OFFICE OF RAIL AND ROAD

Cost benchmarking of Network Rail’s maintenance and renewals expenditure

Annual report: year 2 of control period 6

30 July 2021

Contents

Executive summary

Context

1. Understanding the main drivers of Network Rail's expenditure (i.e. the reasons expenditure changes from year to year) and assessing the scope for it to improve its cost efficiency are central to ORR's work. To achieve this, we use different analytical approaches, ranging from the bottom-up assessment of Network Rail business plans, projects and efficiency improvement measures to top-down cost benchmarking using statistical methods.

2. As part of the 2018 periodic review (PR18), we committed to carrying out cost benchmarking analysis on an annual basis and that we would make greater use of comparative regulation in control period 6 (CP6), with cost benchmarking playing an important role.

3. This report presents our latest cost benchmarking statistical analysis, which compares maintenance expenditure and conventional track renewals unit costs (renewals expenditure divided by work volume) across Network Rail's routes, regions[1] and Maintenance Delivery Units (MDUs) for 2020-21.

4. We published our first cost benchmarking report of CP6 in July 2020, covering maintenance expenditure and focussing on the year 2019-20. That report demonstrated that it is possible to build a statistical model that can explain the majority of the variation in maintenance expenditure between Network Rail routes as a function of a few key cost drivers. We noted last year that these results should be seen as a comparison of maintenance expenditure across routes rather than as an indication of Network Rail's overall efficiency. The same caveat applies to this year's analysis.

5. In this year's report, we update our analysis of maintenance and expand our work into conventional track renewals unit costs. The methodology and data in this

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[1] Our statistical model is based on the 10 routes that were introduced in control period 4 (CP4). At the start of control period 5 (CP5), the number of routes fell to eight as the result of two mergers. At the beginning of CP6, Network Rail once again reviewed its organisational structure, resulting in the creation of five geographical regions sitting above 14 routes. The reasons we have continued to base our analysis on the 10 CP4 routes are: (1) using routes rather than regions increases the number of data points thereby increasing the sample size, which is likely to result in more robust estimates; (2) it maintains comparability over time, which is also important for the statistical robustness of this work; (3) Network Rail has only relatively recently changed to a regional structure; and (4) there is a clear statistical relationship between maintenance expenditure and key cost drivers at this level of analysis.

report will form the basis for the cost benchmarking input into ORR's initial advice to funders as part of the 2023 periodic review.

6. The methodology in this year's report is broadly similar to last year's. We use historical data to establish a statistical relationship between expenditure and underlying cost drivers. We use the model to predict expenditure for the latest year as a function of observable cost drivers at the region, route and/or MDU level; and then compare that figure against actual expenditure. We refer to the difference between these two figures as the **unexplained difference**. The larger the unexplained difference, the more interested we are in understanding what is different about the business unit in question relative to others and relative to previous years, be it efficiency, headwinds (cost increases outside of Network Rail's control), tailwinds (cost reductions outside of Network Rail's control), data reporting or some other factor.

7. The key changes relative to last year's analysis are that we now:

(a) include additional information in the analysis on the duration of possessions[2] required to undertake engineering work, weather condition (rainfall), route criticality[3] and asset condition, which improves the robustness of our statistical model;

(b) we present maintenance results at the region as well as at the route level; and

(c) analyse renewals unit costs for a sub-set of asset types at a route and regional level but present the results just for conventional track renewals.

8. The year 2020-21 has been highly unusual for the rail industry and COVID-19 restrictions have led to large reductions in rail traffic. COVID-19 has impacted renewals volumes and the composition of work undertaken, e.g. high-output renewals in Scotland were deferred. Also, social distancing, reduced staff availability and supply chain pressures have made it more difficult and expensive to carry out work on the infrastructure. Our own analysis (as reported, for example, in the Annual Efficiency and Finance Assessment and in the Annual Assessment

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[2] Possessions is the term used to describe the periods when Network Rail restricts use of the network to undertake engineering works.

[3] Network Rail defines route criticality as a "measure of the consequence of the infrastructure failing to perform its intended function, based on the historic cost of train delay per incident caused by the track asset". Using this measure, each strategic route section (SRS) of the network has been assigned a route criticality band from 1 to 5. The lower the number of the criticality band, the more a delay is likely to cost should infrastructure fail. The classification of each SRS into criticality bands is used in the development of Network Rail's asset policy as a first step to matching the timing and type of asset interventions.

of Network Rail) suggests that Network Rail has largely delivered its planned maintenance and renewals work despite the pandemic but at a higher cost.

9. These effects may have distorted our results to some extent. For example, the average unit cost of conventional track renewals across Network Rail is significantly above the background trend[4], and there is much greater variation in the unexplained differences in maintenance expenditure across routes than in last year's analysis.

10. We have been working with Network Rail (including its region-based teams) to understand the factors underlying our results and will continue to do so in the coming months.

Key messages

11. The key messages from our analysis are:

(a) the range of unexplained differences in maintenance expenditure at a **route** level this year (-18% and +27%) is much greater than in last year's analysis (−8% to +6%), even though our current model includes additional information and is statistically more robust. This suggests that COVID-19 may have been an important contributing factor to these results and that it has had a differential impact across routes. This makes it more difficult to understand other potential causes of unexplained differences, though we are working with Network Rail to explore these issues further;

(b) the range of unexplained differences in maintenance expenditure at a **regional** level this year (-18% to +12%) is larger than that implied in last year's analysis (−5% to +4%);

(c) there has been an average annual, real terms, increase in maintenance expenditure of 8% per year. Also, route-level maintenance expenditure in 2020-21 was, on average, 7% below the background trend. But, as this result was not statistically significant we cannot draw a strong conclusion about it; and

(d) we have also looked at renewals unit costs and provide some indicative findings for conventional track renewals only, as this is the first time we have used this approach. Our results show a relatively narrow range for

[4] The background trend represents the average annual real terms increase in expenditure across Network Rail routes since 2014-15 that is left after we have taken out the effect of changes in outputs and other cost drivers.

unexplained differences at the regional level (-10% to +10%), but a much wider range at the route level (-26% to +25%); and

(e) both conventional track real terms average unit costs and volumes have been on an upward trend since 2017-18 and the average unit cost for conventional track renewals in 2020-21 was 31% above the background trend.

2023 periodic review (PR23)

12. It is not ideal that the impact of COVID-19 on 2020-21 data has likely distorted some of the results of our analysis this year. But, given recent development to the models, the point that we have a long data series and that we can adjust for the Network Rail-wide effect of one-off events such as COVID-19, we consider that we can still use it to inform our initial 2023 periodic review (PR23) assessment of Network Rail business plans alongside other work.

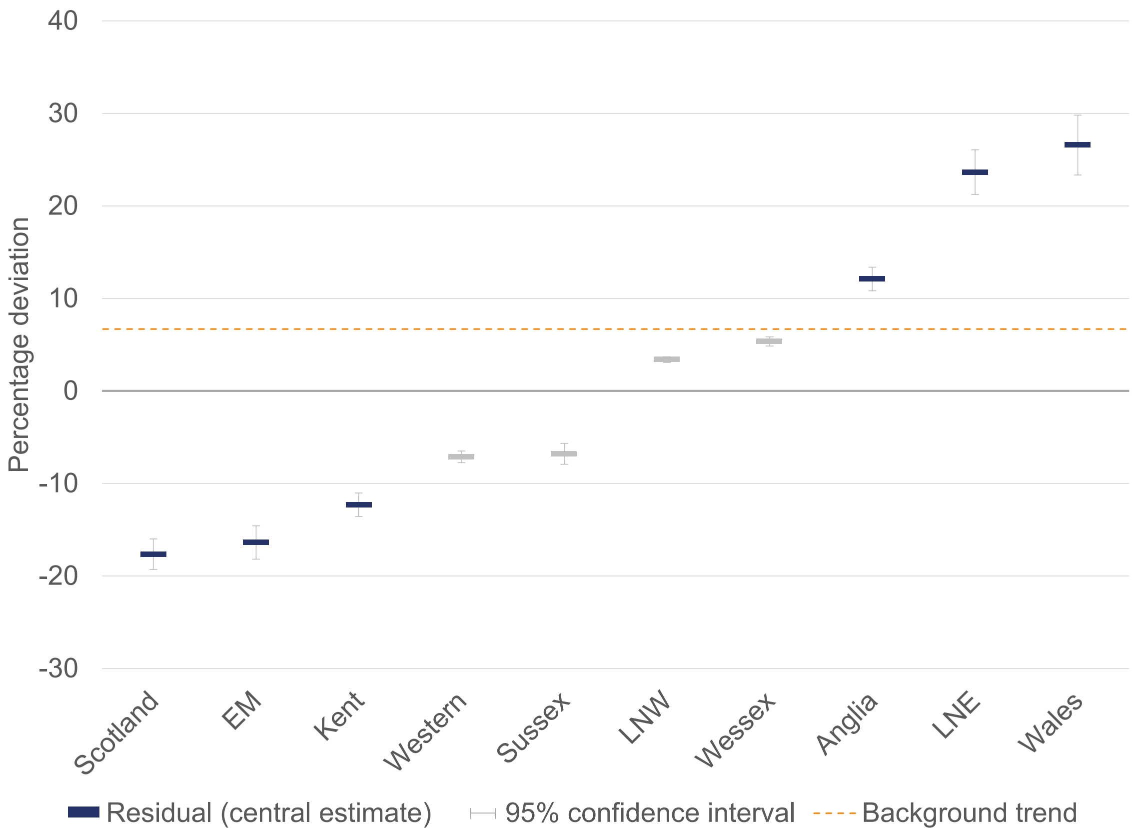
13. Our cost benchmarking approach provides useful comparative information and adds a different dimension to our analysis of Network Rail's expenditure. In particular, we envisage applying our cost benchmarking models to Network Rail business plan data to generate expenditure forecast ranges for CP7 at the region level (and possibly the route level). This evidence will serve as a reference point for assessing Network Rail's business plans.

Summary of findings

Maintenance expenditure

14. Our analysis suggests that there has been an average annual, real terms, increase in maintenance expenditure of 8% per year over the period 2014-15 to 2020-21, which cannot be explained by observable cost drivers. Also, as shown in Figure 1 below, route-level maintenance expenditure in 2020-21 was, on average, 7% below the background trend estimated from our model[5] , after taking account of changes in observable cost drivers. However, this result is not statistically significant at the 90% level, which implies that the patterns in our data are not consistent enough to be able to inform a strong conclusion about it.

Figure 1: Deviation between outturn and expected (modelled) maintenance costs by Network Rail route, 2020-21[6]



[5] The average maintenance expenditure predicted by our model is indicated by the x-axis (the darker horizontal grey line) in the figure. The background trend is indicated by the dashed orange horizontal line.

[6] Given the uncertainty associated with any statistical model, we consider any route or region that is within +/−10% of our modelled prediction (as shown by the x-axis at zero) and any MDU that is within +/-20% of modelled prediction to not be an 'outlier'. These business units are marked grey. Business units that are marked blue are therefore considered 'outliers'. This applies to all charts in this report that illustrate the

15. Once we take out the average difference from the background trend (so that we focus our comparison on relative expenditure in the latest year only), we see that maintenance expenditure at the route level was between -18% and +27% of that predicted by our model. **Scotland** and **East Midlands** are at the lower end of the distribution, whilst **Wales** and **London North Eastern (LNE)** are at the upper end. Both East Midlands and London North Eastern are part of the Eastern region.

16. The range of unexplained differences in expenditure is much greater than in last year's analysis (where it was -8% to +6%), even though our current model includes additional information and is statistically more robust. The impact of COVID-19 may have been a contributing factor to these results though Network Rail was unsure that this had been the case.

17. The Eastern region has told us that one explanation for two of its routes being at the extremes of the distribution could be hosting arrangements, whereby one route carries out some types of work on behalf of another. A related factor is that some routes (or certain MDUs within a route) can tend to carry out more complex types of work than others in the same region. The Eastern region is investigating this further.

18. The Wales & Western region has suggested that one reason for the Wales route being at the upper end of the distribution could be its geographical spread and poorer accessibility by road compared to other routes, leading to long average travel times between its two MDUs at Cardiff and Shrewsbury and work sites. Other factors could include the higher relative age of its infrastructure (leading to greater maintenance requirements) and the more limited potential for the route to benefit from economies of scale, especially following the transfer of the Core Valley Lines to the Welsh Government. Whilst we consider these to be plausible explanations in theory, we need to look into the data in more detail to establish the extent to which the Wales route is different from other parts of the network in these respects.

19. When route results are aggregated up to a regional level, as shown in Figure 2, we see that actual maintenance expenditure matches our model's predictions more closely. This is unsurprising as there will be a degree of averaging out between routes that are above and below the model predictions. It also reinforces the point

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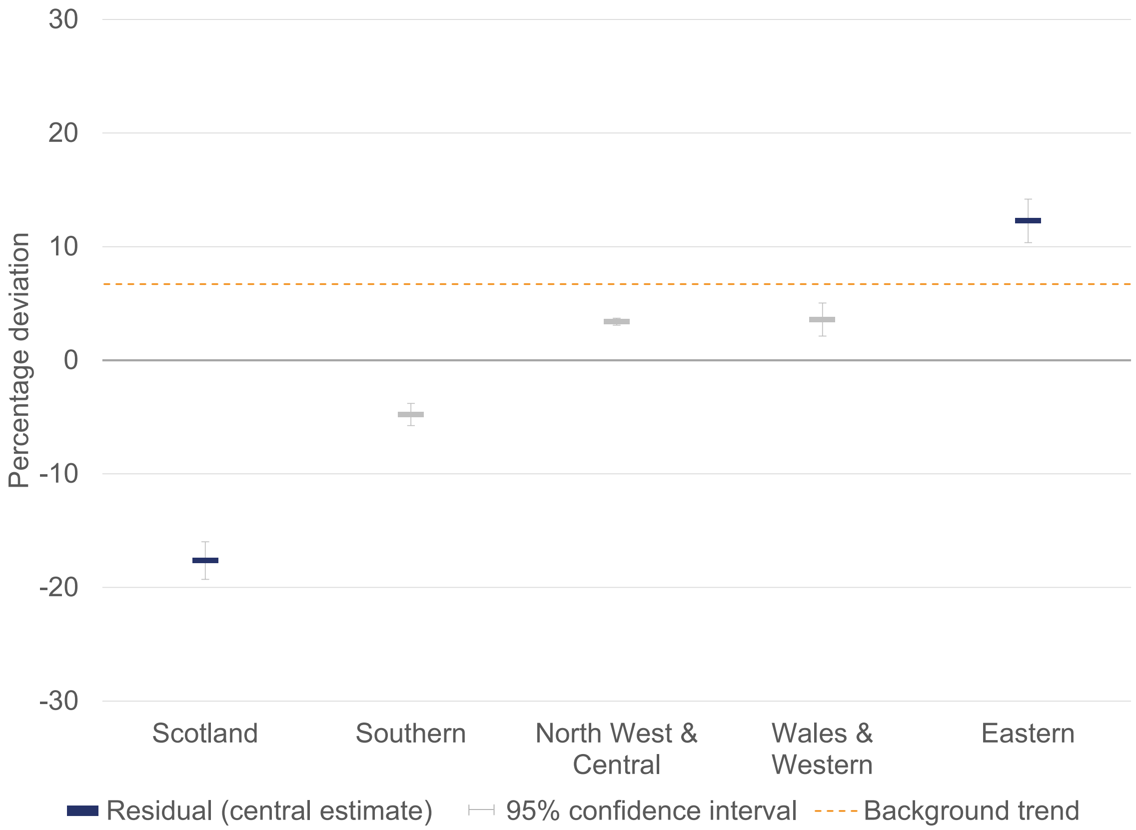
deviation between outturn and expected cost. The lines surrounding the central estimate of a given business unit's deviation between outturn and modelled cost indicate a 95% confidence interval. In other words, given the data available and the robustness of our model, there is a 95% probability that this estimated confidence interval contains the actual deviation. A tighter interval indicates a more precise estimate.

that hosting arrangements between routes could be one factor behind the route-level results.

Figure 2: Deviation between outturn and expected (modelled) maintenance costs by Network Rail region, 2020-21



20. **Scotland** (which has a single route and therefore the same result for the route and region-level analysis) and **Eastern** are the biggest outliers at a regional level.

21. The **Eastern** region's actual maintenance expenditure was 12% above the model's prediction. The region suggested that a factor that could explain this difference is the complexity of maintenance work carried out by different regions. According to the region, this could be the result of differences in the number and type of structures (in particular, cuttings/embankments, viaducts and tunnels), which is a factor our model does not take account of. This requires further investigation.

22. It is not clear why **Scotland's** expenditure is so far below the model prediction compared to other regions. The region pointed to improved co-ordination in the planning and delivery of maintenance and renewals, though it is unclear to what extent this is unique to Scotland. Another possible explanation could be the

comparatively large volume of enhancements and renewals activity carried out in this region in recent years, leading to better than average infrastructure condition and lower maintenance requirements in the short term. However, these explanations require further investigation.

23. We will continue to work with Network Rail over the next few months to look into the potential underlying causes for these results, and to improve our model where possible.

24. We have also compared maintenance expenditure across MDUs. This analysis has suffered from some of the same data quality issues as last year's analysis. We have discussed this with Network Rail and have identified some possible causes. However, there has been a further issue this year due to train-km information not being available for 2020-21 due to a change in Network Rail's data recording systems. We have identified a workaround in collaboration with Network Rail but this will have likely introduced some measurement error. So, whilst we have made progress, some issues persist and this part of our analysis should be interpreted with caution.

25. We will continue to work with Network Rail to investigate these issues and identify ways in which the MDU dataset can be improved in future.

Renewals unit costs

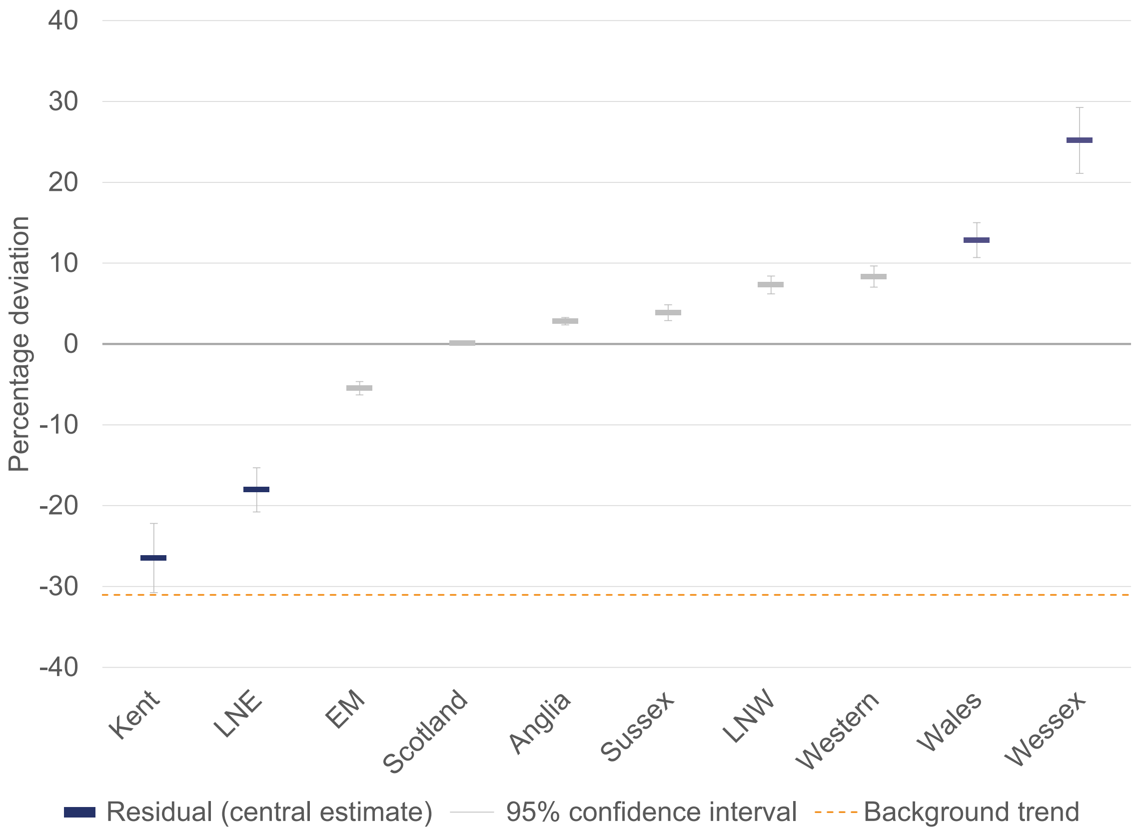
26. In last year's cost benchmarking report, we acknowledged that our previous approach to benchmarking renewals expenditure had some shortcomings and said that we intended to explore alternative methods in this year's analysis.

