs:

- Foundations – Specification required 30 Piles per night, 3 concrete foundations.
- Steelwork – Specification required minimum of 30 masts (STC) per night

The system was delivered in 2014[47] and it was soon found that the piling system was not achieving the required outputs. As described earlier (Section 8.0) this was, in large part, due to the piles being longer and positioned further from the track than had been assumed when the HOPS system was designed. The 2016 NAO report found:

> *The original plan relied on a new 'factory train', carrying out much more work each night than could be accomplished using traditional construction techniques, at lower cost. The original plan assumed that the train would complete 18 piles (for foundations) per shift and complete 80% of the work. While Network Rail has demonstrated that the train is capable of installing up to 24 piles per shift, it has not been able to do this routinely, and Network Rail now plans for it to complete eight piles per shift on average. On average, the train completed five piles per shift between April and September 2016 (35% of the work completed during this time). It installed seven piles or fewer on 68% of nights it was used.*

13.3 Conclusion and Lessons Learnt

Great reliance was placed on the High Output System (the HOPS and the OLE) to deliver electrification quickly, efficiently and with the minimum possible disruption to passengers and freight. This was a very laudable objective, but the outputs assumed in the programme were not achieved in practice. The greatest difficulty was with the productivity of the piling system to which the overlong piles were a significant contributory factor. **This is arguably the root cause of all cost and programme overrun on GWEP**, once the piling output fell behind and gaps were left requiring return visits the programme, which lacked resilience, rapidly became unrecoverable.

Conceptually High Output, or at least minimising disruption, was the right approach. It was not however entirely new with a long track record of piling and wiring trains in the UK and internationally. The problem (apart from the overlong piles) was that an entirely new and ambitious process including the OLE design range and associated plant was central to a very large and high-profile project with a fixed end date. Had the programme allowed, the whole system (HOPS and OLE)

47 https://www.railengineer.co.uk/2014/10/03/great-western-electrification-arrival-new-high-output-plant-system/

should have been proven on a smaller project. At the very least, a significant 'fire break' should have been built into the programme to allow the inevitable 'teething troubles' to be ironed out. The test track trials proved to be no substitute for 'real life' experience. All of this was exacerbated by too much being promised in extensive publicity before the HOPS had even been built.

13.4 Where are we now

There is now an established OLE design range (See Section 10), there has been a return to smaller piled foundations (See Section 8) and there is valuable experience of OLE installation using both the HOPS and contractor owned plant such as that shown in Figure 23. That means industry is now in the position it should have been at the start of the 2012 electrification programme with a proven system and process and a good understanding of productivity.

However, there has been a loss of confidence and it seems, because of the previous difficulties, estimates are including very conservative assumptions on productivity and risk. There is an entirely understandable tendency to under promise and over deliver. However as shown in Section 6.0 some of the most recent projects are already delivering at much more acceptable costs and this needs to be built on.

Fig 23. A typical contractor owned wiring 'train'

(Picture courtesy of Alstom)

13.5 Recommendations for future projects

The choice of plant for a project depends on many variables but the trade-offs between disruption, access and productivity are probably the most significant. The UK now has experience with and access to a wide variety of plant and so it should be possible to make the appropriate project specific trade-offs. The recommendation to establish a 'rolling programme' of electrification would both reduce the competition for scarce plant by allowing forward planning and create the incentive to, over time, invest in more productive plant, process and skills to further optimise delivery.

14. Delivery Methodology

14.1 Background

The reader will by now hopefully understand that the electrification system is not particularly technically complex and should be well understood. Therefore, perhaps the greatest challenge to cost efficient delivery is how this system is built on a linear site extending over 10's and sometimes 100's of kilometres. This is further compounded by the fact that, in the UK at least, construction is usually happening on an operational railway and therefore there is an imperative to minimise disruption. This brings significant planning and logistical challenges which can have a huge impact on productivity and therefore cost including for example:

- Track Access – is the opportunity to work compatible with the optimum resource productivity? For example, the team/ plant may be paid for an 8-hour shift but there is only 3 hours[48] productive track access available.
- Track Access – distance/ time to Road Rail Access Points (RRAPs) or train stabling facilities
- Packaging and sequencing – is the work of different 'trades' kept separate or overlapping?
- Choice of plant
- Choice of OLE system for constructability including consideration of offsite work
- Productivity assumptions
- Design Maturity
- Site Investigation
- Materials and Logistics including lead times
- Availability of skilled and experienced staff
- Management Processes
- Contracting Strategy

14.2 Great Western Experience

This has been well covered elsewhere in this report and the 2016 NAO report.