27. We have previously looked at total renewals expenditure at a route level, either on its own or combined with maintenance expenditure. However, the volume and composition of renewals activity can fluctuate substantially year-on-year and different types of renewals activity can also have very different costs. In this year's analysis, we have therefore looked at average unit costs (expenditure divided by work volume) and have done this separately by main asset class and for different types of renewals activity. Given this is the first time we have done this, the results are indicative and we have just included them for conventional track renewals.

28. Our analysis shows that the average unit cost for conventional track renewals in 2020-21 was 31% above the background trend over the period 2014-15 to 2020-21, after taking into account changes in observable cost drivers. COVID-19, with its effect on productivity due to social distancing and higher rates of staff absence,

could be one factor explaining this difference. Network Rail told us that another possible explanation could be year-on-year changes in the composition of work banks, though it is unclear whether there are major differences in work banks between 2020-21 and previous years across the regions. Also, both conventional track real terms average unit costs and volumes have been on an upward trend since 2017-18.

Figure 3: Deviation between outturn and expected (modelled) unit costs for conventional track renewals by Network Rail route, 2020-21



29. Once we take out the average difference to the background trend, we see that average unit costs at the route level are between -26% and +25% of those predicted by our model. **Kent** and **LNE** are at the lower end of the distribution, whilst **Wessex** and **Wales** are at the upper end.

30. The Southern region has suggested that the relative position of Wessex (especially in contrast with Kent, which is part of the same region) could be explained in part by: the high prevalence of third-rail electrification in Wessex (third-rail being expected to result in more expensive track renewals compared to track with overhead line); delivery partners tending to carry out a larger proportion of short jobs over the past year (shorter jobs resulting in lower productivity than

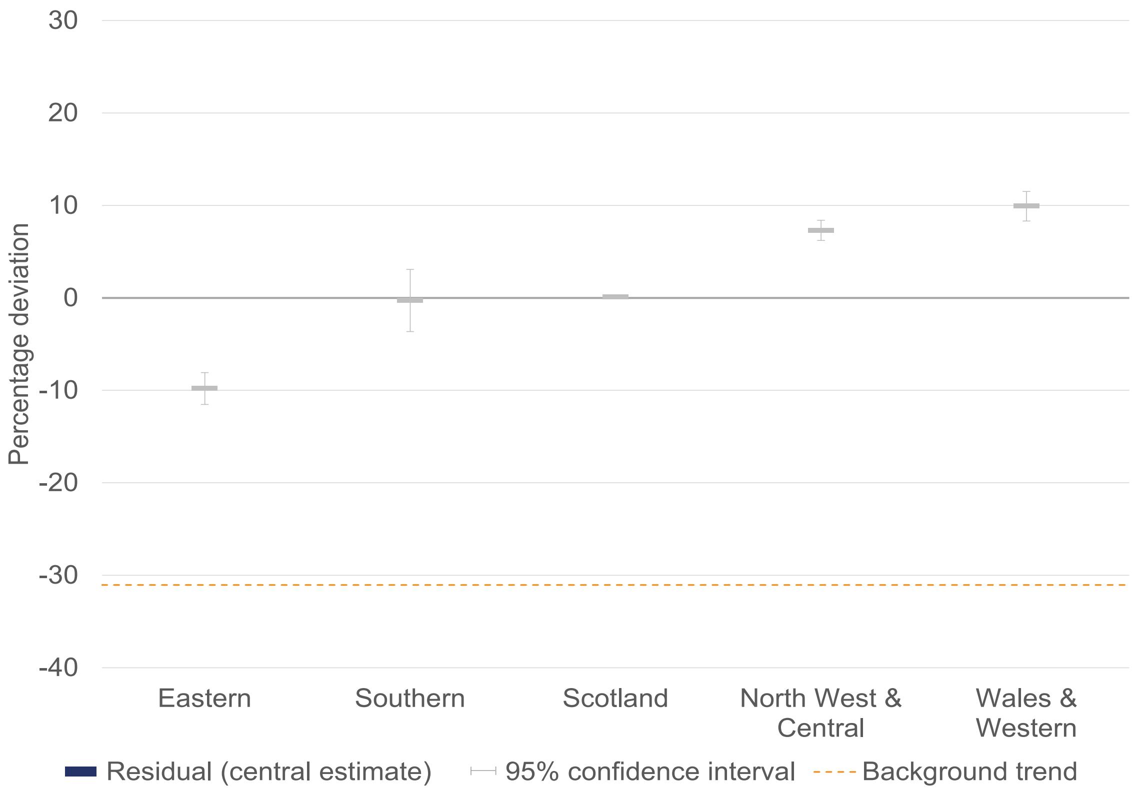
longer jobs); and the possibility that renewals projects in Wessex have tended to cluster closer to London.

31. We comment further on the relative position of LNE, Wales and Kent in the renewals chapter of the main body of the report.

32. When we aggregate route results up to a regional level, we see that actual average unit costs match our model's predictions more closely, with **Eastern** at the lower end of the distribution (-10%) and **Wales & Western** at the top end (+10%). This degree of consistency between actual and predicted unit costs is surprising given the much wider range in **actual** average unit costs, and further underlines the robustness and usefulness of our statistical model in predicting expenditure for this type of asset and activity, especially at the regional level.

33. At the same time, it is important to note that the unit cost of renewals is influenced by a wide variety of project-specific factors, which cannot be taken account of in a top-down analysis of this sort. So, the results above should be read as indicative of the relative position of different routes and regions rather than as precise estimates of what unit costs should be in each case.

Figure 4: Deviation between outturn and expected (modelled) unit costs for conventional track renewals by Network Rail region, 2020-21



1. Introduction

1.1 Understanding the main drivers of Network Rail's expenditure (i.e. the reasons expenditure changes from year to year) and assessing the scope for it to improve its cost efficiency are central to ORR's work. To achieve this, we use different analytical approaches, ranging from bottom-up assessment of Network Rail business plans, projects and efficiency improvement measures to top-down cost benchmarking using statistical methods.

1.2 This report presents ORR's latest cost benchmarking analysis of Network Rail, which compares maintenance expenditure across routes, regions and MDUs, and conventional track renewals unit costs across routes and regions, for 2020-21.

1.3 Last year's report demonstrated that it is possible to build a statistical model that can explain the majority of the variation in maintenance expenditure between Network Rail routes as a function of a few key cost drivers. We noted that these results should be seen strictly as a comparison of maintenance expenditure across routes rather than as an indication of Network Rail's overall efficiency. The same caveat applies to this year's analysis.

1.4 The methodology in this year's report is broadly similar to last year's. We use historical data to establish a statistical relationship between expenditure and underlying cost drivers. We use the model to predict expenditure for the latest year as a function of observable cost drivers at the region, route and/or MDU level; and then compare that figure against actual expenditure. We refer to the difference between these two figures as the **unexplained difference**. The larger the unexplained difference, the more interested we are in understanding what is different about the business unit in question relative to others and relative to previous years, be it efficiency, headwinds, tailwinds, data reporting or some other factor.

1.5 Our analysis aims to provide a comparison of expenditure across Network Rail's business units and to improve our understanding of underlying cost drivers. Together with other strands of ORR's work, such as our Annual Efficiency and Finance Assessment, it provides a deeper context for our overall assessment of Network Rail. We intend that this analysis will be an increasingly influential part of our reporting toolkit.

1.6 We also envisage that the methodology and data in this report will form the basis for the cost benchmarking input into ORR's initial advice to funders as part of the 2023 periodic review (PR23).

What is cost benchmarking?

1.7 Cost benchmarking involves comparing expenditure across organisations or business units, after controlling for the effect of observable underlying differences. By ‘controlling for’ we mean that we separate out the effect that differences in observable cost drivers are expected to have on overall expenditure. We do this by identifying statistical patterns in past data using regression methods[7].

1.8 Cost benchmarking results can be used for a number of purposes. These include: to set efficiency targets (for example as part of a periodic review); to identify unexplained cost differences and underlying sources of good or bad practice; to set prices (or access charges in the case of rail infrastructure); or to forecast future costs as the result of changes in outputs.

1.9 Our analysis can be used in part as a reputational tool to help drive improved performance within Network Rail, and in part as an indication of where ORR should focus its detailed analysis, monitoring and engagement.

Applicability and limitations

1.10 Any statistical model is only as good as the data it is based on. Measurement error (for example, by wrongly attributing cost incurred in one area to another), omitted variables (the absence of important cost drivers from the data), or too small a sample size can all weaken the robustness of results.

1.11 Despite some outstanding issues[8], we consider that the quality and size of our dataset, and the model specification we have used, are robust enough to enable a meaningful comparison of maintenance expenditure and of conventional track renewals unit costs between routes and regions. This evidence base should also provide reasonable range estimates of future expenditure and renewals unit costs to benchmark business plans against, which we intend to do as part of our initial work on the PR23 cost assessment.

1.12 On the other hand, we have only partly been able to resolve the issues around the recording of maintenance expenditure at the MDU level that we suggested could be behind the unexpected MDU-level results in our previous year’s report. This problem has been further reinforced by the absence of data for 2020-21 on traffic levels at the MDU level, due to a change in Network Rail’s data recording systems. We have identified a workaround in collaboration with Network Rail but this will

[7] Regression methods aim to find the coefficients in a mathematical model that best fit observed data.

[8] In particular, to do with information on a proportion of possessions at the MDU and route level and likely inconsistency in the recording of maintenance expenditure at the MDU level.

likely have introduced some measurement error. We are therefore placing little weight on the comparison of maintenance expenditure across MDUs and continue to work with Network Rail to resolve these issues.

1.13 More generally, it is important to underline that benchmarking is a high-level tool. It is useful in identifying significant discrepancies across organisations/business units, and in producing reasonable, though not highly precise, expenditure forecasts. We should also not expect cost benchmarking to provide in-depth insights into the reasons between such discrepancies.

Background

1.14 Cost benchmarking has been used by ORR to help set efficiency targets for Network Rail in the 2008 and 2013 periodic reviews (respectively, PR08 and PR13). In both cases, we compared Network Rail, as a whole, against a number of European peers. Whilst we used this international comparison to inform our determinations, we also recognised that there are limitations in this type of analysis, especially in the absence of high quality and consistent data across countries.

1.15 In PR18, our approach shifted towards comparing Network Rail's domestic business units, i.e. operating routes and MDUs, building on internal analysis undertaken by Network Rail during PR13. Although we recognised that there remained inherent differences between these business units that could not be controlled for, this analysis provided a useful top-down check on efficiency targets calculated through a more granular, bottom-up, assessment of Network Rail's business plans.

1.16 We published our PR18 cost benchmarking analysis and committed to updating it annually. We also stated our intention to make greater use of comparative regulation in CP6, and we expected cost benchmarking to play an important role in this.

1.17 We published our year 1 of CP7 cost benchmarking report in July 2020 and the present document is the second report in this series.

Progress since our year 1 of CP6 report

1.18 We have continued to improve our models. Notably, we have broadened the range of explanatory variables tested in our maintenance model as the result of input from Network Rail. This year's analysis has taken into account information on the duration of possessions, overall asset condition (through the composite reliability index), weather condition (through average rainfall) and route criticality. Some of these variables have been found to have only a very limited effect on maintenance expenditure but being able to test them means that we can exclude them as the potential source of disparities between business units. In the case of possessions, we have concerns over data quality and we will continue to work with Network Rail to improve it.

1.19 In last year's report, we compared total annual renewals expenditure between Network Rail routes. However, renewals activity can be lumpy (with some types of activity concentrated in specific years) and vary substantially in its mix across routes, and from year to year. This means that it is difficult to statistically predict total renewals expenditure for a given business unit in a given year, and that it is not especially informative to compare business units on the basis of total renewals expenditure.

1.20 In this year's analysis we have taken a different approach. Firstly, we split renewals expenditure by main asset category and, where relevant, by type of work undertaken. This makes for much more meaningful comparisons, given that different types of work are likely to be delivered at very different costs. Secondly, we analyse unit costs (actual expenditure divided by volume of work undertaken) rather than total expenditure. This removes the problem of large fluctuations in total expenditure from year to year. Average unit costs for a given asset and work type should, in principle, remain more stable than volumes (even though unit costs can vary considerably between individual projects).

Reporting our results

1.21 The key focus of our analysis is the comparison of outturn maintenance expenditure and renewals unit costs in 2020-21, against expected expenditure derived from our statistical models, which are calibrated on past data. Results are presented as percentage deviations from expected expenditure/average unit cost – a positive number means that outturn expenditure has been higher than that predicted by the model and vice versa. These results represent cost variances that cannot be statistically explained by observable business unit characteristics and therefore merit further investigation.

1.22 We present results both at the level of Network Rail routes, regions and MDUs, and highlight the largest outliers.

1.23 We have discussed our key findings with Network Rail, and this has been helpful in sense checking our interpretation of the results and in identifying other potential factors at play.

1.24 Whilst we have sought to reflect Network Rail's input in this report, we would note that it has only had a small amount of time to digest the results and provide a response. We will continue to engage with Network Rail to discuss its views on the methodology and data that support this analysis; and on the factors that could explain our results.

1.25 We are publishing this analysis as soon after the data has become available as possible, so that it is of most value to interested stakeholders. This also gives us the best chance to incorporate any feedback into our work before this analysis feeds into PR23.

Quantitative context

1.26 Below we provide some high-level quantitative information by way of context for the analysis that follows.

1.27 In this report, we cover maintenance and a proportion of renewals. As shown in Figure 5, maintenance represents 18% of Network Rail's total expenditure (excluding financing costs) for 2020-21; renewals represent (in total) 38%. The proportion of renewals that we concentrate on in this report (conventional track renewals) represent 14% of renewals expenditure for 2020-21 and 12% of average renewals expenditure over 2014-15 to 2020-21.

1.28 Figure 6 shows the trends in total maintenance and renewals expenditure, in 2020-21 prices. Maintenance expenditure has been on a steady upward trend since 2013-14, whereas renewals expenditure has fluctuated considerably.

Figure 5: Breakdown of expenditure categories (excl. financing costs), 2020-21[9]

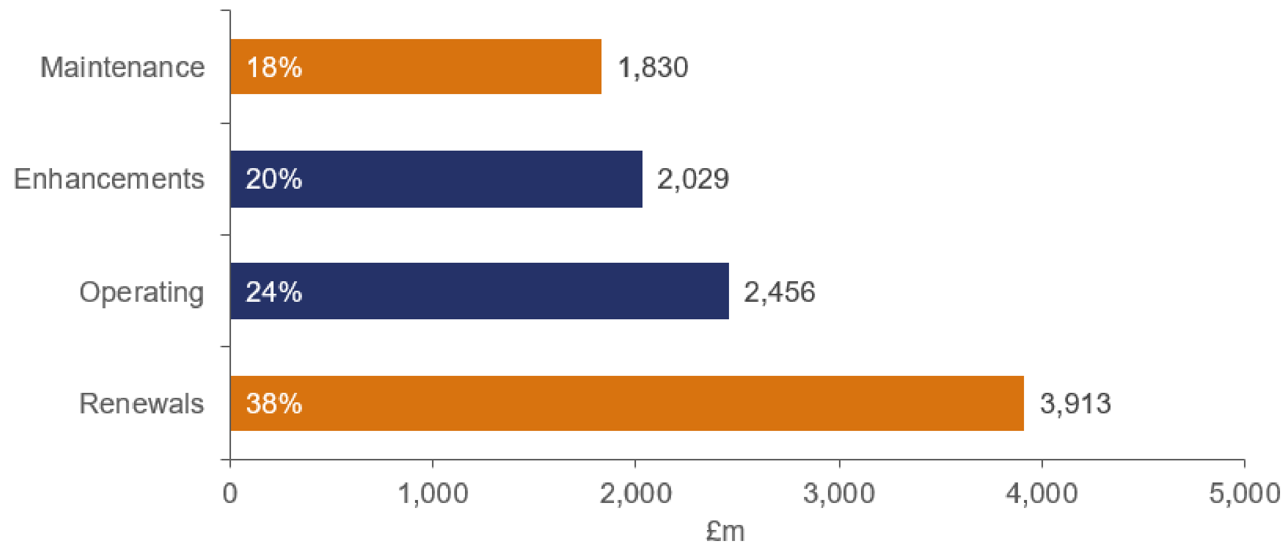
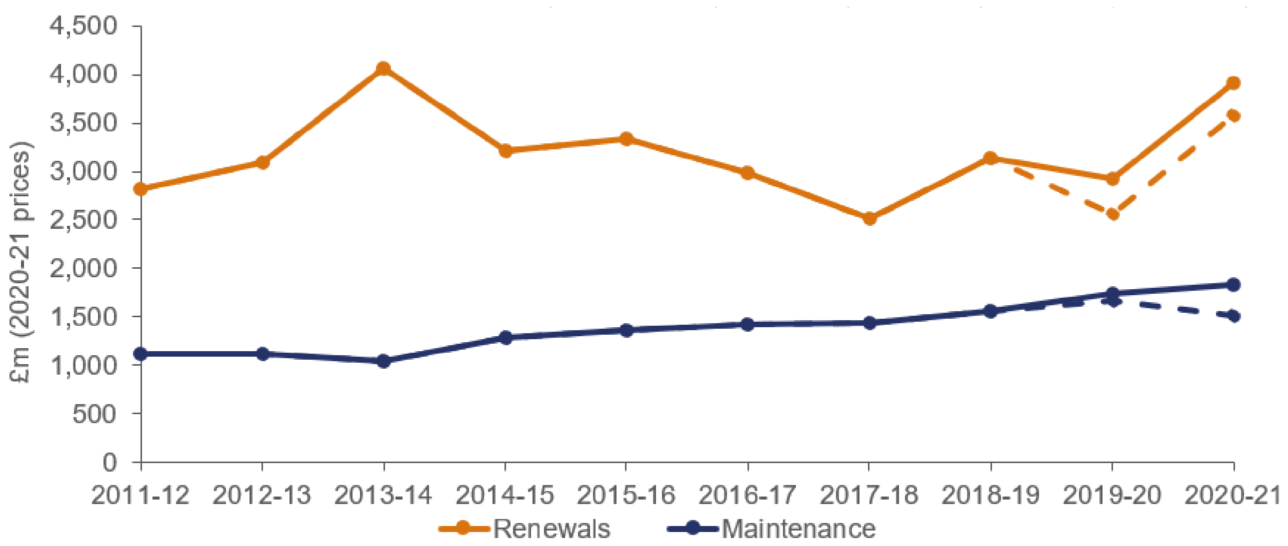


Figure 6: Total maintenance and renewals expenditure, 2011-12 to 2020-21 (2020-21 prices)

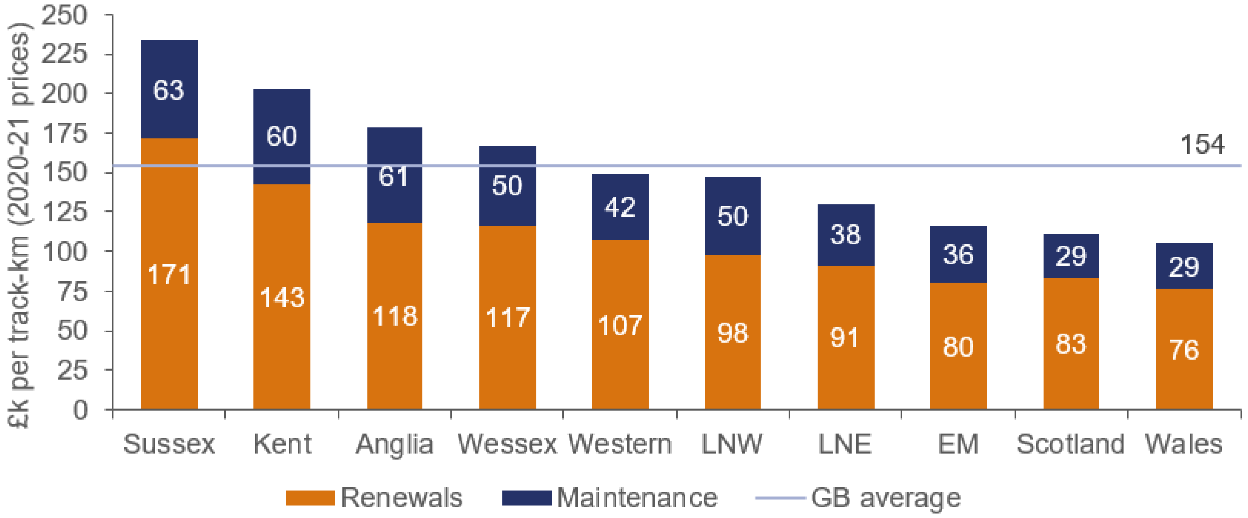


Note: Prior to 2019-20, Network Rail was able to allocate all of its central expenditure to the 10 routes. It is now not able to do that. The dashed lines show the lower level of expenditure that excludes the element of central expenditure that cannot be allocated to routes. We use the dashed line for our analysis.