14.3 Conclusions and Lessons Learnt

Again the lessons drawn from Great Western have been covered earlier but are summarised well by these extracts from the NAO report:

- The 2012 infrastructure programme was unrealistic and driven by delivery dates for the trains rather than a bottom up understanding of the work required.
- There was no critical path programme developed, showing the minimum feasible programme and dependencies, before work commenced.
- Assumptions in the 2014 cost estimate were unrealistic.

48 For example, 6 hour no trains period, access points every 10 miles means 1.5 hour to travel to/ from site and set up/ close down resulting in 3 hours productive work from an 8 hour shift.

- The assumed productivity of the 'factory train' was too optimistic.
- There was insufficient allowance for the challenges and risks of using new technology, specifically a new design for the electrification equipment and a new 'factory train' for installing the electrification equipment and its supporting steel structures.
- The surveys to locate structures not sufficiently detailed which meant that some design work had to be repeated.

14.4 Where we are now

The following section is intended to be draw together the learning from earlier in this report with typical examples of good practice from Stirling Dunblane Alloa (SDA) and other recent projects.

14.4.1 Packaging, Sequencing and Interfaces

Separating independent activities as far as possible may extend the programme but reduces delivery risk by reducing the risk of a delay in one activity impacting on another. The following sequence (not rigid) has been successfully used.

1. Utilities diversion and route clearance (bridgeworks etc) – but see clearances (Section 14.4.9) below
2. Site and ground investigation available at the start of GRIP 4[49]
3. Grid supplies, Major Feed Diagram, Isolation and Switching Design all before foundations
4. Foundations – feeding as-built information back into GRIP 5[50] detailed OLE design and completed well in advance of subsequent stages to ensure a free run for;
5. OLE Installation

The work should be packaged in a way that ensures delivery accountability and minimises interface conflicts. Potential packages are 1 and 2 to 5 above.

On SDA a staged approach was developed that ensured the designers had the site and ground information necessary to deliver quality and accurate designs to enable efficient procurement and right first time construction. Efficient construction was also underpinned by a project specific access strategy

14.4.2 Topographical Survey and Ground Investigation

The security of an accurate topographical survey of the route to be electrified is STET essential to the detailed design process. Extensive Ground investigation was undertaken (see also 14.3.3) to provide ground data at 200m centres throughout the route and at individual planned foundation locations in those areas where particular special foundations were predicted

49 Governance for Rail Investment Projects Stage 4 – Single Option Development
50 Governance for Rail Investment Projects Stage 5 – Detailed Design

Unusually the GRIP 4 OLE design was specified to be more detailed and pick up site information including clearances to bridges, station platforms and buildings, signals and powerline and telecoms crossings. All of which are essential for the accurate development of GRIP 5 detailed OLE designs

14.4.3 Foundation Design

SDA and MML have used the PAN 101 (the ORE empirical) foundation design method wherever possible which proved to be over 80% of the route in both cases. On SDA a desktop Ground Investigation Study (GIS) CAD model was generated by the Civils designer, using previous Network Rail geological studies on the route, BGS maps and all other known sources. This identified where Circular Hollow Section (CHS) piles or Augered Concrete foundations could be expected to succeed and where PAN 101 could confidently be adopted. It also provided the logic for the selection of Ground Investigation techniques including Window Sampling, Dynamic Probing and Rock Coring. The Ground Investigation undertaken at minimum 200m centres enabled review and confirmation of the PAN 101 areas identified in the desktop GIS study and the secure selection of foundation types. CHS piles were selected wherever possible, as the most cost-effective solution and also because they required only one visit to site to deliver a complete foundation, the safest and most economic option. The average pile length was 6m and the maximum 8m.

Prior to foundation installation 1.2m x 1.2m x 1.2m trial holes[51] were hand dug at each planned location to verify it was clear of services and obstructions. All trial hole data was analysed and where any buried services were located, the foundation setting out data (and where necessary the foundation design) adjusted accordingly. There was a strict ‘approval for construction’ process that ensured all this was done before foundations installation was attempted, or later, before mast installation.

Non PAN 101 foundations were deemed ‘special’ foundations that required specific designs developed through the Form 1, 2 and 3 process. Most of the special foundations were CHS piles, augured concrete or rock sockets.