[9] Maintenance, enhancements and renewals figures are based on the bespoke data that we received directly from Network Rail for the purpose of this analysis in May 2021. These figures do not match the figures in the 2020-21 Annual Efficiency and Financial Assessment (AEFA) as that report uses the latest information. Our enhancements expenditure figure in this figure includes third-party funded expenditure. The operating expenditure figure (which includes Schedule 4 & 8 payments, network operations costs, support costs, traction electricity and industry costs and rates) was taken from the AEFA as operating expenditure is not included in our analysis and therefore was not provided as part of the bespoke data we received before the AEFA data was put together.

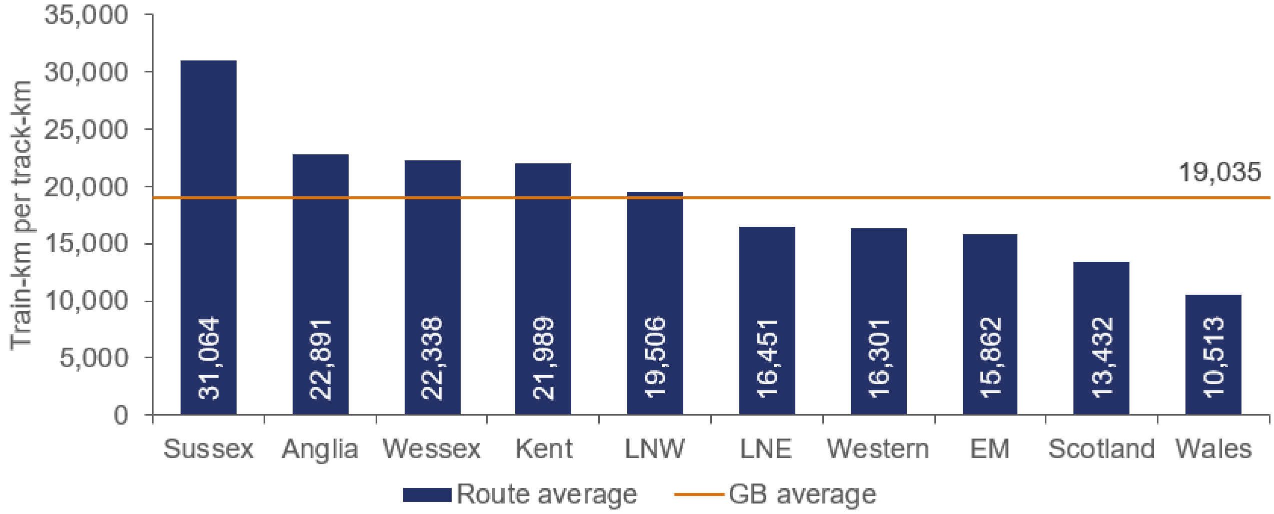
1.29 Figure 7 shows the breakdown of average annual maintenance and renewals expenditure by route, normalised by network size (expressed in track-kms). There is considerable variation across routes. A key purpose of cost benchmarking is to control for the proportion of this variation that is due to observable factors so that comparisons across routes are made on a more like-for-like basis.

Figure 7: Breakdown of average total maintenance and renewals expenditure per track-km, 2011-12 to 2020-21 (2020-21 prices)



1.30 One of the key drivers of maintenance and renewals expenditure is traffic. Figure 8 shows average annual traffic density across routes and it can be seen that there is a good degree of correlation between this variable and the expenditure per track-km in the previous figure. Our analysis aims to control for the effect of traffic, as well as a number of other relevant cost drivers, on maintenance and renewals expenditure across Network Rail's business units.

Figure 8: Average traffic density (train-km per track-km), 2011-12 to 2020-21



Report structure

1.31 Chapter 2 describes our analysis of maintenance expenditure, first focusing on comparisons between routes and regions, and then between MDUs. Chapter 3 covers unit costs for conventional track renewals at the route and regional level.

2. Maintenance

Introduction

2.1 Maintenance expenditure relates to activities that sustain the condition and capability of the existing infrastructure to the previously assessed standard of performance.

2.2 Most maintenance activity on Network Rail's infrastructure is carried out by MDUs. MDUs are operating units within Network Rail's routes, responsible for the majority of the day-to-day upkeep of their designated part of the network. MDUs are not responsible for renewals.

2.3 Most maintenance is carried out, or procured, at the route or regional level. Each MDU is part of a route, and each route is part of a region. On average, MDUs accounted for around 70% of total network maintenance expenditure during the period covered by our analysis. The remaining 30% was centrally managed, covering activities such as structures examination, major items of maintenance plant and other HQ managed activities.

2.4 We carry out our analysis by, first, comparing total maintenance expenditure aggregated to the route level and the regional level, and then by comparing expenditure across MDUs. The route-level analysis is more comprehensive whilst the MDU-level analysis can help identify differences in the effectiveness of working practices at a more granular level. Whilst the two types of analysis broadly agree in their conclusions, there are some differences we discuss at the end of this chapter.

Route-level analysis

Introduction

2.5 In this part of the chapter, we describe our route-level analysis and results. One difference between the present work and last year's analysis is that we now take into account additional cost drivers, namely weather condition (average rainfall), the duration of possessions and enhancement expenditure. This has improved the robustness of our model.

2.6 This part of the chapter is organised as follows: we first describe our data and modelling approach (in the 'Route Analysis' section) and then use this information to compare expenditure across routes and regions (under the 'Route Benchmarking results' section).

Route Analysis

Data

2.7 The analysis is based on data for financial years 2013-14 to 2020-21, recorded at the level of the ten routes that were introduced by Network Rail in CP4[10].

2.8 The year 2020-21 has been highly unusual for the rail industry and COVID-19 restrictions have led to large reductions in rail traffic. COVID-19 has impacted renewals volumes and the composition of work undertaken, e.g. high-output renewals in Scotland were deferred. Also, social distancing, reduced staff availability and supply chain pressures have made it more difficult and expensive to carry out work on the infrastructure.

2.9 Our own analysis (as reported, for example, in the Annual Efficiency and Finance Assessment and in the Annual Assessment of Network Rail) suggests that Network Rail has largely delivered its planned maintenance and renewals work despite the pandemic but at a higher cost. We take the effect of COVID-19 into account in our model by separating out statistically the common change in maintenance expenditure across routes in 2020-21 that cannot be attributed to observable cost drivers.

Dependent variable

2.10 The dependent variable is annual total maintenance expenditure at the route level. For years 2013-14 to 2018-19, maintenance expenditure comes from Statement 1 of Network Rail's Regulatory Financial Statements. For years 2019-20 and 2020-21, the information was provided to us directly by Network Rail for the purpose of this analysis. All expenditure data is inflation-adjusted to 2020-21 prices, using the Consumer Price Index (CPI).

Independent variables

2.11 Table 1 summarises the explanatory variables we retained in the final model, alongside the expected direction of the relationship to maintenance costs and the reasoning behind this.

2.12 In addition, we also tested the following variables: point failures, route criticality, stations, and the composite reliability index. Point failures was included in our year 1 of CP6 analysis. However, we have removed all these variables from the present model because they are either highly correlated with other variables (and therefore

[10] Compared with the dataset in our year 1 of CP6 report (covering 2011-12 to 2019-20), this dataset is smaller. This is because we did not have the data for earlier years in the series (2011-12 to 2012-13) for the new variables we introduced in the model such as the duration of possessions.

it is not possible to separately and accurately estimate the effect of each in isolation) or have been replaced with more appropriate cost drivers.

Table 1: Independent variables used in the route-level maintenance model

Variable	Expected direction for relationship	Reason for relationship
Track-km (length of track)[11]	Positive	A larger network requires more maintenance.
Passenger traffic density[12] (train-km/track-km)	Positive	More traffic on the network would likely cause greater wear and tear. In addition, it is likely that maintenance work is more difficult to undertake in more heavily used areas of the network.
Freight traffic density (train-km/track-km)	Positive	
Switches and crossings (S&C) density (number of S&C/track-km)	Positive	A network with more switches and crossings per track-km requires more maintenance.
Average rainfall[13] (mm)	Positive	Higher rainfall is likely to cause more frequent and more damaging infrastructure failure (e.g. landslides) therefore requiring more regular maintenance. Higher rainfall may also make it more difficult to undertake infrastructure work.
Possessions duration (days per track-km)[14]	Positive	A high number of possession days may imply that the maintenance works to be done are more complicated. More possessions of the network also mean that Network Rail would be likely to spend more in terms of labour cost, materials, Schedule 4 payments, etc.

[11] Where one km of double-tracked route counts as two track-km.

[12] We retained this and freight traffic density over the absolute number of passenger and freight train-kms, which are highly correlated with track-km.

[13] Annual average of monthly total rainfall, published by the Met Office.

[14] Network Rail needs to restrict access to its network to carry out many of its maintenance and renewals activities. These restrictions of access are referred to as possessions. We would have preferred to use the average number of days per possession as this also takes into consideration the efficiency in each possession but we did not have such data. In future, we will work with Network Rail to ensure availability of such data.

Variable	Expected direction for relationship	Reason for relationship
Average number of tracks (track-km/route-km)	Negative	On a network with multiple tracks, maintenance teams may not need to travel as far, on average. Time windows for maintenance activities may be wider on multiple track sections of the network. In addition, there may be less volume of work involved when maintaining one km of double-track route than two km of single-track route (for example, due to the volume of ballast and drainage assets).
Wage levels (£/week)[15]	Positive	If we assume that maintenance work in each route is carried out largely by a local labour force, then it will cost more in areas where labour costs are higher. In practice, this effect may be significantly reduced by the use of national terms and conditions.
Proportion of electrified track (electrified track-km/track-km)	Positive	The presence of electricity and of power supply infrastructure is likely to increase the complexity of track maintenance work.
Enhancements expenditure (£m)	Positive	Undertaking additional work (frequently a different type of work) on the network at the same time may create additional pressure on supply chains, which may lead to increased costs.
Year	N/A	The purpose of this term is to separate out the common annual trend in maintenance costs across routes that cannot be attributed to observable cost drivers. The coefficient on Year can be interpreted as an annual growth rate.

[15] ONS seasonally adjusted median average weekly earnings (AWE) per local authority. These have been adjusted for inflation and represent real median earnings. As specific Network Rail wages data was not available to us, we used this as a proxy. The data only reflects the level of wages (in general) in each MDU's geographical area of operation rather than the actual wages paid by Network Rail. We mapped local authorities to Network Rail's MDUs and then aggregated this at route level. We are also aware that there is a degree of harmonisation of terms and conditions across Network Rail, which may reduce the effect of regional differences in wages.

Variable	Expected direction for relationship	Reason for relationship
Year-specific dummy variable (applies to 2020-21)	N/A	The purpose of this term is to separate out the common change in expenditure across routes due to year-specific exogenous factors that cannot be attributed to observable cost drivers. The coefficient can be interpreted as a deviation from the average annual growth rate given by the coefficient on the Year variable. We use a dummy for year 2020-21 to reflect the impact of COVID-19.
Year-specific dummy variable (applies to 2019-20 and 2020-21)	N/A	From 2019-20, Network Rail changed its cost allocation methodology by allocating a proportion of its maintenance expenditure to central functions. This amount is therefore not included in the expenditure data at route level as in previous years. We use a dummy for years 2019-20 and 2020-21 to reflect this change in cost allocation methodology.

Descriptive statistics

2.13 Table 2 below presents some summary statistics that describe the variables in our models:

Table 2: Summary of variables

Variable	Mean	Std. Dev.	Min	Max
Maintenance expenditure (£m)	135	81	52	406
Track-km (km)	3,117	1,712	1,124	6,917
Passenger traffic density (train-km/track-km)	17,828	5,919	6,588	32,113
Freight traffic density (train-km/track-km)	1,207	576	171	2,258
Switches and crossings density (number of S&C/track-km)	0.6	0.13	0.4	0.9
Average rainfall (mm)	86	31	36	150

Variable	Mean	Std. Dev.	Min	Max
Possessions duration (days per track-km)	0.30	0.17	0.01	0.80
Average number of tracks (track-km/route-km)	2.0	0.2	1.6	2.5
Wage levels (£/week)	596	40	518	702
Proportion of electrified track (%)	48%	31%	0%	96%
Enhancements expenditure (£m)	295	237	11	1,158

Model specification

2.14 We have adopted the same functional form as in last year's report, namely the Cobb Douglas log-log formulation (i.e. where the dependent variable and most explanatory variables are entered in natural logarithms). With this functional formulation, most coefficients can be interpreted as constant elasticities that measure the percentage change in cost resulting from a percentage change in the relevant cost driver.

2.15 For this updated analysis, we have estimated a number of variants of the following model but settled on the following specification[16]:

$$\begin{aligned}\ln(cost) = \beta_0 &+ \beta_1 \ln(track\ km) \\ &+ \beta_2 \ln(passenger\ traffic\ density) \\ &+ \beta_3 \ln(freight\ traffic\ density) \\ &+ \beta_4 \ln(switches\ \&\ crossings\ density) \\ &+ \beta_5 \ln(\boldsymbol{average\ rainfall}) + \beta_6(\boldsymbol{possessions\ duration}) \\ &+ \beta_7 \ln(average\ number\ of\ tracks) \\ &+ \beta_8 \ln(wage\ levels) \\ &+ \beta_9 \ln(proportion\ of\ electrified\ track) \\ &+ \beta_{10} \ln(\boldsymbol{enhancements\ expenditure}) + \beta_{11}(year) \\ &+ \beta_{12}(\boldsymbol{dummy_{2020-21}}) + \beta_{13}(\boldsymbol{dummy_{2019-20\ and\ 2020-21}}) \\ &+ error\ term\end{aligned}$$

2.16 Relative to last year's report, we include the following new cost drivers: average rainfall, and duration of possessions (days per track-km) and enhancements

[16] A bold font means the variable is new relative to our year 1 of CP6 report.

expenditure. These changes reflect feedback from Network Rail following publication of last year's report.

2.17 Network Rail previously suggested that our model should include the composite reliability index (CRI) to control for asset quality, in place of the number of point failures that we used in last year's analysis. We tested this variable in the present model and obtained a consistently positive and statistically significant relationship, which would suggest that routes with higher CRI spend more on maintenance. However, CRI is also highly correlated with other variables in the model (notably traffic density and track-km). Moreover, there is also the likelihood of reverse causality, whereby higher CRI reflects higher maintenance spending in previous years. The same argument would apply to point failures. These variables could therefore be reflecting historical patterns of expenditure that are unrelated to current maintenance need. We have therefore decided not to include CRI or point failures in our final model.

Estimation approach

2.18 As in last year's report, we have used the pooled ordinary least squares (OLS) method to estimate our model[17]. This approach has the advantage of being simple to implement and its results easy to understand.

2.19 With OLS, we estimate a line that passes through the centre of the observed data points. This means that, given the information available, the OLS line defines the average cost that an organisation/business unit should incur given the cost drivers we control for in our model. The distance between the OLS line and observed/outturn points is the residual. We use these residuals to describe routes' performance relative to the average of the peer group, after controlling for differences in relevant cost drivers[18].

Model estimates

2.20 Below, we present and analyse the results of our OLS model estimates.

Table 3: OLS coefficient estimates results for maintenance expenditure model

Variable	Coefficient estimates
Track-km	0.93***
Passenger traffic density	0.40***

[17] We also tested panel methods and stochastic frontier methods.

[18] See our year 1 of CP6 report for more details on how this is done.

Variable	Coefficient estimates
Freight traffic density	0.12***
Switches and crossings density	0.83***
Average rainfall	0.05
Possessions duration	0.17
Average number of tracks	-0.12
Wage levels	0.18
Proportion of electrified track	0.00
Enhancements expenditure	-0.02
Year (average annual unexplained growth rate in maintenance expenditure)	0.08***
Dummy for 2020-21 (deviation from the annual growth rate due to COVID-19)	-0.07
Dummy for 2019-20 and 2020-21 (deviation from annual growth due to changes in accounting)	-0.09
Constant[19]	-8.60***
Number of observations	90
R^2	0.96

*** Statistically significant at the 99% confidence level[20]

[19] The constant has no meaningful physical interpretation. Its role is to improve the fit between the model and the data. The coefficient is provided here for completeness and so that our calculations can be repeated by other people.

[20] Technically, statistical significance (expressed by the number of stars in the table) tells us that the patterns in the data provide evidence for a strong relationship between the dependent and the independent variables and that this is unlikely due to chance, while the size of coefficients tells us what the scale of the relationship is. The higher the number of stars the more confident in the results we are. More precisely, when we say that a coefficient is statistically significant at the 99% level, this means that there is a 99% probability that the actual underlying parameter is different from zero. In other words, we are almost entirely certain that the parameter is different from zero. This assessment is based on the assumption that the parameter follows a normal, or bell-shaped, probability distribution across the population, with its most likely value being the parameter estimated.

2.21 Table 3 above shows that there is a statistically significant relationship (at the 99% confidence level) between the amount that a route spends on maintenance and: the size of the network it maintains, i.e. track-km; traffic density (both of passenger and freight trains); and the density of switches and crossings.

2.22 The model's R^2 is 0.96. R^2 is a measure of goodness-of-fit. It represents the proportion of the variance in maintenance cost that can be statistically explained by the independent variables in the model. This means that our model can explain 96% of the variance in maintenance costs across routes and over time, which suggests that the model is a very good predictor of outturn maintenance expenditure.

2.23 Our results suggest no clear relationship between maintenance expenditure and: average rainfall, possessions duration, average number of tracks, wage levels, proportion of electrified track or enhancements expenditure. These variables may well influence maintenance expenditure but there is no clear statistical relationship in the data that is not already accounted for through other variables.

2.24 The results in Table 3 above show that, all other factors held constant:

(a) increasing track length by 1%, is associated with 0.41%[21] higher maintenance expenditure. This suggests that there are economies of scale in network size, i.e. maintenance expenditure increases less than proportionally with the length of track;

(b) increasing passenger traffic by 1%, increases maintenance expenditure by 0.40%; also, an independent 1% increase in freight traffic increases maintenance expenditure by 0.12%. These results show economies of density – costs increase less than proportionally with traffic; and

(c) increasing the density of switches and crossings by 1% increases maintenance costs by 0.83%. It is likely that this variable is picking up the effect of network complexity more generally.

2.25 The results also show that there has been an average annual, real terms, increase in maintenance expenditure of 8%[22] per year over the period covered by our sample, which cannot be explained by changes in network size, traffic or other

[21] We calculate this as the difference between the track-km coefficient and the sum of the traffic density coefficients [0.93 - (0.40 + 0.12)] = 0.41. This is because the traffic density coefficient reflects both the effect of an increase in traffic and of an increase in track-kms. To obtain the overall effect of a change in track-kms we therefore need to take account of all three coefficients that contain that variable. Mathematically, the elasticity of maintenance expenditure with respect to track-kms equals the coefficient on track-kms minus the sum of the coefficients on the traffic density variables.

[22] Calculated as $(e^{0.08} - 1)$

observable factors. Also, after accounting for observable differences between routes, maintenance expenditure in 2020-21 appears to be 7%[23] below this historical trend. However, this result is not statistically significant at the 90% level, which implies that the patterns in our data are not consistent enough to be able to inform a strong conclusion about it.

2.26 Note that the main purpose of the present work is to compare maintenance expenditure across routes in the most recent year, whilst controlling for differences in observable cost drivers, rather than to measure routes against an external efficiency benchmark or to examine performance changes over time. We therefore take no view here on the cause of the trend identified above. ORR's separate publication, the Annual Efficiency and Finance Assessment, provides a view on Network Rail's efficiency; our PR18 final determination set out our expectations for Network Rail's efficiency improvement over CP6.

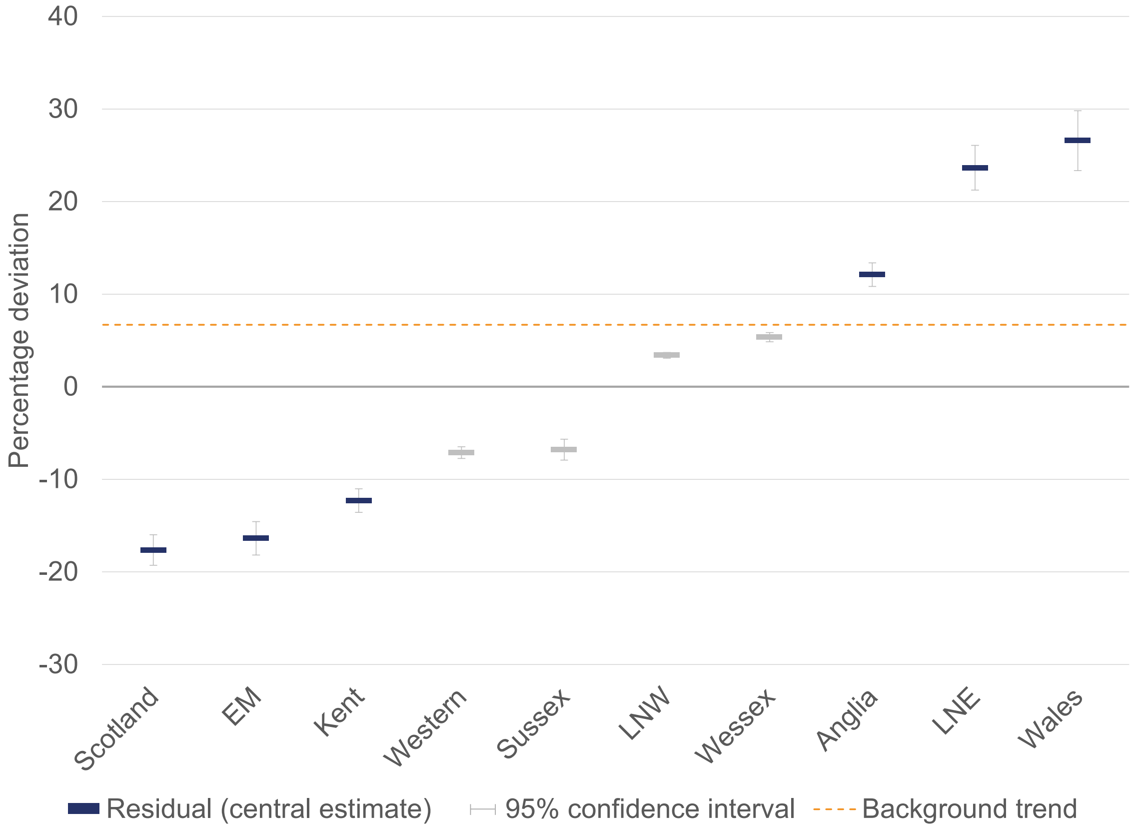
Route benchmarking results

2.27 The present analysis compares outturn maintenance expenditure against expected spend as predicted by our model, given each route's characteristics. We then order routes and regions according to the amount of unexplained variation (i.e. the difference between outturn and predicted expenditure).

2.28 Figure 9 below shows, for each route, the proportion of unexplained cost variance in 2020-21. A negative number means that the route spent less than expected (according to our statistical model) while a positive number means that the route spent more than expected (according to our statistical model).

[23] Calculated as $(e^{-0.07} - 1)$

Figure 9: Deviation between outturn and expected (modelled) maintenance costs, by route 2020-21[24]



2.29 Our analysis shows that, after taking out the average difference between 2020-21 expenditure and the background trend identified by our model (so that we focus our comparison on relative expenditure in the latest year only), maintenance expenditure at the route level was between -18% and +27% of the model's prediction. **Scotland** and **East Midlands** are at the lower end of the distribution, whilst **Wales** and **London North Eastern (LNE)** are at the upper end. Both East Midlands and London North Eastern are part of the Eastern region.

2.30 The range of unexplained differences in expenditure is much greater than in last year's analysis (where it was -8% to +6%), even though our current model includes additional information and is statistically more robust. The impact of COVID-19 may have been a contributing factor to these results, though Network Rail was unsure that this had been the case.

[24] Given the uncertainty associated with any statistical model, we consider any business unit (route or region) that is within +/−10% of our modelled prediction (as shown by the x-axis at zero) to not be an 'outlier'. These business units are marked grey. Business units that are marked blue are therefore considered 'outliers'.

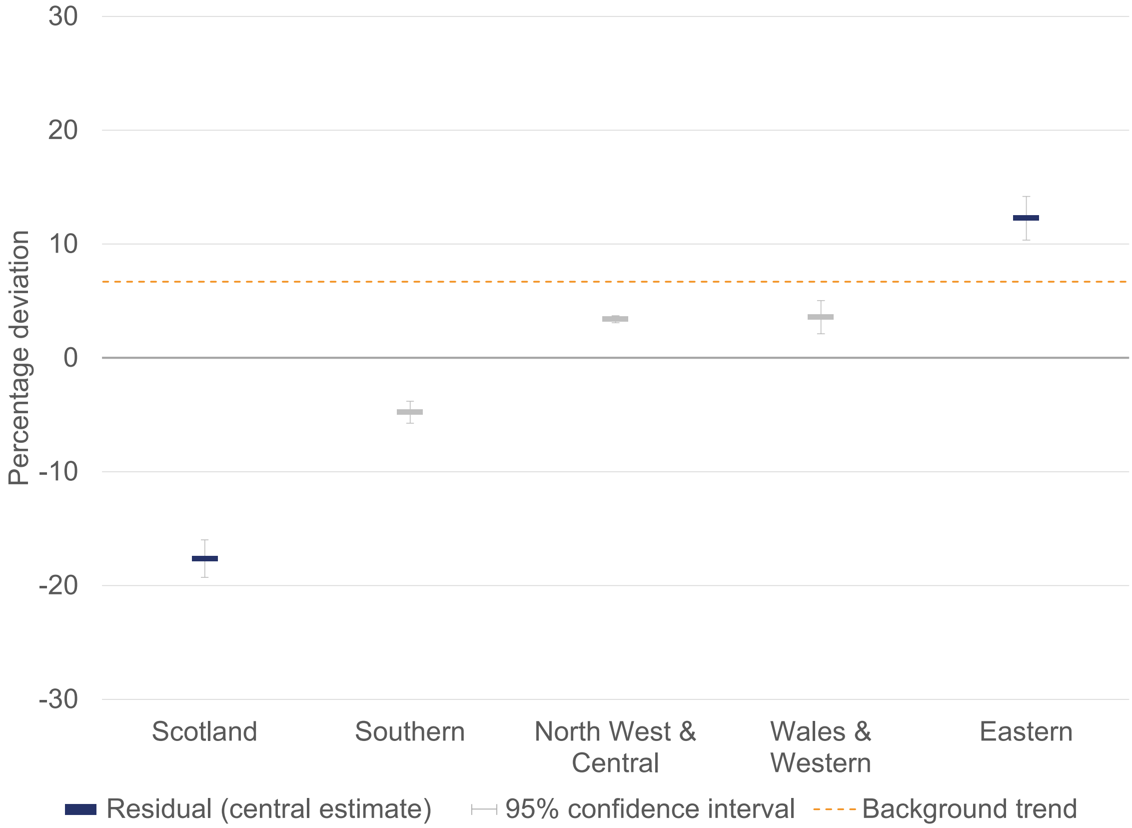
2.31 In terms of the relative position of different routes, the key differences to last year's results are LNE (which has gone from -4% to +24%), Anglia (which has gone from -4% to +12%) and Kent (which has gone from +5% to -12%).

2.32 The Eastern region has told us that one possible explanation for two of its routes being at the extremes of the distribution could be hosting arrangements, whereby one route carries out some types of work on behalf of another. A related factor is that some routes (or certain delivery units within a route) can tend to carry out more complex types of work than others in the same region. The Eastern region is investigating these potential explanations further.

2.33 The Wales & Western region has suggested that one reason for the Wales route being towards the top end of the distribution could be its geographical spread and poorer accessibility by road compared to other routes, leading to long average travel times between its two MDUs at Cardiff and Shrewsbury and work sites. Other factors could include the higher relative age of its infrastructure (leading to greater maintenance requirements) and the more limited potential for the route to benefit from economies of scale, especially following the transfer of the Core Valley Lines to the Welsh Government. We consider these to be plausible explanations in theory but need to look into the data in more detail to establish the extent to which the Wales route is different from other parts of the network in these respects.

2.34 When we aggregate route results up to a regional level, we see (Figure 10) that actual maintenance expenditure matches our model's predictions much more closely. This is unsurprising as there will be a degree of averaging out between routes that are above and below model predictions. It also reinforces the point that hosting arrangements and relative specialisation between routes could be one factor behind the route-level results.

Figure 10: Deviation between outturn and expected (modelled) maintenance costs, 2020-21- Regional comparisons



2.35 **Scotland** (which has a single route and therefore the same result for the route and region-level analysis) and **Eastern** are the biggest outliers at regional level.

2.36 The Eastern region's actual maintenance expenditure was 12% above the model's prediction. The region suggested that a factor that could explain this difference is the complexity of maintenance work carried out by different regions. According to the region, this could conceivably be the result of differences in the number and quantity of structures (in particular, cuttings/embankments, viaducts and tunnels), which is a factor our model does not take account of. This requires further investigation.

2.37 It is not clear why Scotland's expenditure is so far below the model prediction compared to other regions. The region pointed to improved co-ordination in the planning and delivery of maintenance and renewals, though it is unclear to what extent this is unique to Scotland. Another possible explanation could be the comparatively large volume of enhancements and renewals activity carried out in this region in recent years, leading to better than average infrastructure condition and lower maintenance requirements in the short term. However, these explanations require further investigation.

2.38 Other possible factors that could account for differences between regions arising from wider discussions with Network Rail include: the proportion of staff based in, and the proportion of work carried out in and around the London area (though we note Southern is actually below the model's prediction); and the need to carry out work at night and weekends (over and above that implied by higher traffic volumes alone).

2.39 We will continue to work with Network Rail over the next few months to look into the potential underlying causes for these results, and to improve our model where possible.

MDU-level analysis

Introduction

2.40 In this section, we describe our MDU-level analysis and results. As noted in our year 1 of CP6 publication, Network Rail previously reduced the number of MDUs from 37 to 35. To maintain comparability with historical data and as Network Rail can still allocate costs based on its previous MDU structure, we have analysed maintenance costs using the previous 37 MDU structure.

2.41 This involved some judgement on our part in apportioning data for the explanatory variables for the most recent year, between the MDUs affected by the change, based on historical data[25]. Annex B maps the 37 MDUs to Network Rail's CP4 ten route structure used in our route benchmarking analysis and to regions.

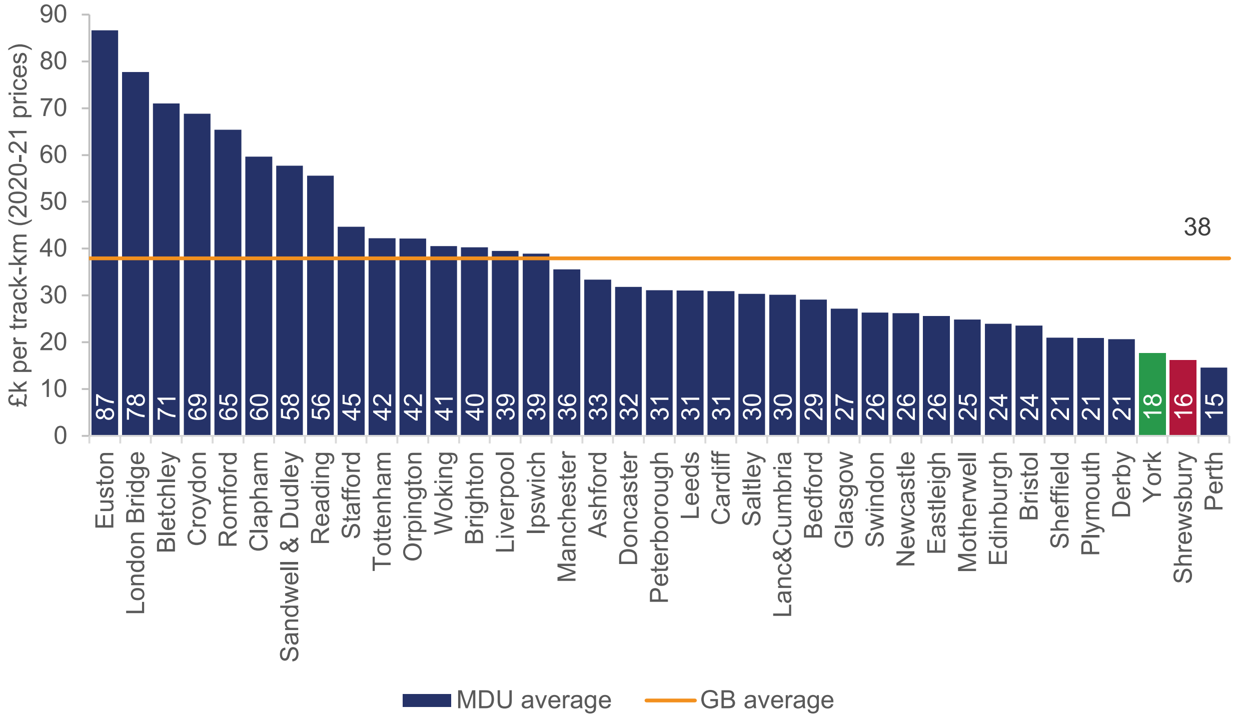
2.42 This part of the chapter is organised as follows: we first compare the 37 MDUs in terms of their respective expenditure, asset characteristics and network usage to provide context to the analysis (in the 'MDU context' section). We then describe our data and modelling approach (in the 'MDU Analysis' section). Finally, we use this information to compare expenditure across MDUs and we compare these findings with those from our route-level analysis (in the 'MDU Benchmarking results' section).

[25] Woking closed in 2017-18 with activities previously undertaken by Woking moved to Clapham and Eastleigh, which then became Wessex Inner and Wessex Outer. Bristol, Plymouth, Reading and Swindon MDUs were restructured into Western Central, Western East and Western West. We have generated missing information for old MDUs by interpolation and extrapolation from historical trends.

MDU context

2.43 **Maintenance expenditure**: Figure 11 below shows that MDUs spent, on average, c. £38k per track-km each year. Euston MDU spent the most, £87k per track-km, whilst Perth MDU spent the lowest amount, £15k per track-km.

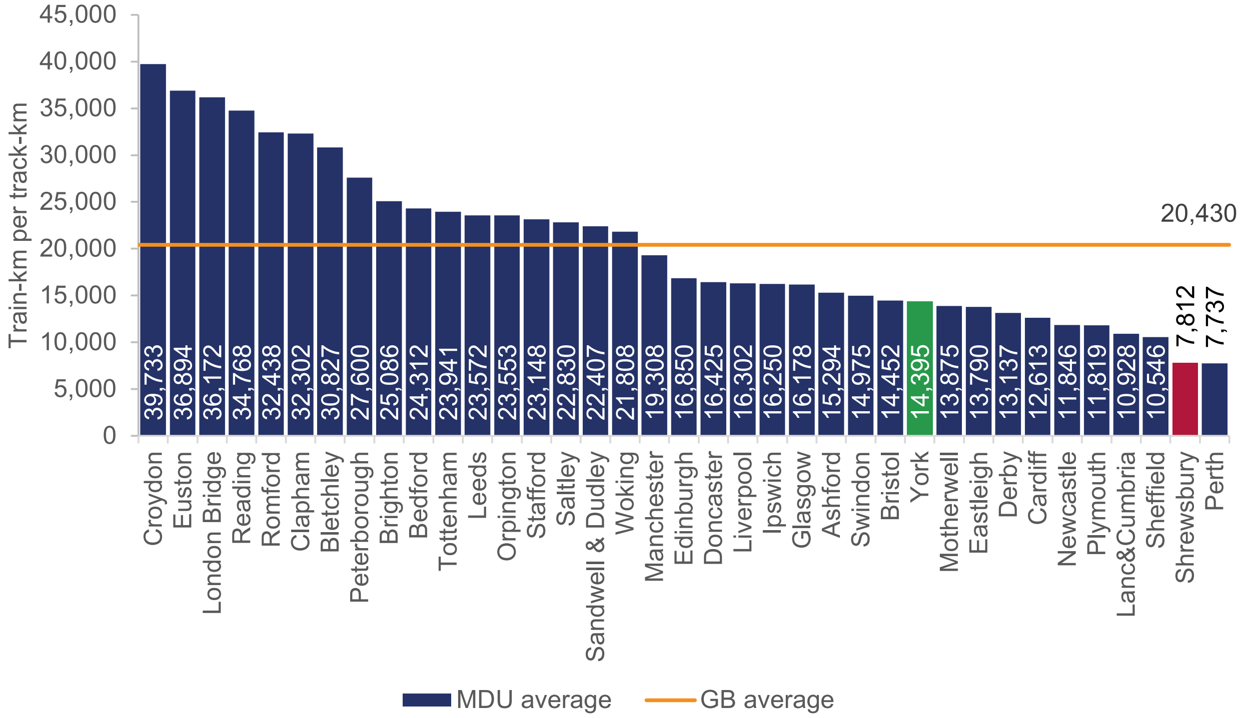
Figure 11: Average maintenance expenditure per track-km, 2014-15 to 2020-21 (2020-21 prices)[26]



2.44 **Traffic Density**: Figure 12 below shows that traffic density (passenger and freight traffic per train-km) varied widely across MDUs. Croydon was 39,733 train-km per track-km, on average, per year. On the other hand, Perth was 7,737 train-km per track-km per year. The average GB-wide track density was 20,430 train-km per track-km.