A staged approach to OLE design and appropriate design maturity is important. A key enabler to foundation positioning is the Isolation and Switching Design and therefore this should be an early deliverable and foundation positions should not be designed without it. Normally GRIP 4 is a largely desktop exercise but on SDA for example, foundation locations were verified and/ or modified through a designer site walkout to identify surface obstructions, buried cable routes and any potential embankment and cuttings problems that would prevent foundation installation at the proposed foundation locations.

The foundation designs were issued in two stages; the first for setting out and trial holing, the second on completion of the trial holes and verification of each planned foundation location. This process allowed detailed foundation designs for construction using GPS location which, in turn, allowed the as-built foundation information to feed into the OLE detailed design. In this way the long lead time Series 2 OLE equipment was allocated correctly first time, rather than by anticipating where the OLE foundations were to be installed which is a temptation on projects faced with long lead procurement programme constraints. In the GRIP 5 design the number of foundations was reduced by approximately 10% compared to the GRIP 4 assessment using self-supporting anchors wherever possible at OLE terminations and midpoints.

51 There is a trade-off between securing this information to reduce risk and the longer piles needed to deal with the disturbed ground from the trial holing

14.4.4 Foundation Installation

The CHS piles were installed using MOVAX vibrating units (similar to those used on the HOPS) mounted on Road Rail Vehicles (RRVs). Occasionally the pile unexpectedly refused when part driven. Post-augering was used to drill through the obstruction enabling the pile to be driven to level. Each foundation was surveyed after installation to ensure that installation was within design tolerances in terms of level and orientation. A mast with slotted baseplate holes was allocated if the orientation required.

14.4.5 Common Data Model

The project aimed to ensure consistency and availability of data. The initial issue of foundation setting out information was included on the Steelwork Foundation Schedule (SFS). This was expanded to include:

Material Allocation Details – including foundation loading information and allocation references for CHS pile foundations together with concrete alternatives – in the event of a pile refusal

Ground Investigation setting out details

Masts and Small Parts Steelwork Schedules

The Ground Investigation locations and types were also included in the GIS model, the wiring CAD model and the SFS schedules – thereby ensuring compatibility in data

14.4.6 Mast Installation

Masts were allocated by the designer on completion of the foundations as a further interim design stage in the OLE ‘Form B’ design. As a result, there was very little re-work when masts were installed. Allocation drawings for the masts identified the Small Parts Steelwork (SPS) mast attachments which were fixed to the mast in the yard during the day shift prior to transporting to site, rather than at height during night time possessions. Masts were therefore erected ready to receive OLE registration equipment. Masts were installed using a RRV mounted manipulator (See Figure 24), rather than a crane avoiding the need to sling the mast from a RRV crane and greatly reduced the need for staff to work at height in night time possessions.

Fig 24. RRV and manipulator installing mast with pre-fixed small part steelwork

(Picture courtesy of Costain)

14.4.7 Overhead Line Installation

Each OLE tension length of Contact Wire and Catenary requires all foundations, masts, booms, drop tubes and registration equipment to be installed prior to running the OLE wires. As had been the experience on GWEP only one missing foundation will prevent the running of 1.5km of OLE. Therefore, SDA ensured that ‘special’ foundations were given the same attention as PAN 101 foundations and the ‘Approved for Construction’ process used to ensure the wiring train only went to site when the site was ready to receive it and the overall programme was maintained.

The designer allocated the Series 2 cantilevers and other registration equipment, and these were procured in advance of the OLE Form B approval, but in a measured way based upon the as built foundation locations. This enabled cantilever installation immediately after OLE Form B approval. As a matter of course each cantilever and its registration arms was pre-registered to +/- 50mm tolerance prior to running the OLE.

14.4.8 Access Strategy

The normal or Rules of the Route (ROTR) regime on the SDA route is intended for maintenance and provided minimal track time midweek, Monday to Thursday. Network Rail were able to negotiate Extended Rules of the Route (eROTR) covering 60% of the SDA route with the train operator which provided the regular possession availability 6 nights each week that supports safe, repeatable and efficient OLE installation. This was complemented by a 4-week Blockade on the Alloa Branch in February 18 and the one week Blockade on the route North of Larbert in October 18.