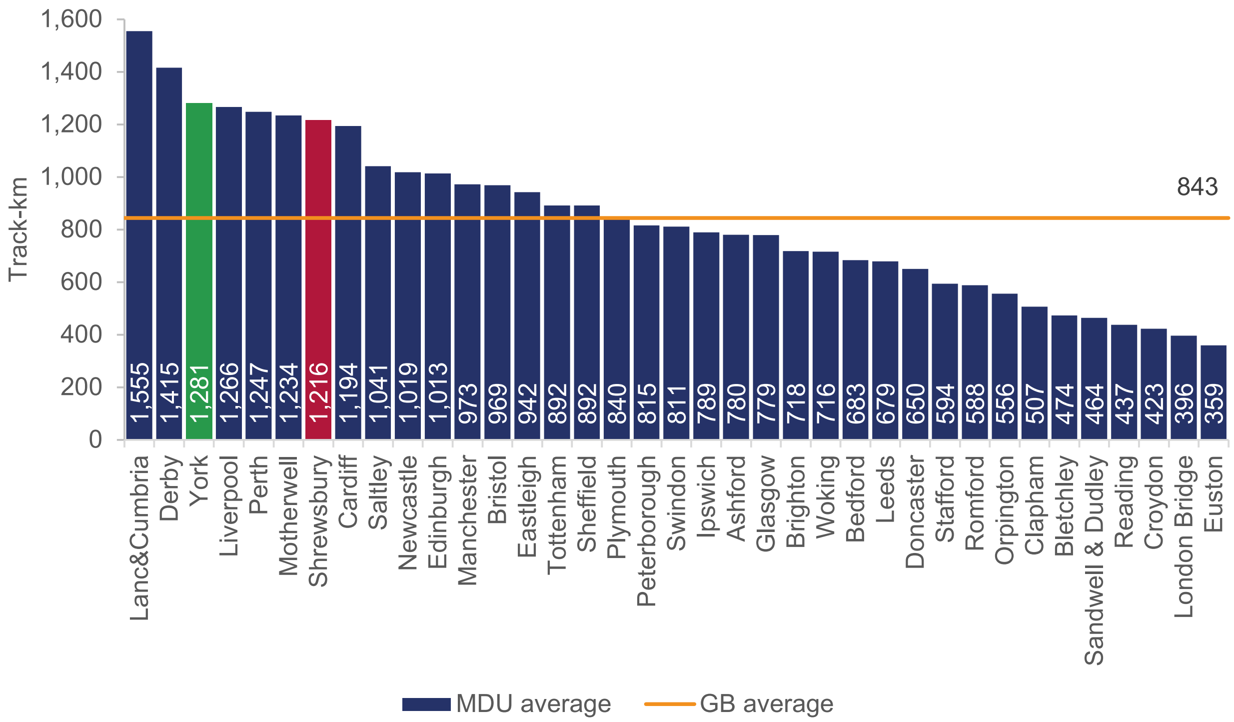
[26] In figures 11 to 14, York is highlighted green and Shrewsbury red. York and Shrewsbury are the MDUs for which expenditure differs most from our model's prediction (York is below prediction, Shrewsbury above). We note that for a number of the variables of interest, these 'outlier' MDUs are not too far apart from one another.

Figure 12: Average traffic density (train-km/track-km), 2014-15 to 2020-21



2.45 **Network size (track-km)**: as shown in Figure 13 below, the Lancashire & Cumbria MDU is responsible for the longest section of network at 1,555 track-km, whilst Euston maintains the shortest at 359 track-km. The average length of track covered by an MDU over the period 2014-15 to 2020-21 is 843 track-km.

Figure 13: Average track-km, 2014-15 to 2020-21

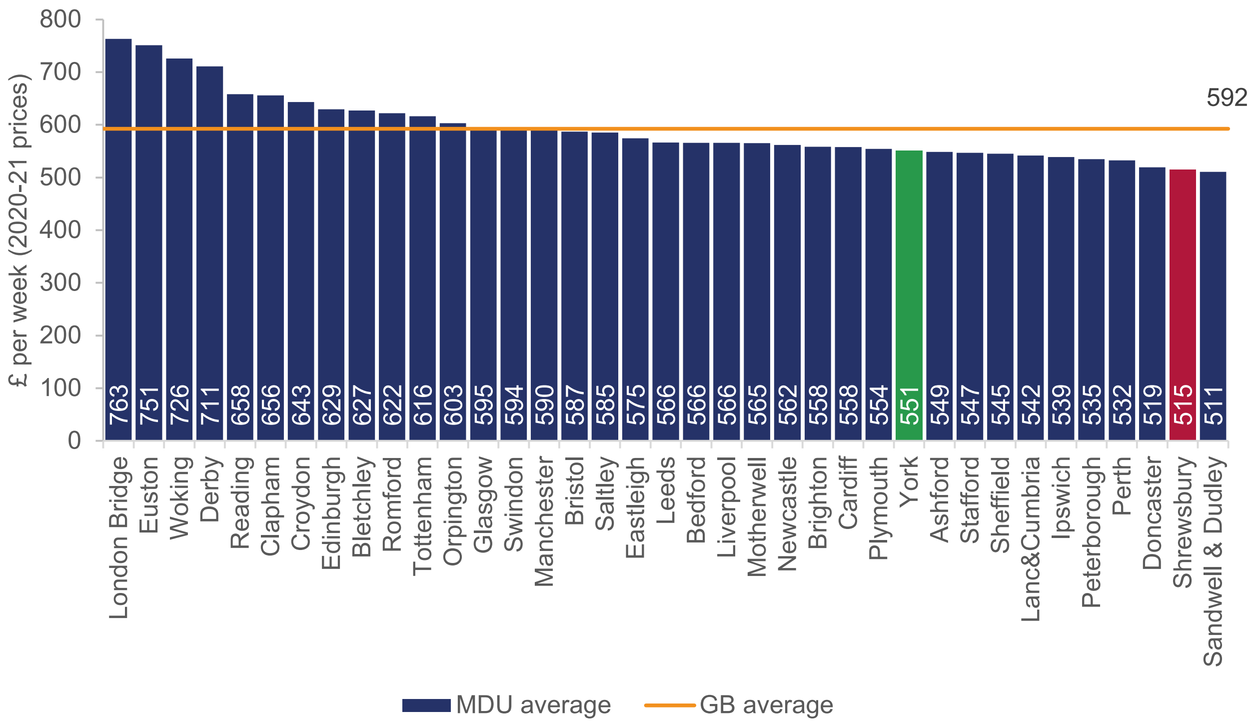


2.46 **Wage levels:** Figure 14 below compares local wages across local authority areas covered by each MDU[27]. The average median wage across all MDUs' local authority areas between 2014-15 and 2020-21 is £592 per week.

2.47 Median wages are highest in the London Bridge MDU area at £763 per week. In contrast, the Sandwell & Dudley MDU area has the lowest median wage at £511 per week, followed closely by Shrewsbury at £515 per week. We note that local wage variations do not necessarily reflect differences in pay across Network Rail routes due to the use of national terms and conditions. We are working to incorporate Network Rail-specific wage data at the MDU-level into future analysis.

[27] Data is sourced from the Office for National statistics (ONS) on weekly earnings by local authority. We matched these local authorities with each of the 37 MDUs geographical area of operation. Note that this weekly wages data is not Network Rail specific. It simply reflects the level of wages in each geographical area covered by MDUs.

Figure 14: Median weekly wages in an MDU's local authority, 2014-15 to 2020-21 (2020-21 prices)



2.48 **Average number of tracks (track-km/route-km)**: the average number of tracks across the network is 2. Reading has the highest average number of tracks at 3.3, followed by Euston and Peterborough at 3.2. Perth has the lowest average number of tracks at 1.3, followed by Glasgow and Shrewsbury at 1.5.

2.49 **Average electrification** across all MDUs was 51% between 2014-15 and 2020-21. Plymouth MDU has no electrified sections, followed by Shrewsbury, Derby, Perth and Sheffield with negligible proportions of electrified track. On the other hand, over 95% of track length in the Clapham, Croydon, Euston, London Bridge, Orpington and Peterborough MDUs is electrified.

2.50 The network is classified into five **criticality bands**. The MDU with the highest percentage of its track length within criticality bands 1 & 2 (combined) in 2020-21 is Reading at 94%, followed by London Bridge at 93%. At the other end, Perth, Sheffield and Shrewsbury have none of their track length in criticality bands 1 & 2.

MDU Analysis

Data

2.51 The analysis is based on data for Network Rail's 37 MDUs for financial years 2014-15 to 2020-21. This year's analysis builds on the model employed in our year 1 of CP6 report, using mostly the same variables but with the addition of another year's worth of data.

2.52 An issue that has arisen this year is that Network Rail has been unable to supply passenger and freight traffic data at the MDU-level. This is due to a data recording hiatus, whilst it transfers between systems[28]. We have therefore estimated MDU-level traffic for 2020-21 by splitting route-level traffic data, based on the proportion of the relevant route's 2019-20 traffic that each MDU accounted for. This introduces some additional measurement error compared to last year's analysis.

Dependent variable

2.53 The dependent variable is maintenance expenditure, allocated to the MDU level. This excludes centrally managed expenditure (covering activities such as structures examination, major items of maintenance plant and other HQ managed activities).

2.54 Although there has been a significant drop in traffic due to the impact of COVID-19 and an associated decrease in maintenance expenditure at the route level, MDU-level expenditure has increased by 5% from 2019-20. This is broadly in line with the trend observed in previous years.

Independent variables

2.55 Table 4 below presents the full list of independent variables that we have included in our analysis.

Table 4: Independent variables used in the MDU-level model

Variable	Expected direction of relationship	Reason for relationship
Track-km (length of track)	Positive	A larger network requires more maintenance.
Passenger train-km	Positive	More traffic on the network would likely cause greater wear and tear. In addition, it is likely that maintenance work is more difficult to undertake in more heavily used areas of the network
Freight train-km	Positive	
Average number of tracks (track-km/route-km)	Negative	On a network with multiple tracks, maintenance teams may not need to

[28] Network Rail has told us that it ceased to record actual traffic data in its 'ACTRAFF' system at the MDU-level in 2020. It has also indicated that a new system should be in place by April 2022 but it is not clear if traffic data will be collected at the MDU-level before it goes live.

Variable	Expected direction of relationship	Reason for relationship
		travel as far, on average. Time windows for maintenance activities may be wider on multiple track sections of the network. In addition, there may be less volume of work involved when maintaining one km of double track route than two km of single track (for example, due to the volume of ballast and drainage assets).
Proportion of electrified track (electrified track-km/track-km)	Positive	The presence of electricity and of power supply infrastructure is likely to increase the complexity of track maintenance work.
Switches and crossings (S&C) density (number of S&C/track-km)	Positive	A network with more switches and crossings per track requires more maintenance.
Criticality 1 & 2 density[29] (criticality 1 & 2 km/track-km)	Positive	More critical sections of the network are likely to require more frequent maintenance (as set out in technical standards) and may need to be kept in a better general condition than other parts of the network. It may also be more difficult to undertake engineering work in more critical parts of the network (for example, due to higher train speeds and usage) and the access time window may be narrower on those sections of line. This effect may also be covered, in part, by the traffic variable.
Wage levels (£/week)	Positive	If we assume that maintenance work in each MDU is carried out largely by a local labour force, then it will cost more in areas where labour costs are higher. In practice, this effect may be significantly reduced by the use of national terms and conditions.

[29] We have been told by asset management experts that there is currently an on-going process aimed at reclassifying track sections into different criticality bands and that this is most likely to have a material impact on the definition of track criticality bands 1 & 2. They have suggested that, rather than controlling for each band separately, a combined variable would better represent criticality.

Variable	Expected direction of relationship	Reason for relationship
Year	N/A	The purpose of this term is to separate out the common annual trend in maintenance costs across MDUs that cannot be attributed to observable cost drivers. The coefficient on Year can be interpreted as an annual growth rate.
Year-specific dummy variable (applies to 2020-21)	N/A	The purpose of this term is to separate out the common change in expenditure across MDUs due to year-specific exogenous factors that cannot be attributed to observable cost drivers. The coefficient can be interpreted as a deviation from the average annual growth rate given by the coefficient on the Year variable. We use a dummy for year 2020-21 to reflect the impact of COVID-19.

2.56 Following feedback from Network Rail on last year's analysis, we have tested the effect of the total duration of possessions on maintenance expenditure. The hypothesis was that longer possessions reflect greater difficulty in gaining access and hence greater maintenance expenditure. However, model estimates instead showed the opposite effect. We have therefore decided not to include this variable in our final model.

2.57 This result is likely due to data quality issues. We have observed that a large proportion of possessions are not linked to individual MDUs, which may be causing substantial measurement error. The effect of this measurement error is likely to be greater for MDUs than for routes because the proportion of possessions that cannot be assigned is likely to be more uniform between routes than between MDUs. We are working with Network Rail to improve the quality of possessions data and hope to be able to include it in our future analysis.

2.58 We would also have liked to test the effect of asset reliability and enhancements expenditure in our model but this data is only available at route level at the moment. We will work with Network Rail to get this data at the MDU level for potential inclusion in future analysis.

Descriptive statistics

2.59 Table 5 below presents summary statistics for the variables in our model.

Table 5: Summary of variables (all monetary variables in 2020-21 prices)

Variable	Mean	Std. Dev.	Min	Max
Maintenance expenditure (£m)	27.7	8.1	15.3	56.6
Track-km (km)	843	315	353	1616
Passenger train-km (million train-km)	13.9	3.9	5.1	23.6
Freight train-km (million train-km)	1.2	0.7	0.1	3.7
Average number of tracks	2.2	0.5	1.3	3.3
Proportion of electrified track (%)	51%	35%	0%	100%
Switches and crossings density (S&C per track-km)	0.6	0.2	0.3	1.4
Criticality 1 & 2 density (%)	33%	28%	0%	98%
Wage levels (£/week)	568	67	455	812

Model specification

2.60 We have adopted the same functional form as in the route analysis; that is, the Cobb-Douglas log-log formulation (i.e. where the dependent variable and most explanatory variables are in natural logarithms). As mentioned above, this functional formulation allows most coefficients to be interpreted as constant elasticities, i.e. the percentage change in cost resulting from a percentage change in the relevant cost driver.

2.61 We have estimated a number of variants of the following model but settled on the following specification:

$$\begin{aligned} \ln(maintenance\ cost) &= \beta_0 + \beta_1 \ln(track\ km) + \beta_2 \ln(passenger\ train\ km) \\ &+ \beta_3 \ln(freight\ train\ km) \\ &+ \beta_4 (average\ number\ of\ tracks) \\ &+ \beta_5 \ln(proportion\ of\ electrified\ track) \\ &+ \beta_6 \ln(switches\ \&\ crossings\ density) \\ &+ \beta_7 \ln(criticality\ 1\ \&\ 2\ density) + \beta_8 (wage\ levels) \\ &+ \beta_9 (year) + \beta_{10} (dummy_{2020-21}) + error\ term \end{aligned}$$

Estimation approach

2.62 As in our year 1 of CP6 report, we use a pooled ordinary least squares (OLS) method to estimate our model.

Model estimates

2.63 Below, we present and analyse the results of our OLS model estimates.

Table 6: OLS estimated results

Variable	Coefficient
Track-km	0.30***
Passenger train-km	0.28***
Freight train-km	0.16***
Average number of tracks	−0.50***
Proportion of electrified track	0.45***
Switches and crossings density	0.27***
Criticality 1 & 2 density	0.09
Wage levels	0.41**
Year	0.02***
Dummy for 2020-21	0.17***
Constant	−8.12***
Number of observations	259
R^2	0.61
** statistically significant at the 95% confidence level *** statistically significant at the 99% confidence level	

2.64 The results show a statistically significant relationship between the amount that an MDU spends on maintenance and: the size of the network it maintains (track-km), the level of traffic (both passenger and freight), network complexity (measured by the average number of tracks, electrification and S&C density) and the level of wages in the local authority covered by that particular MDU. The proportion of the network in criticality bands 1 & 2 does not seem to have a clear effect on expenditure, as its coefficient is not statistically significant at the 90% level.

2.65 The coefficient on the dummy variable for 2020-21 shows that MDU-level expenditure was 19% above the background trend, after taking account of changes in observable cost drivers[30]. This is somewhat surprising given that total maintenance expenditure at the route level in 2020-21 is significantly below the background trend. One explanation is that there may have been a change in the way expenditure is allocated between MDUs and their respective routes/regions. We will investigate this further with Network Rail.

2.66 The R^2 is a measure of overall goodness-of-fit. It represents the proportion of variance in the data that can be explained by the independent variables in the model. An R^2 of 0.61 means that our model explains 61% of the variance in maintenance costs. This moderately low R^2 value could be due to our sample size, the potential omission of important cost drivers or measurement error in the underlying data.

2.67 The results in Table 6 above show that, all other factors held constant:

(a) increasing track length by 1%, whilst keeping traffic (and all other variables) constant, would increase maintenance costs by 0.30%. This suggests that there are economies of scale, i.e. costs increase less than proportionally with the length of track;

(b) an increase in passenger train km of 1%, would increase maintenance costs by 0.28%. The same increase in freight traffic would increase costs by 0.16%[31]. These results show economies of density – costs increase less than proportionally with traffic;

(c) increasing the density of electrified track by 1% would increase maintenance costs by 0.45%. That is, if an MDU went from 50% to full electrification, our model indicates that its maintenance costs would be 37% higher[32];

[30] Calculated as $(e^{0.17} - 1)$

[31] Freight traffic is heavier but slower than passenger traffic. This means weight and speed may work in different directions in the analysis, which may make it difficult to make a prediction on the relative sizes of their coefficients. However, if we consider that in our data, freight traffic is very small as compared to passenger traffic, these coefficients are as expected. This is because the small amount of freight traffic means that the average cost for freight is higher than the average cost for passenger traffic, implying that for a similar marginal cost increase, the elasticity (i.e. coefficient) of freight must be smaller than the one on passenger traffic. Note that marginal cost = elasticity × average cost.

[32] The percentage increase is calculated as $[(1^{0.45}/0.5^{0.45}) - 1] = 0.37$

(d) increasing the density of switches and crossings by 1% increases maintenance costs by 0.27%;

(e) a 1% difference in local wages is associated with a 0.41% difference in maintenance costs; and

(f) it is cheaper to maintain a network with multiple tracks than a single track. Maintaining a given length of track as a single-track route is expected to cost 41% more than the same length of track as a double-track route[33].

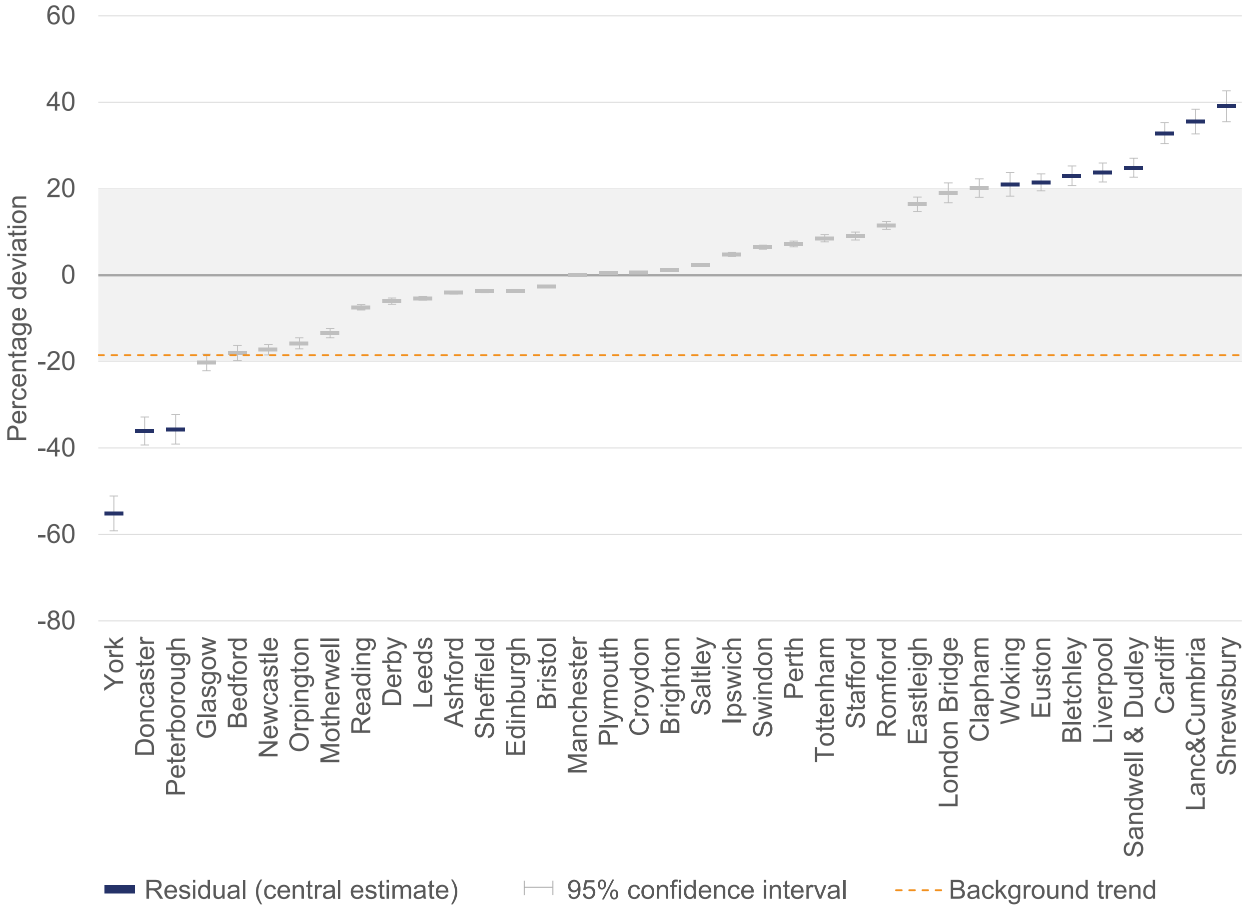
MDU benchmarking results

2.68 Here we compare outturn maintenance costs against expected spend as predicted by our model, given each MDU's characteristics. We then order the MDUs according to the amount of the unexplained variation.

2.69 Figure 15 below shows the proportion of unexplained cost variance for each MDU in 2020-21. A negative number means that the MDU spent less than expected (according to our statistical model), whilst a positive number means that the MDU spent more than expected.

[33] The percentage difference is calculated as $[(1/0.71) - 1] = 0.41$. Note that one km of double-tracked route counts as two track-km. The cost of maintaining a one km line as single-track is therefore $1^{0.3} \times 1^{-0.5} = 1$, whereas the cost of maintaining a one km line as double-track is $1^{0.3} \times 2^{-0.5} = 0.71$. This indicates that it is cheaper to run the same length of line as a double-tracked network.

Figure 15: Deviation between outturn and expected (modelled) maintenance costs, 2020-21[34]



2.70 Given that there is uncertainty in any statistical model, we classify MDUs into three broad bands based on the deviation between outturn maintenance cost and expected, or modelled, maintenance cost:

(a) MDUs for which outturn spend is **lower than expected** by 20% or more;

(b) MDUs for which outturn spend is **higher than expected** by 20% or more; and

(c) MDUs for which outturn spend is **within +/- 20% of that expected** by the model.

2.71 The analysis shows that, in 2020-21, the **York**, **Doncaster** and **Peterborough** MDUs (all in the LNE route) are in the first category (<-20%). **Shrewsbury**, **Lancashire & Cumbria**, **Sandwell & Dudley**, **Liverpool**, **Bletchley**, **Euston** (all

[34] Given the uncertainty associated with any statistical model, we consider any MDU that is within +/−20% of our modelled prediction (as shown by the x-axis at zero) to not be an 'outlier'. These MDUs are marked grey. MDUs that are marked blue are therefore considered 'outliers'.

in the LNW route of the NW&C region) and **Cardiff** are in the second category (>+20%). At the extremes, York spent 55% less than predicted by our model whereas Shrewsbury spent 39% above prediction. In general, the ordering of MDUs is very similar to that generated from last year's analysis[35].

2.72 The results for Shrewsbury and Cardiff are consistent with those for the Wales route, i.e. they are both towards the top of the distribution. We noted in the route section that the difference between outturn and predicted expenditure could be due to the geographical extent of the route and the age of its infrastructure relative to other routes.

2.73 This analysis shows that, for a minority of MDUs, there is a large proportion of unexplained variance between outturn expenditure and that suggested by our statistical model. The result that the three lowest expenditure MDUs are in LNE and most of the higher expenditure ones are in LNW for the second-year running is notable. Whilst this may indicate genuine disparities in performance, it is also possible that it could be an indication of measurement error or omitted variables.

2.74 The North West & Central region (incorporating LNW) pointed out that the Lancashire & Cumbria MDU is one of the most geographically dispersed MDUs, with a number of satellite units delivering work in more remote areas. It also covers some difficult to access rural areas and includes older infrastructure alongside a section of the West Coast Main Line. They also noted the high concentration of running line jointed track and mechanical signalling in the area, which requires more frequent maintenance than other types of track and signalling systems.

2.75 Regarding Sandwell & Dudley, the North West & Central region stated that this MDU hosts overhead line, and distribution and plant maintenance activities on behalf of Saltley MDU, and that this could go a long way to explaining the difference between outturn and predicted expenditure. The region also noted that this type of hosting arrangement is common and may therefore help to explain other outliers.

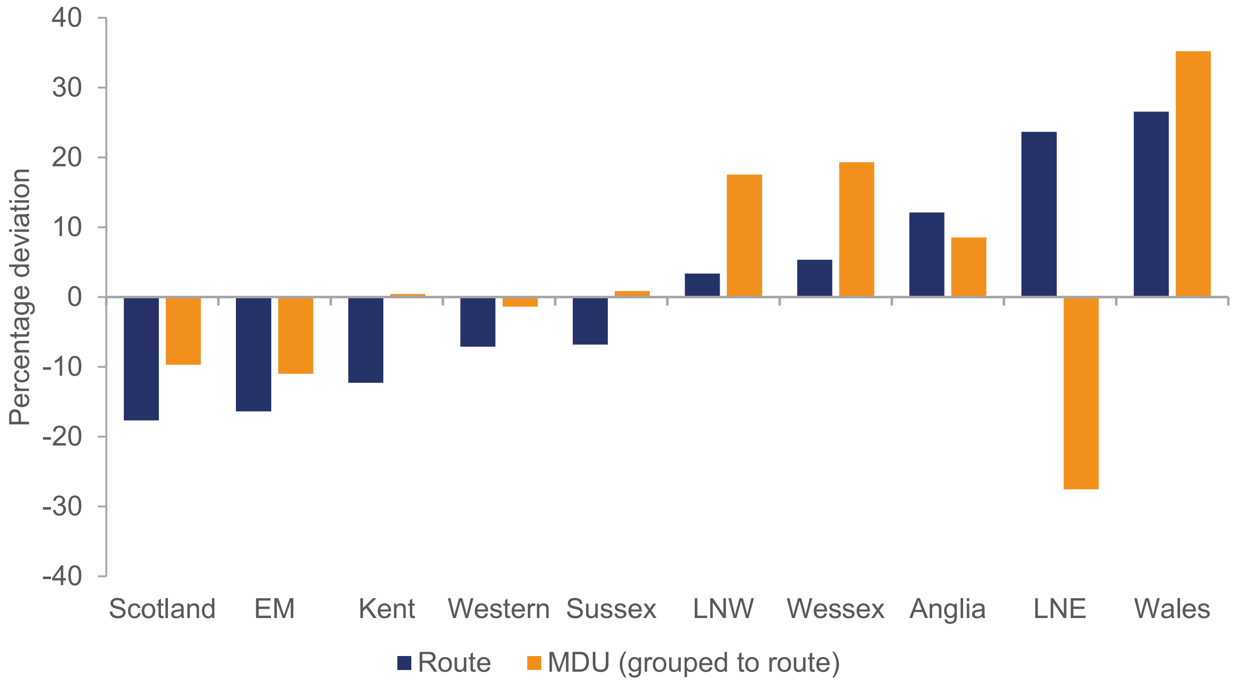
2.76 With respect to Eastern, the MDU-level analysis directly contradicts route and region-level results. This is discussed further in the next section.

[35] In last year's analysis, Lancashire & Cumbria was a more significant outlier. Following discussions with the North West & Central region team, they informed us that there was an error in the mapping of historical MDU expenditure to Lancashire & Cumbria. We have amended the data to reflect their suggested mapping but will continue dialogue with the region and other analysts at Network Rail to further understand this issue and its impact.

Consistency between route, region and MDU results

2.77 In Figures 16 and 17 below, we compare route and region results to those implied by the MDU analysis. To do this, we map MDUs to routes and regions, and then sum outturn and expected (modelled) cost from the MDU data/model up to route and region level.

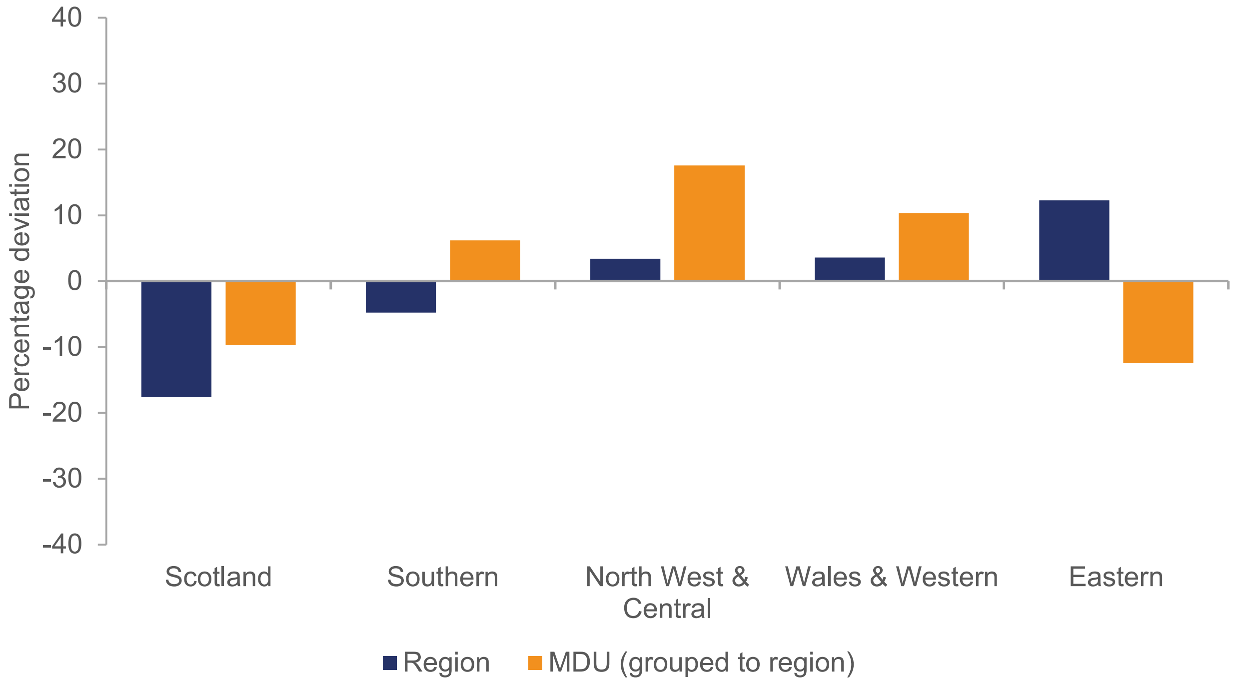
Figure 16: Comparison of route and MDU deviations from expected (modelled) maintenance costs, 2020-21



2.78 Figure 16 above shows that there are still significant differences between unexplained variations from our MDUs and route-level analyses, particularly for LNE. Although the results are in the same direction for most routes and their MDUs, they usually significantly differ in magnitude.

2.79 Figure 17 compares MDU and route-level results when aggregated to a regional level. We observe similar disparities in the case of, Eastern as for LNE (one of its constituent routes), and in the case of, North West & Central as for LNW. There is also a difference in the direction of unexplained differences for the Southern region, but the scale of the difference is relatively small. Both the Eastern and North West & Central regions are currently looking into our MDU-level analysis and we hope to have some insight into what is causing the disparity between MDU and route-level data in the coming months.

Figure 17: Comparison of region and MDU deviations from expected (modelled) maintenance cost, 2020-21



3. Renewals

Introduction

3.1 Renewals relate to activities to replace, in whole or in part, network assets that have deteriorated such that they can no longer be maintained economically. Renewal of an asset restores the original performance of the asset and can add additional functionality as technology improves.

3.2 In PR18, we modelled maintenance and renewals expenditure together. The potential advantages of that approach include that it can capture potential interdependency between maintenance and renewals activities. For example, renewing an asset in one year may reduce maintenance requirements in subsequent years.

3.3 In practice, these two activities are different in nature and may be driven by different factors. Maintenance activities at the route level are less variable over time than renewals, which tend to be undertaken less often and as larger one-off projects to renew specific assets or specific parts of the network.

3.4 Therefore, in last year's report (year 1 of CP6), we estimated separate models for maintenance and renewals. Whilst this change greatly improved our modelling of maintenance costs, it also highlighted that our approach to the modelling of renewals needed further improvement. Notably, last year's renewals model could not account for natural annual fluctuations in expenditure arising from the lumpy nature of the renewals work (e.g. fluctuations due to differences in work mix, decisions to defer some works, etc.) which, if not accounted for, could be misinterpreted as poor/good performance. Also, different types of work are likely to be delivered at different costs.

3.5 We stated last year that we would, in future, be exploring other approaches that could help address these shortcomings, including analysing renewal costs by asset class, e.g. track, signalling, etc. In this year's analysis, we compare renewals unit costs (expenditure divided by work volume) across Network Rail routes, and did this separately by main asset class and for different types of renewals activity.

3.6 This approach has led to much more meaningful comparisons. It also deals with the problem of large fluctuations in total expenditure from year to year. Average unit costs for a given asset and work type should remain relatively stable even if volumes of work fluctuate significantly.

3.7 Network Rail reports renewals volumes and expenditure separately for Track, Signalling, Civils, and Buildings. As this is the first time we have used this approach, we have just focussed on a single asset class and type of work, namely conventional track renewals.

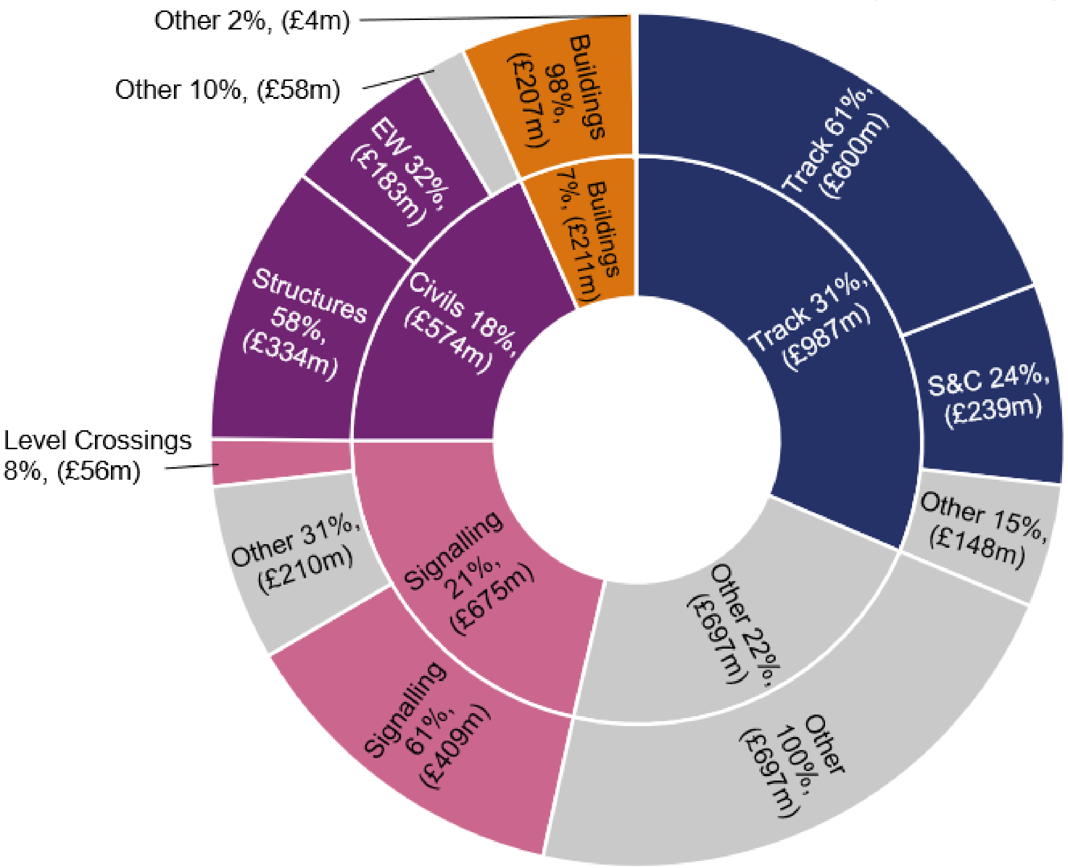
3.8 This chapter describes the statistical models we have estimated to explain conventional track renewals unit costs at a route level as a function of key cost drivers. We then compare routes based on the percentage difference between outturn average unit costs and those predicted by our model. We also present results by Network Rail region by aggregating the route-level results.

3.9 This chapter is organised as follows: the next section ('Context') provides some context on the make-up of Network Rail renewals activity and how routes compare in terms of their overall expenditure and volume of work, asset characteristics and network usage. The following section ('Analysis') describes the data and modelling approach. In the final section ('Benchmarking results') we use this information to compare conventional track average unit costs across routes and regions.

Context

3.10 **Breakdown of renewals expenditure by asset class:** Figure 18 shows the breakdown of average total renewals expenditure by asset class between 2014-15 and 2020-21.