Whilst access would inevitably be more constrained on a main line like Great Western, both Midland Main Line (MML) and NWEP Phase 3 (Preston to Blackpool) also negotiated additional access which helped increase productivity. Midland Main Line negotiated a cyclical extended midweek possession regime which added 29 hours to their fast line access over a 6 week cycle. The Preston to Blackpool project was delivered in a blockade from November 2017 to April 2018 but this was a complete route upgrade rather than a 'pure' electrification scheme involving 11km of track renewal, new and extended platforms, three new footbridges as well as 60 stk of electrification involving 1100 overhead line structures and two substations.

On SDA, apart from use of a wiring train for delivery of 40% of the OLE wiring, all other construction activity including; ground investigation, de-vegetation, foundations, masts, OLE installation and final registration depended on the effective use of Road Rail excavators, manipulators and Mobile Elevated Working Platforms (MEWPs). All of these arrive at site by road and therefore require Road Rail Access Points (RRAPs) at 5km intervals to maximise productive time.

On SDA it was not practical to use the wiring train on midweek nights as limited siding locations and the possession speed limit of 5mph resulted in too much travel time. This contrasts with the strategy on GWEP to use the HOPS train which could move to site at up to 60 mph and illustrates the careful trade-offs that must be considered in balancing plant choice with access availability.

14.4.9 Clearances

An enabling project in 2014 had reconstructed 15 bridges and therefore removed these from the critical path. However, the GRIP 4-5 design for the OLE package identified a further 5 projects which required reconstruction. These were all adjacent to stations and were impacted by the change in 'standard' to a 3.5m rather than 2.75m (See Section 12.2) electrical clearance from a live pantograph to standing surfaces at station platforms without a risk assessment. The increased clearance required at the platform required the wire height to be increased which combined with wire gradient limits has a consequential impact wire height at the adjacent bridge. The SDA project developed a process for Station Electrical Clearance Risk Assessment (SECRA) in parallel with the development of OLE Form B designs for track units containing stations. The OLE Form B design was required to replicate the electrical clearances assessed as acceptable through the SECRA process.

14.4.10 Materials and Logistics

There was an issue across the whole programme with long lead times on some parts specified in the OLE system. Some projects are now considering local sourcing to reduce this risk. On GWEP the materials ordering system did not allow materials to be returned to stock and reallocated causing delay and waste.

An example of good practice on Preston to Blackpool was the system set up by VolkerRail, working closely with Unipart Rail, to manage the tracking of over

250,000 parts required on the project. This involved opening a pre-fabrication facility and using bespoke software to provide live status information of materials both in the facility and out on site. For example, the small parts steelwork (SPS) prefabrications were QR coded and tracked throughout the process to site installation. To support this an overhead line prefabrication course and competence assessment was developed. The team also developed and manufactured specialist equipment including mast distribution modules and a mast 'manipulator' unit (See Figure 25) to mitigate the risks associated with slinging and controlling suspended loads.

Figure 25 Mast Manipulator and Distribution Module

(Photos courtesy of Volker Rail)

14.4.11 Summary of STET lessons learnt

- Construction should not be started until the design mature enough
- Procure route clearance and site/ ground investigation as enabling packages
- Develop foundation and GRIP 5 OLE design on emerging cost basis.
- Mature design through GRIP 5 in advance of construction commencing, based on site/ ground investigation and trial digs to confirm foundation locations
- OLE designed to GRIP 5 in advance of foundation installation, and as built foundations confirmed before detailed OLE design finalised to form B.
- Electrical clearances, around overhead structures, stations etc should be done in GRIP 3[52]-4 design. During GRIP 5 design, bridges, powerlines and stations caused delay to both final OLE design and required significant bridge demolition, and powerline diversions during the construction period.
- Understanding methodology and construction constraints around over bridges and powerlines at GRIP 3 will allow time to provide alternate solutions to demolition. Early engagement with Utilities will confirm scope of powerline diversions and allow third party land agreements to be reached in advance of construction.

14.4.12 Recommendations for future projects

The good practice from recent projects described above illustrates the value of retaining and exchanging knowledge and experience. It also shows the benefit of a source of authoritative advice and support on issues such as interpretation of standards and risk assessments and it will be important that Network Rail retains this 'Technical Authority' expertise as they devolve and reduce the 'centre'.

52 GRIP 3 – Option Selection

There is a case for reviewing the NR GRIP process deliverables which may mean for electrification that some ground investigation and detailed design is needed during GRIP 3 (Option Selection) before moving into GRIP 4 (Single Option Development). The intention would be to ensure that there is sufficient information to support decision making and mitigate cost and programme risk. A risk based approach could be adopted with, for example, more detail acquired around bridges and stations.

It is also a further illustration of the benefit of establishing a 'rolling programme' of electrification that would help this retention and exchange of knowledge and experience and create a platform for continuous improvement.

Appendix 1. Full List of Report Recommendations

Recommendations

Cost

- To establish a 10 year rolling programme of electrification to progressively lower the long-term operating costs of the railway towards European norms and to support investment in people, process and plant.
- To endorse electrification as the first choice in a hierarchy of options for decarbonising the rail network.
- To ensure future projects adopt a realistic programme and risk apportionment.
- To use the Rail Method of Measurement to allow comparison between projects on a consistent basis.

Standards

- Future projects should use proven systems that comply with the relevant standards.
- Avoid developing and obtaining approval for new systems as part of a project.
- Review the Network Rail standards suite and risk allocation to support output specification.
- Implement a 'standards freeze' for the duration of a project.

Foundations

- Continue to use the proven ORE/ OLEMI empirical design method and plant appropriate to the task.
- Adopt a possession strategy which optimises efficient delivery, and a sequential approach to OLE installation.
- Have an appropriate level of design maturity before commencing foundation installation.

Masts

- Encourage designers to adopt the simplest, lightest possible, compliant and approved design consistent with life cycle output requirements.
- Future procurement should allow for alternative designs and site specific modelling that deliver outcome requirements, including life cycle reliability and maintainability against the benchmark of NR Master Series.

Overhead Line Equipment (OLE)

- To maximise value for money, the procurement process should allow for proven compliant proprietary designs to deliver outcome requirements, including life cycle reliability and maintainability against the benchmark of NR Master Series, rather than mandating the use of NR Master Series in major electrification schemes.

Power Supply

- At the optioneering stage, future projects should ensure that all options for traction power supplies are considered, including distribution and traction power storage options.
- Cost comparison should be undertaken on the basis of the basis of lowest overall electrification scheme life cycle cost. Operating and maintenance costs and the resilience of the alternatives should be included in this assessment.

Clearances to Bridges and Structures

- Wherever possible, future projects should secure all necessary consents, such as via a Transport Works Order, and undertake route clearance in advance of OLE works, even if this means extending the programme.
- Work required should be based on developed design options, which include detailed evaluation of the benefits and trade-offs of adopting innovative methods of reducing the need for bridge reconstruction and other route clearance works.
- To provide certainty for a project, the contract should include a ‘standards freeze’.
- Network Rail should develop generic risk assessments for solutions to support site specific risk assessments.
- RSSB should support the industry in examining the case for adopting insulated Pantograph Horns.
- Sufficient detailed design should be undertaken at GRIP 3 (Option Selection)

Plant

- The recommendation to establish a ‘rolling programme’ of electrification would both reduce the competition for scarce plant by allowing forward planning and create the incentive to, over time, invest in more productive plant, process and skills to further optimise delivery.

Delivery Methodology

- Retain and exchange knowledge and experience from recent projects. Establishing a rolling programme of electrification would help this retention and exchange of knowledge and experience and create a platform for continuous improvement.
- Network Rail retains its role as Technical Authority as it devolves further to regions and routes.
- Review NR GRIP process to bring forward detailed design on a risk assessed basis

Appendix 2. Summary of Good Practice Identified in the Report

- Construction should not be started until the design is sufficiently mature
- Procure route clearance and site/ ground investigation as enabling packages
- Develop foundation and GRIP 5 OLE design on emerging cost basis
- Mature design through GRIP 5 in advance of construction commencing, based on l site/ ground investigation and trial digs to confirm foundation locations
- OLE designed to GRIP 5 in advance of foundation installation, and as built foundations confirmed before detailed OLE design finalised to form B
- Electrical clearances, around overhead structures, stations etc should be undertaken in GRIP 3-4 design. During GRIP 5 design, bridges, powerlines and stations caused delay to both final OLE design and required significant bridge demolition, and powerline diversions during the construction period
- Understanding methodology and construction constraints around overhead bridges and powerlines at GRIP 3 will allow time to provide alternate solutions to demolition. Early engagement with Utilities will confirm scope of powerline diversions and allow third party land agreements to be reached in advance of construction.

Appendix 3. Contributors

RIA would like to thank all those Members and Stakeholders who participated in workshops and provided information and comment for this report particularly the following (not exhaustive) list. The Conclusions drawn and Recommendations are however RIA's responsibility.