Figure 18: Breakdown of average total renewals expenditure by asset class, 2014-15 to 2020-21 (2020-21 prices)[36]

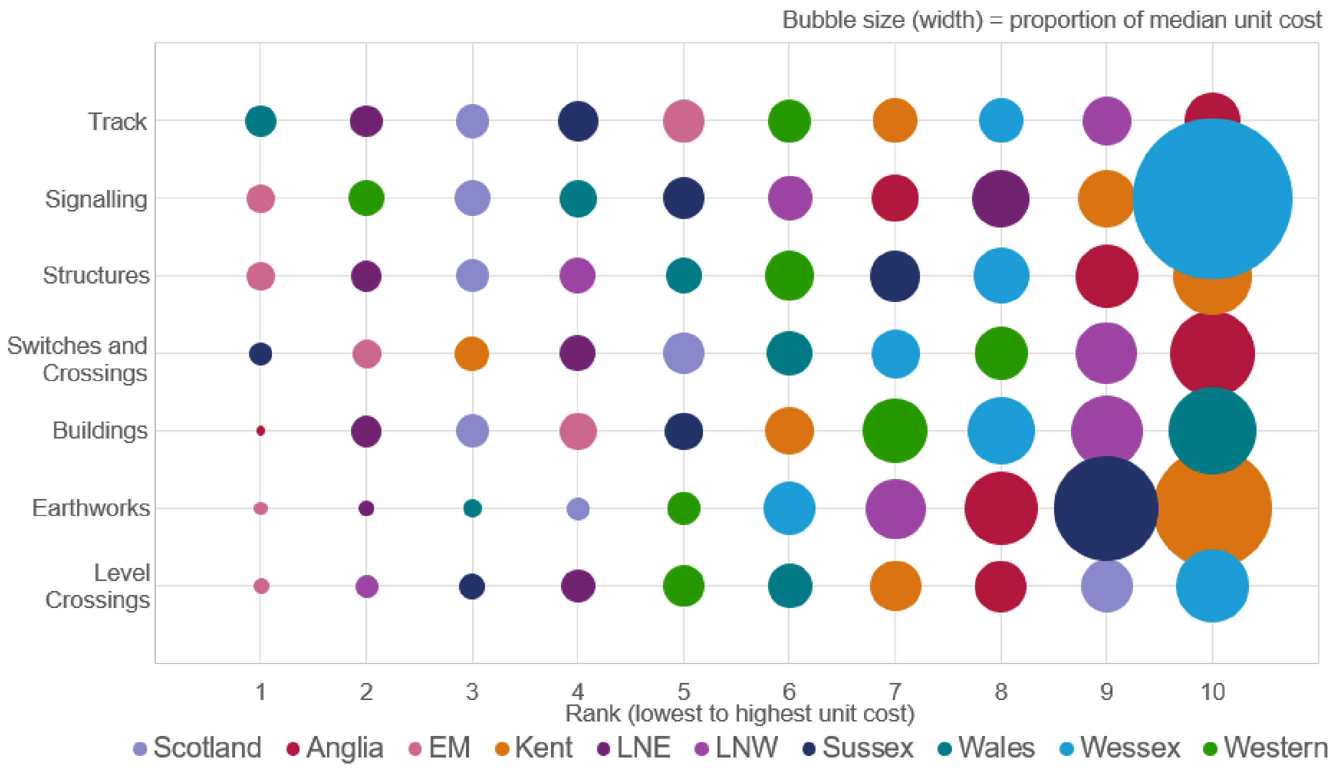


3.11 As indicated by the inner ring, expenditure on Track, Signalling, Civils and Buildings accounted for 78% of the total. Asset classes are further split into sub-asset class or work type in the outer ring of the figure. For instance, the Track and Switches & Crossings sub-asset classes accounted for 85% of average total Track renewals expenditure.

[36] EW stands for Earthworks; S&C stands for Switches and Crossings. The 'Other' categories represent expenditure not captured in our analysis (as we were unable to accurately match expenditure and volumes at the work type level for this data). The 'Other' category in the inner ring of the chart includes expenditure on Electrical Power and Fixed Plant, Telecoms, Wheeled Plant and Machinery and IT, Property and Other renewals.

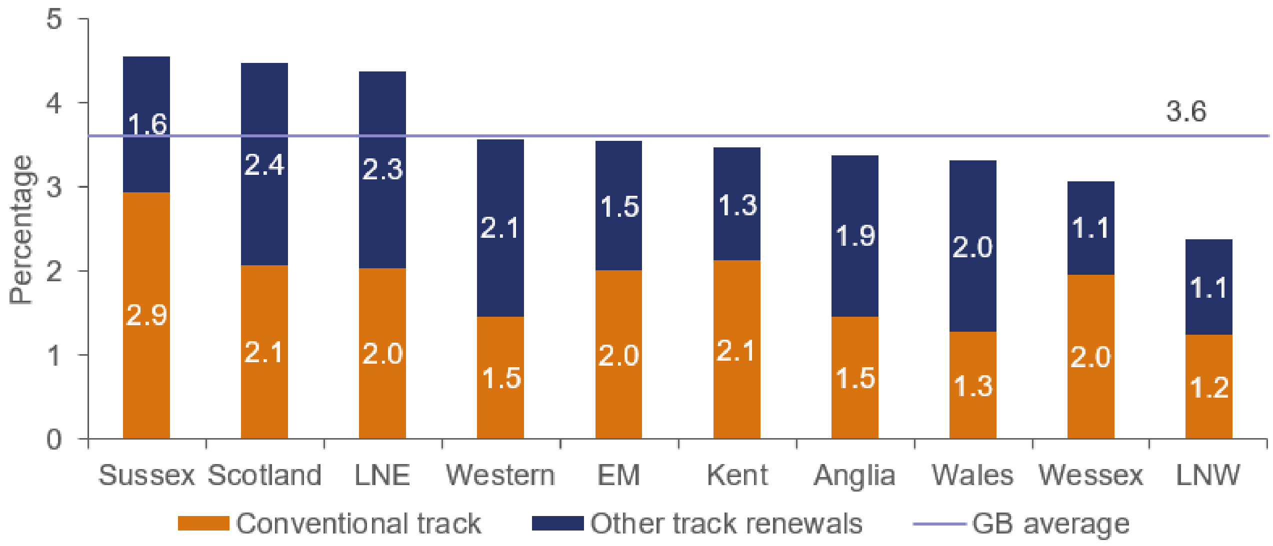
3.12 **Variation in average renewals unit costs:** Figure 19 shows the 7-year average renewals unit cost, by asset and sub-asset class, and by route, with routes ranked for each asset according to their average unit cost. The size of the bubbles shows how large each route's average unit cost is relative to the median route in each asset and sub-asset class. Anglia, Kent and Wessex have some of the highest average unit costs across the majority of asset classes. In comparison, East Midlands consistently has some of the lowest average unit costs across asset classes.

Figure 19: 7-year average unit cost rankings per asset class, 2014-15 to 2020-21



3.13 **Proportion of track renewed:** Figure 20 shows the volume of track renewed as a proportion of total route track-kms. On average, Network Rail renewed 3.6% of its track each year between 2014-15 and 2020-21. The Sussex route renewed its track at the highest rate (4.5%, 2.9% of conventional track renewals and 1.6% of other types of track renewal), whilst London North West (LNW) renewed at the lowest rate (2.3%, 1.2% of conventional track renewals and 1.1% of other types of track renewal).

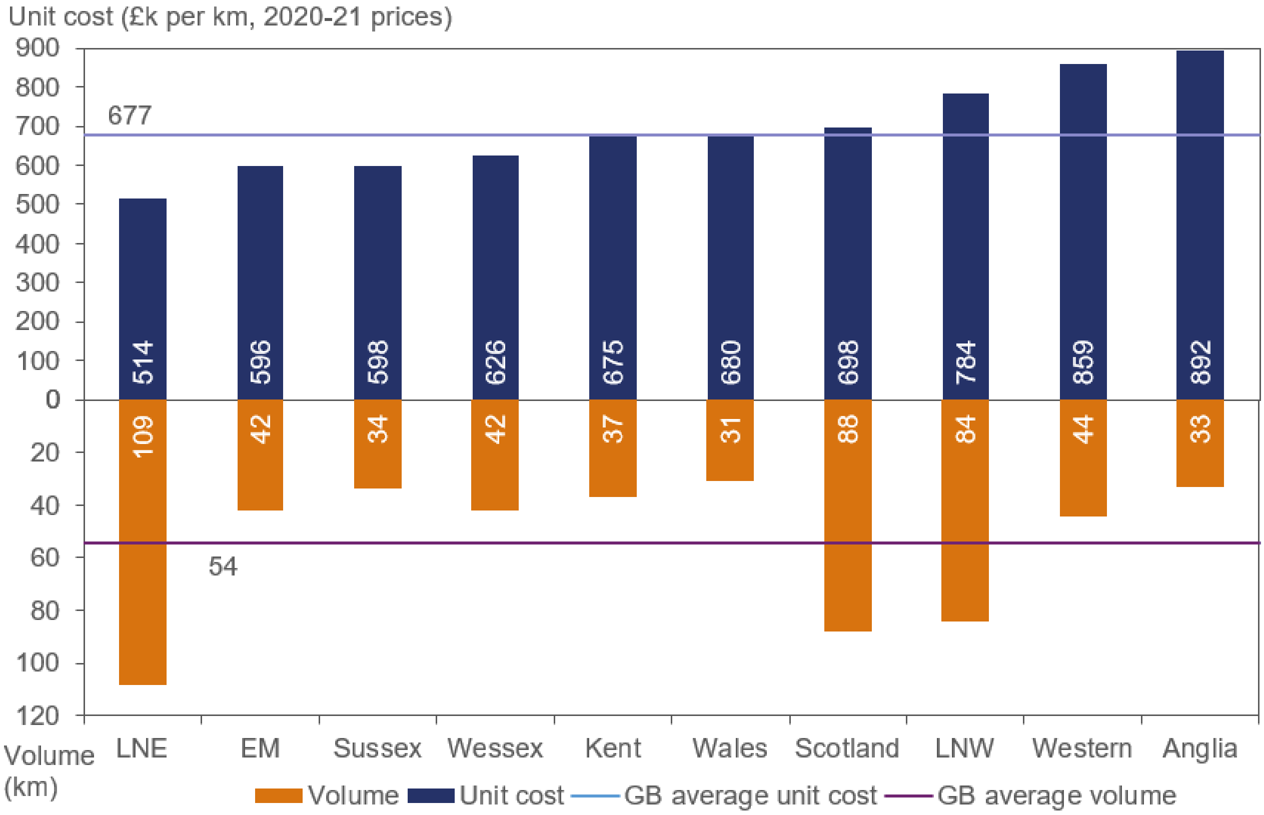
Figure 20: Average proportion of track renewed each year, 2014-15 to 2020-21[37]



3.14 **Conventional track renewal average unit cost and volumes:** Figure 21 shows the 7-year average unit cost and volumes for conventional track renewal by route. The average across all routes is £677k per track-km for unit costs and 54km for volume renewed. On average, Anglia has the highest average unit cost (£892k per track-km) and lowest volume renewed (33km), whilst London North East (LNE) has the lowest average unit cost (£514k per track-km) and the highest volume renewed (109km).

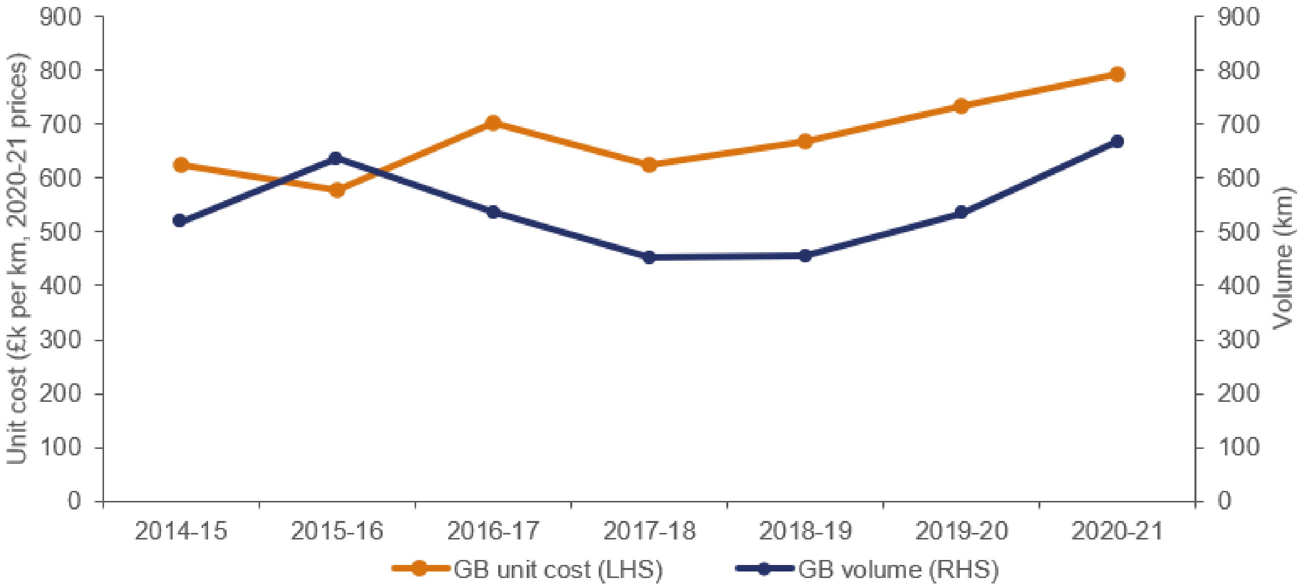
[37] Proportion of conventional track renewed per route is calculated as conventional track renewals costs divided by track-km. Proportion of other track renewals per route is calculated as the sum of high-output renewals and track refurbished, divided by track-km.

Figure 21: Conventional track renewal – 7-year average unit cost and volumes, 2014-15 to 2020-21 (2020-21 prices)



3.15 **Trends in conventional track renewal unit costs and volumes (Network Rail):** Figure 22 shows the trend in the 7-year average unit cost and volumes for conventional track renewal for Network Rail as a whole. Both real terms unit costs and volumes have been on an upward trend since 2017-18. The pattern prior to that is less clear.

Figure 22: Trends in Conventional track renewals – average unit cost and volumes, 2014-15 to 2020-21 (2020-21 prices)



Analysis

Data

3.16 The analysis is based on data for financial years 2014-15 to 2020-21, recorded at the level of the ten routes that were introduced by Network Rail in CP4.

3.17 The year 2020-21 has been highly unusual for the rail industry and COVID-19 restrictions have led to large reductions in rail traffic. COVID-19 has impacted renewals volumes and the composition of work undertaken, e.g. high-output renewals in Scotland were deferred. Also, social distancing, reduced staff availability and supply chain pressures have made it more difficult and expensive to carry out work on the infrastructure.

3.18 Our own analysis (as reported, for example, in the Annual Efficiency and Finance Assessment, and in the Annual Assessment of Network Rail) suggests that Network Rail has largely delivered its planned maintenance and renewals work despite the pandemic but at a higher cost.

3.19 We take COVID-19 into account in our model by separating out the common change in conventional track renewals unit costs across routes in 2020-21 that cannot be attributed to observable cost drivers.

Dependent variable

3.20 The dependent variable is annual average unit cost at the route-level for conventional track renewals. We obtain this variable by dividing total annual expenditure on conventional track renewals by the number of track-km renewed using conventional track renewals methods. For years 2014-15 to 2018-19, expenditure data comes from Statement 9b in Network Rail's Regulatory Financial Statements and volume data comes from Network Rail's published Annual Returns. For years 2019-20 and 2020-21, both expenditure and volume data were provided to us directly by Network Rail for the purpose of this analysis. All expenditure data is inflation-adjusted to 2020-21 prices, using the Consumer Price Index (CPI).

Independent variables

3.21 Table 7 below summarises the explanatory variables retained in the final model, alongside the expected direction of the relationship to conventional track renewals unit costs and the reasoning behind this.

3.22 Network Rail reports against five types of work under the 'Track' asset category:

(a) conventional track renewals (work intended to fully replace the existing track asset utilising conventional track renewal methodologies);
(b) track refurbishment (work intended to extend the life of the existing track asset rather than fully renew it);
(c) high-output track renewals (work intended to replace the existing track asset through utilisation of the specialised high-output machines). The high-output technology is only appropriate for simple stretches of track without switches and crossings, platforms or viaducts);
(d) switches and crossings; and
(e) other.

3.23 In the present report, we focus on conventional track renewals. However, it is possible that there may be an interaction between the unit cost of conventional track renewals and the volume of other types of work, e.g. refurbishments and high-output work. For example, carrying out refurbishment work on the network may change the balance between the volume and cost of renewals. Or it could be that an increase in the use of high-output renewals could leave the most challenging track sections to be renewed through conventional methods, therefore pushing up the unit cost of conventional track renewals. We therefore include the volume of track refurbished and high-output renewals as explanatory variables in our model.

3.24 We also tested whether the intensity[38] of maintenance and enhancements expenditure have a bearing on conventional track renewals unit costs through increased pressure on the supply chain. Model estimates came up with relationships between the variables that were opposite to those we expected and we therefore excluded these variables from the final model.

3.25 In addition, we tested the following variables: track-km, average number of tracks (total length of track divided by total route length), route-km, the composite reliability index, and the number of switches and crossings. All these variables are highly correlated with other variables in the model, which means that it is difficult to separately estimate their respective effects.

Table 7: Independent variables used in the route-level conventional track renewals model

Variable	Expected direction of relationship	Reason for relationship
Number of track-km renewed using conventional methods (km)	Negative	Assuming the existence of economies of scale, a greater number of track-km renewed should lead to a lower average unit cost.
Number of refurbished track-km (km)	Ambiguous	Carrying out refurbishment work on the network may change the balance between the volume and cost of renewals.
Number of track-km renewed using high-output technology (km)	Positive	High-output technology is currently only appropriate for simple stretches of plain line. So an increase in high-output volumes could mean that conventional track renewals are used on average for more complicated parts of the network.
Train-km (passenger train-km + freight train-km)[39]	Positive	More traffic on the network would likely cause greater wear and tear. In addition, it is likely that renewals work is more difficult to undertake in more heavily used areas of the network.

[38] Measured as maintenance and enhancements expenditure divided by track-kms.

[39] We use this variable instead of passenger and freight train-kms separately as we did in our route maintenance model because they are highly correlated with the number of track-km renewed using conventional methods. Also, given the relatively small size of our dataset, reducing the number of variables in our model (by combining two traffic variables) improves on degrees of freedom. This in turn improves the robustness of our model.

Variable	Expected direction of relationship	Reason for relationship
Average rainfall(mm)	Positive	Higher rainfall is likely to cause more frequent and more damaging infrastructure failure (e.g. landslides) and may therefore require more expensive renewals work. Higher rainfall may also make it more difficult to undertake infrastructure work.
Criticality 1 & 2 density (criticality 1 & 2 km/track-km)	Positive	More critical sections of the network are likely to require more frequent maintenance (as set out in technical standards) and may need to be kept in a better general condition than other parts of the network. It may also be more difficult to undertake engineering work in more critical parts of the network (for example, due to higher train speeds and usage) and the access time window may be narrower on those sections of line. This effect may also be covered, in part, by the traffic variable.
Proportion of electrified track (electrified track km/track-km)	Positive	The presence of electricity and of power supply infrastructure is likely to increase the complexity of track renewals work.
Possessions duration (days per track-km)	Positive	A high number of possession days may imply that the renewals works to be done are more complicated. More possessions of the network mean that Network Rail would be likely to spend more, in terms of labour cost, materials, Schedule 4 payments, etc.
Year	N/A	The purpose of this term is to separate out the common annual trend in unit costs across routes that cannot be attributed to observable cost drivers. The coefficient on Year can be interpreted as an annual growth rate.
Year-specific dummy variable (applies to 2020-21)	N/A	The purpose of this term is to separate out the common change in unit costs across routes due to year-specific exogenous factors that cannot be attributed to observable cost drivers. The coefficient can be interpreted as a

Variable	Expected direction of relationship	Reason for relationship
		deviation from the average annual growth rate given by the coefficient on the Year variable. We use a dummy for year 2020-21 to reflect the impact of COVID-19.