ABB

Alstom

Amey

Andromeda

Balfour Beatty

Campaign to Electrify Britain's Railway

Costain

Freyssinet

Furrer & Frey

Jacobs

Keltbray

Institution of Mechanical Engineers
Railway Division

J Murphy

Professor Andrew McNaughton

Network Rail

Rail Engineer

RSSB

Siemens

Skanska

SNC Lavalin Atkins

SPL Powerlines

Transport Scotland

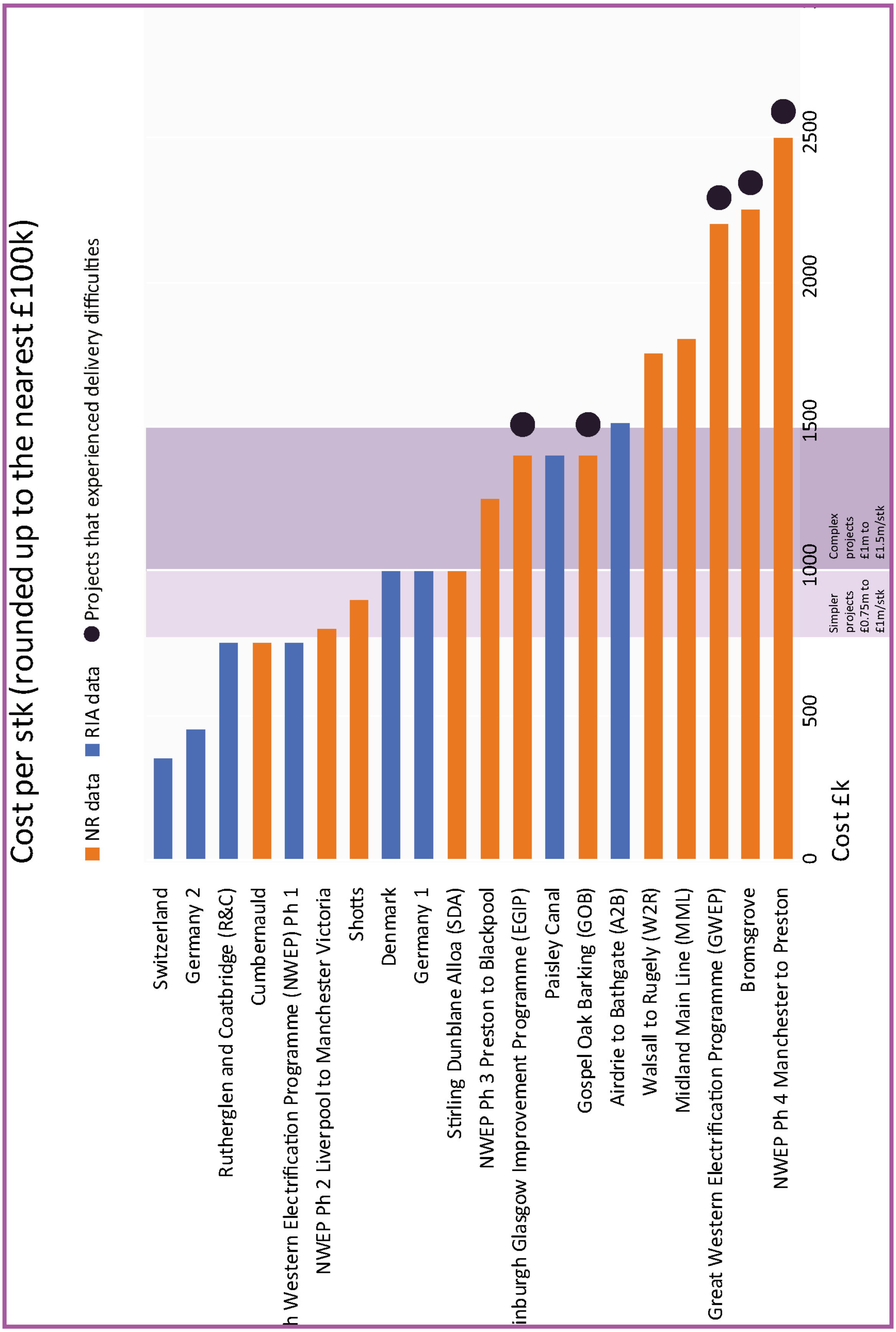
TSP Projects

University of Southampton

Volker Rail

Wentworth House Rail Systems

Appendix 4. Copy of Figure 8



Notes

Railway Industry Association

The voice of the UK rail supply community

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