Descriptive statistics

3.26 Table 8 below presents some summary statistics that describe the variables in our models.

Table 8: Summary of variables

Variable	Mean	Std. Dev.	Min	Max
Conventional track renewals average unit cost (£k per track-km renewed)	702	181	415	1,167
Conventional track-km	54	30	9	133
Refurbished track-km	35	30	0	130
High-output track-km	21	28	0	122
Train-km (million train-km)	55	31	17	143
Average rainfall (mm)	84	30	41	150
Criticality 1 & 2 density (%)	27%	12%	1%	56%
Proportion of electrified track (%)	48%	31%	0%	96%
Possessions duration (days per track-km)	0.29	0.17	0.01	0.80

Model specification

3.27 We have adopted the Cobb Douglas log-log formulation (i.e. where the dependent variable and most explanatory variables are entered in natural logarithms). With this functional formulation, most coefficients can be interpreted as constant elasticities, i.e. the percentage change in cost resulting from a percentage change in the relevant cost driver.

3.28 We have estimated a number of variants of the following model but settled on the following specification:

$$\ln(average\ unit\ cost) = \beta_0 + \beta_1 \ln(conventional\ track\ km) + \beta_2 \ln(refurbished\ track\ km) + \beta_3 \ln(high\text{-}output\ track\ km) + \beta_4 \ln(train\ km) + \beta_5 \ln(average\ rainfall) + \beta_6(proportion\ of\ electrified\ track) + \beta_7(criticality\ 1\ \&\ 2\ density) + \beta_8 \ln(possessions\ duration) + \beta_9(dummy_{2020-21}) + \beta_{10}(year) + error\ term$$

Estimation approach

3.29 We have used the pooled ordinary least squares (OLS) method to estimate our model. This approach has the advantage of being simple to implement and its results easy to understand.

3.30 With OLS, we estimate a line that passes through the centre of the observed data points. This means that, given the information available, the OLS line defines the average cost that a business unit should incur given the cost drivers we control for in our model. The distance between the OLS line and observed/outturn points is the residual. We use these residuals to describe routes' performance relative to the average of the peer group, after controlling for differences in relevant cost drivers[40].

Model estimates

3.31 This section presents and analyses the results of our OLS model estimates.

Table 9: OLS estimated results for the renewals average unit cost model

Variable	Coefficients estimates
Conventional track-km	-0.38***
Refurbished track-km	-0.004
High-output track-km	0.01**
Train-km	0.18***
Average rainfall	0.39***

[40] See our year 1 of CP6 report for more details on how this is done.

Variable	Coefficients estimates
Criticality 1 & 2 density	0.67***
Proportion of electrified track	0.09
Possessions duration	0.13***
Year (average annual unexplained growth rate in renewals average unit costs)	0.02
Dummy for 2020-21 (deviation from the annual growth rate above)	0.27***
Constant	2.89***
Number of observations	70
R^2	0.59
** Statistically significant at the 95% confidence level *** Statistically significant at the 99% confidence level	

3.32 Table 9 above shows that there is a statistically significant relationship between average unit costs and: the volume of conventional track renewals; the volume of high-output renewals; train-kms; average rainfall; criticality 1&2 density; and the length of possessions undertaken. Our results also suggest a small but not statistically significant annual growth in average unit costs. This likely reflects that conventional track renewal unit costs have increased in some years and decreased in others, during the period covered by our data series (see figure 22).

3.33 Model estimates also show that, after accounting for observable differences between routes, in 2020-21 the conventional track renewals average unit cost is, on average, 31% above the background trend[41].

3.34 Our results suggest no clear relationship between the average conventional track renewals average unit cost and either the volume of track refurbished or the proportion of electrified track.

3.35 The model's R^2 is 0.59. R^2 is a measure of goodness-of-fit. It represents the proportion of the variance in average conventional track renewals unit costs that is explained by the independent variables in the model. This means that our model can explain 59% of the variance in conventional track renewals average unit costs across routes and over time. This relatively low R^2 suggests that there are some

[41] This figure is calculated as the exponential of the 2020-21 dummy coefficient: ($e^{0.27}$ -1) =0.31. Note that our model is written as ln(y)=a+b.ln(c)+…+d.2020-21dummy. To obtain the value of y, we exponentiate both sides of the equation, giving y=exp(a).c^b..(…).exp(2020-21dummy).

important factors that drive conventional track renewals unit costs that are not included in our model. These include, for example, location of the project and efficiency in procurement processes[42]. The R^2 is considerably lower than our route maintenance model, which can explain over 90% of observed variance in maintenance expenditure.

3.36 The results in Table 9 above show that, all other factors held constant:

(a) increasing the amount of track-km renewed using the conventional approach by 1%, leads to a decrease of 0.38% in conventional track renewals unit costs[43]. This suggests that there are economies of scale, i.e. the greater the number of track-km renewed, the lower the unit cost becomes;

(b) increasing the amount of track-km renewed using high-output technology by 1% leads to an increase of 0.01% in the unit costs of conventional track renewals;

(c) increasing traffic (train-km) by 1%, increases conventional track renewals unit costs by 0.18%; conversely, a 1% decrease in traffic would reduce costs by the same proportion;

(d) 10% higher rainfall is associated with 3.9% higher conventional track renewals unit costs;

(e) going from 50% to 100% criticality 1 & 2 density would be expected to result in 59% higher unit costs[44]; and

(f) increasing the duration of network possessions days per track-km by 1% leads to an increase of 0.13% in the unit costs of conventional track renewals.

Benchmarking results

3.37 This section compares outturn conventional track renewals unit costs against expected spend as predicted by our model, given each route's characteristics. We

[42] Network Rail has been working with consultants, Deloitte, to develop and implement a more robust and in-depth renewals unit costs reporting framework for its regions. This framework can be thought of as a more detailed and bottom-up version of our cost benchmarking work, taking account of a greater number of potential cost drivers and operating at the project level, rather than at the aggregate route or region level. Much like our analysis, it is based on historical data and establishes expected unit cost ranges based on project characteristics. Where planned unit costs fall outside these ranges, regions are expected to justify them using a template approach based on the list of cost drivers previously identified by Deloitte. This framework should help to provide a more robust and evidence-based approach to this aspect of business planning, and for our cost and efficiency assessment as part of PR23.

[43] We obtained comparable results when we tested a quadratic model (i.e. with a squared variable).

[44] This is calculated as $[(1^{0.67} / 0.5^{0.67}) - 1]$

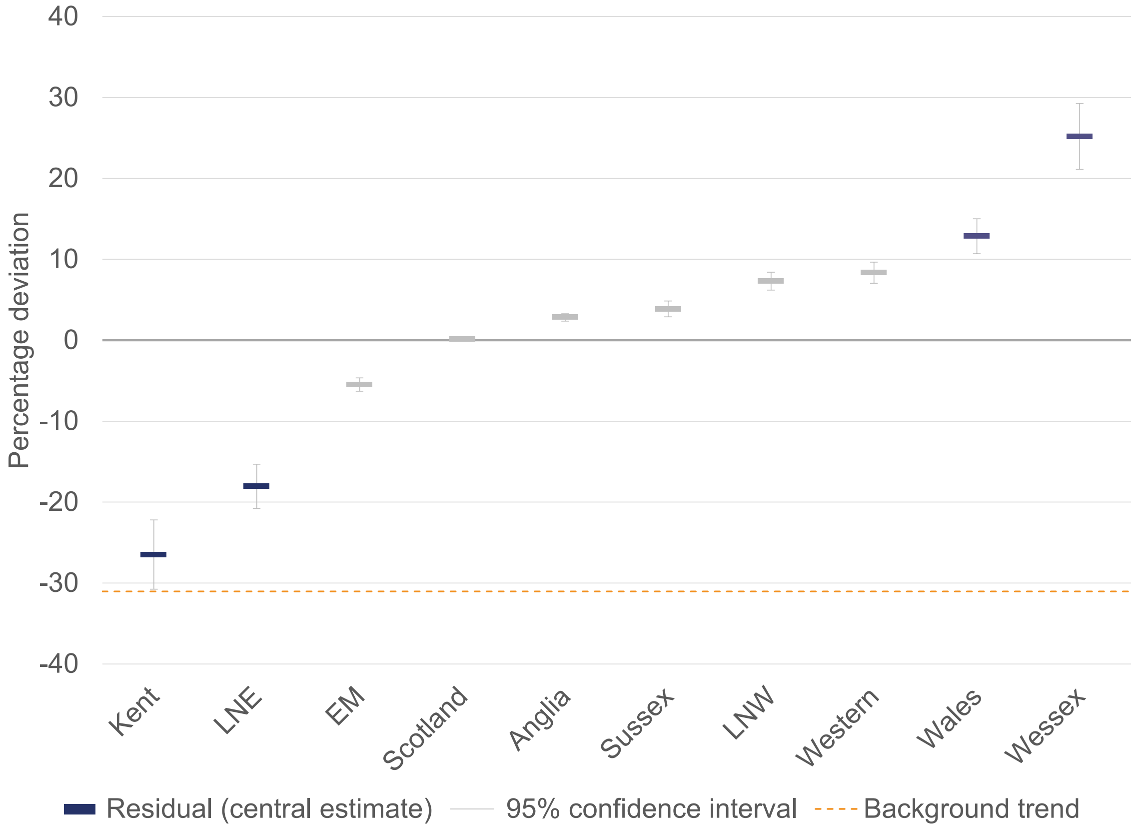
then order routes and regions according to the amount of unexplained variation. Region-level results are obtained by aggregating up the unexplained variations for the relevant routes.

3.38 We note that the unit cost of conventional track renewals is influenced by a wide variety of project-specific factors, which cannot be taken account of in a top-down analysis of this sort. So, the results we present here should be read as indicative of the relative position of different routes and regions, rather than as precise estimates of what the average unit cost should be in each case.

3.39 Figure 23 below shows, for each route, the proportion of unexplained cost variance in 2020-21. A negative number means that the route spent less than expected (according to our statistical model) whilst a positive number means that the route spent more than expected (according to our statistical model).

3.40 The horizontal dashed line indicates the background trend. As mentioned above, we see that the average unit cost in 2020-21 is, on average, 31% above that level. The negative effect of COVID-19 on productivity is one possible explanation. According to Network Rail another explanation could be year on year changes in the composition of work banks, though it is unclear whether there are systematic differences in work banks between 2020-21 and previous years.

Figure 23: Deviation between outturn and expected (modelled) for conventional track renewals average unit costs, 2020-21 – route comparisons[45]



3.41 All routes had average unit costs above the background trend. Once we take out the average difference to the background trend for 2020-21, we see that the average unit costs at the route level are between -26% and +25% of those predicted by our model. **Kent** and **LNE** are at the lower end of the distribution, whilst **Wessex** and **Wales** are at the upper end.

3.42 The Southern region has suggested that the relative position of Wessex (especially in contrast with Kent, which is part of the same region) could be explained in part by: the high prevalence of third-rail electrification[46] in this area

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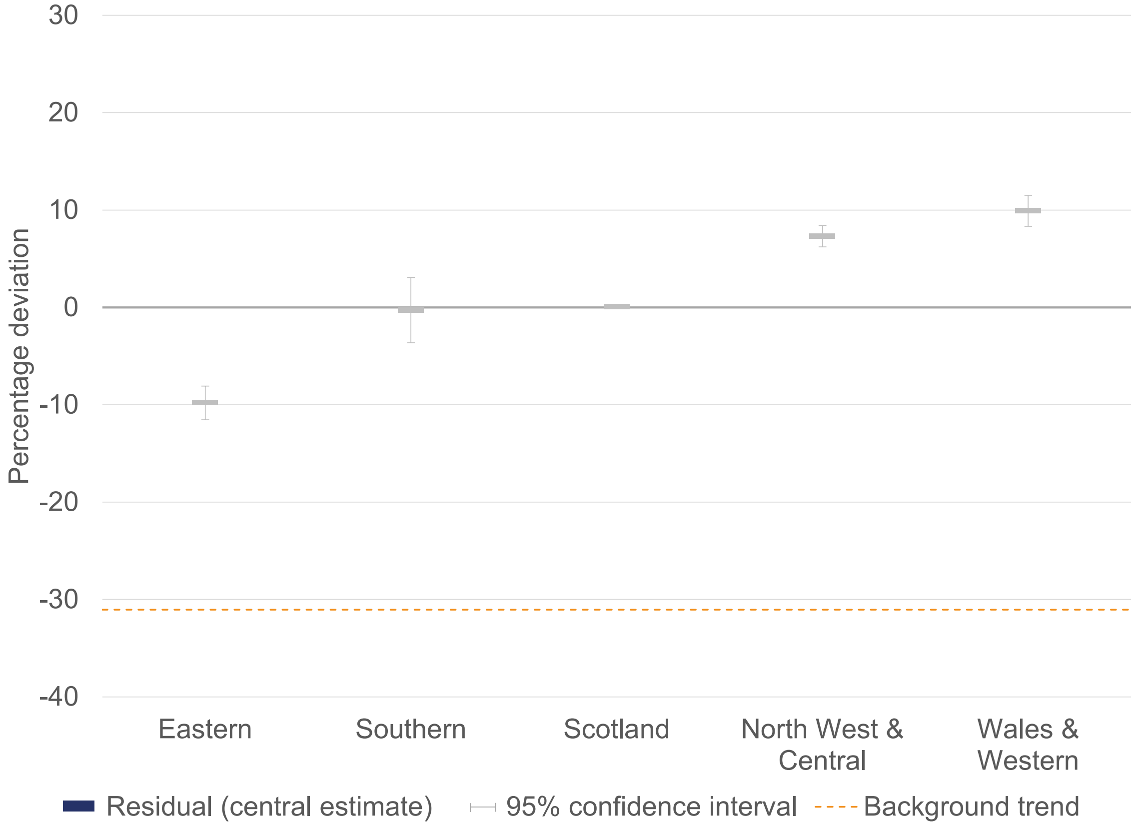
[45] Given the uncertainty associated with any statistical model, we consider any business unit (route or region) that is within +/−10% of our modelled prediction (as shown by the x-axis at zero) to not be an 'outlier'. These business units are marked grey. Business units that are marked blue are therefore considered 'outliers'.

[46] We have attempted to control for differences in maintenance expenditure between third rail and overhead line in previous years. However, that analysis picked up no significant difference in terms of the effect on cost of the two types of infrastructure. It is possible that this could have been due to confounding effects, whereby one type of infrastructure adds cost to certain types of work but saves cost to others. We will consider how best to incorporate differences in electrification infrastructure into our analysis, as a next step in its development.

(third-rail being expected to result in more expensive track renewals compared to track with overhead line); delivery partners tending to carry out a larger proportion of short jobs over the past year (shorter jobs resulting in lower productivity than longer jobs); and the possibility that renewals projects in Wessex have tended to cluster closer to London.

3.43 Figure 24 below shows, for each region, the proportion of unexplained cost variance in 2020-21. This is obtained as an average of the average unit cost for the relevant routes, weighted by renewals volume.

Figure 24: Deviation between outturn and expected (modelled) conventional track renewals average unit costs, 2020-21 – Regional comparisons



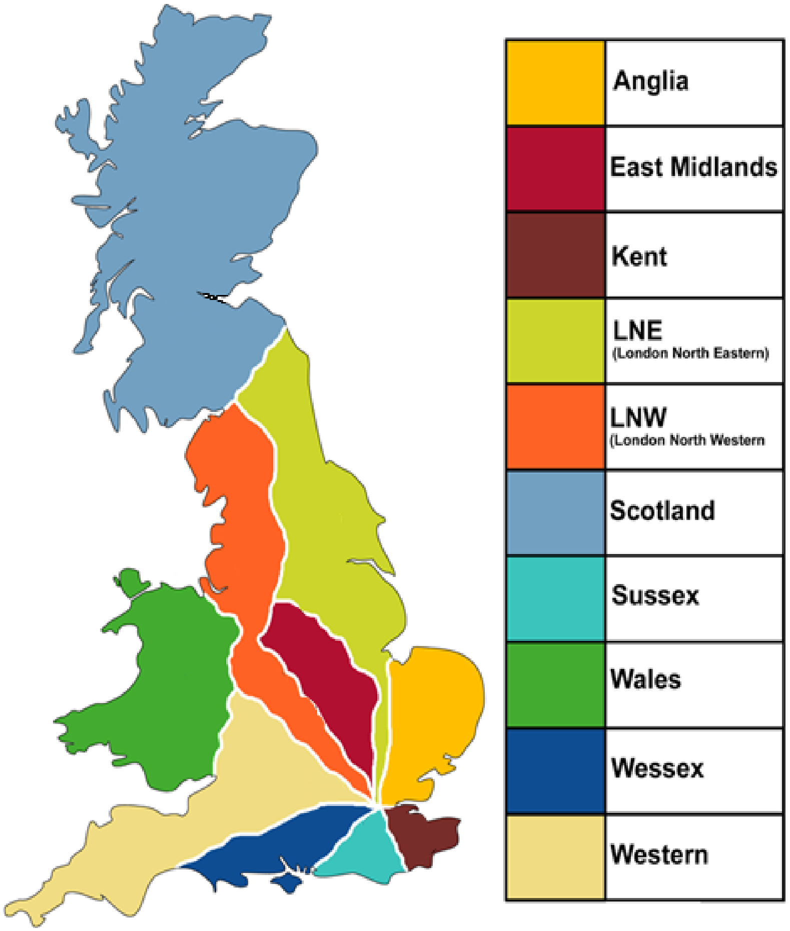
3.44 Actual average unit costs at a regional level match our model's predictions much more closely than for routes, with **Eastern** at the lower end of the distribution (**-10%**) and **Wales & Western** at the top end (**+10%**).

3.45 The Eastern region has told us that it had put conscious effort into analysing its work bank to identify opportunities to improve access, resource utilisation and better matching of delivery partner to job, and that this had resulted in lower unit costs. This is useful feedback, which we will consider further. The relative position of Wales & Western requires further investigation. The result that our model predictions match actual unit costs so closely at the regional level underlines the potential usefulness of this approach in providing indicative unit cost ranges for this type of asset and activity, and this is something we intend to consider in the context of PR23.

Annex

Annex A: Network Rail's geographic routes and regions

Ten routes covered in this analysis	New structure with 14 routes



Annex B: Mapping of Network Rail's regions, routes and MDUs

Region	CP4 ten routes	Maintenance delivery unit (MDU)
Eastern	London North Eastern (LNE)	Doncaster, Leeds, Newcastle, Peterborough, Sheffield, York
	East Midlands (EM)	Bradford, Derby
	Anglia	Ipswich, Romford, Tottenham
North West & Central	London North Western (LNW)	Bletchley, Euston, Lancashire & Cumbria, Liverpool, Manchester, Saltley, Sandwell & Dudley, Stafford
Scotland	Scotland	Edinburgh, Glasgow, Motherwell, Perth
Southern	Wessex	Clapham, Eastleigh, Woking
	Sussex	Brighton, Croydon
	Kent	Ashford, London Bridge, Orpington
Wales & Western	Wales	Cardiff, Shrewsbury
	Western	Bristol, Plymouth, Reading, Swindon

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